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Ing. Melesio Gutiérrez P.

COMMUNITY NOISE:
A STATUS REPORT*

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COMMUNITY NOISE

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The magnitude of the existing urban noise problem is presented in terms of its acoustical characteristics and environmental impact. The current status of community noise research, including acoustical as well as social analysis is summarized. Implicated environmental health effects involving potential hazardous and nuisance responses to community noise are identified. Public as well as political recognition of community noise is compared to other environmental problems. Existing and proposed noise management programs at various governmental levels are assessed in terms of their relative effectiveness, including protecting the public's interest. Presented are examples of a few existing programs that sufficiently address the problem. The current inadequacies and requirements for more active and comprehensive noise management programs are apparent. Effective coordination of environmental programs at all governmental levels is also needed. Present governmental policies and their ability to successfully control community noise is discussed including considerations in establishing standards.

I. INTRODUCTION

Noise associated with urban activity is rapidly becoming a subject of professional interest and environmental concern. The purpose of this paper is not only to appraise the status of community noise, but also to discuss directions for future activity. It is increasingly apparent that the magnitude of the problem is as pervasive as society itself, and its resolution requires a commitment still to be totally recognized by society.

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II. NOISE LEVEL CHARACTERISTICS

Community noise studies, which are increasing in number, generally report similar conclusions. That is, noise intensity, although varying with the type of geographic area and activity, can be generally categorized.

In urban situations the residual or ambient noise level is fairly typical (defined as L_{90}) with a slightly greater deviation in the mean level (L_{50}) and transient noise which intrudes above the ambient (L_{10}).[1]

A. NOISE SAMPLING

There are several major weaknesses with current noise investigations that limit the general applicability of their conclusions. Based upon most community noise sampling techniques, the data obtained should not be considered respresentative of the city or of the urban area as a whole.

More rigorous sampling designs are necessary before such generalizations can be made.[2] Obviously within the same city, significant differences in the noise climate can be observed. In Philadelphia major variations have been noted in similar residential areas due principally to the characteristics of adjacent street activity.[3] Therefore a determination of the required number of sampling stations must be statistically derived.

A second concern is the sampling time utilized for each sampling site or location. Considerable error has been observed, depending upon the sampling time chosen, characteristics of the noise source, and sampling instrumentation.[4,5,6] Many state highway or departments of transportation are developing a variety of noise sampling techniques to calculate existing traffic flow rates over time. However some state established sampling guidelines do not always produce reproducible data and consequently the data obtained has questionable validity.

Thirdly, there are a variety of environmental noise rating methods, but no one method is consistently used. Current research is underway to overcome some of these present limitations, including a major Federal interagency noise research program to establish a reliable sampling methodology. This subject is also of considerable interest to professional societies including the American National Standards Institute, S3-50 Committee (Outdoor Evaluation of Community Noise) which is completing a draft standard for measuring community noise. Certain municipalities such as New York are in the process of developing more satisfactory noise sampling procedures as well.

B. NOISE GROWTH

There is no doubt that as a by-product of our power-oriented technology, the environment is experiencing a rise in the noise level. However, despite earlier opinions that this rise is equivalent to one decibel per year[7] there appears to be no supporting evidence. If this statement were true then our environment would be continuously experiencing a noise climate similar to the occupational environment.

In Germany, a survey team found that between the years 1938 and 1958, street noise in sections of Berlin and Dusseldorf had risen 8 decibels, or less than half a decibel per year.[8] Within the United States, based upon very limited historical data where land use has not significantly changed, the increase has averaged approximately 2 decibels per decade.[1]

Appropriate environmental noise monitoring is necessary to establish a "sound quality level" just as quality levels are being developed for both air and water quality. Well designed longitudinal studies should therefore be instituted in a variety of stable and changing environments to accurately assess community noise temporally and spatially. The U.S. Environmental Protection Agency, Office of Noise Abatement and Control, in compliance with the provisions of the Noise Control Act of 1972[9] is establishing a longitudinal environmental noise sampling program to be ultimately implemented within the ten Federal regions.

Established state and municipal noise control programs should also be encouraged to develop valid historical noise data for selected geographic areas. The City of Chicago Department of Environmental Control is currently proposing an investigation of this type for the purposes of evaluating their noise control program begun in July, 1971[10,11]

C. NOISE EXPOSURE

Perhaps more important than the rise in the level of noise is the increasing numbers of the population exposed. This has occurred due to a variety of changes in our life style including density, urbanization, power generation and mobility.

1. Density

Patterns of human settlement are becoming more dense. The population per square mile has risen from 37.2 in 19[illegible] [illegible] .5 in 1970.[12] However, the population is not equally distributed geographically. Approximately 70 per cent of the U.S. inhabitants live on two percent of the land area.[13] This means that over 142 million people occupy approximately 74,000 square miles in a country having over three million square miles. By 1980, this percentage is expected to increase to 75 percent or three out of every four Americans living on two percent of the land.

2. Urbanization

Urban living is the predominant choice of human settlement. Today over 73.5 per cent of our population (1970) lives in urban areas compared to only 56.5 per cent in 1940.[12] The current urbanization trend is expected to continue and by 1980 approximately eighty percent of the U.S. population will be living in urban areas.

3. Power Generation

This country is producing and consuming enormous amounts of power and energy. The rise in the total horsepower of all prime movers (i.e. automotive, aircraft, railroad, etc.) between 1940 and 1970 has been approximately 900 per cent.[12]

4. Mobility

The U.S. population is highly mobile, more mobile than any other country. Based upon motor vehicle data, the total number of vehicle miles traveled has increased 233 per cent since 1940.[12] Contributing to this mobility is a roadway transportation network exceeding 3.7 million miles.[14] Of greater concern is that vehicle (all modes) is increasing at twice the urban population growth rate.

With an ever growing population locating in urban areas, expending larger and larger amounts of power, becoming increasingly mobile, the accompanying noise impact is proportional to this growth. Perhaps the most critical factor is mobility. Urban activity patterns are rapidly changing. No longer is transportation primarily a day-time activity.

A prime example is major airports utilizing commercial passenger aircraft during off-peak hours to handle residual commercial passenger traffic and air freight. Nighttime aircraft is a major cause for community annoyance. At the Atlanta International Airport there are 37 scheduled commercial flights between 3 and 4 A. M. and 53 between 5 and 6 A. M. A growing number of airline passengers are being attracted to these "early-bird" and "owly-bird" flights since there is significant reduction in the fare over the normal "daytime" ticket prices. Beside aircraft activity build-up in off-peak periods, truck traffic follows a similar pattern. A higher percentage of truck traffic occurs at night and early morning hours than other traffic (i.e. automobile, bus, and motorcycle).

Contrary to popular opinion it appears that mobility is a more accurate predictor of noise generation than land use. Oftentimes noise associated with fixed land use activity is transportation dependent.

III. ENVIRONMENTAL HEALTH IMPACT

The impact of noise upon health has been examined in community noise research but to a very limited degree. A matrix was developed to notate implicated health effects of noise[3] using the World Health Organization definition of health (" a measure of physical, mental, and social well-being, not merely the absence of disease.")[15]

Strategies for community noise problem solving could be established based on general environmental health indices, recognizing the existing limitations of the data and the need for further research.

A. HEARING LOSS

It has been suggested by Ward, among others, that the basis for establishing Federal environmental noise guidelines should be hazards to hearing and speech interference.[16] Both of these health related indices are well investigated in laboratory as well as field research. Nonetheless, the relationship of hearing loss to non-occupational exposure is not completely identified,[17] even though Cohen has proposed guidelines.[18]

The basis for speech interference has been well identified.[19,20] Based upon vocal effort and distance between communicators, background noise levels have been established that can be applied to the community setting. Interference with speech is commonly observed in airport communities. Residences, hospitals and schools are generally the most affected. Aircraft noise can have an adverse effect upon the educational process creating among other phenomena, the undesired "jet pause." These intrusions eliminate communication and disrupt the spontaneity and rhythm of learning as well as affect classroom discipline.[21,22] The total number of educational days lost over a period of time may well be sizeable. Community noise as an intrusive factor affecting the quality of education needs to be thoroughly investigated.

The related impact of speech interference affecting the socialization process, entertaining, and friendship formation also need to be further researched.

B. SLEEP INTERFERENCE

Althought most health related noise research has concentrated on hearing loss and communication, noise relating to sleep interference is useful area to explore. Limited research has been conducted to assess specifically the role of noise in affecting the sleep state, but it is known that all stages of sleep including REM (rapid eye movement) can be disrupted by noise.[23] Furthermore, the noise level necessary for this disruption appears to be relatively low (40-50 dB(A)).[24,25]

There are degrees of sensitivity which become more severe with increasing noise levels. The initial response to noise stimuli is a change in the brainwave pattern (electroencephalographic response) usually altering the stage of sleep. This is normally defined as sleep arousal; however, the individual does not actually awaken.[26] With increasing noise intensity there is behavioral awakening where the subject is no longer sleeping.

The adverse impact of noise upon sleep is not completely known, but sleep disruption does affect the quality and duration of sleep. There appears to be considerable variability among the population. Based on limited data, women are more sensitive to noise during sleep than men and older subjects are more sensitive than middle age or younger subjects (children 5-8 years of age).[27] We can establish a category of low sensitivity (heavy sleepers) and one of high sensitivity (light sleepers).

Although there is some degree of adaptation among a portion of subjects observed, the population does not generally adapt to noise while sleeping. The length of time required to return to sleep after being awakened (sleep defined as sleep stage 2) by aircraft noise averages 5.3 minutes among women.[27] Heavily impacted airport communities are experiencing a considerable amount of sleep loss. Based upon data from an investigation of Philadelphia in certain residential areas, this loss was equivalent to one hour per night.[3]

Sleep disturbance is a primary basis for community noise annoyance, particularly at night. Although sleep interference in itself may not be hazardous to health, compensatory methods employed to "adjust" to this condition may be necessary. A portion of the noise affected population resorts to medication to induce sleep.[3,16,28] Currently I am investigating the extent of barbituate usage by the population in two airport communities (Atlanta and San Juan, Puerto Rico). The use of common over the counter sleep preparations containing certain drugs (i.e. scopolomine) has been reported under certain circumstances to cause mental health problems, including hallucination and behavioral dis-orientation.[29] Further research is needed to determine the affect of low dosages for extended periods of time as well as the prevalance of use in community noise environments.

C. MENTAL HEALTH

The relationship between environmental noise and mental health is currently inadequately defined. Very few investigations have attempted to examine large scale populations, or communities. There are inherent problems in developing an adequate research design and methodology that will provide satisfactory for analysis purposes. However, as Rene Dubois has remarked the "elusiveness of the problem is no excuse for ignoring its importance or neglecting its study."[30]

Reviewing the present literature, Miller concludes that noise induces neither neurotic nor psychotic illness.[21] There are, however, negative mental consequences of noise which suggest that noise aggravates rather than precipitates behavioral disorders.[30] Based upon an epidemiological study of mental hospital admissions in two locations, Abey-Wickrama reports that the highest admission rates were found closes to London's Heathrow Airport.[31] Subsequent research by Herridge appears to support this earlier finding.[32]

Lower order mental health effects, primarily annoyance response, have been commonly observed in community noise studies. The relationship between the perceived intensity of community noise and its believed harmful effect upon health (mental as well as physical) has been found to be statistically significant.[3,33,34] Predominant behavioral responses include anger, irritability and increased nervousness as reported among one-third of the respondents in the Philadelphia community noise survey. It has been suggested that community response is a satisfactory gross indicator of behavior.

Unfortunately opinion varies as to the mental health significance of community noise response. Johansson postulates that individuals who are not annoyed by their noise related environment may be less well adapted to reality than those who are annoyed.[58] Others contend essentially the opposite. That is, that the population complaining generally represent those having mental health problems. It is important to determine what portion of the mental health population is noise sensitive. This portion is then defined as the population at risk. The Council of Europe suggests that those predisposed to mental stress (i.e. with existing neuroses) may be adversely affected by noise.[36] Hallucinatory behavior among certain schizophrenic patients may well be triggered by a noise stimulus. I have observed that noise can create increased nervousness among methadone maintenance patients.

Extensive research is needed in these areas to more effectively identify mental health symptoms and to relate these to noise sensitivity using rigorous research designs. Community noise investigations in the future will require professional input from community psychiatry as well as other health-related disciplines to satisfactorily achieve this goal.

IV. NOISE MANAGEMENT

Environmental noise management is the key to abating community noise. However, the performance record to date has been inconsistent. A primary problem has been the inability to translate this publically expressed concern into a governmental priority or program. Quite often the public has considered noise a major problem area, while governmental officials have been insensitive.

There have been varying degrees of governmental activity in controlling community noise. Initiated at all levels of government, the results to date have ranged widely. Despite the present mixed results, governmental involvement continues to increase.

A. Legislation

Historically the primary interest in community noise has been expressed at the municipal level. The earliest noise regulations within the United States were municipal ordinances dating back to 1850.[36] It was not however until the early 1900's that a national concern for noise control began to develop. Even by 1930, there were less than 20 American cities with laws regulating noise, and those in existence were narrowly defined and non-quantitative in nature.

There have been several historical events that have shaped the evolution of environmental or community noise ordinances since that time. These events include:

1. Publication of City Noise prepared by the Noise Abatement Commission for the New York City Department of Health in 1930.[37]

2. Adoption of the motor vehicle control ordinance by Memphis, Tennessee in 1938.[38]

3. Publication of the National Institute of Municipal Law Officers (NIMLO) model ordinance prohibiting unnecessary noise in 1948.[39]

4. Adoption of the performance zoning ordinance by Chicago, Illinois in 1955, as developed by the Armour Research Foundation.[40]

5. Enactment of the Noise control sections of the Vehicle Code by the California Department of Highway Patrol in 1967.[41]

6. Adoption of the City of Inglewood, California, noise ordinance in 1969.[42]

7. Publication of the revised National Institute of Municipal Law Officials (NIMLO) model ordinance in 1970.[43]

8. Adoption of the revised City of Chicago noise ordinance in 1971.[44]

New York Mayor Jimmy Walker gave approval to the Commissioner of Health to establish a Noise Abatement Commission for studying urban noise and recommending solutions. Appointed in 1929 this Commission (the first ever assembled) completed their report entitled City Noise within one calendar year. This widely circulated report represented the first definitive statement of the city noise problem and the recommended laws for controlling noise were subsequently adopted by many cities beside New York.

The primary noise provisions included muffler requirements for motor vehicles and other internal combustion engines, restrictions on building development in residential areas between 5:00 P. M. and 8:00 A. M., prohibiting the use of horns and whistles, regulation of peddlers, hawkers and vendors, and prohibiting excessive noise from mechanical or electrical sound making or reproducing equipment. Although both stationary and mobile noise sources were identified, the report did not discuss industrial related noise activities in any detail.

Memphis, Tennessee, proclaimed the quietest American city, adopted several of these provisions in their municipal noise ordinance regulating vehicles in 1938.[38] Although it does not specify permissible sound levels in decibels this nuisance type or non-quantitative ordinance has become one of the most successful regulations due to an active enforcement program.

Recognizing there was a need to provide guidance to municipalities establishing proper legal noise ordinances the National Institute of Municipal Law Officers (NIMLO) in 1948 prepared a research report entitled "Municipal Control of Noise- Sound Trucks- Sound Advertising Aircraft- Unnecessary Noises- Annotated Ordinances."[39] This report disseminated to all NIMLO members was later referred to as the "NIMLO Model Ordinance Prohibiting Unnecessary Noise." This model to date has been responsible for most ordinances drafted in the U. S. In a study conducted for the U. S. Environmental Protection Agency 29 out of 83 local jurisdictions (35%) had enacted this NIMLO model.[45] Although the NIMLO ordinance was a further refinement of existing ordinances at the time, it failed to include quantifiable noise limits.

In 1955, the most influential zoning ordinance, restricting noise related land use activity became law. Adopted by Chicago this regulation contained quantitative noise emissions expressed in decibels for various octave bands. It represented a new approach to zoning which placed restrictions not on the type of industry (i.e. light manufacturing, heavy manufacturing) but rather on its performance in terms of noise emission. For the first time industry was being regulated according to specific acoustical criteria rather than by the more vague nuisance provisions. This development now required property line measurements using sound measuring instrumentation. Although initially not enforced, other jurisdictions began to adopt similar provisions in their zoning ordinances. A few cities also started establishing vehicle noise emission requirements expressed in decibels by 1952-53 (Seattle, Washington and Cincinnati, Ohio, respectively).[46, 47]

Not until 1967 was there an effective vehicle noise control law and program established by a government agency. The California Vehicle Code represented the first with quantitative noise emission limits regulating new vehicles sold in the state as well as existing vehicles operating on highways.[41]

California again took the lead in establishing the first comprehensive community noise ordinance and program when Inglewood enacted their ordinance in 1969. Many elements of the Inglewood program have been emulated by other jurisdictions, including specific acoustical provisions.

In obvious response to the need for an enforceable noise ordinance NIMLO modified their earlier model and proposed decibel provisions as an alternative in 1970.[43] Included now are limiting noise levels for use districts (i.e. residential, manufacturing, and commercial), as well as moto vehicles.

Mo recently the City of Chicago has adopted a fully revised noise ordinance, currently the most comprehensive in existence.[44] This newly rejuvenated noise program has generated national attention and is becoming a yardstick by which most other jurisdictions are compared. The influence of both Chicago and to a lesser extent NIMLO are just beginning to be noticed. Numerous cities are either recommending revisions or proposing new laws fashioned after the Chicago type program.

Toda there are over 175 municipalities* in all fifty states encompass a population of approximately 47 million, or 23 per cent

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*Refers to a city government, not a borough, township or county jurisdiction of the total U. S. population.[47] However, a sizeable majority, 85% of those enacted are nuisance type ordinances. That is, they have no specific acoustical criteria consequently they are generally vague and unenforceable. However, the predominant trend among most cities is to amend existing or promulgate new ordinances containing specific noise level provisions. Consequently, the number of performance type regulations are on the rise supplanting nuisance type regulations.

Federal response to the problem of community noise is a comparatively recent development with a legislative history dating back to the passage of the National Environmental Policy Act effective January 1, 1970.[48] For the first time this law required all agencies to include in every recommendation or report on proposals for legislation or other Federal actions, significantly affecting the quality of the human environment, a detailed environmental impact assessment. Noise, among other environmental factors was to be considered in the assessment.

Subsequent environmental impact guidelines issued by the Council on Environmental Quality established Federal agencies to be consulted in connection with preparing environmental statements.[49] Five Federal agencies were designated as having special expertise in noise.

The passage of this act, followed later by guidelines was a major stimulant for Federal noise criteria since these agencies were now required to adopt administrative review procedures. Among the most notable are the efforts by the U. S. Department of Housing and Urban Development, and U.S. Department of Transportation, Federal Highway Administration.[50,51]

There are presently thirteen states that have established similar environmental impact organizations and procedures, several modeled after the Federal program. Noise is being considered to varying degrees by these state programs. California and New York appear to have established the most comprehensive noise provisions.

A second major Federal thrust was the passage of the Noise Pollution and Abatement Act as part of the Clean Air Amendments, Title IV, on December 31, 1970.[52] Although there had been earlier attempts to coordinate Federal noise programs until this time they dealt principally with aircraft, through the Federal Interagency Aircraft Noise Abatement program.[53] Among other provisions this act established the Office of Noise Abatement and Control with the U. S. Environmental Protection Agency. It was mandated by Congress to prepare a status report on community noise as an environmental problem, including making appropriate recommendations.

As a result of EPA's report to the President and Congress,[54] as well as significant Congressional and constituent interest, the Noise Control Act of 1972 was enacted October 27, 1972.[43] This Act, if implemented, will bring about the most profound changes in controlling noise to date. It is the purpose of this Act to:

"establish a means for effective coordination of Federal research and activities in noise control, to authorize the establishment of Federal noise emission standards for products distributed in commerce, and to provide information to the public respecting the noise emission and noise reduction characteristics of such products."[43]

B. Implementation

Despite the increasing number of laws being proposed and many subsequently enacted the future status of community noise control remains questionable. If quieting our environment were based upon the number of ordinances and other regulations passed by our governing bodies; or if it were determined by the number of public pronouncements, public hearings and associated rhetoric; then the ultimate objective of a quieter environment would be at hand. Unfortunately it is not for a variety of reasons, all of which involve implementing what the law now specifies.

Despite the fact that there are over 175 ordinances regulating city noise, a survey conducted by EPA[47] and updated by the author indicates less than 20 cities have adopted budgets to operate noise control programs (See Table 1). Since 90% of the ordinances are not supported by budgets for enforcing existing noise laws, most cities have only "paper regulations." Noise is allowed to persist even though regulations, varying in quality, do exist.

In 1972 approximately $650,000 was being expended annually by cities on non-occupational noise control programs. This is equivalent to 1.6 cents per capita for those cities having noise laws. The bulk of this amount ($482,000) represented the combined budgets of New York City, Chicago, Illinois and Inglewood, California. Of the "big three" New York had the largest budget, but also the largest population served. On a per capita basis Inglewood leads the country with a per capita expenditure of $1.98 compared to Chicago, the second highest of 7.6 cents.

In terms of manpower, New York has the largest noise control staff, 43, which includes 23 directly assigned to the Bureau of Noise Abatement and 20 inspectors which are currently assigned to the Bureau of Enforcement of the Department of Air Resources. Second is Chicago, with a full-staff numbering 23 in their engineering and enforcement divisions. Of the total, 19 are professionals while the remaining four are secretarial and clerical support personnel.[59]

There are problems at the Federal level as well. The environmental impact statement process has several loopholes that can minimize its effectiveness. First of all the Federal agency sponsoring a project is responsible for preparing the impact statement. If for example, the project is a proposed airport or highway, then the sponsoring agency is the U. S. Department of Transportation. Although other agencies may be required to comment or evaluate a project the ultimate responsibility rests with the sponsoring agency. This has been likened to putting the "wolf in the chicken house." Negative comments about possible noise generation can be disregarded or minimized if the sponsor so desires witnout any governmental recourse. The Council on Environmental Quality has only an advisory responsibility and cannot regulate.

Generally speaking the environmental impact process has been sucessful in at least making the sponsor aware of noise as a possible environmental problem. Furthermore, the quality of these impact statements is improving . However, all too often the concern of noise has not been adequately treated. Until recently this has been the case especially with highway and airport projects.[56]

Other problems have involved enforcement of existing Federal noise standards or criteria. Because of the regional nature of administering Federal programs there appear to be discrepancies in enforcement of noise standards enacted in Washington. There are varying degrees of compliance with both DOT and HUD guidelines depending upon the specific geographical region of the country.

Lastly, some Federal grant programs are being administered with noise requirements that may create or influence compatible land use development while others are not. Under the provisions of the Airport and Airways Development Act[57] municipalities are eligibleto receive from the FAA Federal assistance in expanding or constructing an airport facility. Although they do recommend that airport noise contours be developed for the site, there are no requirements that incompatible land use development be restricted, to avoid future residential encroachment. Federal airport development assistance should be contingent on the submission of an <u>effective</u> land use management program (e.g. zoning, subdivision regulations, site design review procedures, etc.) by the municipality to insure that future compatible land use development will continue to occur.

TABLE 1

MUNICIPAL NOISE ABATEMENT EXPENDITURES

CITY	POPULATION (1970)	ANNUAL 1970	BUDGET 1971	(IN THOUSANDS OF DOLLARS) 1972
New York, N. Y.	7,895,563	$ 55	$ 150	$ 200
Chicago, Ill.	3,369,359	40	93	163
Inglewood, Ca.	89,985	...	132	119
Las Vegas, Nev.	125,787	...	...	50
Philadelphia, Pa.	1,950,098	14	26	27
Boston, Mass.	641,070	25	25	38
Atlanta, Ga.	497,421	...	25	25
Honolulu, Ha.	324,871	...	5	10
Dallas, Tex.	844,401	1	3	6
New Orleans, La.	593,471	...	4	4
Freemont, Ca.	100,869	2	2	3
Columbia, S.C.	113,542	1	2	2
Minneapolis, Minn.	434,400	2	2	2
TOTAL	16,980,837	$140	$469	$568

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INTRODUCCION A LA ACUSTICA.

DEFINICIONES.

NIVEL DE PRESION DE SONIDO.

DECIBELES.

NIVEL DE POTENCIA ACUSTICA.

ESCALA LINEAL Y BANDAS DE FRECUENCIAS.

PROPAGACION DEL SONIDO.

ARQ. EDUARDO SAAD ELJURE.

ARQ. CARLOS CASTELLANOS F.

INTRODUCCION.

Cualquier problema de ruido y vibraciones depende de sistemas compuestos por tres elementos básicos: La fuente sonora, el Medio donde se transmite y el Receptor.

Antes de solucionar un problema complejo, deben tomarse consideraciones en los siguientes aspectos :

a) La fuente productora del ruido debe ser conocida.

b) Las características de la transmisión del fenómeno deben ser comprendidas.

c) Se debe adoptar un criterio para considerar el nivel de ruido permisible o deseable en cada situación.

Estos tres elementos no necesariamente actuan independientemente, la potencia sonora que es radiada, depende del medio ambiente alrededor de la fuente; por ejemplo una máquina puede radiar más sonido si es colocada en la esquina de un cuarto; una voz aumenta o disminuye su intensidad dependiendo del tamaño forma y características de reverberación de un cuarto en el que este hablando la persona.

La forma en que setransmite el sonido puede ser afectada por detalles acústicos de la fuente y del escucha; así tenemos que la fuente sonora puede estar en movimiento, puede ser intermitente, etc.. por otro lado, el escucha puede estar sujeto a diferentes ocupaciones, su estado anímico puede ser muy variable etc....

De tal forma que la actitud de las personas hacia el ruido puede ser influenciada no solo por la naturaleza del sonido y sus características de propagación, sino que la percepción del ruido esta sujeta a las mas variables condiciones de subjetividad. Todas estas consideraciones enfatizan que cada problema de ruido esta complicado con un sistema de interacciones de los elementos que anteriormente citamos.

El control de ruido no solamente se puede referir a reducir el sonido indeseable, por ejemplo : En una oficina moderna de diseño abierto sin divisiones aislantes, el ruido de fondo puede ser aumentado cuidadosamente controlando las cualidades tonales, con objeto de enmascarar o encubrir los sonidos indeseables producidos por los ocupantes con sus máquinas, calculadoras, los elevadores, el ruido del tránsito, así la molestia causada por el ruido natural, puede ser reducida añadiendo más ruido.

La solución de un problema de control de ruido involucra generalmente multitud de aspectos. El costo de la protección del oido de cada trabajador de una planta puede llegar a ser prohibitivo, de tal forma que el riesgo de daño podría ser aceptado por algunos trabajadores; la solución podría consistir en una combinación de medidas de reducción de ruido, la institución de un programa de pruebas audiológicas para seleccionar aquellos trabajadores que tuvieran oidos sensibles, los que deberian ser transferidos a otras labores y un plan para compensar a los pocos restantes que sufrieran alguna pérdida auditiva.

Control de Ruido en la Fuente.- Una fuente sonora es creada por el movimiento de un sólido, un liquido o un gas. Una fuente sólida puede ser reducida si su forma de operación es cambiada, de tal forma que su movimiento se reduzca tambien; por ejemplo al reducir las fuerzas que producen el movimiento, ya sea rigidizando, dejando libres o aislando total o parcialmente la estructura.

Las fuentes sonoras en líquidos y gases, pueden ser reducidas eliminando las turbulencias, reduciando la velocidad del flujo, suavizandolo, o atenuando las pulsaciones de la presión. El control de ruido en la fuente, planeado durante la etapa de diseño del producto, es usualmente la medida más eficaz y menos costosa para óptimo funcionamiento. .

Control de ruido en su medio de propagación.- Muchas de las medidas correctivas para un problema de control de ruido consisten en modificar la forma de transmisión de sonido en el medio. En esta parte estan incluídos el control del ruido al aire libre, en los recintos, a traves de las estructuras y en los ductos. Las posibles soluciones podrian ser barreras, materiales porosos, cambiar las relaciones entre las máquinas, silenciadores, aislamiento de vibraciones, etc..

Las necesidades del Escucha.- El nivel al cual un ruido debe ser reducido para ser aceptable por el oido humano, algunas veces requiere del juicio, tanto del usuario, el consultor, como del propietario del edificio o la máquina. Un criterio para un buen control del ruido para los escuchas depende de lo que se desee lograr: Conservar el oido, crear un ambiente propicio para la conversación o proveer comodidad en el hogar, en el trabajo, o en los vehículos de transportación. Los primeros dos aspectos que anteriormente señalamos estan evaluados ya en una forma bastante aceptable, pero la comodidad pude depender de actitudes mentales, las cuales pueden ser muy variables o incluso cambiar repentinamente.

Que es el sonido.- Es palpable que el ruido aumenta dia a dia, lo vemos en todos los medios en donde se lleva a cabo cualquier tipo de actividad; ya sea en el trabajo, en la oficina, en el hogar, en las calles, etc... Para definir el sonido es necesario establecer como se manifiesta, como se transmite en los diferentes medios y como lo capta el hombre.

El sonido es una vibración que se transmite a traves del aire, los liquidos y los solidos elásticos; en donde las moléculas se mueven en for ma de compresiones y depresiones concentricas esféricas, transmitiendo la energia una a la otra.

Antes de establecer las unidades en que se mide el sonido, es necesario conocer como responde nuestro oido. El oido humano es un organo muy sensible, con cualidades que lo mismo, le permiten distinguir la intensidad y la frecuencia del sonido, aparte de estas dos características podemos determinar que instrumento es el que esta produciendo un sonido, o sea el timbre y tambien podemos distinguir de donde viene el sonido, porque tenemos dos canales (oidos), que nos permiten saber la dirección de donde proviene. Ademas de esto discrimina ruidos indeseables, fijando nuestra atención en lo que deseamos. A medida que se va afectando el oido con las altas intensidades de sonido a que estamos sujetos en nuestras ciudades, va perdiendo estas características y en estudios que se han hecho se ha encontrado que un gran porcentaje de los habitantes de las grandes ciudades se encuentran afectados. Se ha comprobado que personas que estan durmiendo cerca de una calle residencial tranquila, con el ruido que produce un automovil normal, sin despertar la persona, cambia su presión sanguinea, segrega jugos gastricos y esto se supone que puede favorecer a la creación de úlceras, infartos y demas malestares.

Para evaluar el sonido es necesario establecer sus dimensiones: En 1° lugar la intensidad, que es la dimensión que nos va a dar la medida fisica en watt/m2. En esta dimensión la máxima intensidad que el oido puede aceptar es de 10^{1} watts/m2 y el mínimo para escuchar es de 10^{-12}watt/m2 que tambien lo podemos llamar el umbral de percepción auditiva (estos datos son en la frecuencia de 1000hz y al nivel del mar). Ademas de la intensidad, tenemos otra de las dimensiones del sonido: la frecuencia, que depende del numero de oscilaciones entre la unidad de tiempo, que tenga una vibración, asi tenemos que un sonido puede ser bajo o alto dependiendo de su tono(como un contrabajo y un violín); el oido humano esta capacitado para captar sonidos desde 16 ciclos/segundo hasta 20 000 ciclos/seg aproximadamente.

El Decibel .- Para explicar esta unidad, comenzaremos con un poco de historia. El primer científico que investigó acerca de la proporción de las sensaciones con respecto a los estímulos fue Gustavo Teodoro Fechner (1801-1887), que haciendo experimentos sobre la sensaciones humanas, llego a la conclusión que nosotros sentimos en proporción logarítmica; asi tenemos que si nosotros escuchamos un piano, para sentir el doble de la intensidad necesitaremos 10 pianos, aunque la intensidad sonora fisicamente siga proporciones directas. Esta cualidad es la que nos permite ver un partido de futbol y escuchar un "gol"coreado por 100 000 personas y que no se nos rompa el oido. La capacidad del oido es fantástica, se puede adaptar a sonidos muy débiles, por ejemplo el reloj en la noche o ruidos tan intensos como un avión.

El decibel es una expresión de cantidad que encuentra su mas amplio uso en la Acústica y la vibración. El decibel esta basado en la ley de Weber-Fechner, como ya lo habiamos apuntado anteriormente, que define la sensación causada por un determinado estímulo y en la que la sensación se cuantifica según se indica en la siguiente ecuación :

$$\text{SENSACION} = 10 \log_{10} \text{ESTIMULO}$$

Esto aplicado a la Acústica tiene una gran utilidad, pues como ya habiamos explicado la gama de intensidades va desde $2 \cdot 10^{-5}$ New/m2 a, 10^{2} New/m2; es por esto claro que una escala lineal sería de una gran amplitud y por esto se ha adoptado la escala de decibeles que se define como:

$$\text{DECIBELES} = 10 \log_{10} \frac{X}{X_o}$$

Donde usualmente X es la cantidad medida, que tiene dimensiones de potencia y Xo es la cantidad de referencia en las mismas unidades, podriamos decir que por convención internacional esta cantidad es el umbral de percepción sonora en el oido humano y es la siguiente en las diferentes unidades usuales en Acústica :

POTENCIA SONORA = 10^{-12} watts

INTENSIDAD SONORA = 10^{-12} watts/m2

PRESION SONORA = $2 \cdot 10^{-5}$ New/m2 o $2 \cdot 10^{-4}$ uBar o $2 \cdot 10^{-4}$ dyn/cm 2

En consecuencia los terminos comunmente usados para nivel de potencia sonora (PWL), Nivel de intensidad sonora (IL), y Nivel de Presión sonora (SPL), relacionados con los umbrales de percepción nos dan los Decibeles.

La definición práctica de Nivel de Potencia Sonora y Nivel de Intensidad Sonora son las siguientes :

$$\text{Nivel de Potencia Sonora PWL} = 10 \log_{10} \frac{W}{10^{-12}} \quad \text{dB re } 10^{-12} \text{watt/m2}$$

$$\text{Nivel de Intensidad Sonora IL} = 10 \log_{10} \frac{I}{10^{-12}} \quad \text{dB re } 10^{-12} \text{watt/m2}$$

Donde W es la potencia medida en watts y, I es la intensidad medida en watt/m2.

Para el Nivel de presion Sonora SPL es necesario conservar la relación de las cantidades proporcionales a la potencia Acústica, por lo que se trabaja con las presiones elevadas al cuadrado. La definición práctica de la presión Sonora es :

$$\text{Nivel Presión Sonora SPL} = 10\log_{10}\left(\frac{P}{2 \cdot 10^{-5}}\right)^2 \quad , \text{o}$$

$$\text{SPL} = 20\log_{10} \frac{P}{2 \cdot 10^{-5}} \quad \text{dB re } 2 \cdot 10^{-5} \text{ New/m2}$$

Donde P es la presión medida en Newton/metro2; en la siguiente tabla podemos observar la correspondencia de algunos niveles sonoros con estas unidades.

Presión de Sonido en uBar (microbar), o dyn/cm2.		Nivel Sonoro en dB	
		140	
1000 u Bar	134		Umbral del Dolor
		130	Taladro Neumático.
		120	
100 u Bar	114		Claxón de Automóvil (1 m.)
		110	
		100	
10 u Bar	94		Ruido en el interior del "metro".
		90	
			Ruido en el interior de un autobus.
		80	
1 u Bar	74		Promedio en una esquina transitada de la ciudad.
		70	Conversación voz normal.
		60	
0.1 u Bar	54		Ruido en una oficina normal.
		50	Habitación en un suburbio.
		40	
0.01 u Bar	34		Biblioteca.
		30	
			Dormitorio en zona tranquila en la noche.
		20	
0.001 u Bar	14		Estudio de Grabación muy bien acondicionado.
		10	
0.0002 uBar		0	Umbral de la audición.

Notese que es de suma importancia establecer la referencia para delimitar los parámetros de las mediciones, puesto que el Decibel es solamente una expresión de la relación entre dos cantidades. En la selección de esa referencia, la relación entre las tres unidades anteriormente mencionadas, fueron seleccionadas con el propósito definido de proveer una conveniente interrelación de los tres niveles. La base fue la presión del sonido --- $2 \cdot 10^{-5}$ Newton/metro2 la cual es apróximadamente la presión de sonido en la frecuencia de 1000 ciclos/seg que puede ser captada por un hombre joven con oido saludable. La intensidad de referencia fue seleccionada de tal forma que la intensidad de sonido (IL) y la Presión del sonido (SPL) fueran casi iguales numericamente para ondas planas y esfericas, a una temperatura media al nivel del mar; en estas condiciones podemos expresar la siguiente relación :

$$SPL = IL + 0.2 \text{ dB re } 2 \cdot 10^{-5} \text{ New/m2}$$

El nivel de Potencia (PWL) se escogió de tal forma que fuera conveniente relacionarlo con el nivel de Presión Sonora (SPL), cuando el área de la superficie sobre la cual la potencia fuera radiada en el punto de medición, expresado en m2, a temperatura media a nivel del mar, es la siguiente relación :

$$SPL = PWL - 10 \log_{10} \frac{S}{So} + 0.2 \text{ dB re } 2 \cdot 10^{-5} \text{ New/m2}$$

Donde S es la superficie total del frente de onda en m2 y So es 1 metro2.

Hay casos en los cuales es necesario sumar o restar niveles de sonido expresados en decibeles; por supuesto esto no es posible efectuarlo algebraicamente, debido a que es una escala logarítmica. Los niveles deben ser convertidos a su unidad inicial de energia, y el procedimiento para hacer esto es a traves de las fórmulas de Potencia sonora e Intensidad sonora que anteriormente se citaron; ya en estas unidades se sumaran algebraicamente los niveles y mas tarde se convertira el resultado a niveles en la escala de los decibeles.

Frecuencias Audibles y concepto de Bandas de Frecuencias.-

La gama de frecuencias audibles abarca como ya anteriormente se dijo, de 16 a 20 000 ciclos/seg (hertz) aproximadamente, pero nuestro oido no escucha con la misma intensidad con respecto a bajas y altas frecuencias, es decir que un contrabajo tendrá que tocar con más intensidad para que tengamos la misma sensación que nos produce un violín, o bien podemos decir que un sonido que pudieramos escuchar a muy baja intensidad a 1000 hz no lo podriamos escuchar en bajas y en muy altas frecuencias. Tambien nos hemos percatado que las frecuencias en que nuestro oido escucha con mayor intensidad es aproximadamente de 300 a 6000 hz.

Asi tenemos que el Umbral de percepción auditiva en 1000hz es aproximadamente 0 dB re $2 \cdot 10^{-5}$ New/m2, en cambio en 100 hz el umbral de percepción estara en + 25 dB.

Si el número de tonos puros estan combinados dentro de un sonido complejó, no solamente la sonoridad y el tono determinan la percepción del sonido en el humano, sino que hay un tercer factor, el timbre, que entra en escena. El timbre depende del contenido de armónicas de un sonido y su comportamiento transitorio. Una gran cantidad de trabajo de investigación ha sido desarrollado para poder medir y calcular el efecto del sonido.

De tal modo que se pueda tomar en consideración durante las mediciones; las investigaciones nos enseñan la existencia de ciertas bandas críticas de frecuencias y tambien que la relación existente entre esas ban- y la forma comoresponde el oido humano es de suma importancia.

Dadas las necesidades de análisis en la investigación Acústica surgieron los filtros, primero basados en las experiencias de la escala musical, se dividieron en bandas de octava, en las que se duplica la frecuencia en cada banda; es decir suponiendo que el DO 4° del piano produce 512 hz, el DO 5° producira 1024 hz.

Conforme ha avanzado la investigación Acústica se han requerido instrumentos que permitan una evaluación mas exacta, por lo que surgieron los filtros de 1/3 de octava, 1/10 de octava y los de banda ancha.

PROPAGACION DEL SONIDO.- Las ondas sonoras y las variaciones de presión son producidas como un resultado de una perturbación mecánica en un medio elástico. La producción, propagación y detección de las ondas sonoras es generalmente relacionada con una oscilación, la forma más simple de oscilación que existe es el movimiento armónico simple, y cuando las variaciones de presión en esta forma son producidas, el sonido resultante es nombrado tono puro, porque las variaciones de presión ocurren en una frecuencia solamente. La propagación de las ondas sonoras puede ser considerada en ondas planas o esféricas. Cuando la fuente sonora esta en un punto cercano al escucha y sin elementos que reflejen la energía, las ondas sonoras se pueden considerar esféricas, pero a grandes distancias, donde la curvatura de la onda frontal sea pequeña puede considerarse como una onda plana.

Si nosotros consideramos una vibración armónica simple tal como una superficie plana vibrando en el aire o en cualquier otro medio aparentemente, dicho movimiento de la superficie causa pequeñas variaciones de la presión local cercana a la superficie. Ello podra ser transmitido a traves de un medio o una velocidad particular de propagación, como si fueran pequeñas ondas en la superficie tranquila del agua, en las cuales la velocidad es proporcional a la densidad y elasticidad del medio.

Podemos establecer tambien que la velocidad de propagación es igual a la longitud de onda entre el tiempo o bien la velocidad es igual a la frecuencia por la longitud de onda, donde el período es medido en segundos, la frecuencia en hertz.

La fuerza de la presión de la onda sonora puede ser medida por las fluctuaciones locales de la presión sobre la presión atmosférica ambiente.

Esta variación de presión son extremadamente pequeñas, proporcionalmente a la presión atmosférica y la unidad mas comunmente usada para estas mediciones es el Newton/metro2, que es aproximadamente 10^{-5} atmósferas.

Así podemos decir que una onda plana y una onda esférica son similares en sus conceptos, y la única diferencia que se observa es que el área se alarga al ser divergente, y la energia de la fuente sonora se distribuye esféricamente en ondas progresivas.

A traves de estos razonamientos llegamos al planteamiento de los conceptos de intensidad sonora, que es el promedio de la potencia Acústica entre la unidad de área. Podemos pensar que si una bocina de un automóvil sonára a una corta distancia de nosotros nos causará molestia, en cambio si la distancia entre la bocina y nosotros es grande, escasamente la escucha remos. De lo cual podemos deducir que la Intensidad sonora esta en función de la Potencia Acústica y es proporcional al cuadrado de la distancia de la fuente al escucha (en ausencia de reflejos sonoros).

Los sonidos resultantes de vibraciones sinusoidales nos dan tonos puros, pero la gran mayoria de los sonidos comunes son mas complejos, teniendo varios componentes y usualmente varias de las frecuencias de la gama audible. Por ejemplo cuando un instrumento musical produce una nota, una frecuencia fundamental predomina sobre otras que estan presentes y que son armónicas del fundamental y que son las que dan el timbre al sonido del instrumento. Para el análisis de estos sonidos que tienen varios componentes de frecuencia se pueden medir a traves del espectro del sonido que es lo mas comunmente usado.

G L O S A R I O .

AUDIO FRECUENCIA.- Corresponde a cualquier frecuencia normalmente audible, la gama de audio-frecuencias aproximadamente es de 15 a 20 000 hz.

FRECUENCIA.- Numero de ciclos entre la unidad de tiempo ciclos/ segundo.

FRECUENCIA FUNDAMENTAL.- La frecuencia principal de un sistema oscilante.

HERTZ.- La unidad de frecuencia ciclos/segundo.

MICROBAR.- La unidad de presión comunmente usada en acustica

$$1 \text{ uBar} = 1 \text{dyn/cm2} = 0.1 \text{ New/m2}$$

ONDA PLANA.- Una onda en la que la onda frontal esta formada por planos paralelos, normales a la dirección de propagación del fenómeno.

TONOS PUROS.- Una onda sonora de presión sonora instantanea, que es una función senosoidal en relación al tiempo.

ENERGIA SONORA.-La energia total en una parte dada en un medio, menos la energia existente en esa parte del medio cuando no hay ondas sonoras presentes.

CAMPO SONORO.- Una región conteniendo ondas sonoras de interes.

INTENSIDAD SONORA (IL).-Es el promedio de la energia sonora transmitida en una dirección específica a traves de la unidad normal de área en esa direccion.

POTENCIA SONORA (PWL).- Es la energia sonora total cruzando una área especifica en la unidad de tiempo.

Nivel de Presion Sonora(SPL).- Es la Presión total instantanea del sonido menos la presión estática en ese lugar.

ESPECTRO SONORO.- Es la representación de la magnitud de los componentes de un sonido complejo, en función de las frecuencias.

VELOCIDAD DE PROPAGACION.- Es la velocidad a que la onda frontal viaja a traves de un medio.

FRENTE DE ONDA.-Es la superficie continua en movimiento de una onda sonora en la misma fase en un momento dado.

LONGITUD DE ONDA.- Es la distancia perpendicular entre dos ondas frontales, que tienen una diferencia de un período completo (distancia entre cresta y cresta).

ABSORCION DE SONIDO.-Es el cambio de la energia sonora en alguna otra forma de energia, usualmente calor, en pasar de un material a otro, o al chocar la energia contra una superficie. La unidad de absorción de sonido es la equivalencia de lo que puede absorber un metro2 de ventana abierta hacia el aire libre, con respecto a lo que pudiera absorber un material determinado con su misma superficie.

AISLAMIENTO SONORO.- Es la resistencia que opone un material a transmitir el sonido entre un lado y otro del mismo; y generalmente esta en función de la masa y de la inercia. Se mide normalmente en decibeles y depende del coeficiente"T" de transmisión de cada uno de los materiales.

TIEMPO DE REVERBERACION.- Es el tiempo en que un sonido, una vez que se ha suspendido su emisión, tarda en disminuir, a traves de las reflexiones de un recinto, 60 dB de su intensidad inicial; o a la 10^{-6} de su intensidad inicial.

I. Importance of hearing

A. It is not until we lose some of our sensory capabilities that we realize how remarkable they are — and how little of the "real" world exists for us without them

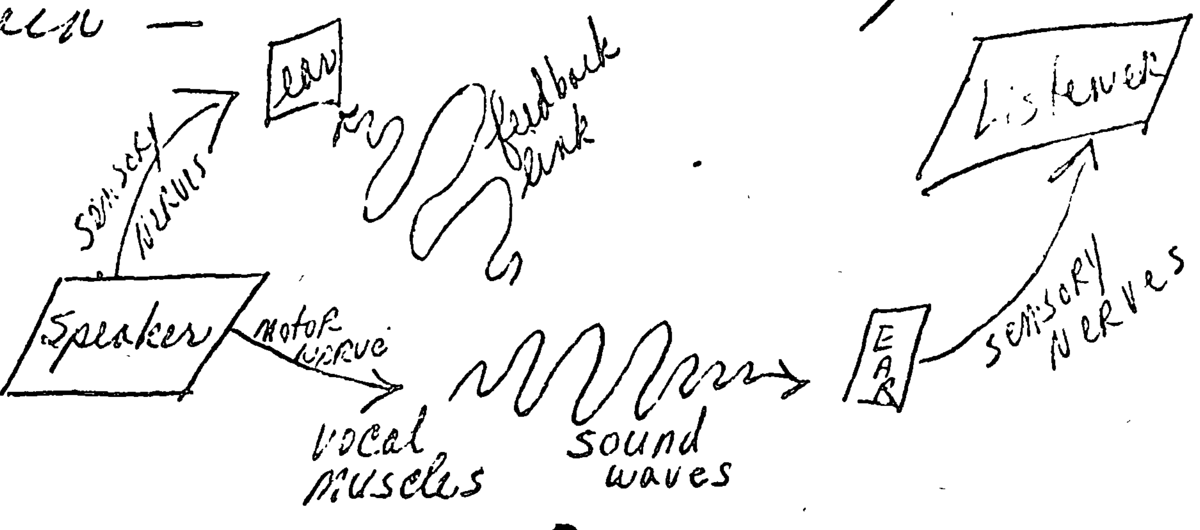
B. Hearing

1. Lower animals — can mean the diff. betw. life + death.

Locating prey
protection
warning

2. Man — also some primitive functions
- but pleasure

Important role in sequence of activities we call the Speech Chain —



II. Anatomy & Physiol.

A. General function—physical function of the hearing sense organs is to receive acoustic vibrations and to convert them into signals suitable for transmission along the auditory nerve toward the brain. Complex processing of these signals in the brain creates the perceptual world of sound

B. Let's walk through the ear
outer - mid. - inner

(1) Outer ear
Auricle - ear canal - eardrum

~~Au~~ Auricle - in animals used to channel & localize sound.
similar function in man - but to very limited extent

EAR CANAL - air filled passage - about one inch long - closed at one end by eardrum - open at other to outside.
Sound waves travel to eardr.
— Acts as acoustic resonator - Amplifies sound waves at freq. near its resonating freq. (3-4000 Hz) - may be 2 to 4 times greater pressure at eardrum than at entrance

— serves to protect eardrum from physical damage + changes in temp. + humidity

EARDRUM (TYMPANIC MEMBRANE) separates outer + middle ear.

(2) Middle Ear
-chamber is cavity in bones of skull

Ossicular Chain
3 small bones - connected
Malleus (hammer) - attached to eardrum - covers over ½ of drum area - receives motions of ear drum transfers to
Incus (anvil) - which is connected to the Stapes (stirrup)

footplate of stapes covers OVAL WINDOW — entrance to inner ear.

2. Functions -
-increases the amount of acoustic energy entering fluid filled inner ear.
— to protect the inner ear from extremely loud sounds — by using some antagonistic muscle actions — but unfortunately this does not occur instantaneously — and sudden loud sounds (gunshot) can cause permanent damage.

Eustachian tube

(3) ~~Middle~~ Inner Ear

a small intricate system of cavities in the bones of the skull.

One cavity - coiled like a snail's shell - THE COCHLEA - accomodates the important transformation from mechanical ~~energy~~ vibrations to nerve impulses.

Cochlea divided - 2 distinct regions - by a membraneous structure called the COCHLEAR ~~PARTITION~~ DUCT PARTITION - the interior of this partition forms a 3rd region

OVAL WINDOW - on entrance to inner ear - on this side of C.P. lies the SCALA VESTIBULI - on the other side is the SCALA TYMPANI.
Both are filled with PERILYMPH - a fluid almost twice as viscous as water.

An opening in the apical end of partition allows perilymph to pass freely between two scalae - opening called HELICOTREMA.

At the basal end of the cochlea the Scala tympani ends at the round window - a membrane covered opening that leads back into middle ear. (accom. flow of fluid - pressure release allows room for vibration)

COCHLEAR DUCT (center of partition)

(~~partition vibrates when excited by~~ sound vibrations - which cause pressure variations in fluid - causes whole partition to vibrate) —

filled with ENdolymph - highly viscous - jelly like -

Reisners Membrane - forms boundary between S.V. & duct

BASILAR MEMBRANE - separates duct from S.T.

central bony ~~me~~ shelf extends out of core of cochlea - one end of basilar mem. is connected - other end conn. to spiral ligament which coils along outside wall of cochlea.

B.M. - very narrow at ~~bony~~ basal end (near oval window) and quite stiff & light

most lax & massive at helicotrema.

Mechanical properties relate to pattern of excitation

~~Low~~ high freq. - vibration in partition is highest near oval window

visa - versa

We still have not converted the mechanical motion of the basilar membrane into electro-chemical nerve symbols that can be transmitted to brain.

The "converting" organ —
The ORGAN OF CORTI — is made up of many minute hair cells

One end of each cell rests on the basilar membrane — and the other end is imbedded in the TECTORIAL MEMBR.

4 ROWS of hair cells
1 row - inner
3 rows - outer
about 3500 inner cells
20,000 outer cells

These cells — in response to vibrations of the basilar membrane — and hair cells are transmitted to the related nerve cells (hair cells receive → nerve cell) — and transfered into electro-chemical energy —

Transmitted along auditory nerve to brain where perceived as sound —

III. Audiometry

hearing is usually measured using a pure tone audiometer
USE AUDIOM + AUDIOG. — air + bone cond.

Results are recorded on an audiogram

Measure:

A. Frequency
125 Hz to 8000 Hz
(range of useful hearing for human ear is 20 to 20,000 Hz at peak)

B. Intensity
decibel -

Audiometric 0 - arbitrary sound pressure level - ~~at which gue~~ - threshold of hearing for "average" normal ear as conducted during a health survey of a U.S. Publ. health service in 1936-37 ~~(mention ISO)~~
ASA adopted 1951
~~Sound pressure levels in dB~~ are based on 0.0002 dyne/cm²

Mention ISO (1964)
European studies - lower thresholds

Sound pressure levels in db re 0.0002 dyne/cm²
for audiometric 0 (ASA & ISO)

	Frequency	ASA	ISO
Aud. 0	125	54.5 db	45.5
	250	39.5	24.5
	500	25.0	11.0
	1000	16.5	6.5
	1500	(16.5)	6.5
	2000	17	8.5
	3000	16	7.5
	4000	15	9
	6000	17.5	8
	8000	21	9.5

diff. shown on audiogram

add # to threshold for ISO (from ASA)

Audiometer should always be checked to see whether calib. is to ISO or ASA.

Frequency = psychological correlate of pitch -

Intensity = loudness

eg. 0 dB - sound barely perceptible (threshold of hearing)

20 dB - av. whisper - 4 ft from speaker

40 dB - level of night noises in city

70 dB - Normal conversation at [illegible]

a distance of 3 ft.
90 dB - pneumatic drill 10 ft. away
115 dB - hammering on a steel plate 2 ft. away
120 dB - threshold of feeling
140 dB - pain

Another reference point - hearing loss

20-40	dB	mild
40-60	dB	moderate
60-75		severe
75-100		profound

Important speech frequencies for speech are 500, 1000, 2000 - a mild loss through these frequencies may be debilitating

<u>Hearing Testing in an industrial program</u>

(1) Reference Audiogram

(A) Room = properly sound treated -

That is - so that a normal-hearing listener can ~~hear~~ respond to all test tones from 250 Hz - 6000 Hz at a hearing level of 0 dB -

Can be ~~accop~~ accomplished if

If the band levels ^in room^ do not exceed:
40 dB - for octave bands) 150-300
300-600
600-1200

48 db for oct. Bands ~~2400-4800~~ 1200-2400
57 for 2400-4800
and 67 for 4800-9600

(B) Audiog. should include thresholds by air conduction for. 250, 500, 1000, 2000, 3000, 4000 + 6000 Hz

3000 cps. (not always used in regular threshold testing) is included because some states in U.S. include it in ~~their~~ computing percentages of hearing loss — and also a loss at 3000 cps is known to affect discrimination of speech materials under conditions of difficult listening.

6000 is the highest frequency tested as results at 8000 are comparatively unreliable.

(C) Audiometer

- Usually a standard pure tone ~~ob~~ audiom. - results often obtained by industrial nurse

(Zenith - Maico - Beltone)

May be obtained by use of automatic audiom. –
subject pushes a button and results are automatically recorded
(Rudmose ARJ)
– as described in
James F. Jerger, ed.
(1963) Modern Developments in Audiology
Academic Press
New York, N.Y.

For all new & current employees
– esp. if working under hazardous noise conditions.

(2) Monitoring
first within 90 days
– If no change at any freq. of more than 10 dB – then yearly monitoring

Since 4000 cps is most sensitive to sound –
monitoring ~~bay~~ may be done at that freq. only.

NOISE INDUCED HEARING LOSS

All - in our modern society exposed to noise -
possible that our daily exposure to ~~noise~~ ordinary environmental noise contributes to the aging of our hearing mechanism.

PRESBYCUSIS - sensori-neural hearing impairment often attributed to advancing age - was called SOCIOCUSIS (re: sociological) - as there is evidence to suggest that primitive tribesmen in Africa - do not show any appreciable decrease in hearing acuity with advancing age.

(1) Acoustic Trauma
- sudden loss of hearing - due to blast, explosion - etc.
may cause ruptured ear drum as well as permanent damage to the hair cells in the Organ of Corti

(2) Noise Induced Hearing Loss
— Your main concern
A. Amt. of hearing impairment incurred from noise exposure is proportional to the intensity of the stimulus and the length of the exposure
— also - consider individual susceptibility - No reliable tests for

susceptibility — but anyone showing dip at 4000 cps should take precaution in noisy situations

B. Loss associated with noise exposure is sensori-neural (as oppos to conductive) — and cochlear in origin.

Usually begins with a dip or notch in audiogram at 4000
gradually shows a deepening and widening notch.
(use Audiogram

C. ~~T~~ Temporary Threshold Shift vs Permanent Threshold Shift

TTS — after short exposure to noise — notch in audiogram may disappear after period of rest — i.e. hair cells become fatigued but are not damaged permanently
TTS may be induced with as little as 15 min. of exposure to intense noise.

After continued exposure — 4000 — notch begins to widen — eventually does not recover after rest — becomes Permanent Threshold Shift.

Typical progression in hearing loss as a function of years of exposure to industrial noise of high intensity

AUDIOGRAM

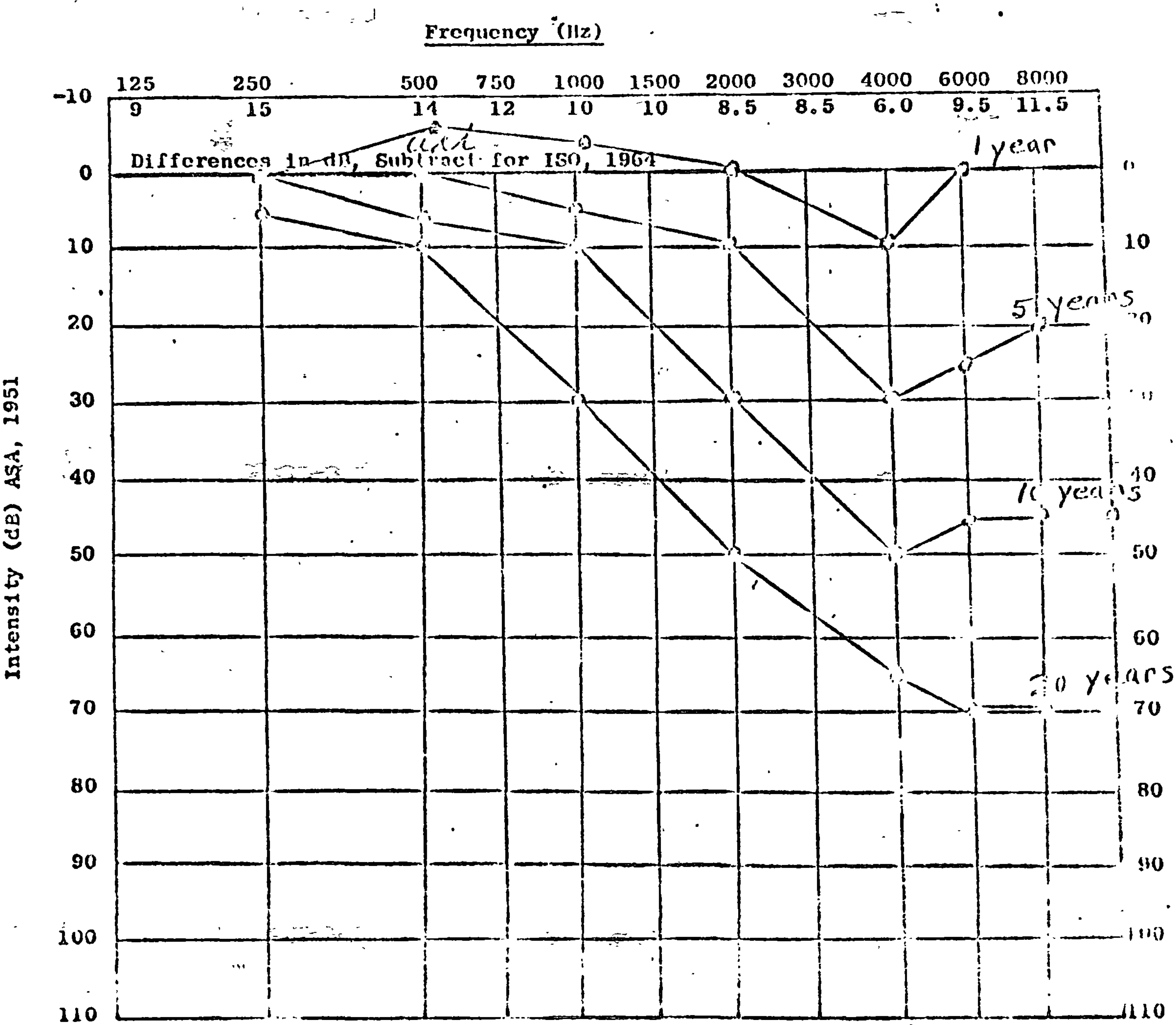
☐ 1964 ISO Reference Thresholds

☐ 1951 ASA "

NAME: ______________________ DATE: __________

AGE: ______ SEX: ______

OCCUPATION ______________________ YRS. ON JOB: ____



Air Conduction (O = Right Ear (X = Left Ear

Bone Conduction (> = Right Ear (< = Left Ear

(14)

Noise induced hearing loss can occur without the affected individual being aware that his hearing is being damaged -

Noise - sound is not uncomfortable (painful) until it reaches 120-140 db - but sounds much lower can produce damage

Also - early damage usually does not include speech frequencies - 5 - 2

only when notch widens ~~is there~~ (i.e. to include 2000) is there any noticeable effect on speech - by then it may be too late to reverse damage.

③ Other effects of noise

Interference with communicatio (esp. if safety is concerned.)

Psychological effects

Interference with production rates, etc.

EAR PROTECTORS

Most effective – to control noise at the source

If this is impossible – use ear protectors

Two types

① Inserts

Ⓐ disposable – such as wax-impregnated cotton

Ⓑ or. of rubber or neoprene — these are usually made in 5 or 6 sizes as the must fit the ear canal snugly to be effective –

may require a diff size for each ear.

Inserts should be fitted by a trained person – to insure proper size selection.

Can be uncomfortable

diff. for supervisor to check at a glance

② Muffs

do not require special fitting

May be more comfortable for long wear.

Somewhat more efficient than inserts.

disadvantages - may not get a tight seal when worn with glasses - are very hot if working in a warm area.

- Some muffs come with liquid filled seals that increase attenuation
- May be fitted with helmets that protect the whole head
- May be used as cushions for earphones and serve a dual purpose.

(c) In conditions of extreme noise

maximum attenuation is provided by the use of inserts and muffs. (see chart)

Difficulties in getting employees to cooperate - almost has to be a mandatory program

WARNING - Dry cotton is is almost useless as an ear protector.

Attenuating Characteristics of Ear Protectors 17 *EAR PROTECTORS*

AUDIOGRAM

☐ 1964 ISO Reference Thresholds

☐ 1951 ASA " "

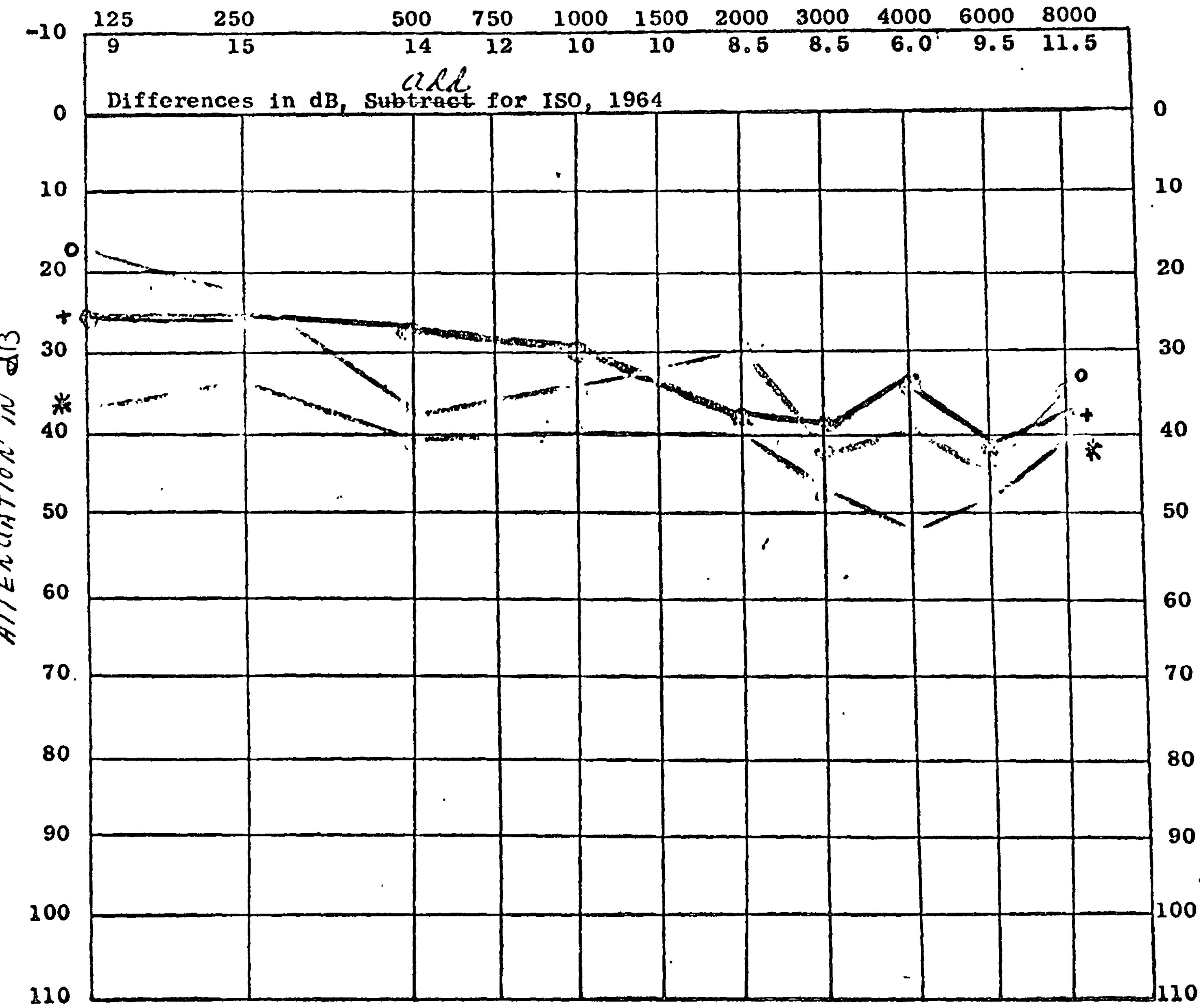
NAME: ____________________ DATE: __________

AGE: ______ SEX: ______

OCCUPATION ____________________ YRS. ON JOB: ______

O —— Ear Muffs
+ —— EAR plugs (Inserts)
** —— Combination*

Frequency (Hz)



Air Conduction (O = Right Ear (X = Left Ear

Bone Conduction (> = Right Ear (< = Left Ear

Urban Planning & Noise Control

Clifford R. Bragdon, Contributing Editor

Noise represents a major environmental problem capable of being a nuisance or a hazard to the population. Several land use management techniques for noise abatement are discussed, including site design analysis, environmental zoning, building codes, noise ordinances, and Federal environmental legislation. The future noise status of urban areas is dependent upon controls either initiated by or implemented by the urban planning profession.

With diminishing resources available to meet the requirements of an expanding population, the need for managing the urbanizing environment becomes more urgent. By virtue of his position the urban planner is frequently called upon to assess and plan for the preservation of the environment. Whether it is the evaluation of a proposed transportation route, an airport facility an industrial park or enforcing general zoning performance requirements, the planner's course of action oftentimes influences the level of environmental protection. Noise represents one of the environmental pollutants festering in the cities, and the need for urban planners to render effective solutions is growing in importance.

Environmental Noise Impact

The impact of noise upon human health[1] is becoming well documented[2-5] with the range of influence from nuisance to hazardous effects (Figure 1). The Report to the President and Congress prepared by the Environmental Protection Agency indicated that within the United States approximately half of this total are adversely affected in terms of physical health.[6] Most urban generated noise sources are predominately nuisance problems capable of interfering with human efficiency or personal comfort and enjoyment.

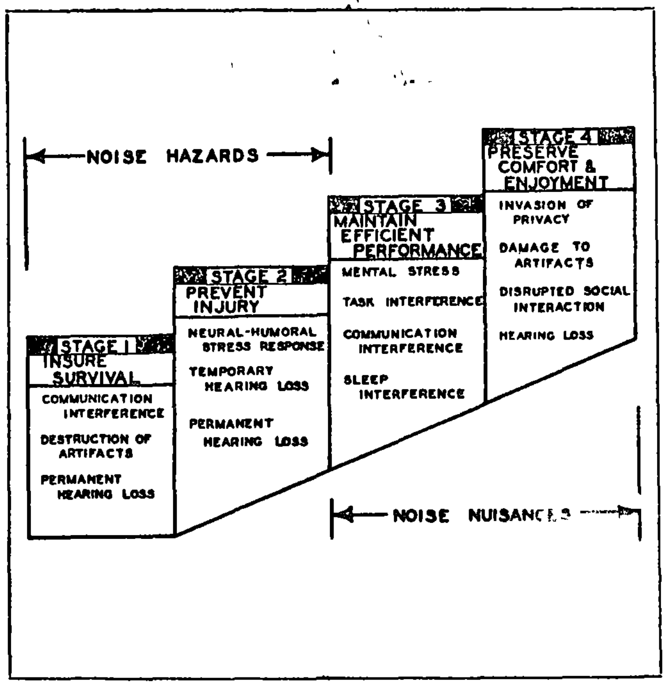


Figure 1—Implicated health effects of noise.

Damage to Physical Objects (Artifacts). Many natural and man-made features in the environment have become increasingly vulnerable to an ever expanding technology of which noise is a by-product. It is estimated that over 2,000 square miles of land area associated with airport and highway development can be classified as noise sensitive.[7] Noise sensitive land is defined as that land area, exclusive of airport and highway ownership, exceeding a Community Noise Equivalent Level (CNEL) of 65 dB. Certain land use activities, principally involving trans-

Table 1—Airport noise litigation: 1971.

Airport	Location	Case	Plaintiff	No. of Plaintiffs	Damages Sought
Charlotte Municipal	Charlotte. North Carolina	1	Citizen	1	$ 16,800
Houston International	Houston, Texas	1	Citizen	4	384,060
			Citizen	9	1,895,000
			Citizen	1	18,171
Jefferson County	Beaumont, Texas	1	Citizen	38	551,639
Lambert Field	St. Louis, Missouri	1	Citizen	1	117,000
Logan International	Boston, Massachusetts	1	Municipality	1	10,000,000
Los Angeles International	Los Angeles, California	1	Citizen	94,000	2,350,000,000
		3	Citizen	3	150,000,000
		28	Citizen	28	3,957,000
		1	Municipal		1,500
New Haven	New Haven, Connecticut	1	Citizen	7	18,400
			Municipality	1	
O'Hare International	Chicago, Illinois	1	—	—	17,800
Philadelphia International	Philadelphia, Pennsylvania	1	Citizen	1	2,000
San Francisco International	San Francisco, California	1	Citizen	12	360,000
		1	Citizen	30	300,000
		1	Citizen	20	—
Tucson International	Tucson, Arizona	1	—	—	—
Will Rodgers World	Oklahoma City, Oklahoma	1	Citizen	13	130,000
Total		48			$2,517,769,970

portation are generating a significant degree of community annoyance occasionally resulting in litigation. Intruding noise from airport and highway activity for example has constituted a legal taking of property without just compensation, and some residents have sought relief through the court system. Between 1955 and 1972 over $2,000,000 was awarded to property owners in civil airport noise cases. Although court settlements are generally much smaller than the amount sought by the litigant, the dollar value for damages is geometrically increasing. In 1962 plaintiffs were seeking $14,500,000 in airport noise litigation. This figure had reached $200,000,000 by 1968, and in 1971 it climbed to approximately $2.5 billion,[8] (Table 1). Present indications are that the total sought by plaintiffs exceeds $5.5 billion, with a major portion associated with the Los Angeles International Airport. Highway noise litigation is also gaining prominence where similar land use compatibility problems exist. During 1971 the New Jersey Superior Court awarded $160,000 to Elizabeth, New Jersey Board of Education because highway noise interferred with the educational learning process, including the oral control of pupils.[9] The ultimate court award is scheduled for acoustically treating the structure sufficiently to resume classroom instruction free from external noise intrusion.

The basis of complaints, and possibly subsequent legal action is not solely due to transportation or mobile noise sources however. Industrial activities are commonly involved in litigation proceedings. Based upon complaints to the Chicago Department of Environmental Control nearly 40% of all complaints received over a 16 month period have involved stationary noise sources[10] (Table 2).

Table 2—Community noise complaints: Chicago, IL (July 1971-October 1972).

Noise Source	Number	Percent
Stationary	1277	39.7
Mobile	1935	60.3
Total	3212	100.0

Table 3—Airport community response.

Zone	NEF Rating	Community Response
A	<30	Essentially no complaints would be expected.
B	30 to 40	Individuals may complain, perhaps vigorously.
C	>40	Individual reactions would likely include vigorous complaints, if repeated.

Invasion of Privacy. Unlike other senses, noise possesses a penetrative ability that respects few boundaries. Physiologically there is no effective self-regulating method for shutting off acoustic stimuli; consequently it is a 24 hour, 360° sense. Since environmental noise occurs independently of territorial restrictions, and there is limited human adaptive capability it oftentimes invades individual privacy.

To assess the impact of airport noise on metropolitan residential areas the U. S. Department of Housing and Urban Development instituted a Metropolitan Area Noise Abatement Policy Studies (MANAPS) program at a selected group of airports. Noise Exposure Forecasts (NEF) were prepared, based on certain acoustical and operational aircraft information to predict airport community response (Table 3). A land use compatability classification was developed using expected airport community response criteria. Based upon the NEF rating a Zone C (NEF 40) or a Composite Noise Rating (CNR 115) is considered a heavily impacted noise area unsuitable for residential development while a Zone B condition (NEF 30 and 40) or (CNR 100 and 115) is a moderately impacted noise area suitable for residential development when specific acoustical controls are instituted. Only a Zone A condition (NEF 30) or (CNR 100) is always satisfactory for urban development.[11]

Invasion of acoustical privacy is widespread, based upon the results of three MANAPS involving O'Hare International Airport, Chicago, Illinois[12]; John F. Kennedy International Airport, New York City[13]; Cape Kennedy Regional Airport, Melbourne, Florida[14] (Table 4). Applying the NEF contours to the existing residential areas of New York, Chicago, and Melbourne indicates that over 22,000 residences having a market value in excess of $2 billion are in Zone C, while an additional 153,000 residences valued at $7.4 billion are located in Zone B. In total, nearly 175,000 residences valued at approximately $10 billion are situated on land considered undesirable for residential development (based on 1970 land use information).

Environmental Noise Controls

The proper management of environmental noise requires a study of three interrelated components of the problem: the source, path and ultimate receiver. The failure to consider any one of these components will reduce the effectiveness of any proposed solution.

Treating the noise at the source is clearly the most direct and desirable approach. However, apart from the fact that this solution may be technologically and/or economically impractical, communities may not have the necessary legal jurisdiction. The operational control of

Table 4—Noise exposure forecast.

Urban Area	Airport	NEF 30 (Zone B No. of Residents	NEF 30 (Zone B Estimated Market Value	NEF (Zone C) No. of Residents	NEF (Zone C) Estimated Market Value
Chicago, Illinois	O'Hare International	81,226	$2,296,489,000	9,714	$ 236,143
New York City, New York	John F. Kennedy International	72,111	5,160,176,648	12,918	1,814,633
Melbourne, Florida	Cape Kennedy Regional	81	810,470	—	—
Total		153,418	$7,457,476,118	22,632	$2,050,776

navigable airspace, including the noise generated by aircraft in flight, is exclusively a Federal responsibility. There appear to be certain controls available to the operator that may reduce land use impact (e.g. runup-maintenance restrictions, preferential runway usage, nighttime curfews). The extent to which these techniques may be applied by non-Federal agencies is a legal question still to be decided. Adequate site design considerations, including a master land use plan prior to initiating a project is a desirable preventive measure. Treating the path along which noise travels, rather than the noise source itself is a common solution. Some type of barrier, either man-made or natural, which diverts, reflects, absorbs or dissipates the sound are typical applications at industrial sites or along major roadways. The last resort, and often the least desirable solution, is to treat the noise at the site of the receiver. There are a variety of urban planning techniques that are applicable to all three components of the noise control problem.

Comprehensive Plan. The comprehensive plan, sometimes referred to as the general or master plan, usually is an official public document adopted by a municipality. This plan is a policy guide to decisions about physical development,[15, 16] consequently it is concerned with land use management practices. It is comprehensive because it encompasses an entire municipality and also general since the plan summarizes policies and proposals but does not often denote specific locations or detailed regulations. To be useful in guiding the future growth of an area these plans are usually long range, covering a period from 10 to 30 years.

Basic elements of the comprehensive plan include: the private uses of land, community facilities and circulation or transportation.[15] All three of these elements involve decisions influencing land use compatibility and potential environmental impact. The recognition of community generated noise, among other environmental insults, is an important ingredient to a successful comprehensive plan.

Historically the urban planner has all too often neglected to consider noise among other factors in the comprehensive plan. Fortunately the situation is changing due to a variety of influences.

Occasionally municipalities have recognized the potential noise problem, and consequently have recommended solutions in the general plan. This is particularly so with municipalities having a commercial airport facility. The Syracuse-Onondaga County Planning Agency comprehensive plan for Salina, New York was one of the earliest successful efforts.[17] It incorporated environmental factors associated with airport development in the comprehensive plan. Due to the local nature of the airport noise problem a specific neighborhood plan was ultimately adopted for that portion of Salina in May, 1967.

Based upon the U. S. Department of Defense Manual, *Land Use Planning with Respect to Aircraft Noise*,[18] and a Federal Housing Administration mortgage policy on residential development a series of goals were issued as part of the comprehensive plan to specifically:

> "discourage, within the airport noise zone, the construction of residential structures, etc., that cannot be sufficiently insulated against externally generated aircraft noise, at a reasonable cost;
>
> recommend and adopt a comprehensive land use plan for that portion of the Town of Salina within the Airport Noise Zone, which would: (1) permit the owners of vacant parcels of land to develop their properties with (and uses that would be compatible with aircraft noise, and surrounding land uses); and (2) provide land uses and physical buffers for the protection and preservation of existing, established residential neighborhoods;"[17]

Other cities including Atlanta,[19] and Detroit[20] during this same time period recognized the airport noise problem however their plans ultimately achieved less success. A growing number of municipalities are considering airport noise provisions in their general plan since the adoption of the U. S. Housing and Urban Development policy circular on noise abatement and control, in late 1971.[11]

The eligibility for any HUD related programs are dependent upon satisfying these noise standards. Municipalities seeking Federal funds for airport noise impact sites exceeding the policy criteria (Table 5) do not receive HUD assistance. Although these residential standards are not universally enforced by all HUD region and area offices, planning without regard to noise impact can prove costly. Funds for running trunk and lateral utility lines into the city of Robertson, Missouri were denied by this Federal agency.[21] A requested $360,000 grant was withheld because of the noise problem associated with the adjacent Lambert Municipal Airport operated by the city of St. Louis. These utility lines would have further encouraged residential development in a non-compatible land use area.

Besides airport development, comprehensive plans are beginning to consider surface transportation development and its potential impact. To be eligible for Federal-aid participation, as specified in the Federal Highway Act of 1970, all applicable projects shall meet noise standards requiring highways to be compatible with different land uses. Effective July 1, 1972,[22] allowable design noise levels have been established for various land use categories. It is based on that noise level exceeded 10% of a given time period, expresed in dBA (Table 6). If these

Table 5—External noise exposure standards: Department of Housing and Urban Development.

General External Exposures	Assessment
Exceeds 80 dBA 60 minutes per 24 hours Exceeds 75 dBA 8 hours per 24 hours Noise Exposure Forecast (NEF)>40 Composite Noise Rating (CNR)>115	Unacceptable Exceptions are strongly discouraged and require a 102 (2) C environmental statement and the Secretary's approval
Exceeds 65 dBA 8 hours per 24 hours Loud repetitive sounds on site Noise Exposure Forecast (NEF) 30-40 Composite Noise Rating (CNR) 100-115	Discretionary—Normally Unacceptable Approvals require noise attenuation measures, the Regional Administrator's concurrence and a 102 (2) C environmental statement
Does not exceed 65 dBA more than 8 hours per 24 hours	Discretionary—Normally Acceptable
Does not exceed 45 dBA more than 30 minutes per 24 hours Noise Exposure Forecast (NEF)<30 Composite Noise Rating (CNR)<100	Acceptable

levels are exceeded in the planning of a Federally aided highway then noise abatement measures must be incorporated in the highway design.

Open space areas associated with public parks, or similar tracts of land where noise intrusion will adversely affect the land use activity is the most sensitive category. This requires a design noise level, L_{10}, of 60 dBA. With each succeeding category of land use a higher noise level is permitted. Residential areas are permitted to be 70 dBA, along with active recreational areas.

The State of California under their planning enabling legislation requires that each locally designated planning agency establish a general plan. A recent amendment to this planning law requires that agencies incorporate noise as an element in the general plan.[23] Equal energy noise contours are necessary for all existing and proposed transportation related activities, including: (1) highways and freeways, (2) ground rapid transit systems, and (3) ground facilities associated with all airports operating under a permit from the State Department of Aeronautics. These contours presented in minimum increments of five decibels are continued down to 45 dBA for areas having sensitive land uses (e.g. hospitals, rest homes, long-term medical care, and outdoor recreation areas). For all other land uses a threshold of 65 dBA is required. Although no noise criteria are specified, conclusions regarding appropriate site or route selection alternatives or adverse noise impact upon compatible land uses shall be in the general plan.

It appears that the use of similar type provisions will be expanded to other states as well. The Second Annual Symposium on State Environmental Legislation recently recommended a state enabling noise control act.[24] Sponsored by the Council of State Governments, this act, among the several provisions, recommends that local jurisdictions include a noise control plan as part of the comprehensive planning process.

Although some cities have prepared comprehensive plans containing noise elements they are few in number. As earlier mentioned, planners have either been insensitive to the impact of noise or have yielded to political pressures. Permisiveness on the part of the New York City Planning Commission in 1967 paved the way for the construction of two high-rise apartment towers directly under the approach pattern to La Guardia Airport. These towers, subsequently completed, house over 8000 persons who are exposed to aircraft noise described as being: "equivalent to a diesel freight train traveling at 50 miles per hour passing at a distance of 100 feet every 45 seconds" Outdoor sound level measurements in the vicinity of these apartments approach 100 dBA during these aircraft flyovers. The planning commission has adopted a similar attitude toward the location of heliport facilities in heavily populated areas of Manhattan. This permissiveness is not unique to New York; similar examples are found throughout the United States. However, the situation will improve as the present legislation at all governmental levels is enacted and implemented.

Zoning. To be effective the comprehensive plan must be implemented. The urban planner has at his disposal a variety of techniques to accomplish this objective of which zoning is the most popular. Zoning is a legal technique that regulates various aspects of land use development including:

(1) Height and bulk of structures.
(2) Area of a parcel which may be occupied and the size of required open spaces.
(3) Density of population.
(4) Use of structures and land for residential, commercial, industrial or other purposes.

A zoning ordinance usually classifies or subdivides land into use districts. Permitted uses are usually specified for each district, including various physical requirements.

Ordinances containing acoustical criteria are generally designed to regulate fixed (stationary) noise sources. The use of zoning is a specific urban planning technique that may contain emission performance requirements, including noise. Initially adopted by Chicago in March, 1955, there are now at least 53 municipalities which regulate the type of land use based upon noise emission requirements.

The City of Chicago, with assistance from the Armour Research Foundation, produced the first industrial performance zoning ordinance.[25] Rather than specify the allowable land uses according to type of industry permitted (i.e. heavy, or light industry), it classified industrial activity by performance standards. Revised in 1971, the provisions of this ordinance for example contain a maximum allowable noise level of 61 dBA at the nearest residential property line for industrial areas zoned M3-1 to M3-5.

In many cases, the ordinances have limiting noise levels for residential, commercial or business, and manufacturing or industrial districts. This technique is capable of controlling the type of land use that may be located in a prescribed urban area. There is however a wide range in the maximum noise limits among city ordinances.

Table 6 — Design and noise level/land use relationships.

Land Use Category	Design Noise Level L_{10}	Description of Land Use Category
A	60 dBA (Exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 dBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playground, active sports areas, and parks.
C	75 dBA (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	—	For requirements on undeveloped lands see paragraphs 5.a(5) and (6) of PPM 90-2.
E	55 dBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

By converting the maximum limits in 23 ordinances into A-weighted sound levels expressed in dBA comparisons are possible (Figure 2).[26] The permissible fixed source noise levels allowable at residential boundaries range from 60 dBA to 40 dBA. A narrower range in the permitted noise level among these city ordinances is necessary to produce regulations that are enforceable and also protect the public health, safety and welfare.

There is a trend beginning among certain states to establish state-wide noise emission requirements. State requirements are in various stages of development in California, Colorado, Illinois and New York.[23, 27-29] Colorado enacted land use emission requirements in 1971, the first state to do so. Although using different land use classification systems three states have specific sound level criteria which generally correspond to three land use classes: residential-institutional, commercial, and industrial (Table 7).

In a few instances metropolitan areas composed of several local municipalities have attempted to plan for regional noise problems. Regional zoning can be an effective solution around airport environments. The Minnesota Airport Zoning Act is a tool for limiting the proliferation of noncompatible uses adjacent to any airport in the Minneapolis-St. Paul metropolitan area. The Metropolitan Council, a successor to the Metropolitan Planning Commission, is directed to develop and adopt a metropolitan development guide that includes the necessity for and location of new airports. This Council through the Airport Zoning Act has authority to establish aircraft noise zones, including acceptable levels, for all land uses. A similar scheme is being proposed on a regional basis with the development of the Dallas-Fort Worth Regional Airport. A regional airport zoning ordinance has been prepared for the North Central Texas Regional Planning Commission. Normal land use activities are classified into four groups with different sound exposure sensitivities. The city is divided into sound exposure zones which control the type of activity that may be located within each zone. The more sensitive the particular land use the lower the permissible noise level zone (Table 8). Although proposed for the Dallas-Fort Worth regional airport in February 1970 this ordinance has yet to be adopted. It is expected to be adopted as a "model" by the North Central Texas Council of Governments for 11 affected communities by July of this year.[32] In Europe some of the governments have adopted noise zone emission levels for various land use categories. Although noise criteria for land development do exist oftentimes they are not enforced.

Despite the preventive efforts to avoid subsequent noncompatible development in noise sensitive areas, zoning variances are routinely granted in most communities. The result is continued pressure to develop all possible areas as the real estate market dictates, without regard to environmental criteria.

The U.S. Department of Housing and Urban Development noise standards are an attempt to restrict certain types of development. Similarly the Federal Highway Administration standards can offer guidance to cities establishing or revising ordinances. Other Federal programs provide loopholes allowing noncompatible development to persist. Under the provisions of the Airport and Airways Development Act[34] municipalities are eligible to receive, from the FAA, Federal assistance when expanding or constructing an airport facility. Although they do recommend that airport noise contours be developed for the site, there are no requirements that incompatible land use development be restricted, to avoid future residential encroachment. Federal airport development assistance should be contingent on the submission of an *effective* land use management program by the municipality to insure that present and future compatible land use development will continue to occur.

Table 7 — State land use emission requirements: zoning.*

Category	Land Use	New York	Illinois	Colorado
Class A	Residential-Institutional	65 dBA Day 45 dBA Night	60-53 dBA Day 50-43 dBA Night	55 dBA Day 50 dBA Night
Class B	Commercial	65 dBA	65-53 dBA	60 dBA Day 55 dBA Night
Class C	Industrial	80 dBA	68-60 dBA	70-80 dBA Day 75-65 dBA Night

* The land use categories and A-weighted sound levels represent appoximate comparisons. See the specific proposed state laws for the details.

Table 8 — Noise sensitivity zones: Irving, Texas.

Zone	Land Use Classes	Noise Criteria*
I	Insensitive	>105 CNR
II	Moderately Sensitive	105-100 CNR
III	Sensitive	100-90 CNR
IV	Very Sensitive	<90 CNR

* Calculated by Composite Noise Rating or the equivalent exposure as calculated by any other noise method.

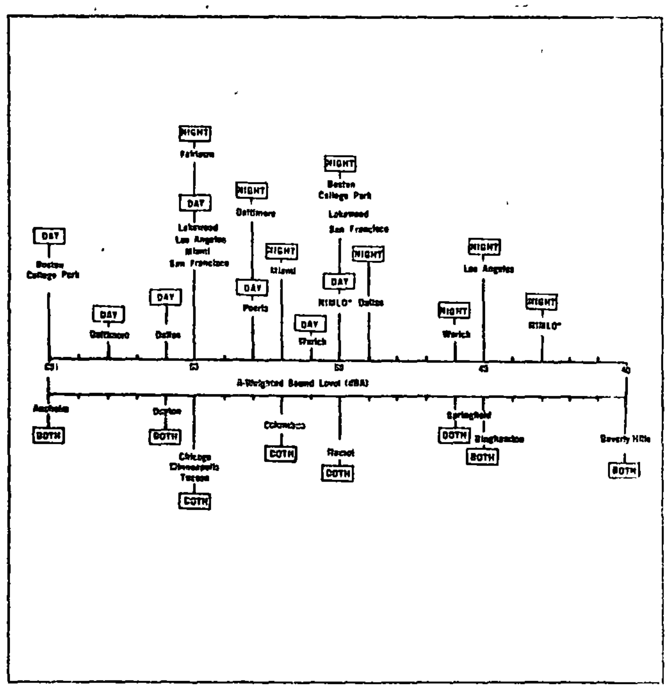


Figure 2—Fixed source noise levels allowable at residential boundaries.

Environmental Design/Site Planning. Environmental design and site planning review represents a major urban planning function. As part of the review process a developer could be required to prepare noise contours, or at least representative noise measurements for a site being developed Site design solutions would have to include noise control provisions if the prevailing or anticipated noise within the site would exceed a prescribed sound level. This has been a required procedure since 1967 in London whenever a town planner or architect is designing a public housing development. The London Housing Authority reviews such schemes with acoustical intrusion in mind.[35] Similarly many other major European cities have either formal or informal programs in this area.

Municipal or state agencies having noise control programs can greatly assist the urban planner in reviewing or evaluating various development proposals. Both the Chicago and Inglewood, California noise programs, because of their staff capability, are providing technical assistance to their respective planning departments.

A variety of site planning considerations can influence the impact of community noise. Setback requirements to minimize surface transportation noise have been developed by the National Board of Urban Planning in Sweden.[33] Street width requirements and their pattern (linear vs curvilinear) can alter the propagation of street generated noise.[36] Noise generation increases at street level with greater building density[2] therefore building density requirements, including varying amounts of height as well as open space can be effective environmental design solutions. The exterior treatment of buildings can also reduce the so-called "canyon effect" in high density areas caused by reverberation and reflection. Models are being developed to reproduce typical urban environments, and their acoustical patterns, in an effort to develop design solutions.[37] The orientation of interior building activities can be planned to minimize outdoor noise intrusions. In reviewing large scale development plans sensitive activity areas (eg. bedrooms) are recommended to be situated on the non-street side of the residential structure. Parking areas and other less sensitive site activities, oftentimes are used as buffers. In Oslo, for example, shops and commercial land uses are located adjacent to the freeway to act as a buffer between the highway and residential development.[33]

The actual type and design of the transportation system are critical planning decisions influencing the acoustic quality of the urban environment. In England the maximum allowable noise level for highway planning purposes is an L_{10} of 70 dBA. If this level is exceeded in the ultimate operation of the roadway affected residents are eligible to receive compensation from the British government to acoustically treat their homes.

The construction costs of alternative highway designs vary significantly based on experiences in England (Table 9).[38] Using a highway constructed at ground level as an index of 1, more sophisticated designs rise rapidly in cost. An alternative to modifying the actual highway are the utilization of various types of barriers. Consideration should be given to their attenuation properties, esthetics, maintenance as well as costs. Based upon limited barrier development experiences in England and Canada their relative costs will vary considerably (Table 10). (This cost data information is for specific installations and it may not be applicable to other sites, or geographical areas. More important than the specific costs are the relative ranking of the various highway and barrier design alternatives.

Table 9 — Construction costs of highway designs.

Highway Design	Average Index No.	In Millions Per Lane/Kilometer*
Ground Level	1	0.175
Depressed Open Cutting	1.5	0.263
Elevated On Embankment	2	0 350
Elevated: Retained	5	[illegible]
Depressed: Retained	5.5	0.962
Elevated: Viaduct	7.5	1.312
Tunnel: Board	13	2.275
Tunnel: Immersed Tube	25	4.375
Tunnel: Cut and Cover	14	2.624
Tunnel: Bored Under River	50	9.650

*Costs based on 1969 estimates (England)

Table 10 — Construction costs of barriers.

Barrier Type	Thickness	Cost/Lin. Ft. for 10-Ft. Barrier
Wooden Wall	¾"	$12*
Earth Berm	60" (Top)	$25*
Concrete Wall (Pre-Cast Cellular)	6"	$42 - $55*
Brick	—	$25**
Aluminum	3"	$40*
Gabion (Stone)	36"	$60*

** Estimate—Ontario Ministry of Transportation.
* Estimate—Greater London County Council.

A major reason for the increased interest in environmental site analysis is the promulgation of the National Environmental Policy Act (NEPA) which requires the preparation of environmental impact statements on proposals for legislation and other Federal actions significantly affecting the quality of the human environment.[39] Subsequent guidelines issued by the Council On Environmental Quality detail, among other things, environmental factors that must be considered in preparing an impact statement including noise. There are presently thirteen states that have established similar impact organizations and procedures, several modeled after the Federal program. Noise is being considered to varying degrees by these state programs. California and New York appear to have established the most comprehensive noise provisions.

Conclusion

Beside comprehensive planning, zoning, and environmental design-site review there are other urban planning techniques useful for controlling urban noise. These include subdivision regulations, housing and building codes, among others.

The future success of urban development will depend in part on recognizing and solving environmental problems. Various planning techniques offer a suitable vehicl for incorporating noise criteria. The acoustical engineer and related noise specialists can play a major role in assisting the urban planner in accomplishing his responsibilities.

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Procedures of a Sound Survey

By E. L. Alpaugh, P.E., industrial hygienist, International Harvester Company, Chicago.

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Procedures of a Sound Survey

The fourth in a series of articles outlining the fundamentals in the development of an industrial hearing conservation program discusses types of sound surveys, types of noise, the equipment needed, survey procedures, the recording of data, and the interpretation of results.

INDUSTRIAL HYGIENISTS often refer to their work as the recognition, evaluation, and control of occupational health hazards. As excessive noise may be a contaminant in the industrial environment, it must be evaluated using accepted industrial hygiene techniques.

Unlike some health hazards recognition of a noise problem is relatively easy, or at least obvious enough to make a person recognize that some evaluation measurements should be made. Complications arise when one attempts to evaluate the exposure in terms of hearing damage risk, although the recent development of a suggested *Threshold Limit Value* for broadband noise does offer a guideline in this respect. Control of excessive noise exposures may range from very simple to extremely complex engineering measures, or in some cases there may be no reasonable solution other than using ear protection devices.

Types of Sound Surveys

A survey of a noisy area may be made to evaluate hazard to hearing, as part of an engineering study, to determine speech interference levels, or to estimate annoyance levels. The survey made to evaluate possible detrimental effects on hearing acuity is the most common and the one that will be discussed here in the greatest detail. A survey of this type is reasonably easy to perform if the operating characteristics of the noise meters used are well understood by the person conducting the survey. In addition, the noise to be measured must be steady and broadband. That is, it must have an energy spectrum covering a fairly wide range of frequencies. The survey made to evaluate speech interference levels and annoyance levels also is relatively easy to perform but somewhat difficult to evaluate. This is especially true for the annoyance survey because of the extreme variation between individuals and their reactions to noise.

Sound surveys may also be classified by the amount of information that is needed. A screening survey, using a sound survey meter, can be made for rapid evaluation of the noise problems and to determine where a more detailed study is needed.

A detailed noise survey to evaluate hearing damage risk would be made to determine the overall noise intensity, the intensity of each of several octave bands, and the "on-time, off-time" pattern of exposure to the noise. This requires the use of a sound-level meter and an octave band analyzer in order to determine the sound pressure level in each octave band.

The various areas in the plant in which the noise survey is to be made should be investigated to determine what measurements would be representative. Work areas in which it is necessary to speak loudly into a person's ear to be understood are the logical places to start the survey.

Hearing Conservation Survey

The noise surveys made to evaluate hearing damage risk, annoyance, or speech interference are the types of surveys that the majority of safety professionals find most helpful. However, the safetyman ordinarily is far more concerned about what may happen to the hearing of a person who spends considerable time in a high noise level area. Thus, the results of a hearing damage risk survey become important to the man responsible for safety.

Engineering Surveys

Noise surveys for engineering purposes can be much more complex than the hazard evaluation survey.[1] As a general rule, the engineering noise survey requires a wider selection of noise measuring equipment as well as a good knowledge of acoustics by the people using the equipment. In addition, many more readings are required than are necessary to establish hearing damage data. The reason that fewer readings are required to evaluate hearing damage risk is that usually the sound pressure level at a single location, depending upon duration of exposure, relates fairly well to the effects of that noise upon people working in that particular area. Consequently, an octave band analysis of the noise, made at perhaps two or three different times, may be all that is needed, plus knowledge about exposure time, to evaluate the situation. This does not hold true for an engineering noise survey where one wishes to determine what noise level the source will generate in a different environment (for example estimating the effect that acoustical lining of a noisy room might have) or the noise level that might be observed at different distances. To make this kind of survey requires detailed information about the sound power output, its directional characteristics, and the variations in sound pressure levels as one moves radially away from the source of noise. A large number of octave band analyses and the use of specialized noise measuring equipment — such as a narrow band analyzer, impact meter, broadcast quality tape recorder, oscilloscope, or vibration measuring equipment and stroboscope—often are required to obtain enough information for evaluation of an engineering noise problem (see Figure 1). The subject

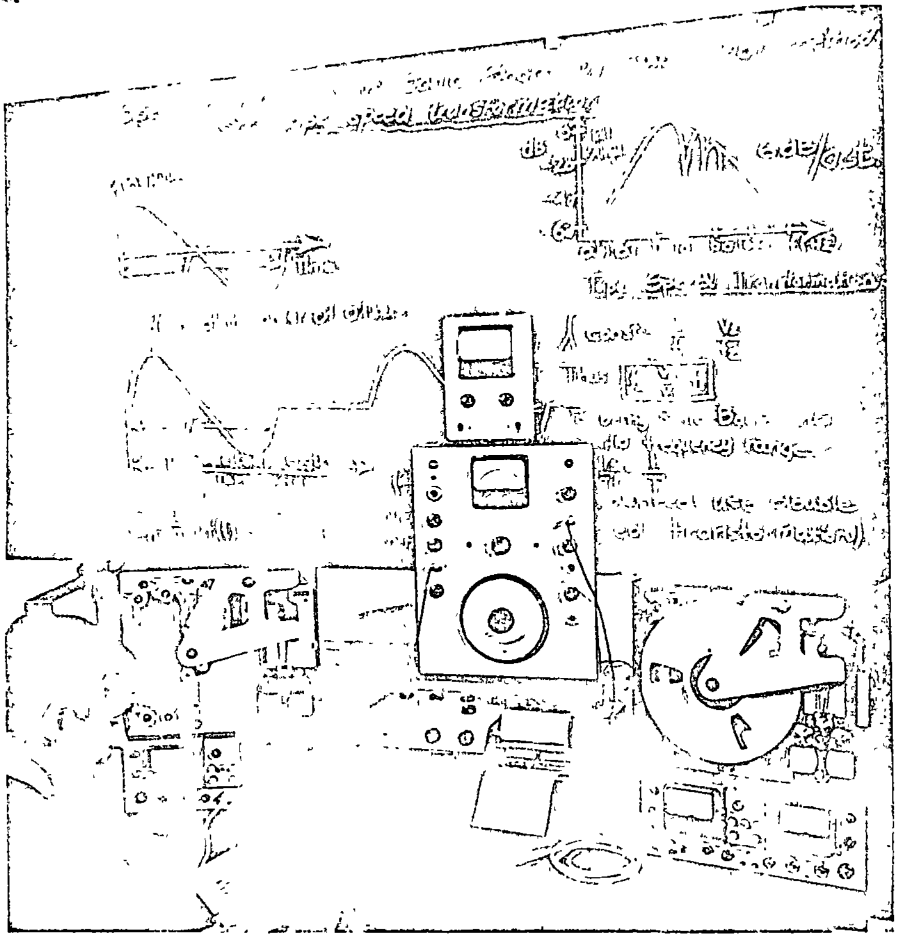


Figure 1 illustrates the complexity of instrumentation and interpretation of data required from engineering surveys.—Photo courtesy Bruel & Kjaer Instruments, Inc.

is complex and for further study the reader is referred to the references appearing at the end of this article. [1,2,3,4,5]

Types of Noise

The types of noise to be measured in a survey determine the equipment necessary for accurate measurements. Noise may be classified according to type as follows: wide-band; narrow-band; impulse; repeated impulse, and transient. Any of these could be steady, intermittent, or cyclic in nature, except transient which as its name implies, is not a steady noise. A passing train or aircraft generates noise of a transient nature.

Wide-band noise is defined as noise in which the energy is spread over a wide range of frequencies. Examples of this kind of noise are the noise generated in weave rooms in textile mills, in piston type aircraft, and in air moving through a duct.

Narrow-band noise is where the noise energy is concentrated in a narrow frequency range. Examples include noise produced by circular saws, generators, sirens, and compressors.

Impulse noise is characterized by its short-time duration and is created, for example, by explosions, drop hammers, punch presses, and similar operations.

Repeated impulse noise would be the type generated by chipping hammers, riveting operations, and foundry shakeouts.

Often during the noise survey, impact noise will be mixed with broadband noise, or there may be areas where impact noise predominates. It should be emphasized that efforts to measure impact noise with an ordinary noise meter will give completely inaccurate readings. The peak levels of the impact noise will be very much higher than the maximum meter readings obtained. Consequently, impact meters should be used to measure sudden sharp noise. If impacts are repeated at a rate of about 200 per minute, a noise survey meter will give an estimate of the overall noise level, although there is some difference of opinion in this respect. Some experts believe that any impact noise, even at rates exceeding 200 impacts per minute, should be measured with an impact meter if good accuracy is required. Nevertheless, most safety engineers do not have impact meters available and it is still a useful procedure to measure and evaluate *rapidly* repeated impact noise with an ordinary survey meter.

Instruments Needed

The actual taking of noise measurement readings is not too difficult. Two types of noise meters are necessary to obtain a reasonably detailed picture of the noise exposure involved. A sound survey meter and an octave band analyzer are essential and, in order to insure accurate readings (see Figure 2), it is necessary to have a calibration device to check the meters. These meters are complicated electronic devices, even though their physical dimensions may be rather small; frequent calibration checks are necessary to make sure they are functioning properly.

Auxiliary equipment that can be of great value in making a noise survey is a good set of headphones. Their use allows better evaluation of the noisy environment as well as a "running" check on the operation of the meters.

Sound level measuring instruments should fulfill at least the following requirements: [15]

- It should be accurate—a crude measurement is of limited value.
- Its accuracy, response, and other characteristics should be fully predictable and completely supported by readi-

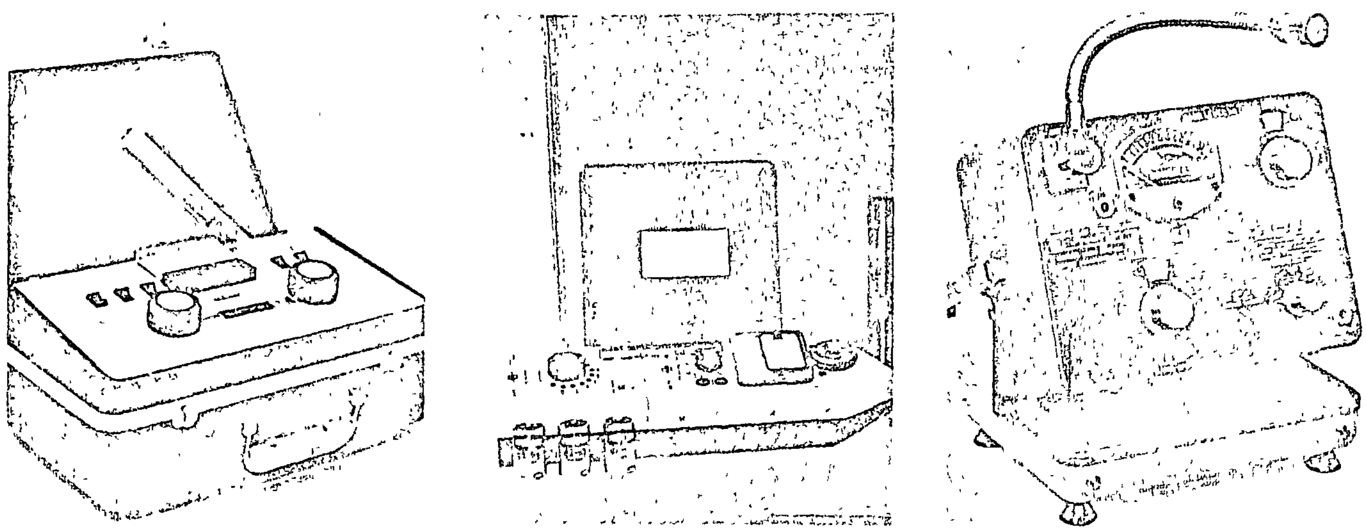


Figure 2 shows representative types of octave band analyzers (from l. to r. Tracor, Inc., B. & K. Instruments, Inc., and General Radio Co.).

ly available, published factory specifications and data.

- It should be rugged and simple to operate.
- When connected to its octave filter, it should be fully portable and convenient to use — preferably hand held (so that the free hand can operate it).
- It should have a dynamic range in decibels *re* .0002 microbar, including the octave band filter that will cover the region of interest.
- It should have a linear frequency response through the important range of 25 to 10,000 cps
- It should be substantially unaffected by temperature, humidity, vibration, and the electrical or magnetic fields normally encountered in noise surveys.

The USASI Standard Sl.4-1961 is frequently cited by both manufacturers and purchasers of sound-level meters as a minimum standard.

Interpretation of Instrument Readings

Before going into detail about noise surveys, there are several rather important facts about the measurement of noise that should be emphasized. First of all, if you have accurate, well-calibrated noise meters, if you are completely familiar with your equipment and the correct operational procedures, and if the noise being measured is steady broadband noise, the accuracy of your readings will probably lie within the range of plus or minus two decibels. In other words, do not try to read the noise level meter to a fraction of a decibel. In fact, unless the noise source is remarkably steady or a pure tone noise with no nodal patterns, an interpolation of the needle swings will be necessary even when using the slow scale. Better accuracy can be obtained if the microphone is mounted on a tripod and an extension cable used so as to put some distance between the microphone and the noise meter.

Occasionally a peculiar combination of noise source and environment will produce a noticeable standing wave pattern. The noise level increases or decreases as one moves a few feet toward or away from the source. If this nodal pattern occurs, the average of the maximum and minimum readings should be recorded. If the differences between the maximum and minimum readings are greater than 6 dB, record a level of 3 dB less than the maximum readings that occur most frequently.

If the noise level being measured fluctuates markedly, because of sudden erratic impulse noises, or is affected greatly by the physical nature of the surroundings, an error of several decibels in accuracy of readings can result. If, for some reason, the noise meter is not used exactly as recommended in the equipment instruction manual, or its limits of measurement are not recognized, errors in reading can result. Rapid air movement past an unprotected microphone can cause large errors in readings. Thus, for example, in a hearing conservation type noise survey the purely mechanical aspects of making the survey are not as simple as they may seem. In addition, the difficulties involved in following a man closely enough during his workday to account for on-time off-time periods of noise as well as fluctuations in the noise levels to which he is exposed adds to the problems involved in performing a realistic noise survey.

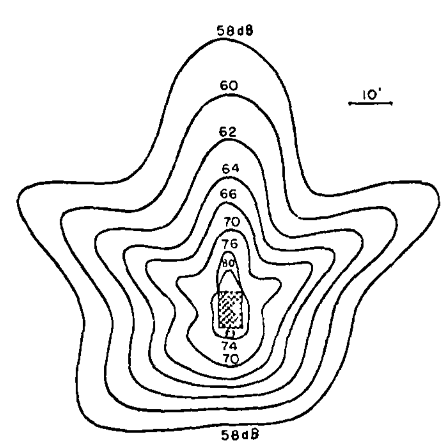


Figure 3 shows how contours of equal sound pressure level vary with distance and direction around a large power-distribution transformer. Illustration printed through courtesy of Handbook of Noise Measurement, General Radio Co.

There is no substitute for experience with an instrument. This article cannot provide the familiarity to be gained by sitting down with an instrument and its instruction book and familiarizing oneself with the instrument.

Much valuable information is contained in the equipment instruction book. For example, it will specify maximum and minimum pressure levels, humidity limitations, and microphone directional characteristics, operational temperature ranges, filter characteristics, and the effects of electric fields, the observer, and of vibration upon readings.

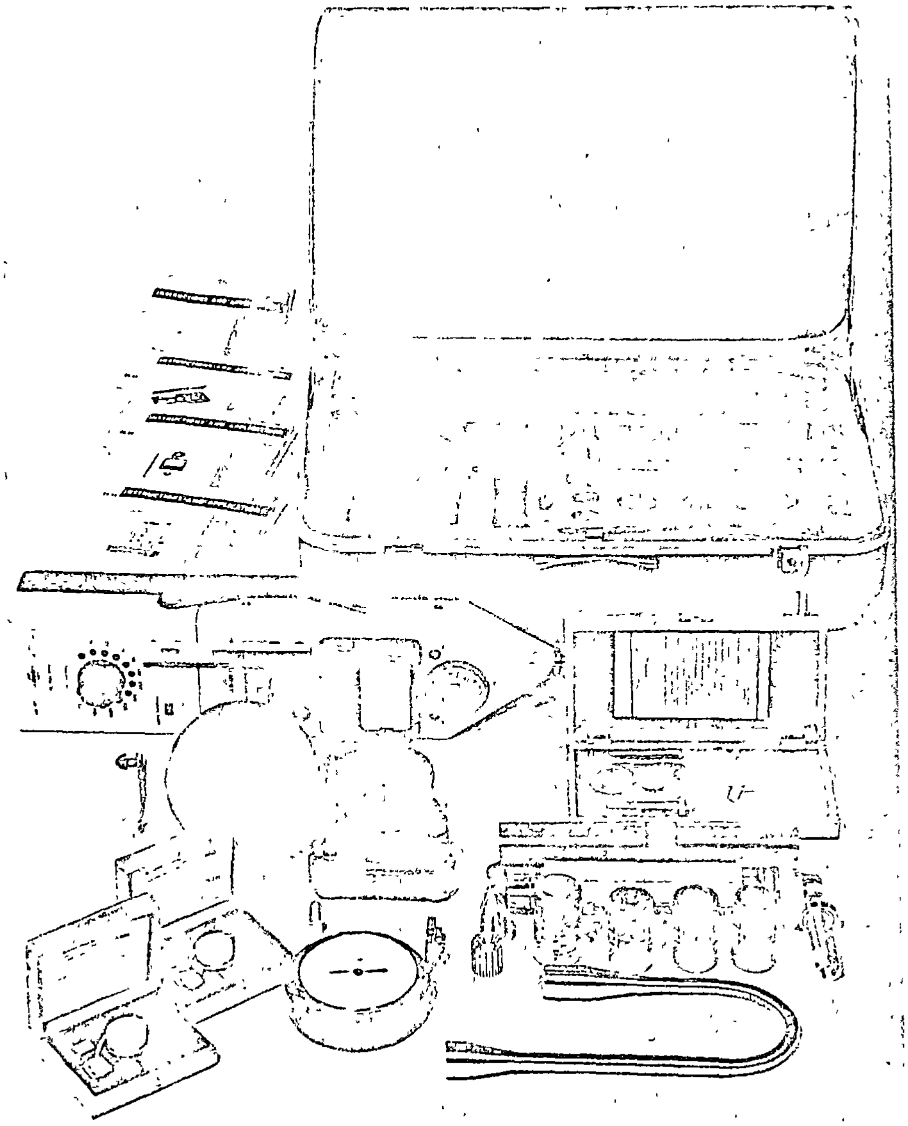


Figure 4 includes equipment for a portable sound and vibration laboratory. Shown is a combined noise survey meter and octave band analyzer plus auxiliary equipment such as wind screen, artificial ear, piston phone calibrator, etc.—Photo courtesy B & K Instruments, Inc.

Calibration of Equipment

Whether the sound survey meter in conjunction with the octave band analyzer or the A-scale of the sound survey meter (commonly referred to as dB A readings) is used, the pre-survey operational steps are the same. They seem simple but are quite important. Before leaving the office or laboratory, make sure the meters are operating properly. Check the batteries and electrical calibration as described in the instrument manual. Make sure the microphone is functioning properly by using a calibrating device. Never use a calibrator that is not specifically designed for the meters being used. A calibrator is a device that impresses a noise of known intensity and frequency upon the microphone and is discussed in some detail in a previous article in this series.[9] In addition to checking with a calibrator, if an octave band analyzer is being used, it is a good practice to make an octave band analysis of some familiar noise. A small noisy air pump or almost any broadband noise source that does not change over a period of time will do. The idea is to check the response of the meter in every octave band. If the noise levels of a noise source that has been accurately measured many times in the past suddenly differ in one or more frequencies, the chances are something is wrong with the meter.

The noise measuring equipment normally used is battery powered electronic equipment, and the user should constantly be aware of faulty operation. The equipment should be checked before it is used to take noise measurements. A suggested series of steps to check the instrument is as follows:

1) Connect and turn on the instruments, and allow them to warm up for a few minutes.

2) Check batteries as per the instructions supplied with the instrument.

3) Make acoustical calibrations as per instructions.

4) Make octave band measurements of a convenient wide band steady noise.

5) Remove the microphone and make electrical background measurements.

6) Recheck acoustical calibration.

If a malfunction of the equipment is indicated in any of the listed steps, the instruction manual supplied with the instrument should be consulted for necessary adjustments or repairs. Step 4, for example, can expose a defective octave band cut off filter. Step 5 will indicate a faulty tube or oscillating amplifier. Step 6 could indicate weak batteries if the calibration has changed by more than one decibel. If it has changed, the batteries should be replaced before making measurements. If the instrument cannot be

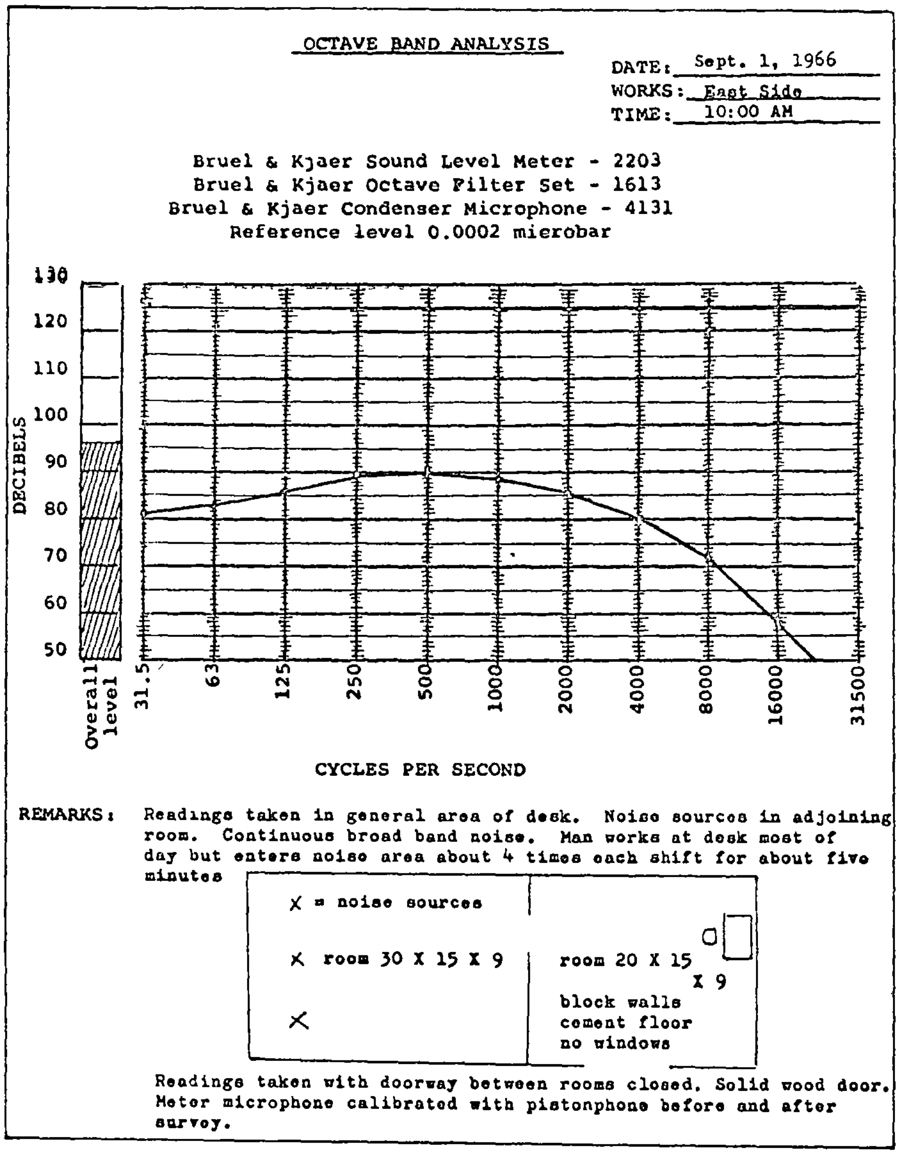


Figure 5 is an example of the results of a noise survey plotted on a graph. Note diagram of location of noise sources in relation to general working area and employee's work station.

made to operate properly consult the manufacturer.

Care of Equipment

Protect the microphone from dust and moisture. If the microphone is a Rochelle salt type never subject it to high temperatures, such as the temperature observed in a closed automobile on a hot summer day. Newer development in noise meters have avoided the use of the Rochelle salt microphone.

The sensitivities of microphones can be expected to change when they are exposed to extremely high or extremely low temperatures. If a microphone is to be used in an unusual temperature environment, calibration information should be obtained at comparable temperatures.

The presence of high humidities can cause moisture condensation to occur in electrical connections. Certain types of condenser microphones malfunction in the presence of high humidities to cause a "popping" or "frying egg" sound to appear at the microphone output. Most of these humidity problems disappear when the equipment is dried out.

At high noise levels vibration may be present to such an extent that it will affect the readings obtained. It may be necessary to remove the meter from the area and use an extension cable to the microphone. A test for the effect of vibration is to disconnect the microphone from the sound level meter and observe if a reading is obtained on the meter. If a reading is noted, the meter can be held or placed on a rubber pad or rubber-tired cart. Electronic equipment can be damaged by shock. Extreme care must be taken in transporting the equipment. When the equipment is to be transported by commercial carrier, care must be taken in packing it.

Location of Microphone

While making the survey keep in mind the fact that unless the noise is completely random, such as that generated by ventilating systems, blowers, etc., there will be some variation in meter readings, depending upon how and at what angle the noise is directed toward the microphone. The microphone pressure response diagram appearing in the previous article of this series[7] illustrates this point. Do not hold the meter so that your body reflects sound waves toward the microphone. Discourage people from crowding just to see how high the noise level is because they also can partially reflect or block sound waves. Try to obtain the readings in such a way that the noise source is not directly in front of you but as close to a 90 degree angle as possible. Also note that noise level readings at a given distance from a noise source may be different in different directions as shown in the varied contours of Figure 3.

When measurements at only one location are made near a single noise source, a large error may result; however, in a large room with a number of sources of noise, if readings are made at a distance from the predominant noise source, only small errors would be expected.

Almost all surfaces reflect sound to a certain extent. As a result, within most rooms the sound field can vary from one point to another. As a general rule, any object will reflect sound at wavelengths comparable to and smaller than the dimensions of the object.

It is not necessary to hold the microphone up to the ear of the employee to determine the noise level to which he is exposed because the two of you are then acting as noise reflectors. Try to measure the noise at the employee's work station that is typical of the area in which he works. If the man is doing something like operating a chipping hammer, it may be necessary to use an extension cable on the microphone.

As mentioned previously, rapid air movement past a microphone will give inaccurate readings. If, for example, it is necessary to do a noise survey in a hot area where man-cooler fans are being used, be sure the microphone is protected by a wind screen. These are available commercially (see Figure 4) or can be made with simple materials.

Before entering the noisy area in which the survey is to be conducted, make a last minute check for the condition of the batteries, the microphone, and note the reference reading for electrical circuitry. It is a good idea to repeat these checks at least once during the day if the survey requires several hours.

Recording Data

Noise levels can be recorded as numbers or plotted on a prepared graph as readings are taken. Because it is easy to misread a noise meter, one argument in favor of plotting a graph is that an obviously incorrect reading can be noted quickly. However, if one is working alone, it may be easier to record numbers in a column than to juggle the meter, take readings, and plot data on a graph all at the same time. To avoid mistakes in an octave band analysis, review the readings as soon as all octave bands have been measured. Ordinarily, a reading that is out of line by plus or minus 10 dB or more will be obvious and a re-check can be made immediately. Be sure that no individual octave band level equals or exceeds the overall level because this is an indication that one or the other of these two readings has been recorded incorrectly. Another check is to add readings in the octave bands to determine if the sum approaches the overall reading. Remember, however, this is not a simple arithmetical addition. The readings are logarithmic in nature and the rules for addition shown in Table 1 must be observed.

If the sum differs considerably (±2 decibels) from the overall level, something is wrong. Perhaps there is an error in addition. Also, if the sum is larger than the overall level there is the possibility that too much impact noise is present in the noise being measured. Table 2 illustrates the application of this summation procedure.

In addition to recording noise levels, it is important to record everything of interest about the environment being measured: A brief description of the noise source or sources; the number of employees exposed; duration of exposure; characteristics of the environment with respect to its ability to reflect, dissipate, or absorb noise.

The kind of data sheet used to record readings varies according to the preferences of the individual making the survey and the kind of information he wishes to record. If it is preferred to present data graphically it can be done as illustrated in Figure 5. Special graph paper is available from the Kodex Book Company, Norwood, Mass., that can be used to plot readings as one conducts a survey. Figures 6 and 7 are examples of data sheets that can be used if it is desirable to record data rather than to plot it on a graph. As indicated in Figure 5, it is often desirable to make a rough sketch of the situation. In many

SOUND SURVEY

Date: ____________ Time: ____________

Wind Velocity: ______ Wind Direction: ______ Temperature: ______

Sound Level Meter: Type ______ Model ______ Serial No. ______

Microphone: Type ______ Cable Length ______

Analyzer: Type ______ Model ______ Serial No. ______

Other Equipment: ____________

Location: ____________ Sketch

Location or Situation	Over-all Level	Sound Pressure Levels - Re 0.0002 Microbars Octave Band Center Frequencies (cps)								
		63	125	250	500	1000	2000	4000	8000	8-Octave added

Remarks. ____________

Recorded by: ____________

Figure 6 is an example of a sound survey form using USASI S1.6-1960 preferred series center frequencies. From Industrial Noise, U.S. Public Health Service, Hosey, A.D. and C R. Powell, Supt of Documents, Washington, D.C. 1967.

Table I

If the difference in decibels between the two levels being added is:	Add to the higher level
0	3.0
1	2.6
2	2.2
3	1.8
4	1.4
5	1.2
6	1.0
7	.8
8	.6
9	.5
10	.4
13	.2
16	.1

cases the environment being measured will be much more complex than the simple example shown and the sketch will be of great help in reporting the data.

If it is necessary to make a large number of readings, the data can be handled as shown in Figure 7. In this example a blue-print of the work area could be used to locate areas where readings are taken. The blue-print could then become a part of the report. Note that in cases where the arithmetic average of the levels in the speech frequencies exceeds 85 dB the readings are circled to emphasize the problem.

Interpretation of A Scale Readings

Recently, as the result of well documented work by the National Research Council Committee on Hearing, Bioacoustics, and Biomechanics,[8] James Botsford, Bethlehem Steel Corporation, proposed that "the A-weighted sound level of a manufacturing noise reveals the hazard to hearing just as reliably as do the octave-band sound pressure levels."[9] The validity of this new proposal to use the A-scale reading rather than octave band analysis is borne out by the fact that the American Conference of Governmental Industrial Hygienists recently proposed a Threshold Limit Value for noise that includes limits for A-scale readings as well as the octave bands embracing the speech frequencies. Despite the apparent simplicity of using the A-scale readings obtained with a sound survey meter, evaluation of the effects of noise exposure cycles requires careful study of the proposed new procedure and some appreciation for the reasoning behind its development.

It is possible to make a screening survey using a survey meter only. If an octave band analyzer is not available or it is necessary to survey a very large area in a short time, a quick survey using the A-scale of a sound level meter will pinpoint the questionable areas and the areas in which problems definitely exist. If such an approach is followed, criteria developed by the *Ad Hoc* "Inter-Society Committee on Guidelines for Noise Exposure Control"[10] can be used. These guidelines point out the following relationship between the decibel readings obtained by the use of the A-scale (dBA) of a sound survey meter and the arithmetic average of readings in the three octave bands —300 to 600, 600 to 1200, and 1200 to 2400 cps — by use of an octave band analyzer. With some meters this could also be the arithmetic average of the octave bands having mid-point frequencies of 500, 1000, and 2000 cps.

For example: 85 dBA is approximately the same as an average of 78 dB in the 300 to 600, 600 to 1200, and the 1200 to 2400 cps octave bands; 92 dBA is approximately the same as an average of 85 dB in those bands; 95 dBA is approximately the same as an average of 88 dB in those bands; 97 dBA is approximately the same as an average of 91 dB in those bands.

Thus, a screening type survey can be made with a sound survey meter using one of the above dBA levels as a reference level. Assume that the 85 dB decibel average in the speech frequencies (equivalent to 92 dBA) has been selected as a Threshold Limit Value for continuous exposure to broad band noise. Then in doing a rapid screening survey, areas in which people are exposed for eight hours a day to dBA readings of 89 dB or less can be considered safe. Areas in which dBA levels lie between 90 and 95 dB and there is exposure for eight hours a day, require an octave band analysis of the noise to validate the degree of hazard. Areas in which dBA readings are above 95 dB for the full eight-hour work day can be considered risk areas, which require further study. If there are intermittent or part time exposures, as is usually the case, it will be necessary to refer to the specific criterion being used —ACGIH, Botsford, Air Force, etc. —for evaluation of risk.

The preceding article[7] in this

Table II

Step, or Sequence of Addition	Frequency: cycles/second	Octave band Noise level reading in decibels	Noise levels to be added	Difference between levels	dB to be added from Table I	Addition	Sum
	Overall Reading	101					
7	31.5	83	100.8 + 83	17.8	0.1	100.8 + 0.1	100.9
6	63	87	100.6 + 87	13.6	0.2	100.6 + 0.2	100.8
4	125	91	99.6 + 91	8.6	0.5	99.6 + 0.6	100.2
2	250	94	96.0 + 94	2	2.2	96.0 + 2.2	98.2
1	500	96	96				
3	1000	94	98.2 + 94	4.2	1.4	98.2 + 1.4	99.6
5	2000	89	100.2 + 89	11.2	0.4	100.2 + 0.4	100.6
8	4000	83	100.9 + 83	17.9	0.1	100.9 + 0.1	101.0
9	8000	74	101.0 + 74	26.9	INSIGNIFICANT		
10	16000	63	101.0 + 63		"		
11	31500	47			"		

NOTE: Start with highest band level (Step 1) and add to second highest band level as shown in Step 2. Then add this result to third highest octave band level as shown in Step 3 and continue until the contributions from each of the bands are summed up. If two octave band levels have the same value, treat as separate readings, as in steps 2 and 3. (Note: Steps 9, 10, and 11 may be disregarded.)

series discussed noise measuring instruments and their characteristics in considerable detail. The reader is urged to review this information carefully as well as that contained in the references listed at the end of this article before undertaking a noise survey. Typical examples of noise levels common to a number of industrial operations are shown in Figures 8 and 9 taken from a survey[13] made several years ago by Karpus and Bonvallet. The results are still valid and will give the reader some idea of the range of noise levels he might find in similar environments.

The octave band sound pressure levels of a few widely used machines are given in Figures 8 and 9. The shaded area shows the range of observations.

The loudest operations shown are chipping and riveting on large steel tanks and aircraft assembly. Similar operations on smaller or more massive pieces, like small castings or concrete, are grouped with other pneumatic power tools such as drills and wrenches. Note: the noise is more a function of the work than of the tool. A chipping hammer used on large steel plates caused vibrations with large amplitudes. Massive castings or concrete structures are less easily excited and radiate less noise.

The range of observations for saws, Figure 8, include a metal friction saw, circular wood saws, and stone saws. A circular wood saw measured close to 90 dB in every octave band; stone saws were about 85 dB.

The graph for planers includes operations on wood and stone. A wide range of intensities is shown. Planing a flat surface on fairly soft stone is the least noisy, whereas planing a concave stone surface was fairly close to the upper limit of the range. Finish planing on pine was close to the lower limit, whereas planing operations, making a deep cut on hardwood, were found close to the upper limit.

Steam and air hiss, as encountered in many operations, are shown in Figure 8. Tumblers, in which small castings are knocked together in a deburring operation, grinding, welding, and machine shop operations like lathe work, drilling, milling, and boring are in general less noisy as shown in the graphs.

Furnaces and mixers are examples of machines having down-sloping spectra. Furnaces have fairly high overall levels, but are not usually judged to be very loud because of the low intensity in the high frequency region. Mixers were the least noisy class of machines listed here.

WORKS: East Side DATE: Sept. 2, 1967

INSTRUMENT
Bruel & Kjaer Sound Level Meter - 2203
Bruel & Kjaer Octave Filter Set - 1613
Bruel & Kjaer Condenser Microphone - 4131
Reference level 0.0002 microbar

Freq.	NOISE SOURCE LOCATION NUMBERS 1	2	3	4	5	6	7	8
Lin	98	93	102	87	89	94		
31.5	84	82	86	78	71	73		
63	85	85	88	74	72	74		
125	88	86	93	76	75	78		
250	92	86	94	78	79	82		
500	92	87	97	81	85	89		
1000	92	84	95	80	82	90		
2000	86	80	90	76	80	85		
4000	83	74	86	69	74	78		
8000	75	70	82	60	68	72		
16000	65	58	70	52	60	58		
31500	--	--	--	--	--	--		

1. General area readings just north of office near column 29; Three people working in this area four hours per day. Noise coming from sorting machines.
2. Same noise source as #1 above - readings taken at shipping dock near column 25 one person exposed 8 hrs/day.
3. Readings taken approximately 10 feet due north of sorting machines - no one directly exposed at this point.
4. Readings near foreman's desk- dept. 10, column 40 - typical activity
5. Levels observed in small utility room, extreme west end of building- no one working in this area continuously.
6. Area adjacent to tool crib in dept. 5 - Several people spend 8 hours per day in this general area.

Figure 7 is a typical data sheet used to report results. Note circle readings indicating values which exceed 85 dB in speech important frequencies.

Writing the Report

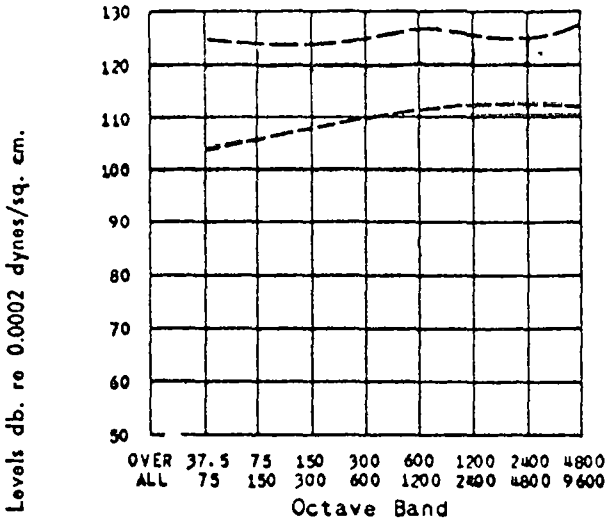
Perhaps the most important part of the noise survey is the summation of the results in the form of a written report.

Whenever we ask someone to read our writing, we ask him for his time and his energy. The less time and energy he must devote to comprehend the actual report, the more time and energy he will have left to do something about it. The way the report of the noise survey is to be used and the requirements of those who will use it determine the length, form, style, and details of treatment.

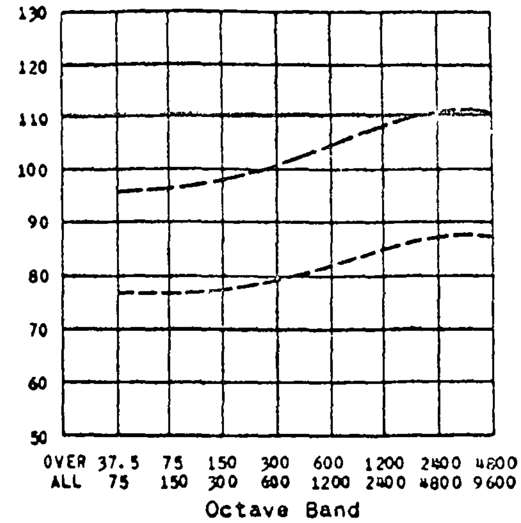
Think out and write down a brief statement of the purpose of the noise survey. Then gather your facts and data. Organize them in order of importance, based upon the purpose of the report, into a simple, briefly stated topical outline. Next, using this outline as a guide, write your message in terms [illegible] understandable to [illegible] whom the report is [illegible]ted. Perhaps it would be best to prepare a one-page abstract or digest containing all the substantial facts. in the most condensed form possible, of the conclusions and recommended course of action to be taken. Further details on this topic can be found in "4 Steps to Easier Writing."[14]

Figure 8

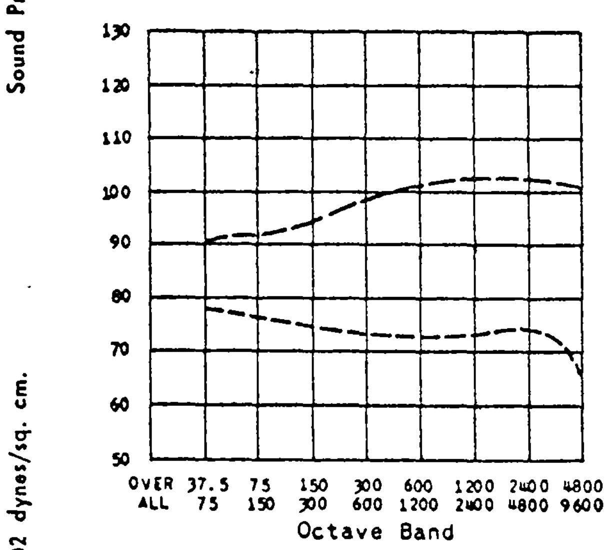
SOUND PRESSURE LEVELS OF TYPICAL TOOLS



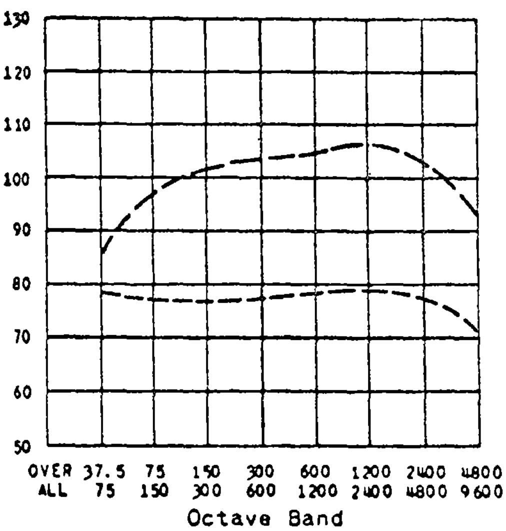
Riveting and chipping on large metal plates.



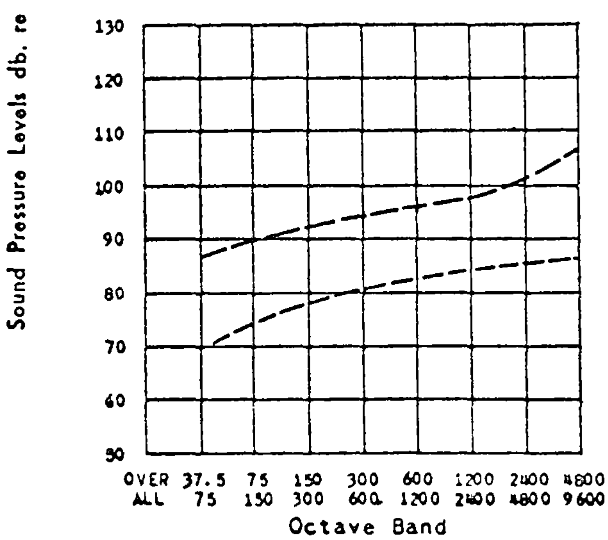
Riveting and chipping on small castings, and other pneumatic tools.



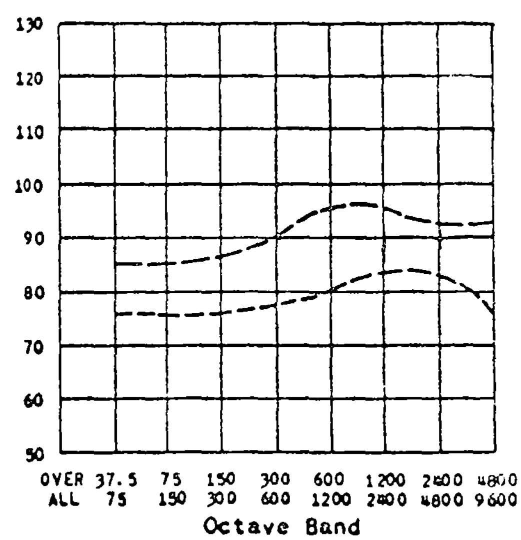
Saws



Planers



Tools with steam or air hiss

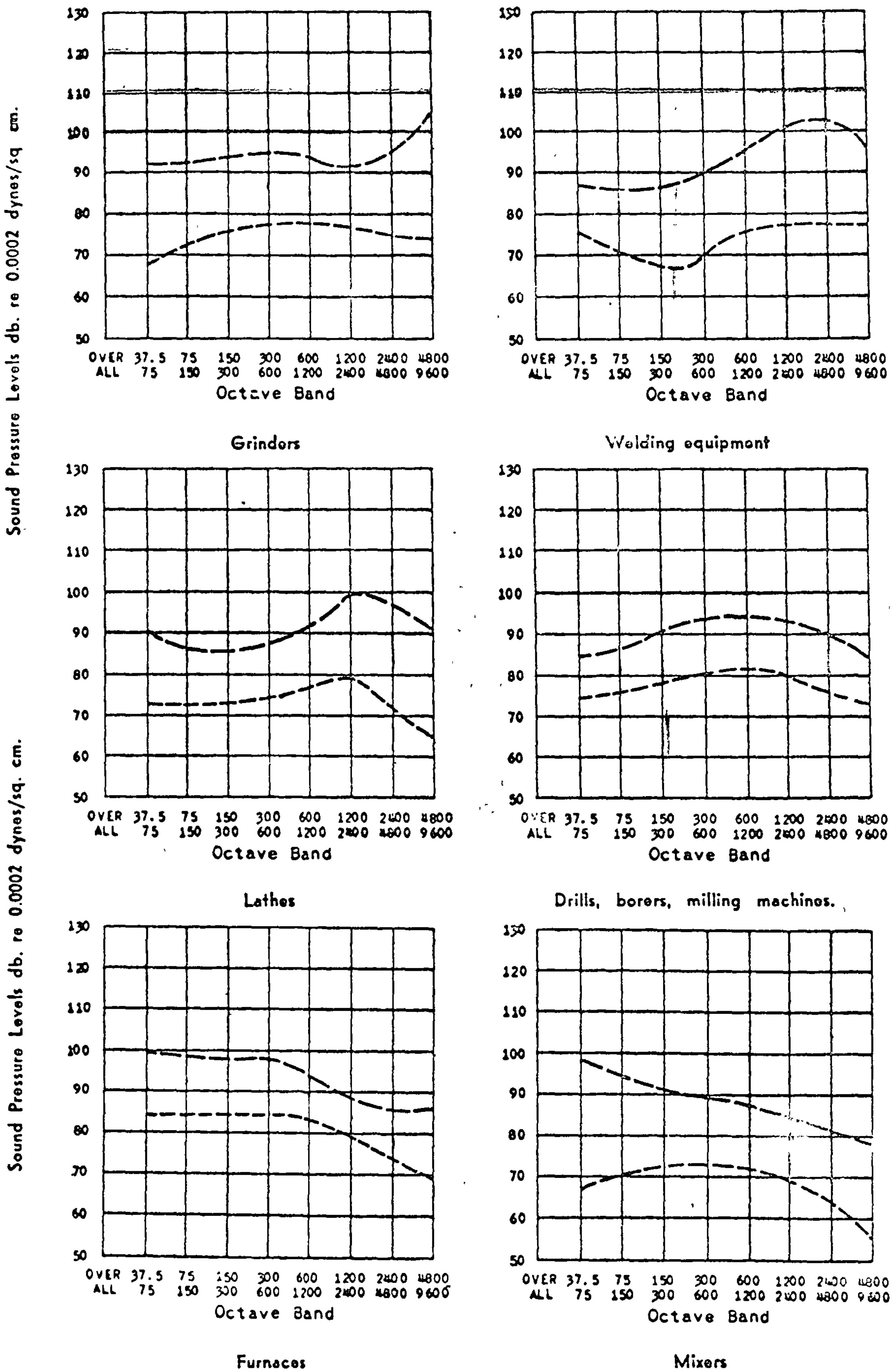


Tumblers

The shaded areas in Figures 3 and 9 show the range of noise level readings observed for machines listed. (Adapted

Figure 9

SOUND PRESSURE LEVELS OF TYPICAL TOOLS



from "A Noise Survey of Manufacturing Industries," Karplus, H. B. and G. L. Bonvallet. A.I.H.A. Quarterly.)

It is not difficult to use modern noise measuring equipment and to obtain a large amount of noise level data in a relatively short time. The difficulty lies in making sure the measuring equipment is accurate, that readings are obtained with as little environmental bias as possible, and that readings truly represent the noise levels to which people are exposed.—**End.**

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8 pp. 111.17-42 (November 1968)

An Industrial Hearing Conservation Program. The introduction to a series of articles, based on the NSC Safety Training Institute's course on Industrial Noise, provides the basic concepts.
8 pp 111.17-37 (August 1968)

Instruments and Techniques of Sound Measurement. The third article in a series on the fundamentals of industrial hearing conservation discusses sound-level meters, octave band analyzers, and auxiliary equipment plus calibration techniques.
10 pp 111.17-44 (December 1968)

Procedures of a Sound Survey. Types of noise, types of sound surveys, the equipment needed, and survey procedures are outlined.
12 pp 111.17-46 (January 1969)

Ear Anatomy and Effects of Noise on Man. The physiology of the ear helps explain the effects of noise on behavior, communication, and hearing.
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Harrison

Hearing Measurement And Audiometry

Coauthored by James H. Delk, director of audiological services, Royal Industries, Phoenix, Ariz., and Charles A. Lowe, president, Charles A. Lowe & Associates, Chicago.

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National Safety Council, 425 N. Michigan Ave., Chicago, Ill. 60611

In an Industrial Hearing Conservation Program

Hearing Measurement

The procedures for measuring employee hearing acuity and thresholds are discussed in this seventh article in a series on the development of an industrial hearing conservation program. Audiometric equipment is explained and a program for its care and maintenance is discussed.

PRIOR TO WORLD WAR II little attention was given to noise induced hearing loss. Workers in factories with excessive noise took it for granted that they might develop a "little trouble" hearing — might even become a little "deaf." However, in the early 1950's damage to hearing due to industrial noise was ruled compensable in Wisconsin. Since then, a great deal of time and money was spent by industry, insurance carriers, various governental agencies and others investigating this problem.

It soon became apparent that hearing damage by excessive noise is a slow and insidious process. It is invisible, painless, and slow. Rarely is the individual aware of his problem until it is beyond correction. In the highly industrialized Calumet area of Chicago, it is reliably estimated that over 50 per cent of the workers are exposed to environments that can lead to a hearing loss. And, they carry this potentially compensable affliction from job to job. Thus, it is imperative that a new employee's hearing be tested or the employer may have to pay for a hearing loss that he did not cause. Further, if the employee is to work in a noisy area (any noise level over 90 dB could be injurious) his hearing should be checked at least every six months.

Today the only medically and legally accepted hearing test is the audiometric examination. Such a record makes a valuable contribution to the total program designed for hearing conservation. It offers a method to gage the effectiveness of noise reduction or engineering control efforts. It becomes the final test of the effectiveness of personal hearing protection devices because an audiogram indicates just what the worker's threshold of hearing acuity is at any time.

Audiometric examinations are at present the best way to detect an individual's susceptibility to noise. By comparing the audiograms taken at intervals, we know just how well a person is bearing up under the strain of a noisy working environment (see Figure 1 for an example of an audiogram). If hearing acuity continues to decrease in spite of

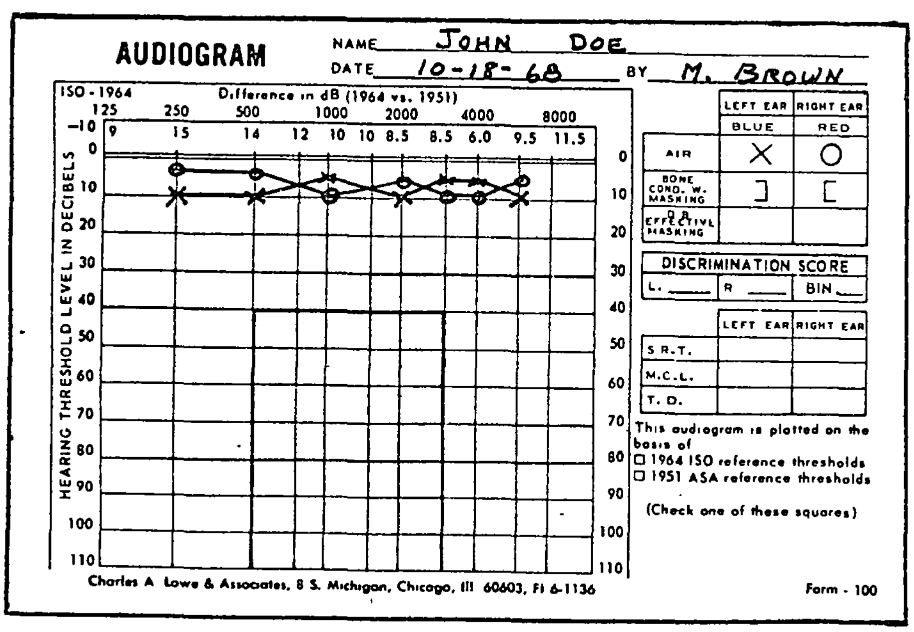

Figure 1 is an example of an audiogram of an individual. It depicts hearing levels within the normal range for both ears. Note: The "O" graph is for the right ear and the "X" graph is for the left.

And Audiometry

Coauthored by James H. Delk, director of audiological services, Royal Industries, Phoenix, Ariz., and Charles A. Lowe, president, Charles A. Lowe & Associates, Chicago.

noise-reduction measures and personal hearing hearing protection devices, the matter becomes a grave problem for both the physician and the personnel director.

When a noise-induced hearing loss has been acquired, normal hearing acuity cannot be restored. Such a loss is due to destruction of certain ear structures that cannot be replaced (see Figure 2). First affected is man's hearing of sounds higher in frequency than those necessary for communication by speech. Therefore, most early noise-induced hearing losses pass unnoticed unless they are detected by suitable hearing tests.

As yet, there is no predictive test that will identify persons with highly susceptible ears. Therefore, a hearing conservation program should include preplacement hearing tests and routine periodic follow-up tests. The first recheck should be after 90 days. The balance of the program, as established by the medical director, should continue on a basis of every 90 days for employees in high-risk areas. Less often — at intervals of every one or two years — is acceptable for employees not exposed to high noise levels.

Incidentally, by showing the worker his personal record of hearing acuity, the nurse or physician may have an effective method to promote the use of hearing protective devices.

The success of an effective hearing conservation program is dependent to a great extent upon the validity and reliability of the audiometric data obtained by the personnel responsible for the hearing measurement of employees.

To emphasize the importance of accuracy in conducting the audiometric tests it is well to remember that legal decisions involving large sums of money may be based on the work of the audiometric technician. Even more important may be medical decisions affecting a man's hearing for the rest of his life. In this connection, it is well to remember that the amount of hearing loss produced by a given noise exposure varies from person to person, and it is vitally important to discover early noise-susceptible individuals.

Acoustic Environment

Basically, a quiet area — usually found to be best in the basement or on the top floor — is requisite for audiometric testing. It should be away from outside windows, walls, elevators, noisy halls, or other uncontrollable noises. Pre-fabricated booths are available and have many advantages. They are probably the best for the purpose.

There are several charts available that show the noise levels allowable in the testing room (see Figure 3). *Valid measures of hearing acuity cannot be made unless noise levels in the examination room are low enough so as not to mask or interfere with the puretone thresholds of the test frequencies.*

It is recognized, of course, that the location will also be governed by convenience considerations so employees will not lose too much time from work. If possible, have the booth located within the general medical dispensary area.

Background of Audiometry

The audiometer was developed to replace electronically the tuning fork, and originally it utilized the same octave frequencies. More recently, half-octaves have been added. While many otologists still prefer to use tuning forks, in at least one respect the audiometer is superior: Intensities can be controlled much more accurately; therefore, the results can be more carefully quantified.

An audiometer is a frequency-compensated audio-signal generator. It produces pure tones at various frequencies and intensities for use in measuring hearing acuity (see Figure 4).

Vacuum tubes made possible the first audiometers and were continued in exclusive use until recent years. Instruments of that type require a "warm-up" period of at least five minutes. Ideally, they should be turned off only at the end of the day.

"Solid-state" circuitry is basic in newer audiometer design. These instruments are not only lighter and more compact, but they require no warm-up period if fully transistorized. They may be turned on and off as needed. As there is no heat generated, they are also more stable and more reliable than vacuum tube instruments.

No matter which type of audiometer — regardless of the make or model — an audiometrician must know his instrument intimately before he starts testing others.

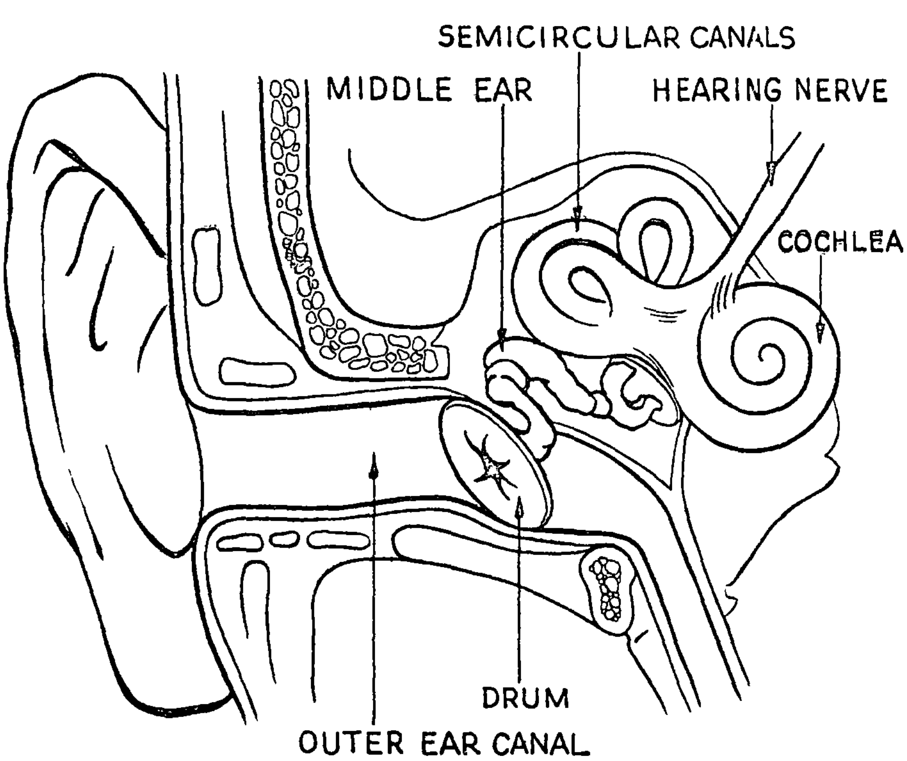

Figure 2 depicts a cross-section drawing of the outer, middle, and inner ear structures. Noise-induced hearing loss is due to the destruction of certain ear structures (any of areas shown in color).

Dials or Controls

The labels or names may differ on different audiometers, but basically, the function is the same regardless of where the control may be located on the panel—or whether the control is a dial, a pushbutton, or a toggle switch.

Power Switch — This may be labeled simply "Off" and "On." It may be a position on the "Output Control" or "Phone Selector" switch. There will usually be an indicator light that will glow when the current is "on." Sometimes will be a light behind the dials to shine through when the instrument has power. If the light doesn't light, check the connection to the electrical outlet first; then check the audiometer fuse and finally the bulb itself.

Output Control — This permits selection of "Right" or "Left" earphone or bone oscillator. As noted before, it may also be used as an "off and on" switch. The earphones are color-coded to indicate the ear: red or grey for right; black or blue for left.

Tone Interrupter — This is used either to interrupt the audible signal or to present a tone signal when it is depressed — depending on the position of the Tone Interrupter (TI) Reverse Control switch.

TI Reverse Control — When this switch is in the "Normal" or "On" position, the tone is continuously on and the Tone Interrupter switch interrupts the tone. When in the "Reverse" or "Off" position, the tone is introduced when the Tone Interrupter switch is depressed. It then becomes a tone "Presenter." This is the recommended position of this switch so it will always be a tone presenter.

Hearing Level Control—Formerly often called a "Hearing Loss" dial, rotation of the Hearing Level Control knob provides variable control of the signal intensity. Usually the intensity is varied in five dB steps in reference to the so-called "normal" threshold. This control is often referred to as the "Attenuator" dial or "Decibel" or "Volume" control.

Frequency Control — Turning this dial selects the frequency of the pure tone to be used as the test signal.

Under the agreed standards for work, audiometric technicians in industry are not concerned with bone conduction, masking, speech audiometry, loudness balance, or any of the other tests which your audiometer may make possible. While these tests are important to the otologist as the basis for diagnostic and rehabilitation studies, the industrial audiometric technician should not be asked to make them.

Audiometers are delicate instruments and every technician should routinely follow some simple but basic rules:

1) Handle every instrument with care;

2) Handle receivers with "tender loving care." They are *not* interchangeable and must not be bumped or allowed to become overheated. Avoid exposure to any sharp temperature change. The earphones should be stored with the cushions touching and facing each other.

Every technician should know his own hearing thresholds in order to check the audiometer.

Each morning the technician should check through the test frequencies on each earphone. In doing this the cords near the receiver and near the instrument should be flexed while the hearing level dial

MAXIMUM ALLOWABLE BACKGROUND OCTAVE BAND SOUND PRESSURE LEVELS FOR AUDIOMETRIC TESTING

Octave Band Frequencies, Hz	250	500	1,000	2,000	4,000	6,000	8,000
Sound Pressure Level dB re 0.0002 μ bar	40	40	40	47	57	62	67

Figure 3 shows a portion of the criteria, published by USASI, for the maximum allowable Sound Pressure Level (SPL) that will permit hearing tests to be made at various frequencies without the danger of masking. The amount of noise attenuation required for a satisfactory testing environment depends upon the lowest hearing level to be measured in the room, the frequencies to be tested, and the noise level of the particular location.

is set at 50 dB (or louder) to be sure there is not intermittency or scratchiness.

The headband should be checked to assure sufficient tension.

If the instrument is not used daily it may be necessary to rotate the attenuator (hearing level dial) rapidly to eliminate scratchiness.

Monthly — or at the most every 90 days, make a "biological" check of the instrument's calibration. That is, keep records on three to five normally hearing young adults (if possible) and check the level of hearing acuity of this group each month. Have these people listen for hum in the output circuit by listening through the receivers alternately with the hearing level dial set at zero, 50 dB and 90 dB with the tone "On" and with it "Off."

Check for tone in the "quiet" earphone by disconnecting one and then the other. In two-room arrangements the shielded wires may touch and cause the tone to cross over.

Any time there appear to be too many losses at the same frequency, check the two earphones for loudness balance. That is, check one ear with the red earphone, for example, then check the same ear with the blue earphone to see if the threshold of acuity is the same with both earphones.

Annually — return the instrument to the dealer from whom it was purchased for a "Certified" calibration. When the instrument is returned, recheck the "biological recalibration group" to be sure that nothing has happened in transit to upset the calibration, and to be sure group records are correct.

There are two distinct types of audiometers (see Figure 5) — the conventional or manually operated model, and the automatic, which allows the subject to conduct his own hearing test. Consider the definite "pros and cons" before selecting the type for your program.

Control of subject — The technician can observe the response of the subject when using a manually operated unit. Is he cooperating? Is he trying to malinger? Does he understand what is being asked of him. The technician can determine all of these and can instruct and control the subject as the test progresses.

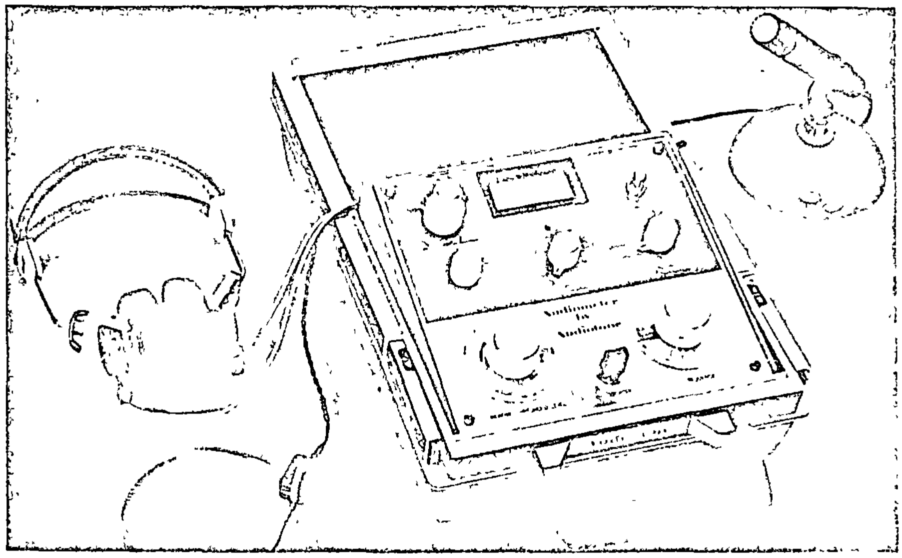

Figure 4 shows an example of a typical audiometer. Note the ear-phone and microphone attachments.

Time — The average industrial hearing test for a pure tone audiogram usually averages ten minutes time. When a worker is retested at periodic intervals, the tests usually proceed much faster. There is another factor to consider, however. After a technician conducts manual hearing tests for several hours, there is a tendency to become bored and either lose interest or use some excuse to delay further testing. Periodic rechecks are the first to "go" or suffer from this factor.

Cost — A basic pure tone air conduction audiometer with masking lists between $275.00 and $375.00. It is *not* necessary for the industrial clinic to invest in the more sophisticated models capable of conducting bone conduction and speech discrimination tests.

Service—Whereas audiometers of reliable manufacturers carry a one-year guarantee, calibration and frequency accuracy should be checked every six months. Out-of-guarantee service charges are usually modest.

Control of Subject — The worker is instructed to push the button on the subject signal cord when he hears the tone and release it when he can no longer hear it. This procedure sounds simple, and it is. Theoretically, the technician is free to do other things and leave the worker alone.

Time — A worker of average intelligence and cooperation can finish the test in six minutes. However, a slow-witted individual can waste a lot of time learning the procedure. The audiometer continues to move when the recording stylus is set in motion. This confuses many people, and a worker can produce some bi-

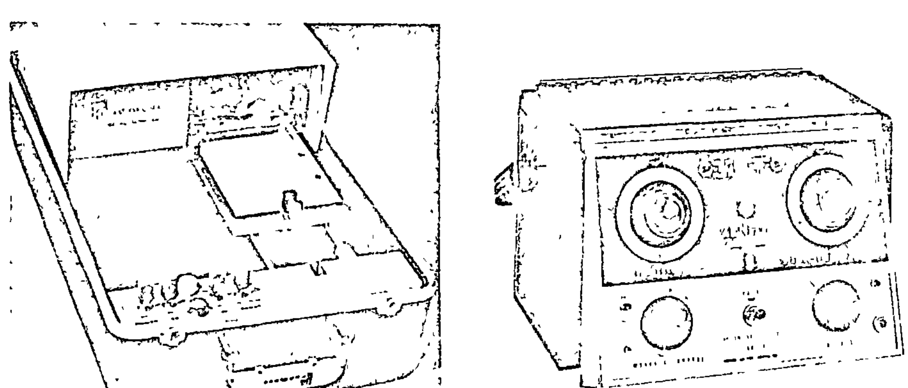

Figure 5 depicts representatives of the two types of audiometers. On the left is a fully automatic unit — one that is operated by the subject — and on the right is the manual one that requires a technician.

Audiometer Zero Reference Levels—A comparison of 1951 American Standards Association (now USASI) values and 1964 International Organization for Standardization values.

Frequency	Reference Threshold Levels		
	1951 ASA	1964 ISO	Differences
125	54.5 dB	45.5 dB	9 dB
250	39.5	24.5	15
500	25	11	14
1000	16.5	6.5	10
1500	(16.5)	6.5	(10)
2000	17	8.5	8.5
3000	(16)	7.5	(8.5)
4000	15	9	6
6000	(17.5)	8	(9.5)
8000	21	9.5	11.5

The figures shown in parentheses ( ) are interpolations.

Figure 6 is a conversion table. It can be used to reconcile the figures from two audiograms that have been plotted to the different reference levels — ASA and ISO.

zarre audiograms requiring several retests.

Cost — Automatic audiometers list for approximately $1,700.00. A factory with less than 500 employees will usually find the manual type better suited to its needs.

Service — The Automatic audiometer is guaranteed for one year. Calibration and frequency accuracy should be checked every six months. However, this type of machine does require more frequent service calls. The moving stylus, ribbon, gears, etc., cause problems not found in manual types.

Normal Thresholds—The "zero" line on the audiometer is supposed to represent the average threshold level of hearing acuity for young, normally hearing adults. The first zero reference level resulted from the United States Public Health Survey, made in 1935-36 and commonly known as the "Beasley Report." The American Standards Association (Now USASI) used those figures as a basis for the standard known as ASA-1951.

Several European countries used a "norm" that was lower (better) than the U.S. standard. The International Standards Organization (ISO) finally brought about agreement on a new set of figures to use as a basis for the zero line of the audiogram. These are known as the 1964 ISO reference levels, which are gradually being accepted and used throughout the United States. The ISO levels average about 10 dB less than the U.S. levels. Example: Zero at 1,000 Hz would be -10 dB on a U.S. audiogram, etc.

The audiogram should always be checked as to whether the ASA-1951 or ISO-1964 reference level is being used. That is, to which threshold standard has the audiometer been calibrated.

There is a conversion table (see Figure 6) that can be used if it is necessary to reconcile the figures from two audiograms that have been plotted to the different reference levels.

(It is well to remember that the numbers govern the expression as to whether a threshold is "lower" or "higher": Lower numbers in the threshold indicate better hearing and, though the lines will be higher on the graph, the threshold is said to be "lowered." Higher numbers indicate a worse, or poorer threshold of hearing acuity, and it is said that the threshold is "raised" even though the lines are lower on the graph.)

The Audiogram — This chart will vary according to the need or the habit of the medical department but, basically it consists of a graph with frequency indicated along the abscissa and intensity along the ordinate.

The symbols for the air conduction threshold for the right ear may be kept in mind by remembering the three "R's": Red, Round, and Right. Blue or black crosses are used for the left ear.

Numerical charts facilitate the keeping of records for successive audiograms. Frequencies are set out at the top of vertical columns. Dates of the tests usually appear on the left and the initials of the tester on the right side of each row of figures.

There are other types of forms, which have been suggested by the Subcommittee on Noise in Industry but they are simply different versions of these basic types adapted to particular usage. For example, one form is especially adapted for use with computers for research purposes.

The *frequencies involved* in a test vary with requirements of medical departments and state laws. The basic ones are 500, 1,000, 2,000 3,000, 4,000, and 6,000 Hz. Sometimes 1,500 Hz is used — when available on the audiometer. Some state regulations or medical departments call for 250 and 8,000 Hz tests. Generally speaking, most medical departments ignore 250 Hz as being of little significance; 8,000 Hz is ignored because of the unreliability of measurements made at that frequency.

Time of Day to Make Measurements — Ideally, before start of work in a noisy environment and at least 16 hours after the last exposure are the best times to test hearing acuity. Employees will thus have time for recovery from a threshold shift of a temporary nature (TTS) that has resulted from noise exposure.

A reminder — Always turn the instrument "on" to give it a few minutes to warm up before starting the test if you are using a vacuum-tube audiometer.

Have the subject seated in a comfortable chair and facing to the side. In this way the tester can watch the facial expression and the subject cannot observe the manipulation of the controls. If both subject and operator are in the same room, the subject should be seated on the opposite side of the audiometer from the operator. To help the subject relax he should rest his arm on a table or on the arm of his chair.

It must be emphasized that the following suggested procedure does not purport to be the ONLY successful method of establishing a threshold. On the other hand, it should be emphasized that the testing technique adopted or taught the medical department must be followed consistently without deviation. That is, the technician must not attempt different testing procedures to try to expedite his work or to relieve monotony.

Before starting the test, instructions must be given clearly and reviewed to be sure they are understood.

The following is an example of instructions that might be given:

> *I am going to test how well you can hear faint sounds. These sounds will be like this* . . . Demonstrate by holding earphones in hand while tones are shifted in high and quite audible intensities of 90 or 100 dB. (In a two-room set-up let the subject hold the earphones in his hands.) *Just as soon as each tone comes on, and as long as each tone is on, raise your finger and keep it up to show me you are hearing the tone. Lower your finger quickly when the tone disappears.* (Demonstrate!) *Any time the tone is off or you cannot hear it, keep your finger down. No matter how soft, faint, or far away the tone sounds, as soon as you think you hear it, raise your finger and keep it up as long as you think you hear it. I will test your right ear first and then your left unless you think your left ear is a great deal better than the right — in which case I will test the left ear first.*

Be sure the subject understands the instructions before proceeding with the test.

The headset must be placed carefully on the head of the subject, by the operator, so the openings of the earphones will be properly in line with the ear canal. Earrings and glasses with heavy bows should be removed so the receivers will fit comfortably and snugly and help shut out external noises. The receiver cords should be *in back of* the subject to minimize distracting noises, which may result from the rubbing of the cords during the subject's movements. Be sure the color code on the receivers corresponds with the ear under it. A good practice is to form the habit of always taking the red receiver in your left hand and the blue one in the right when placing the earphones on the head of the subject.

It is always wise to check the controls of the audiometer before starting the test: *Power Switch*, ON (as mentioned earlier, this should be done before the subject is seated and the instructions are given so the instrument will have time to warm up); *Frequency Control*, 1,000 Hz; Hearing Level Control (attenuator), Zero dB; *Tone Interrupter Reverse Control*, REVERSE or OFF (Remember to make the TI Switch a "Presenter"); *Output Control*, AIR or RED (these controls may be separate or together). If there is a *Masking Switch* be sure it is in the OFF position.

Step by step, the usual testing procedure is as follows:

1) Have the subject close his eyes to shut out visual distraction. Start at 1,000 Hz with the *Hearing Level Control* set at zero. Hold the Tone Interrupter switch down while the Hearing Level Control dial is gradually rotated upward through the numbers until the subject raises his finger to indicate he is hearing. Release the Tone Interrupter switch immediately so the tone will not continue to be presented. It is wise to form the habit of re-presenting the tone at this level to be sure the subject is well acquainted with the tone he is expected to hear.

2) Reduce the intensity by turning the Hearing Level Control dial down to a 10 dB lower number and present the tone once more. If the subject responds at this level, reduce the intensity another 10 dB and present the tone again. This second step is rarely necessary if the intensity was raised slowly enough through step one and the instructions were understood. If necessary, however, reduce the intensity in 10 dB steps until the subject no longer responds when the tone is presented.

3) Turn up the Hearing Level Control five dB and re-present the tone signal two or three times. If the subject fails to respond, the intensity is increased another five dB and the TI switch is again depressed briefly two or three times. This procedure is repeated only until the subject responds. This threshold indication is then bracketed by lowering and raising the intensity in five dB steps until the subject responds at least 50 per cent of the time when the tone is introduced. It is thus a determination of the point of least audibility to be recorded on the audiogram.

Do not, however, record this point at 1,000 Hz as it is considered to be practice by the subject to be sure he understands the instructions. The first point to be recorded is that determined by going through the same procedure at 1,500 Hz — or 2,000 Hz if the 1,500 Hz is not to be tested.

Repeat the three steps for all fre-

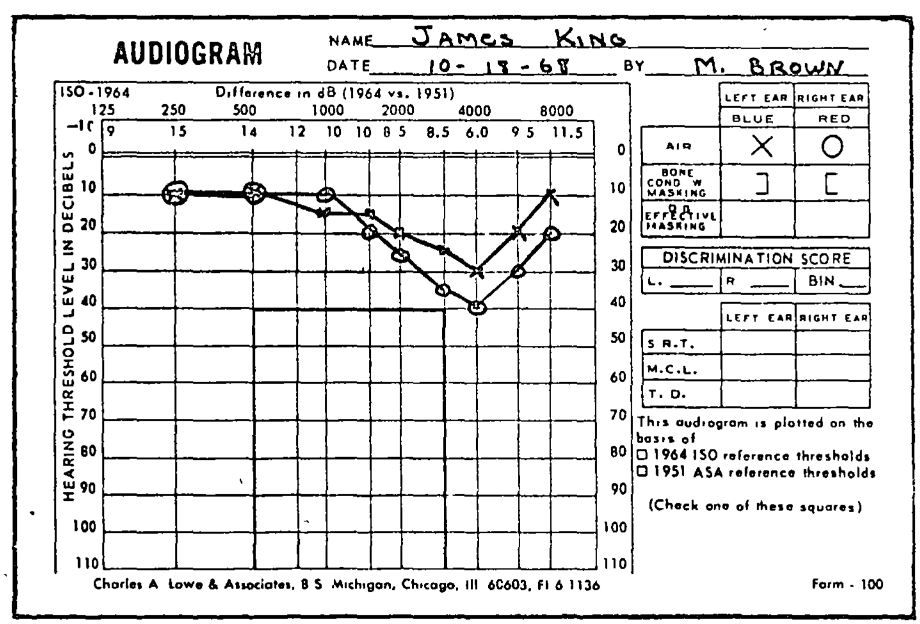

Figure 7 is an audiogram of an individual showing the first stages of acoustic trauma or the effects of prolonged exposure to excessive noise. Note the decided "notch" at the 4,000 Hz frequency.

quencies by rotating the *Frequency Control* clockwise. After checking 6,000 Hz, check 1,000 Hz, then 500 Hz and 250 Hz, if necessary.

Carefully avoid a rhythmic pattern in all operations to prevent anticipatory or inadvertently incorrect responses by the subject.

After all frequencies have been tested and recorded for one ear, turn the *Phone Selector Switch* or *Output Control* to the other ear and repeat the outlined procedure. If the subject has demonstrated that he has understood and followed the initial directions without difficulty, it is not necessary to repeat the "practice" session with 1,000 Hz tone in the second ear. Start at the lowest frequency and work upward.

Upon completion of the test fill out all the required forms. At this time the "recheck" audiograms may be compared to determine if there is need for otologic attention. Should there be any substantial variance in the threshold of acuity, the subject may be recalled for further testing, a shift in noise environment, additional ear protection, or whatever the medical director may prescribe.

Figure 1 indicates a normal hearing subject. Responses at 10 dB and 15 dB can also be considered normal or not compensable. However, they may indicate a trend, especially if there is a drop at 2,000, 3,000, or 4,000 Hz. Prolonged exposure to excessive noise usually results in a "notch" at 4,000 Hz (see audiogram Figure 7) that indicates a noise-sensitive ear. Continued exposure can result in a serious loss as shown in Figure 8.

The only medically and legally accepted hearing test is the audiometric examination. —**End.**

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Davis, Halowell and Richard Sil-

Training Courses for Audiometric Technicians in Industry

The American Association of Industrial Nurses, in an effort to standardize and improve audiometric techniques, has worked with representatives from the American Speech and Hearing Association, the American Industrial Hygiene Association, and the Industrial Medical Association in preparing an outline for training audiometric technicians for industry.

Similarly, the American Speech and Hearing Association Executive Council passed the following resolution:

Whereas, there is a need for hearing tests to be performed in industrial settings; and

Whereas, representatives of the American Industrial Medicine Association, the Industrial Hygiene Association, the American Industrial Nurses Association, and the American Speech and Hearing Association have been devising a syllabus for a course of study for audiometric technicians in industry; and

Whereas, it is desirable that ASHA assume a position of leadership in training audiometric technicians; therefore,

RESOLVED, that the Executive Council endorse in principle a two and a half day program of training for audiometric technicians in industry as outlined in the draft of Guide for Training Technicians in Industry, *dated March 10, 1965.*

COURSE OUTLINE

Topic I—one hour

1) Hearing conservation in industry—why?
   Audiograms—A routine part of physical examination programs.
   Economic and social aspects.
2) Objectives of training program
   Valid audiograms and records
   Medical referral and follow-up
   Ear protection

Topic II—one hour

1) Basic discussion of how the ear functions (Anatomy and Physiology) See instructors guide for recommended films
2) Causes of deafness

Topic III—one hour

1) Physics of sound and its measurement
2) Demonstration of noise measurement with noise level meter and analyzer

Topic IV—one hour

1) The Audiometer
   What it is and how it works
   Its calibration and care

Topic V—four hours

1) Demonstrate audiometric techniques (AIHA Noise Manual Chapter 8) including instructions to the subject—one hour
2) Pitfalls in audiometery ½ hour

The objective of the program is to train industrial audiometric technicians to:

1) perform pure tone air conduction audiograms;

2) implement an adequate hearing protection program;

3) assist management in planning and carrying out a hearing conservation program in industry under medical supervision.

Additional guidelines for developing courses are as follows:

- Courses should be planned through local speech and hearing centers that have adequate equipment and personnel to conduct the course as recommended;
- The director of the course should be an otologist, otolaryngologist, other physician, or an audiologist, who has experience in industrial hearing conservation programs;
- The guide for instructors should be followed both for selecting faculty and developing lectures;
- The course must follow the guide and cover 20 hours of instruction and practice;
- Students should be encouraged to purchase some reference books (see bibliography).
- Students should be encouraged to take a refresher course of at least one day, six months to a year from the date of the original course;
- All audiometers used should meet AAOO specifications;
- Booths should meet USASI specifications;
- Various types of ear protective devices should be demonstrated.

verman, *Hearing and Deafness*, Holt and Rinehart, New York, 1960.

Industrial Noise Manual, 2nd Edition, American Industrial Hygiene Association, Detroit, 1966.

Oyer and O'Neill, *Applied Audiometry*, Dodd, Mead, New York, 1959.

Guide for Industrial Audiometric Technicians, Employers Insurance Company, Wausau, Wis., 1967.

American Standard Specifications for Pure-Tone Audiometers for Screening Purposes (Z24.12-1952), USASI, New York.

3) Supervised Audiograms—2½ hours (Practice)
Each student performs audiograms on numerous people (all audiogram records are kept by technician for discussion purposes; Topic VI).

Topic VI—four hours

1) Review of audiograms performed and additional practice—one hour
2) Types of audiograms—their significance and interpretation—one hour
3) Practice—two hours

Topic VII—two and one-half hours

1) A Hearing Conservation Program in industry—one hour (Film may be used with lecture)
2) The Nurse's Responsibility in a Hearing Conservation Program—one hour
3) Record Keeping—½ hour

Topic VIII—one hour

Medical-Legal Aspects and Trends in Compensation Laws

Topic IV—two hours

Hearing Protection and Noise Control
Lecture - Film - Demonstration

Topic X—two and one-half hours

1) General Review and Examination
2) Continued practice in taking audiograms
3) Certificate of attendance.

GLOSSARY

AAOO—The American Academy of Ophthalmology and Otolaryngology is a professional organization of medical specialists who establish standards pertaining to vision and hearing. It is also the sponsor of the Subcommittee on Noise in Industry's Research Center.

Air Bone Gap—is the difference in decibels between the hearing levels for a particular frequency as determined by air conduction and bone conduction.

AMA Hearing Impairment Formula — The American Medical Association, with the support of the American Academy of Ophthalmology and Otolaryngology, has established a formula for hearing impairment based on the average of the hearing levels of the three speech frequencies of 500, 1,000, and 2,000 Hz.

Barotrauma—is an injury to the ear caused by a sudden alteration in barometric pressure.

Acuity—in this sense pertains to the sensitivity of hearing.

Attenuate—is to reduce in amount as in audiometry by turning the hearing level dial in units of 10 or five decibels in order to obtain a threshold of hearing.

Audible Range—is the frequency range over which normal ears hear—approximately 20 cycles through 20,000 cycles. Above the range of 20,000 cycles, the term ultrasonic is used. Below 20 cycles, the term subsonic is used.

Audiogram—is a record of hearing loss or hearing level measured at several different frequencies — usually 500 to 6,000 cycles. The audiogram may be presented graphically or numerically.

Audiologist—is a person trained in the specialized problems of hearing and deafness.

This glossary has been adapted from the *Guide for Industrial Audiometric Technicians*, published by the Safety and Health Services, Employers Insurance of Wausau, Wausau, Wis.

Audiometer—is a signal generator or instrument for measuring objectively the sensitivity of hearing in decibels or intensity, frequency or pitch.

Audiometric Technician—is a person who is trained and qualified to administer audiometric examinations.

Automatic Audiometry—is the method most often used for testing large numbers of persons. It eliminates the need for a technician except to begin the test. The subject controls the presentation of sound and records his response.

Bone Conduction Test—is a special test conducted by placing an oscillator on the mastoid process to determine the nerve-carrying capacity of the cochlea and the eighth cranial (auditory) nerve.

Calibrate—is to check an audiometer for uniformity or accuracy. It may be done biologically and electronically.

Cerumen—is hardened ear wax.

Cochlea—is the auditory part of the internal ear, shaped like a snail shell. It contains the basilar membrane on which the end organs of the auditory nerve are distributed.

Conduction Deafness—is an impairment of hearing due to the failure of vibrations to be transmitted to the cochlea. This type of deafness can often be corrected medically or surgically.

Damage Risk Criteria—is the suggested base line of noise tolerance which, if not exceeded, should result in no hearing loss due to noise.

Deaf—is the term used to describe a person who has lost his hearing before the speech patterns were established.

Deafened—refers to a person who has lost his ability to hear after normal speech patterns were established.

Decibel—is a dimensionless unit expressing the logarithmic ratio of two amounts of pressure, power, or intensity.

Eustachian Tube—is a structure about 2½ inches long leading from the back of the throat to middle ear. It equalizes the pressure of air in the middle ear with that outside the eardrum.

Hearing Level—was formerly called "hearing loss" and is the deviation in decibels of an individual's threshold from the zero reference of the audiometer.

Frequency—is the number of vibrations (expressed in cycles per second or Hertz). It is sometimes called pitch or the highness or lowness of sound. High frequencies damage more easily than low frequencies in noise-induced hearing loss.

Hearing Conservation—is the prevention or minimizing of noise-induced deafness through the use of hearing protection devices and the control of noise through engineering methods.

Interrupter Switch—is usually called the "presenter switch" because it permits the stimulus to be presented or cut off from the earphones but it leaves the audiometer circuits in operation, making it possible to change the frequency and intensity level of the tone.

High Frequency Loss—refers to a deficit starting with 2,000 Hz and beyond.

Ear Defenders—or simply plugs or muffs designed to keep noxious noise from the ear to preserve hearing acuity.

Malingerer—is one who pretends deafness or other abnormalities.

Masking—is the stimulation of one ear of a subject by controlled noise to prevent his hearing with that ear the tone or signal given to the other ear. This procedure is used where there is at least 15 to 20 dB difference in the two ears.

Meniere's Disease—is the combination of deafness, tinnitus, and vertigo.

Monaural Hearing—refers to hearing with one ear only.

Noise—is any unwanted sound.

Noise-Induced Hearing Loss—is the terminology used to refer to the slowly progressive inner ear hearing loss that results from exposure to continuous noise over a long period of time as contrasted to acoustic trauma or physical injury to the ear.

Nonauditory Effects of Noise—refers to stress, fatigue, work efficiency, and performance effects of loud noise that is continuous.

Octave Band—is an arbitrary spread of frequencies.

Organ of Corti—is an aggregation of nerve cells lying on the basilar membrane that picks up vibrations and transmits them to the brain where they are interpreted as sound. It is the "heart" of the hearing mechanism.

Ossicle—is a small bone, any member of a chain of three bones from the outer membrane of the tympanum (eardrum) to the membrane covering the oval window of the inner ear.

Otitis Media—is an inflammation and infection of the middle ear.

Otologist—is a physician who has specialized in surgery and diseases of the ear.

Otosclerosis—is hardening of the ear caused by a growth of bony tissue about the foot plate of the stapes and the oval window of the inner ear. It results in a gradual loss of hearing. Surgery can often correct this.

Paracusis Willisii—is the sensation of a deafened person indicating that he can hear better in a noisy area.

Presbycusis—is the hearing loss due to age and the loss of nerve capacity. It is believed by some to be the degeneration of the nerve cells due to ordinary wear and tear on their structure as a result of environmental noise.

Psychogenic Deafness—is that originating in or produced by the mental reaction of an individual to his physical or social environment. It is sometimes called functional deafness or feigned deafness.

Recruitment—is the condition in which an individual perceives an abnormally rapid increase in loudness as the sound pressure goes up. It is usually characteristic of severe sensorineural deafness.

Sensorineural Deafness—is nerve deafness or the lack of sensitivity of the auditory mechanism in the cochlea or paralysis of the acoustic nerve. This was formerly called inner ear impairment or perceptive deafness.

Semicircular Canals—are the special organs of balance that are closely associated with the hearing mechanism and the eighth cranial nerve.

Single Frequency Screening Test—is a fast method of rechecking hearing acuity using the 4,000 Hz frequency. The measured value of the threshold of 4,000 Hz up to 50 dB can be considered an upper limit for any threshold shift that might have occurred at other lower frequencies.

Sound—is the sensation produced through the organs of hearing—usually by vibrations transmitted in a material medium, commonly air.

Sound Level Meter and Octave Band Analyzer—are instruments for measuring sound pressure levels in decibels referenced to 0.0002 microbars. Readings can also be made in specific octave bands, usually beginning at 75 Hz and continuing through 10,000 Hz.

Speech Perception Test—is a measurement of hearing acuity by the administration of a carefully controlled list of words. The identification of correct responses is evaluated in terms of norms established by the average performance of normal listeners.

Speech Reading—is also called lip reading or visual hearing.

Temporary Threshold Shift (TTS)—is the hearing loss suffered as the result of noise exposure, all or part of which is recovered during an arbitrary period of time when one is removed from the noise. It accounts for the necessity of checking hearing acuity at least 16 hours after a noise exposure.

Threshold—is the point at which a person just begins to notice the tone is becoming audible.

Tinnitus—is a ringing sound in the ears.

Tone Deafness—is the inability to make a close discrimination between fundamental tones close together in pitch.

Watch Tick or Coin Click Test—are crude testing devices now outmoded by audiometric measurements, which are claimed to be as much as 10 times more accurate.

Audiometer Room Criteria

Introduction

It is desirable to have a uniform set of criteria for the sound pressure level of the background noise that is allowable in a room used for audiometric tests. Such criteria make it possible for the designer to plan appropriate acoustic treatment and for the user to assure himself of sufficiently quiet testing conditions. The criteria will be stated in physical terms, but are based upon psychophysical data. The determination of these criteria is influenced, therefore, by individual differences in the ability to detect signals in noise, and by individual differences in the fit of the earphones on the ears.

The criteria presented apply to most situations that require a measurement by earphone of hearing loss for pure tones. It has been assumed that the masking of "negative" hearing losses (hearing better than the reference value) is tolerable, but that all hearing losses *greater* than zero must be measured accurately. The criteria given will usually be met only in specially designed and carefully constructed audiometric rooms, or in prefabricated rooms erected at carefully selected locations.

TABLE 1

Maximum Allowable Sound Pressure Levels for No Masking Above the Zero Hearing-Loss Setting of a Standard Audiometer

(Decibels ref 0 0002 Microbar)

Audiometric test frequency (cps)	125	250	500	750	1000	1500	2000	3000	4000	6000	8000
⅓ octave band center frequency (cps)	125	250	500	800	1000	1600	2000	3200	4000	6400	8000
Sound pressure level (db)	35	35	35	35	35	37	42	47	52	57	62
½ octave band cut-off frequencies (cps)	106-150	212-300	425-600	600-850	850-1200	1200 1700	1700-2400	2400 3400	3400 4800	4800-6800	6800-9600
Sound pressure level (db)	37	37	37	37	37	39	44	49	54	59	64
Octave band cut-off frequencies (cps)	75-150	150-300	300-600	600-1200	600-1200	1200-2400	1200-2400	2400-4800	2400-4800	4800-10,000	4800-10,000
Sound pressure level (db)	40	40	40	40	40	42	47	52	57	62	67

General Considerations

If the sound pressure levels measured are greater than the appropriate values specified in Tables 1 and 2, it will be necessary to provide a quieter environment for the test. This may be done by building an enclosure, which will exclude sound to the requisite degree, or by selecting an alternate site. It is frequently desirable to investigate both possibilities and to select the most economical or practical combination.

The detailed design of structures for sound reduction is complex. There are general rules, however, that must be observed. And, there is a range of outside levels that may be acceptable with several different kinds of room construction. Such information will be helpful when preliminary plans are made. Detailed plans should be made only with expert help or after careful study of information in books on the subject.

Features of test rooms

While the primary and necessary requirement in test rooms is a sound pressure level below the appropriate values specified by Tables 1 and 2, it is also desirable to have a minimum amount of distraction for the observer. It is strongly recommended that individual rooms—or at least sections of a room—acoustically and visually well separated from each other be provided for each subject, and that the floor be covered with a carpet or a cushioning material to reduce impact and scraping noises in the room. An absorbent acoustical treatment for walls and ceiling is recommended to provide an appropriate atmosphere for the test while securing maximum quieting of sounds arising inside the room and those arriving from outside. Comfort is important; therefore, the furniture should be comfortable, and ventilation should be provided. It is also important to employ a ventilating system that does not produce noise exceeding the levels specified. The hum, which may be produced by a poorly designed fluorescent fixture, should be avoided.

The addition of absorbing material to the proposed room for audiometer measurements is effective by itself only where conditions are nearly acceptable as found. When the walls of the proposed audiometer room are heavy, and the noise transmitted through the floor and ceiling are unimportant, the major source of the background noise in the room may be acoustic leaks around doors, windows, pipes, and ducts. It may be necessary to install acoustical treatment in ventilating ducts leading to and from the room, and to maintain low air velocities to minimize grill noise.

TABLE 2

Maximum Allowable Spectrum Levels for No Masking Above the Zero Hearing-Loss Setting of a Standard Audiometer

(Decibels ref 0 0002 Microbar for 1-cps band)

Audiometric test frequency (cps)	125	250	500	750	1000	1500	2000	3000	4000	6000	8000
Spectrum level of narrow band sound whose center frequency is nearly that of the test tone	21	18	15	12	12	11	16	18	23	25	30

NOTE 1: Consider only those frequency bands that contain test tones

NOTE 2: These levels are approximate averages of criteria previously proposed [4, 5] Minor fluctuations were removed from the average and the results verified by data from Glorig [6] that apply to the important frequency range below 1000 cps.

NOTE 3: These tables apply to audiometers calibrated according to American Standards Z24.5-1951 and Z24.12-1952.

Reduction by isolation

Large amounts of noise reduction can be obtained only by providing a completely enclosed testing space. The characteristics of a sound insulator—a wall, ceiling, or floor—differ from those of a sound absorber. The isolator must be nonporous, and is principally effective in proportion to its weight per square foot of surface. This effect increases slowly with weight, and large sound reductions are obtained economically only by the use of double-wall structures wherein a complete separation between the walls is maintained throughout by an air space or resilient connections.

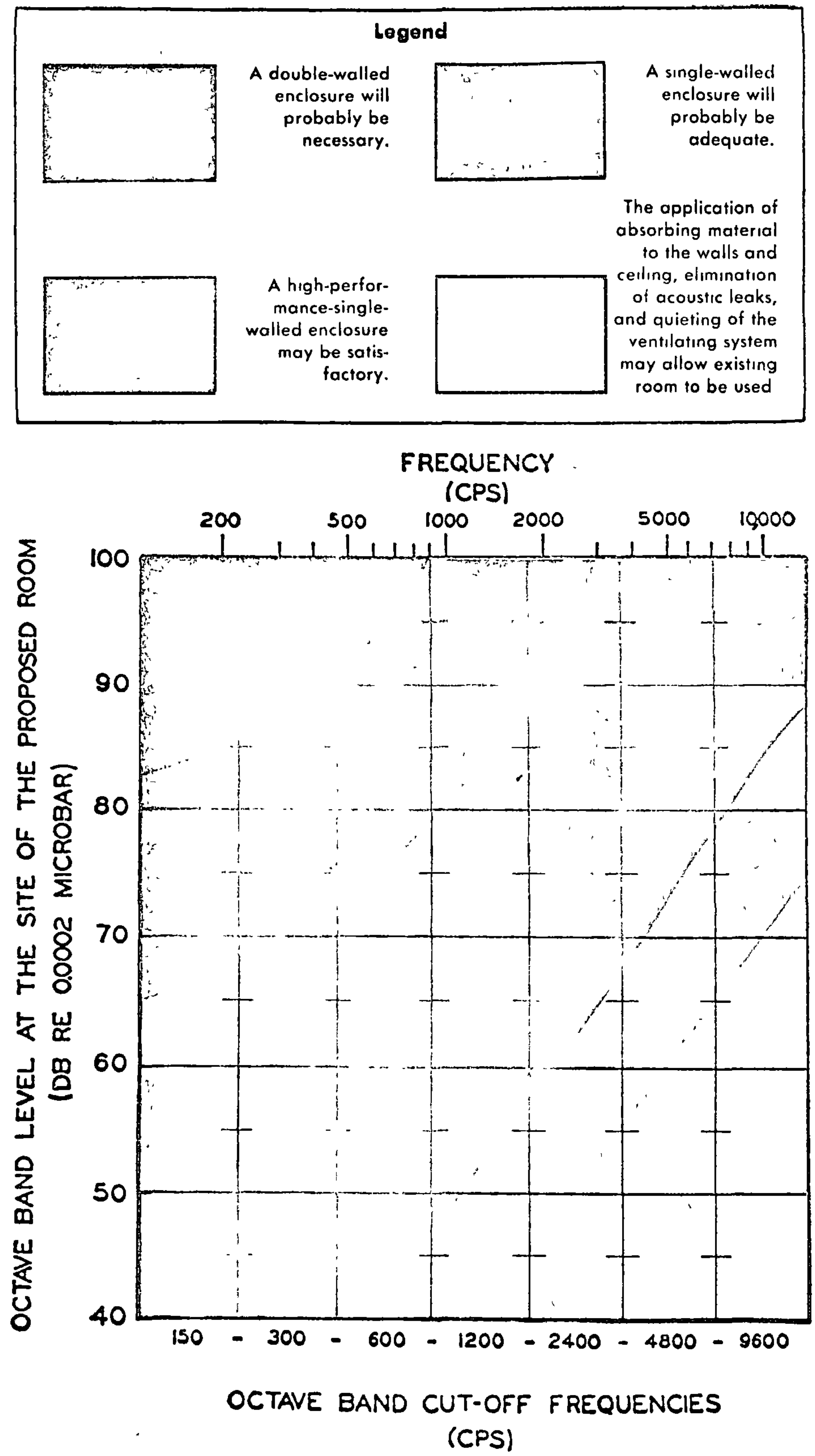

Figure 1: Plot the sound pressure level in the octave bands containing test tones on the graph shown. Observe the highest region into which these data fall (see legend above).

Construction method

The following procedure gives a rough indication of the kind of construction that may be necessary. In the octave bands, which will contain test tones, measure the sound pressure level at the site of the proposed test room. Plot these as a graph on Figure 1. The highest range in which the measured levels fall determines which of the three general classes of room modifications is probably necessary. It is assumed that noise radiated by the floor is negligible or that a floating floor is to be installed, that a ceiling construction will be provided that is equivalent to the walls in noise reduction and permits no excessive transmission of impact sound from above, and that doors and windows will maintain the effectiveness of the walls and ceiling.

A single-wall prefabricated audiometric test room employing metal demountable panels, and equipped with ventilation and vibration isolation from the floor can, in many cases, be used where the sound pressure level falls in the upper half of the area indicated on graph in Figure 1 (see legend of the various shaded areas). For extreme cases, such rooms can also be provided with double walls and can, in many cases, be used where the sound pressure level falls in the "double-wall" area of the graph. Prefabricated test rooms often prove to be an economical method for obtaining a satisfactory environment for tests.—**End.**

EDITOR'S NOTE: The material used here was extracted by permission from *Criteria for Background Noise in Audiometer Rooms* (S3.1-1960). The standard is published by USASI and copies of the complete standard may be obtained from them by writing to USASI, 1430 Broadway, New York City.

Industrial Hearing Conservation

Administration And Human Relations Aspects

By **Charles W. Wyman,** retired senior staff engineer, Industrial Hygiene and Safety Engineering, Western Electric Co., Hawthorne Works, Chicago, now a consultant to industry.

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Administration And Human Relations Aspects

By **Charles W. Wyman,** retired senior staff engineer, Industrial Hygiene and Safety Engineering, Western Electric Co., Hawthorne Works, Chicago, now a consultant to industry.

This is the eighth part in a series of articles on the development of an industrial hearing conservation program. It points out that the safety specialist has to do more than simply set up a program and offer a variety of hearing protectors. He has to motivate the employees to wear those protectors. All articles in the series are available as reprints from NSC.

INDUSTRY'S PRIME CONCERN with noise is its potential harmful effect on employees' hearing. Prolonged exposure to excessive noise levels can cause serious permanent hearing loss unless protective measures are taken. Permanent hearing loss caused by excessive exposure is now a recognized occupational hazard and is compensable in some 35 states.

Dr. Aram Glorig, director, Callier Hearing and Speech Center, Dallas, one of the leading authorities on noise-induced hearing loss, has stated that industrial noise is now the most important single cause of hearing loss.

One does not fully appreciate the magnitude of the noise problem until he sees figures that indicate half of the machines used in industry are capable of producing hazardous noise levels—and that some 16½ million workers operate these machines.

Thus, excessive noise has become another industrial hazard to be evaluated and controlled, similar to head, eye, lung, and foot hazards, which have been with us for a long time.

The purpose of this article is to provide information which has been found helpful in selling a hearing conservation program to employees.

The effects of noise on man can be summarized as follows:

1) Excessive noise exposure can produce a permanent hearing loss that may affect speech communication.

2) Noise-induced hearing loss can be either temporary or permanent or a combination of the two.

3) Permanent noise-induced hearing loss is due to destruction of certain parts of the inner ear that cannot be repaired or replaced.

4) Some persons are more susceptible to hearing loss than others.

5) Noise-induced hearing loss first affects man's hearing of sounds higher in frequency than those found in normal speech communications. For this reason early noise-induced hearing losses frequently pass unnoticed unless detected by suitable hearing test instruments.

6) The major factors that determine the potentially harmful effects of noise exposure are:

- overall noise level
- composition of noise
- exposure time

In addition to hearing loss, high noise levels can cause fatigue, inefficiency, high labor turnover and loss of production. Noise and vibration transmitted through a building structure or air can become a source of annoyance in a neighborhood or community, creating ill will and possible litigation.

Fundamentally, management h the responsibility for providing a safe and pleasant working environment for its employees. Emphasis on mechanization and speed-up to increase productivity has greatly increased employee exposure to noise

Management must therefore give consideration to the human relation aspects of noise abatement and establish an effective hearing conservation program to protect the welfare of its employees.

Currently management's reaction to noise abatement and hearing conservation has been varied, but on the whole it has been favorable. The "let's not talk about it and it may go away" attitude is disappearing in view of impending state and federal legislation covering noise exposure and compensation claims for noise-induced hearing loss. Limiting factors to establishment of a hearing conservation program include: 1) lack of an adequate budget to cover the increased engineering and medical expenses; 2) lack of trained personnel to organize and carry out the program; 3) employee reluctance to wear ear protective devices.

Programs may vary from one plant to another depending on such factors as the characteristics of noise exposure, engineering and medical facilities, compensation laws, and general company policy.

Essentially, a good hearing conservation program can be divided into four parts:

1) Surveying operations to evaluate noise exposure and hazard;

2) Instituting controls to minimize noise exposure;

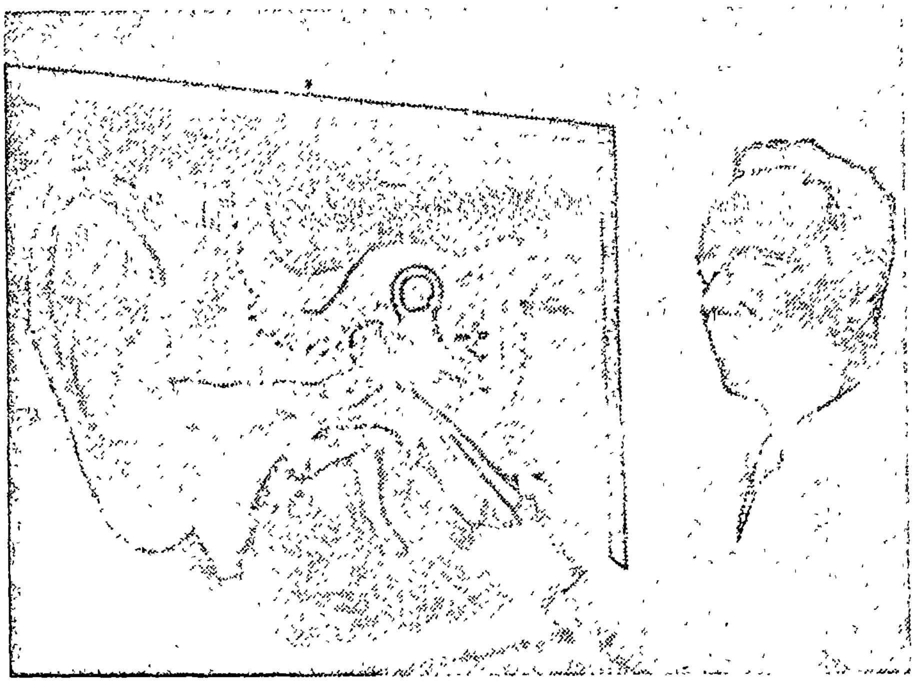
3) Requiring employees to wear ear protectors when harmful noise level exceeds safe limits;

4) Providing pre-placement and routine periodic audiometric examinations to check employee hearing.

Setting up a Program

Before such a program can be started, the hazards and plans for a hearing conservation program should be discussed with top management as well as labor leaders, and their agreement obtained Full cooperation between management and labor is essential for an effective program.

One individual should be made responsible for coordinating the team effort necessary for carrying out the program, which will involve the organization responsible for safety, plant and product engineers, plant physician and nurse. Generally, the coordinating is done by the physician or organization responsible for safety.



Anatomical diagram of the various parts of the human hearing mechanism is used by Dr. Joseph Sataloff at Union Camp Company to help employees visualize how prolonged exposure to excessive noise levels can result in irreparable hearing loss.

Noise Level Surveys

The first step in a hearing conservation program should start with a plant-wide survey using appropriate sound level measuring equipment to locate operations which may expose workers to potentially hazardous noise levels.

A decision will have to be made as to whether sound level measuring equipment should be purchased and personnel trained to use it, or the work should be done by an outsider. The size of the plant and nature of the work will, of course, affect this decision. In most plants surveys are made by a qualified industrial hygienist or safety engineer.

As a rule of thumb, a noise level that seriously interferes with normal speech communication so that one must shout to be heard at arm's length is probably in the harmful range. In such a situation, sound level instrument readings in the speech frequency bands should be taken.

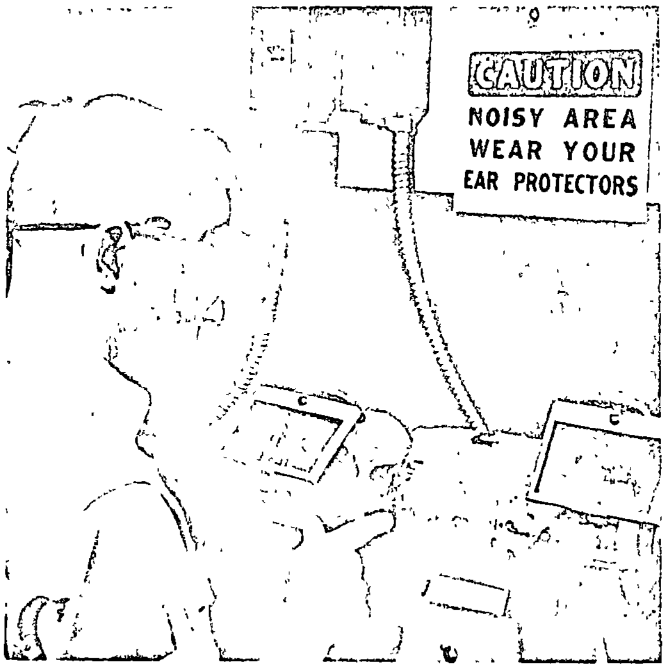
Damage Risk Criteria

The American Conference of Governmental Industrial Hygienists at their May 1969 meeting have adopted threshold limit values for sound pressure levels to which nearly all workers may be exposed repeatedly without adverse effect on their ability to hear and understand normal speech.

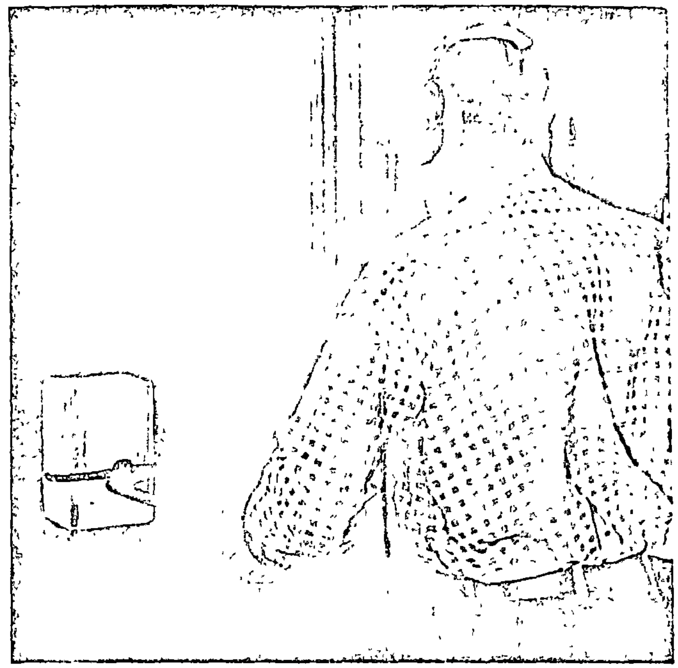
• The boundary between noises that cause hearing losses and those which do not appears to be somewhere between 80 and 90 decibels in any of the octave bands above 300 Hz. (A decibel is the unit of measurement for sound intensity.) According to current thinking, continuous exposure to noise in the speech frequency range (300 to 2,400 Hz) is believed to have the following effects on hearing.

Band Level Effects
80 decibels—no permanent damage
85 decibels—damage risk minimal
90 decibels—damage to about 10%
95 decibels—damage to about 80 to 85%

Noise-induced hearing loss can vary from one person to another depending on individual susceptibility. The highly susceptible employee would be the first affected by 90 and 95 decibel levels.



With a little getting used to, and with an understanding of their importance, employees will wear plugs (or muffs) when exposed to hazardous noise.



Foundry workers are subject to high decibel noise. Hearing protection is a must but many companies let the employees choose the type of protection on the basis of comfort.

Engineering Controls

After making surveys to determine the overall noise level, composition of the noise, and exposure time, a comparison can be made with available damage risk criteria to evaluate the hazard and consider necessary engineering control measures for lessening noise at the source, such as:

1) Change in plant design or location of operation;

2) Substitution of quieter equipment, processes, or materials;

3) Confining or absorbing the sound by barriers, enclosures, or acoustical treatment.

The ultimate goal should always be to eliminate or reduce noise *at the source* to safe limits.

Non-Engineering Controls

Experience has shown that in many instances the reduction of noise at the source to safe limits is impracticable because of cost, time interval requirement to make the change, and loss of much needed production. Progress in controlling noise at the source has, therefore, been slow, and the need for hearing protection has become so urgent that many noise problems have to be solved by providing employees with personal protective equipment in the form of ear plugs and ear muffs. These devices, if correctly worn, reduce the intensity of the noise striking the inner ear by 25 to 30 decibels. This amount of reduction is usually sufficient to bring the loudest noise encountered in most industries to within safe limits.

Safety engineers agree that selling employees on the wearing of ear plugs and muffs is much tougher than selling other items of personal protective equipment such as hard hats, safety glasses, and safety shoes. Hearing loss does not lend itself to pictures or posters showing cracked skulls, damaged eyes, or smashed toes to remind the worker of immediate serious injury if authorized personal protective equipment is not worn.

Noise-induced hearing loss is so gradual over a long period of time that the average worker is not aware of it. The first loss is in the range above that needed for good speech communication and then the loss progressively drops down to the speech frequency range. Early hearing losses, which the employee does not recognize, point up the need for pre-assignment and periodic reexamination.

Most employees, even after being told of the hazard, do not become particularly concerned over a little hearing loss that may take place in 15 to 20 years. Similar apathy is displayed by cigaret smokers, who are being continuously warned of the possibility of lung cancer.

Just making hearing protectors available to employees does not constitute a hearing protection program. To overcome an employee's resistance, careful fitting and education are needed.

Getting employees to wear ear plugs or muffs will require a persistent and continuous selling job that may tax the patience of supervision, safety engineer, physician, and nurse.

Another form of non-engineering control over hazardous noise exposure is to reduce exposure time by rotating employees. Employees found particularly susceptible to noise can be transferred to work in a less noisy area. Transferring employees has its limitations as it can cause personnel problems due to loss of seniority and prestige, lower productivity and pay.

Audiometric Examinations

Pre-employment audiometric measurements of employees' hearing acuity will detect a hearing loss incurred elsewhere and will protect the employer against possible false claims.

These measurements, commonly referred to as an "audiogram," will also serve as a base line for comparison of future audiograms to detect any progressive hearing loss.

It has been reported that as many as 27 out of 100 young workers first entering employment may show significant hearing loss. It is not uncommon to bring to light non-occupational hearing defects, which can be called to the employee's attention and be corrected.

Periodic rechecks should be scheduled at 1½ to 18 month intervals depending upon the nature and intensity of the noise and length of exposure to detect any progressive hearing loss due to noise exposure. This is the only way the effectiveness of a hearing conservation program can be evaluated.

To be successful, a hearing conservation program must be sold to the employee. In this way he will be made to understand and appreciate the effect of noise on hearing, and realize that he is being required to wear ear plugs or muffs for his own protection—just as he is required to wear other devices, such as a hard hat, safety glasses, gloves, protective clothing, etc.

Obviously this calls for a continuous selling job by all levels of supervision as well as the plant physician, nurse, safety organization, and others associated with the hearing conservation program.

Some of the procedures and practices used successfully to implement and sell a hearing conservation program may be of assistance.

Western Electric Company's Hawthorne Works began its first hearing protection program in 1952. Employees exposed to very high noise levels on specific jobs were provided with ear plugs. While wearing plugs was authorized and encouraged, this was not mandatory and their use was left up to the individual employee. This voluntary program was not well accepted by employees. The average worker accepts noise associated with his work without complaint or no particular concern as to his possible hearing loss. Very few continued to wear ear plugs after a brief trial period. It was obvious that a voluntary ear plug program could not be relied upon to protect employees' hearing.

By 1961 sufficient data had been accumulated to show that an enforceable hearing-protection program was essential to the protection of employees' hearing. Management, after reviewing available hearing loss criteria, established 90 decibels in any octave band as the maximum permissible level for exposures of five or more hours per day.

Now the problem became one of how to implement and enforce such a program. The solution appeared to be an educational campaign to impress on the employee as well as all levels of supervision that:

1) Excessive exposure to noise can cause hearing loss;

2) Until noise can be reduced to safe levels, wearing of hearing protectors in the form of ear plugs or ear muffs is mandatory;

3) A program to reduce noise exposure to safe levels will be continued by the company.

To implement mandatory wearing of ear protectors, the medical director, noise control engineer and safety organization formulated an indoctrination program to be given to supervisors and employees before ear protectors were issued. This educational program lasted about 45 minutes and was on "company time." Groups consisting of employees and their supervisors ranged in size from 10 to 25 members.

The medical director explained the anatomy of the ear and the harmful effect of excessive noise exposure on the hearing mechanism.

LET'S REVIEW THE FACTS

1. It is necessary for employees in certain noisy areas to wear ear protectors
2. Prolonged exposure to excessive noise can harm the delicate hearing mechanism
3. Ear protectors such as ear plugs or ear muffs will reduce the noise before it reaches the ear drum.
4. Your job assignment will determine whether you should wear ear plugs (inserts) or muffs (covers)
5. Speech and warning signals can be fully heard with ear protectors in noisy shop areas

WEAR YOUR EAR PROTECTORS

1. The nurse will fit them and instruct you how to wear them
2. Wear them for short periods to start and gradually increase the wearing time After a few days you will be able to wear them all day with minimum discomfort.

Suggested Wearing Time Schedule

	A.M.	P.M.
1st day =	30 minutes	— 1 hour
2nd day =	1 hour	— 1 hour
3rd day =	2 hours	— 2 hours
4th day =	3 hours	— 3 hours
5th day =	all day	— all day thereafter

3. If after five days the ear protectors feel uncomfortable, come in and see the nurse in the Company hospital
4. Ear protectors should be replaced when they become worn, stiff or lose their shape.
5. If ear protectors are misplaced, a new pair should be obtained without delay.
6. Never put soiled ear plugs into your ears Wash the ear plugs at least once a day with soap and water
7. With proper care, ear plugs should last for several months and ear muffs should last for several years

OTHER POINTS TO REMEMBER

1. The best ear protector is the one that is properly fitted and worn
2. Good protection depends on a snug fit. A small leak can destroy the effectiveness of the protection.
3. Ear plugs tend to work loose as a result of talking or chewing, and they must be re-seated from time to time during the working day.
4. If ear plugs are kept clean, skin irritations and other reactions should not occur.

YOUR HEARING IS PRICELESS

PROTECT IT

Here's a sample of a card that one company issues to all of its employees who are required to wear some form of ear protective device. It highlights the care and use of the protectors.

A Typical Indoctrination Program For Industrial Hearing Conservation

Here's how one company introduces the various aspects and importance of its hearing conservation program. The person in charge of the program meets with new employees and conducts the session as follows:

Introduction

The purpose of this meeting is to familiarize you with our program for the conservation of hearing. We will present briefly the medical, industrial hygiene, and safety aspects of our program and outline the roles each of us plays to make the program effective.

Following these brief discussions, we will show a film, which will give you further understanding regarding the important factors involved in noise control. An opportunity will be available during the latter portion of this session for you to ask questions, and for us to discuss any points that may not be clear to you.

This company has been outstanding in its leadership in the development of health and safety programs for its employees. We have accomplished a great deal with many safety devices, and now progress is being made in preventing hearing fatigue — the conservation of hearing as related to industrial noise.

The Ear — And How We Hear

The ear is the organ of hearing and is the most complex of the special sense organs. It serves as a source of communication and protection. It is divided into three main sections:

- External Ear
- Middle Ear
- Inner Ear

Each section has a particular job to perform. The outer ear collects and directs sound energy into the hearing mechanism. When the sound waves strike the ear drum, it vibrates and sets into motion three small bones, which are located in the middle ear. These bones carry sound as vibrations to the inner ear. There it is changed into electrical impulses and is transmitted to the brain for interpretation.

Types of Hearing Impairments

1) The ear canal may be plugged by wax, a foreign body, or by infection so that sound cannot reach the ear drum.

2) The middle ear may be injured by an explosion, or infection after a cold, or the small bones may become affected so that they cannot carry the vibrations to the inner ear.

3) The inner ear and its sensitive nerve endings may be damaged by diseases, childhood infections, head injuries, certain drugs, and age.

4) Prolonged exposure to excessive noise is now known to cause nerve damage.

In cases of external and middle ear conditions, a physician can often cure them This is not always true of inner ear damage. Once the nerve endings are damaged, there is no way of restoring them, and they will not respond to treatment—medical or surgical.

Ear Examinations

Ear examinations are conducted by the company physician and his trained medical assistants.

The Hearing Tests

Hearing losses are found by testing with an electronic apparatus, called an audiometer. This instrument measures the sensitivity of hearing. Regular, routine hearing tests enable us to measure any changes in your hearing ability.

The audiometric test consists of finding the faintest sound that you can hear at six different test frequencies. The point at which you can just hear each test frequency is marked on a card made for this purpoes. These points are connected by a line, and the resultant graph of hearing is called an audiogram.

Ear Protectors

Scientific research shows that prolonged exposure to excessive noise can harm the delicate hearing mechanism. Ear protectors—such as ear plugs or ear muffs—will reduce the noise before it reaches the ear drum.

It is our company policy for all employees in certain noisy areas to wear ear protectors, just as it is to use other safety equipment.

Types of Ear Protectors Available

1) Ear plugs or inserts are designed to fill the ear canal. Some are made of a soft pliable material, which is molded by hand to fit the ear canal. Others are solid, made of a rubber-like material, which is both easy to insert and comfortable to wear.

2) Ear muffs are designed to cover the external ear. They are made of plastic ear cups with rubber-like pads to insure a good seal around the ears. They are held to the ears by a band.

Some employees prefer one type of ear protection to another. The important thing is that you wear properly fitted protectors of whichever is most comfortable for you.

The nurse will fit you and show you how to wear your ear protectors properly. Once you are fitted properly, you will always be able to tell whether you are wearing them correctly.

In a quiet room, ear protectors will muffle sounds; in a noisy work area, sounds such as speech and warning signals can be heard with ear protectors worn because the protectors reduce the background noise.

Points To Remember

1) The best ear protector is the one that is properly fitted and worn.

2) Good protection depends on a snug fit. A small leak can destroy the effectiveness of the protector.

3) Ear plugs tend to work loose as a result of talking or chewing, and they must be reseated from time to time during the working day. Never put soiled ear plugs into your ears. Wash the plugs at least once a day with soap and water. With proper care, ear plugs will last for several months.

4) Don't try to adjust an ear protector yourself. If, after wearing for a couple of days, your ear protectors are uncomfortable, see the company nurse for adjustment or replacement. Whenever ear protectors become worn, stiff, or lose their shape, they should be replaced.

The noise control engineer discussed problems associated with reducing noise at the source and what the engineers had done and were doing to reduce noise exposure.

The safety engineer emphasized that employees would be required to wear ear plugs or muffs for their own protection—just as they are required to wear safety goggles, respirators, and other items of personal protective equipment. Periodic inspections would be made to determine compliance. Enforcement for wearing of ear plugs or muffs would be the responsibility of supervision.

After these talks, a 16 mm movie, *Ear Protection and Noise,* produced by the American Academy of Ophthalmology and Otolaryngology, was given. This is an excellent film for selling a hearing protection program.

Employees were then given an opportunity to examine various types of ear protectors. It was agreed that ear plugs are preferable for most operations and that ear muffs should be provided for short, intermittent exposures.

A question and answer period followed, giving employees an opportunity to ask questions and to express opinions on the program. At the conclusion each was given a small pocket folder summarizing the need of ear protection and suggestions on wear and care of such devices (see illustration). Later these employees were sent to the Works hospital to receive their initial audiometric examination, be fitted with ear plugs, and instructed on their use and care

Proper fitting of the ear plug was found to be the most important part of the program as far as hearing protection is concerned. If the plug is too large it will exert too much pressure on the ear canal and be very uncomfortable. On the other hand, it must exert sufficient pressure on the ear canal to make and maintain a good seal.

Here are some of the most frequent complaints raised by ear plug wearers, including answers to these problems:

1) "They hurt the ear and cause headaches."

Answer: Properly fitted and adjusted ear plugs should cause only mild discomfort, which should disappear when the employee gets accustomed to wearing them. Pain or headache indicate that a refitting or change to a differently designed plug may be required.

2) "They interfere with conversation."

Answer: Regular wearers of ear plugs report that in high noise areas wearing of ear plugs makes it easier to converse because much of the high frequency background noise is eliminated.

3) "They keep one from hearing how machines are operating."

Answer: Regular wearers report that after becoming used to the change in a familiar sound, they can recognize machine sounds without difficulty.

4) "They cause ear infections."

Answer: We have had no reports of ear infections due to ear plugs. Ear plugs can be kept clean by washing them when you wash your hands. When not being worn, keep them in their protective container.

5) "They get misplaced and get lost easily."

Answer: So do safety glasses unless one is careful.

Conclusions

Prolonged exposure to loud noise encountered in industry can produce permanent hearing loss. Noise-induced loss does not respond to treatment and cannot be restored. This type of hearing loss is now a recognized compensable occupational hazard in many states.

Management has the responsibility of protecting its employees against hearing loss and its company against potential compensation claims by instituting an effective noise abatement and hearing conservation program by:

1) Reducing employee noise exposure to safe limits through engineering controls;

2) Providing employees with suitable ear protection devices and seeing that they are correctly worn, whenever engineering controls are impracticable.

When personal protective devices are employed, there must be an effective and continuing educational campaign to convince the employee that he is being required to wear ear plugs or muffs for his own hearing protection.

The success of a hearing conservation program will depend upon full cooperation and support of top management, all levels of supervision and employees, as well as those concerned with the health and safety of the employee.—**End.**

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Getting Employees To Wear HEARING PROTECTION

RESPONSIBILITY for hearing protection rests initially with management. Administering a hearing protection or conservation program, however, usually is up to the safety director It is his job to work out the details of whom to protect, the devices to use, how to fit those devices, when to distribute them, and all the other details of coordinating the program and establishing control measures.

Management's support is not enough. The employees have to be won over, too.

Promoting Hearing Protection

Because of its relative newness, hearing protection is sometimes difficult to get started in a plant. Merely making good ear protection devices available does not insure an effective program. Simply saying that the wearing of ear protection for certain jobs and in certain areas is a condition of employment is naive. It's not that easy.

Finding a system that works is often a case of trial and error, and no one system will work for everyone.

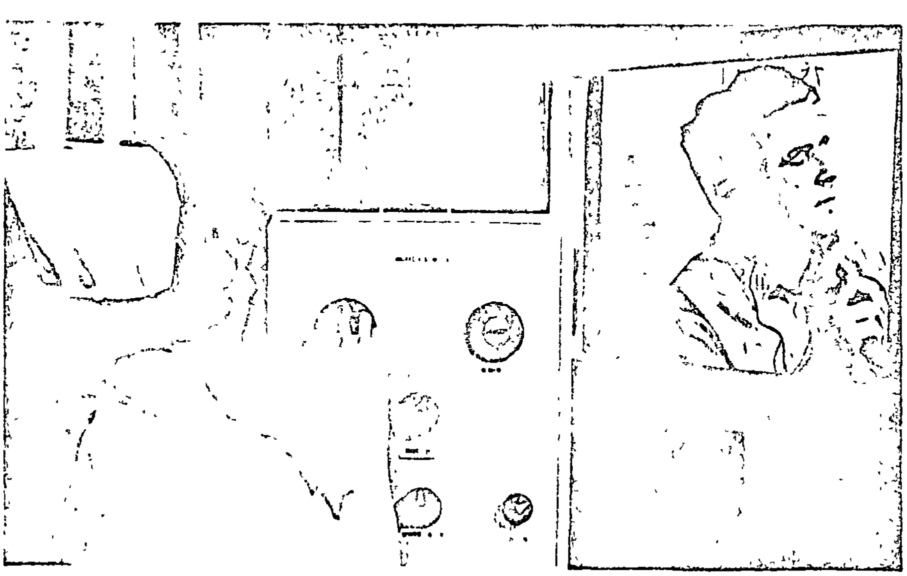
Employers Insurance of Wausau (Wisconsin) has made a long-time study of techniques that have helped them achieve a practical and effective program of personal hearing protection. The ideas and suggestions that follow are the contributions of many industrial nurses and safety consultants.

• The logical time to acquaint a new employee with hearing protection is at the time he is also briefed on the pre-employment physical examination, group insurance, and first aid facilities, and told about other safety devices. It should be explained that management provides the hearing protection devices for his protection and welfare. One nurse told each new employee, "Our management has concern for your ears. We don't want you to work for us and retire with deafness, which can be prevented."

• Hearing protection is much more successful if the nurse, doctor, or trained employee explains its purpose and fits the worker properly. This type of protection should be handled the same way other safety measures are handled. A pre-employment audiogram will indicate the employee's present status of hearing. Because many workers will have high-frequency deficits above the speech or conversation range (sounds that are somewhat expendable), the technician can point this out and say. "In the higher sounds, your ears are less sensitive than they used to be. Fortunately, it is probably not serious at this time, but in order to prevent further damage or deterioration to your hearing mechanism, the wearing of ear protectors will help you keep your ears intact. We do not want you to have 'dead ears' when you reach the age of 65."

• Each supervisor can be asked to give earplugs a fair trial by using them for short periods of time; then gradually work up to longer periods until the plugs can be worn for a full shift without discomfort. This method can sell the supervisors on the value of ear protection and also convince them that it is not unreasonable to require employees to use it.

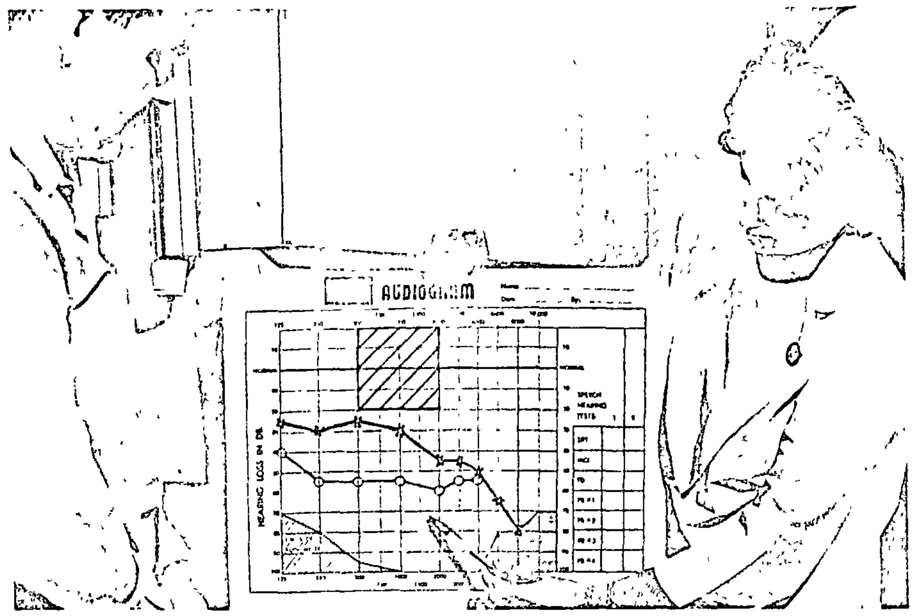
• At one plant an alert foreman



An employee is shown signalling (with his up-raised finger) that he hears the tone presented by the [illegible]dustrial nurse began a conversation with an employee in a noisy area. It was only natural for the two of them to shout and strain. Then the foreman handed the worker a pair of ear protectors and explained that he should try them, not only because he would be able to hear more easily but also because he would feel more comfortable and eliminate a cause of possible permanent damage to his hearing. It doesn't take long for this type of information and approval to spread around a plant.

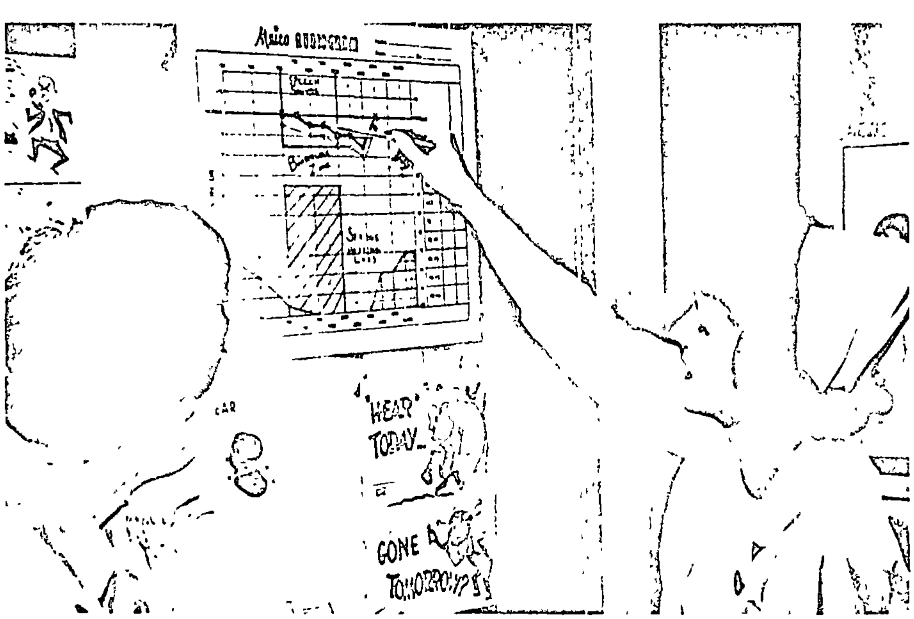
• At another plant, a safety director suggested during the monthly safety meeting that six employees try out ear protectors for one month and make a report at the next meeting. Everyone of the experimenters gave enthusiastic reports on their experience. One man, who worked in noise that was in excess of 95 dB, said that since he began wearing protection, he could go home and enjoy television much more because the ringing in his ears was gone, and he felt less fatigued at the end of the day.

• At one foremen's meeting, where hearing protection was emphasized, the occupational health nurse used an audiometer and checked the foremen's hearing at the 4,000 Hz frequency—with and without ear protectors. The demonstration proved quite convincing when the group found that it took 25 more decibels to obtain a response from a worker when he was wearing protectors.



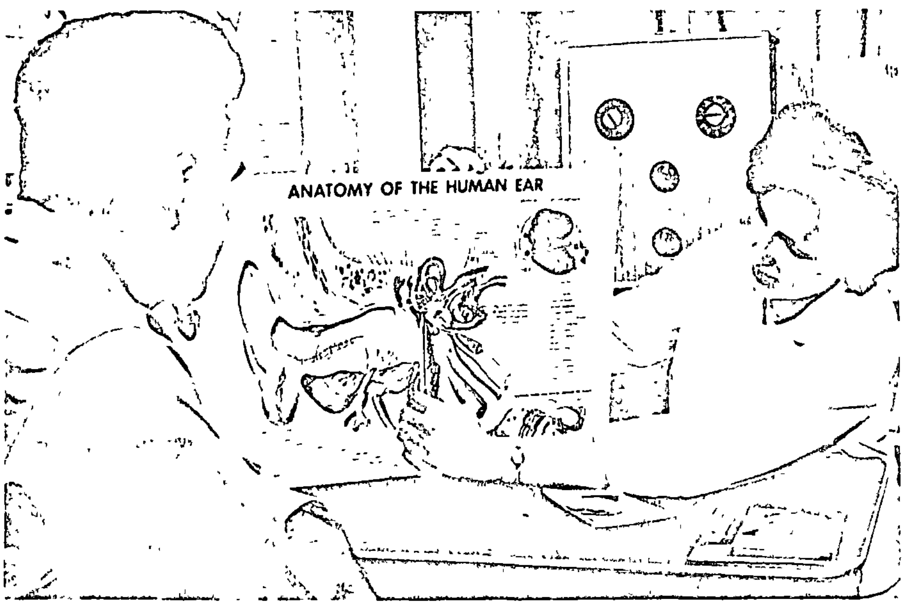
An employee with marginal hearing loss will better appreciate the importance of wearing ear protection when a nurse takes the time to interpret his hearing test results.

• One nursing supervisor reported that the task of selling ear protection to the employees in her plant had not been as bad as she thought it would be after she recovered from the initial shock and disappointment of learning that workers just do not rush to the health service for ear plugs or muffs when told that they are available. Damage to the delicate nerve endings in the inner ear continues without warning and without pain. A worker can experience a hearing loss without actually noticing it until he is unable to hear speech sounds. The nurse stated: "We have something to offer the worker that we have overlooked until now. What man wants to lose his hearing needlessly? Who wants to be rewarded at retirement time with deafness that medicine or surgery is unable to correct? The real answer is simply to explain the facts by using the sound and sensible argument that the employee benefits most. It is no different from the reason for wearing safety glasses or any other safety device or equipment. Who wants to retire with dead ears?"



A non-medical explanation of an audiogram by a nurse or trained technician will help point out the need for wearing personal protective devices.

• Another occupational health nurse reported on her success in providing hearing protection in a large paper mill. "In our firm, the problem was solved when I began to explain audiogram results to the workers. I interpret vision test results in a simple and unmedical manner. Why shouldn't I take the mystery out of the dips and curves of an audiogram, especially when they are high frequency scores, which are indicators that the noise is damaging their hearing long before it encroaches on the valuable speech frequencies?" This same nurse developed another idea that worked for her. Because their plant worked rotating shifts, there is always one crew that sleeps in the daytime. Taking advantage of this



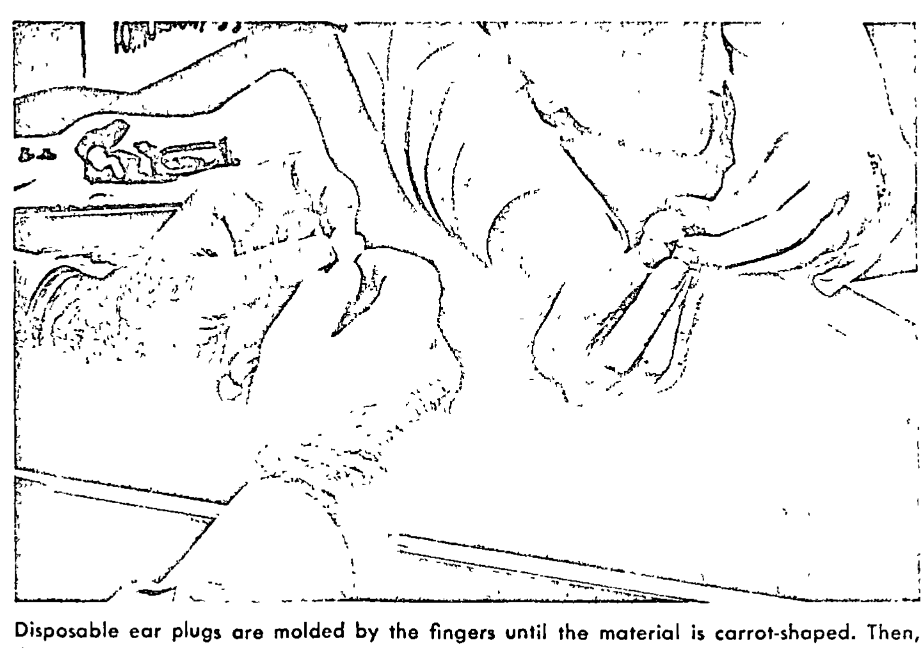
An ear chart is a valuable aid to the nurse or technician when explaining how ear protection prevents hearing loss due to noise exposure — also that plugs or stopples will not injure the eardrum, a fear many employees have.

situation, the nurse called each man to her office before the shift changed and fitted him with ear plugs to wear while sleeping. The men came back to her and enthusiastically reported on the value of this protection in eliminating or curbing the noise of children at play and even that of the vacuum cleaner in the adjoining room while they were trying to sleep. The same workers found that ear plugs were as successful at work as they were at home because they added to their personal comfort. This discovery, of course, is what the nurse had in mind all the time.

• With the help of a foreman, another occupational health nurse solved the problem of getting men to audiometric rechecks before they were exposed to saw and planer noise. It is necessary for men to have a 16-hour reprieve from noxious noise before they are given an audiometric examination, but this wasn't practical in order to check all the employees working on a particular shift because there wasn't enough time to check them at 7:00 in the morning. The foreman suggested that on the following day the nurse talk to each man scheduled for a hearing check about the necessity of wearing ear plugs until the nurse scheduled him for audiometric evaluation. The worker was properly fitted by the nurse, with firm instructions to wear the device before entering the plant the next morning. What were the results? The nurse now had ears to check that were not affected by temporary deafness, and she was able to continue her audiometric examinations throughout the entire day. The employee found personal comfort because the ear muffs cut down the 120 dB noise as much as 35 dB. Needless to say, these men became faithful wearers of hearing protection devices because they had actually tried them out and proved their value.

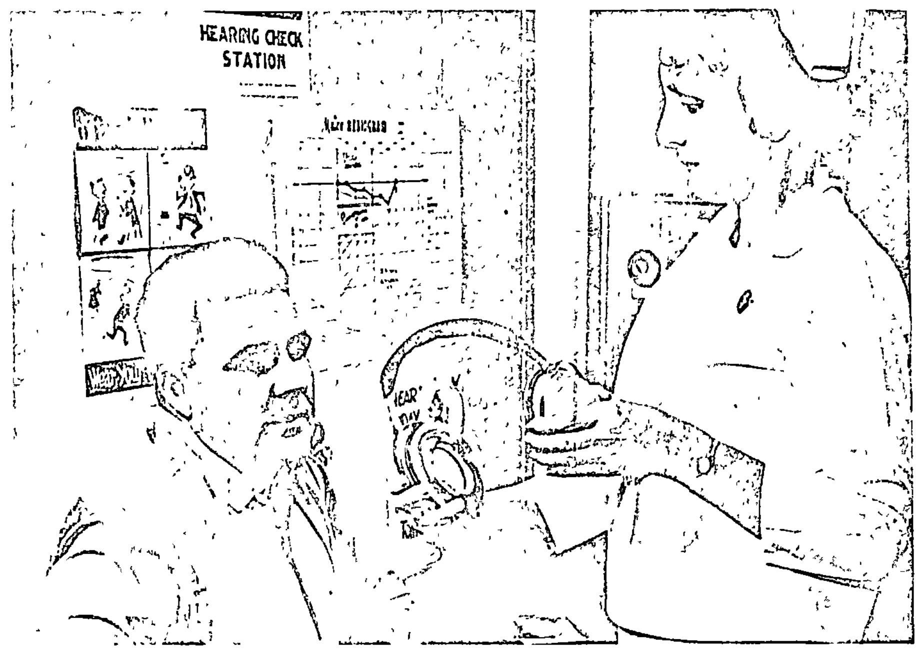
• Education can do a great deal in shaping proper attitudes and defeating prejudices, clearing up misunderstandings, and gaining acceptance of the idea. Ear protection is a long-range educational enterprise. Supervisors and foremen must bring the problem squarely and forcefully to the workers in the plant through meetings and conferences. It would be well to have a physician or trained technician explain the anatomy of the hearing mechanism in simple terms. It should be explained that an occupational hearing loss is not necessary if proper protection is worn. The employees should be reminded of a world without sound. Imagine suddenly being cut off from voices of your family and friends. Think of losing all the pleasure and meaning of speech, music, telephone, radio, television, and many other things that we enjoy through hearing. Noise deafness cannot be cured by medicine or surgery. Posters on ear protection and hearing conservation, feature articles in employee publications, and special bulletin board displays will all help to promote the wearing of ear protectors.

• Many plants have learned that it helps considerably to have a variety of ear protectors. Unfavorable reactions are bound to occur when a man is told, "This is the kind that *we* have decided you should wear."



Disposable ear plugs are molded by the fingers until the material is carrot-shaped. Then, the soft wedge is pressed firmly into the ear canal. All employees should be instructed how to fit their protective devices, and given a chance to select a type that provides both comfort and protection.

Individual fitting of plugs is extremely important. The technician, shown here, finds it helpful to pull up on the outer ear slightly. This enlarges and tends to straighten the entrance to the ear canal making it easier to insert the proper size device. Some trial and error is necessary; a plug should not be too loose or tight.



Whereas ear muffs are not as complex to fit as are plugs, employees must be shown how to seat them properly to obtain a seal around the ear. Otherwise, the whole purpose of using the device is negated, and the employee is not receiving proper protection. Besides the overhead supension model, muffs are available with under-the-chin and nape suspension. There are also safety hats available that have muffs attached. After being shown how to fit the muffs to his ears, an employee must be instructed also not to stretch or spring the headbands and not to deface the muff itself in any way. Otherwise, he will not receive proper protection from the device.

Employees will have a far different attitude when they are told, "Try this type and come back in a week and let us know how it works. You are welcome to try other available kinds until you feel that you have the one that suits you best." None of us likes to be told exactly what we must do, think, or wear. The more choices we have, the more attractive the proposition becomes. The medical director in a large foundry recorded a statement made by his nursing supervisor: "I have given up trying to get our people to wear hearing protectors. It is a fruitless task." The doctor said: "I am convinced that every nurse would desire the assurance that employees will never come back to her after retirement and ask, 'Why didn't you do something to help protect my hearing? Why didn't our company provide hearing protection and insist that we use it like many other companies do?'" If nurses would promote hearing protection as skillfully and persuasively as they have promoted other health and safety objectives, they would eventually see their efforts take hold. Two ingredients of success are requisite:

1) Unqualified management support and thorough medical supervision;

2) A tireless explanation by all staff personnel, foremen, and supervisors of the "why" of hearing protection.

Enforcement

Should management institute compulsory or mandatory programs of ear protection? For expediency, many safety directors, with the backing of plant superintendents and medical directors, have insisted that everyone wear ear plugs or muffs, but they have found it difficult, later on, to apply penalties, which were meaningful and effective.

After a trial period, many safety directors have decided that the best results are obtained through long-range educational efforts, which achieved 70 to 80 per cent coverage of the workers exposed to hazardous noise. As one explained, "Very few things in life are 100 per cent, but if we get the majority of workers protected, we can take some comfort in the fact that we are making valuable progress. Hearing protection will never spread like colored television, but we can take some comfort in the fact that each year we seem to do a better job. More workers are faithfully and continuously wearing the protection offered, because they feel it is the proper thing to do and their hearing will be saved."

Veteran safetymen say that ear protection is no different than the introduction of safety glasses, respirators, shoes, hats, gloves, and other personal protective equipment. Hearing conservation programs are relatively young. Few are more than 10 years old. The objections and difficulties will eventually be overcome.—**End.**

ACKNOWLEDGMENT

The ideas for promoting ear protection were adapted, by permission, from *Industrial Noise and Hearing Protection*, 1967, published by Employers Insurance of Wausau, Wausau, Wis.

The photos used to illustrate this article were supplied by Employers Insurance of Wausau.

An Industrial Hearing Conservation Program. The introduction to a series of articles, based on the NSC Safety Training Institute's course on Industrial Noise, provides the basic concepts.
8 pp 111.17-37 (August 1968)

Physics of Sound. A review of the basic physics of sound provides the background for minimizing, limiting, or preventing excessive exposure to noise. Includes a Glossary of Terms. (Second in a series of articles based on the NSC Safety Training Institute course on Industrial Noise.)
8 pp. 111.17-42 (November 1968)

Instruments and Techniques of Sound Measurement. The third article in a series on the fundamentals of industrial hearing conservation discusses sound-level meters, octave band analyzers, and auxiliary equipment plus calibration techniques.
10 pp. 111.17-44 (December 1968)

Procedures of a Sound Survey. Types of noise, types of sound surveys, the equipment needed, and survey procedures are outlined.
12 pp 111.17 46 (January 1969)

Ear Anatomy and Effects of Noise on Man. The physiology of the ear helps explain the effects of noise on behavior, communication, and hearing.
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Personal Ear Protection. Discusses requirements of ear protectors in regard to the acoustic problems and describes types of personal ear protection devices available.
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Hearing Measurement and Audiometry and Audiometer Room Criteria. Discusses procedures for measuring employee hearing acuity and thresholds. Audiometric equipment is explained and a program for its care and maintenance is discussed. Criteria for sound pressure level of background noise in test rooms is given.
12 pp. 111 17-49 (April 1969)

Administration and Human Relations Aspects of Industrial Hearing Conservation and Getting Employees to Wear Hearing Protection. Discusses how the safety specialist can motivate employees to wear hearing protectors.
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Engineering Control of Noise and Engineering Noise Control Effectively. Discusses basic principles of controlling industrial and occupational noise hazards through engineering.
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Harrison

Ear Anatomy

and

Effects of Noise on Man

By **Edward R. Hermann**, Ph.D.,
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Reprinted from National Safety News **National Safety Council, 425 N. Michigan Ave., Chicago, Ill. 60611**

Ear Anatomy and Effects of Noise on Man

The fifth in a series of articles on the fundamentals of developing an industrial hearing conservation program discusses the anatomy and physiology of the ear and shows the effects of noise on the auditory mechanism, behavior, communication, and hearing.

Anatomy of the Ear

THE HUMAN EAR enables man to perceive and interpret sound. Anatomically the ear is a complex of skin, flesh, membranes, muscles, cartilage, bones, and nerves. Physiologically its function is to transmit to the brain an accurate pattern of all sound vibrations received from the environment, their relative intensity, and the directions from which they may emanate.

The human ear may respond to sound waves in a frequency range from as low as 16 Hertz (Hz) to as high as 30,000 Hz. There is a great deal of individual variation, however. As a general observation, perception of high frequencies is best in early childhood with a gradual decrease throughout life, so that a normal adult may have difficulty hearing sounds pitched higher than 10,000 or 12,000 Hz. Persons who hear over a frequency range from 20 to 20,000 Hz have an unusually broad frequency response; whereas those who can hear tones in the range from 20 to only 2,000 Hz have hearing that is quite adequate for speech communication if their ability to perceive such sounds at normal intensities is unimpaired.

System Components

The auditory hearing system in man may be divided into three main sections:

1) the external ear;

2) the middle ear;

3) the inner ear.

External ear

The external portion of the ear consists of an auricle, or pinna, and external auditory meatus (canal), and the ear drum. Even though fixed in position and lying close to the head, the pinnae tend to concentrate sound waves, especially those of high frequency, and conduct them into the auditory canal, which terminates at the ear drum. The two ears provide stereophonic hearing so that we can discriminate the direction of a sound. This is accomplished by means of an ability to sense the difference in the phase of a sound vibration as it arrives at the two ears, and also by the differences in intensity and quality of the same sound reaching each ear due to the angular placement and attenuation of the head. Even the shape of the auricles enables man to sense whether a sound is coming from directly behind or directly in front.

The external auditory meatus shelters the ear drum and maintains the relatively constant conditions of temperature and humidity necessary to preserve its elasticity. In addition it acts as a tubal resonator, especially for frequencies in the range between 2,000 and 5,500 Hz.

The ear drum is composed of both circular and radial fibers. It is kept tense for better reception of vibrations by the tensor tympani muscle. Here, the pressure variations of sound in air are transformed into very minute mechanical vibrations In addition to acting as a receptor of vibrations, the drum also serves as a barrier to shelter the delicate contents of the middle ear. It also provides an acoustic dead space so that air vibrations in the middle ear will be broken up and dissipated by the irregular walls, epitympanic recess, and mastoid cells, and thus will not exert pressures against the *round* window in competition with vibrations coming through the cochlea in the other direction from the *oval* window.

Middle ear

The anatomical components comprising the middle ear are: the malleus, incus, and stapes bones; the oval and round windows; the tensor tympani and stapedius muscles; the eustachian tube, which vents the middle ear to the pharynx. An overall schematic of the ear is shown in Figure 1[1].

The three ossicles, located in the middle ear, function as a linkage between the ear drum and oval window. These delicately suspended bones not only transmit vibrations almost completely without distortion, but also provide part of the increased force that is essential when going from a lighter conducting medium (air) to a heavier medium — the perilymph. This is partly accomplished by leverage. Because the incus is shorter than the long process of the malleus, vibrations received at the oval window are reduced in amplitude but increased in force by a ratio of about 10-to-1 when transmitted onto the much smaller area of the oval window.

Inner ear

The major components of the inner ear include the vestibule, semicircular canals, and the cochlea. The latter contains three passages —the *scala tympani;* the *scala vestibuli,* and the *cochlear duct.* A cross section of the snail-shell-shaped cochlea with various anatomical features is shown in Figure 2.

Vibrations transmitted into the oval window by the footplate of the stapes set up vibrations in the perilymph, which surrounds and bathes the end organs of hearing and balance. The wedge-shaped cochlear duct, lying between the two scalae, contains the organ of Corti, hair cells with bristles, and the tectorial membrane. The cochlear duct is separated from the scala vestibuli by Reissner's membrane, and from the scala tympani by the basilar membrane. The cochlear duct contains a fluid called endolymph and resembling intracellular fluid; whereas the scalae, along with the rest of the vestibule, contain perilymph, which resembles extracellular or cerebrospinal fluid.

The function of the endolymph is probably the nourishment of the organ of Corti; freeing it of any vibrations or noise that its own intrinsic blood supply would produce. As the cochlear duct is closed at the helicotrema, there is no direct passage between endolymph and perilymph. However, it is continuous *via* the duct of Hensen *(ductus reuniens)* with the semi-circular canals — a fact that explains the combination of symptoms present in Meniere's disease.

The organ of Corti, previously mentioned as lying upon the basilar membrane, is composed of a complex assortment of supporting cells. Interspersed between and lying upon the organ of Corti are the hair cells which are considered to be the sensory end organs. These hair cells are arranged segmentally in well-defined rows — a single row of inner hair cells and several rows of outer hair cells. The total number of inner hair cells is about 7,000—of outer hair cells, about 24,000. Each hair cell terminates on its free surface in a clump of hairs similar to a small bristle — 40 per cell in the lower cochlear turn and as many as 100 per cell at the apex.

Overhanging the hair cells is a gelatinous structure known as the tectorial membrane in which the hair ends are embedded. The arrangement and details of the inner ear hearing components are shown in the illustration Figure 3.

Transmission of Sound In the Inner Ear

Vibrations of the stapes at the oval window are transmitted to the perilymph throughout the scala vestibuli (Figures 2 and 4). These vibrations are transmitted through Reissner's membrane to the endolymph and then through the basilar membrane to the scala tympani. From here they pass downward to the round window. The vibrations of the round window thus follow those at the oval window, but in opposite phase. Thereby, when the oval window is forced inward, the round window flexes outward.

Transmission of Mechanical Energy To Electrical Potential

As can be seen in Figure 3, vibrations of the basilar membrane will cause compression, tension, and shear on the hair cells, which are attached to the tectorial membrane. It is that action that transforms the mechanical energy of sound vibrations into electrical impulses that stimulate the fibers of the acoustic nerve to the brain. It is generally agreed that hair cells transmitting different frequencies are arranged segmentally. Those mainly responsible for transmitting the higher tones are located at the lower end of the cochlea near the windows, while those transmitting lower tones are located near the apex (Figure 4).

Transmission of Neural Impulses To the Brain

Each hair cell is supplied by a nerve fiber and some by more than one. Also, each nerve fiber contacts one hair cell; some will contact several. In general, the inner hair cells are each served by only one neuron — the outer by many.

Apparently, the overlapping of nerve connections provides flexibility of hearing functions and a capacity to compensate for damage to single hair cells or to certain neurons. The auditory nerve consists of some 30,000 individual neurons —approximately the same number as the estimated number of hair cells —despite the overlapping of distribution. The nerve cells are located in the spiral ganglia shown in Figures 2 and 3, and from which axons

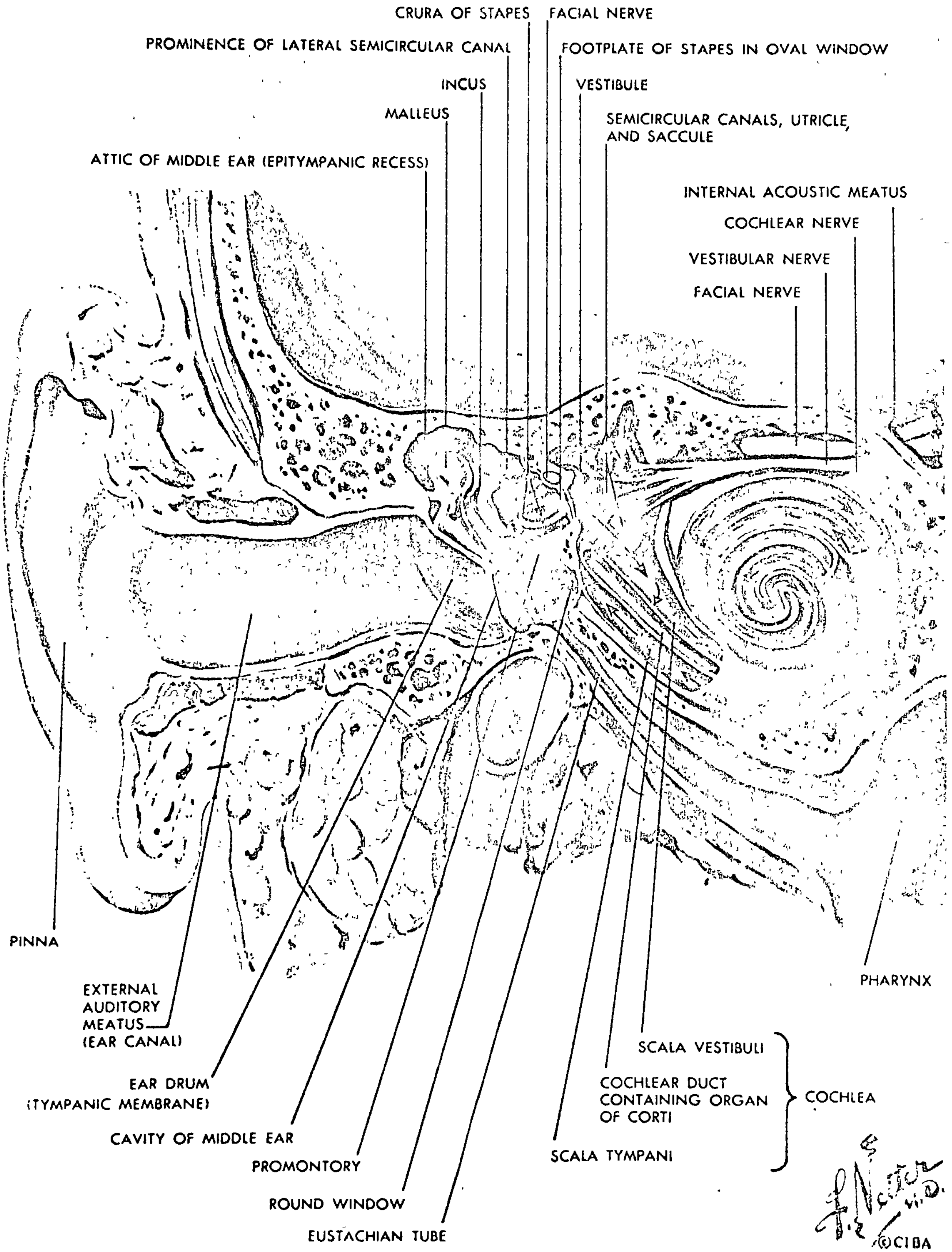

Figure 1 shows the pathway of sound reception.

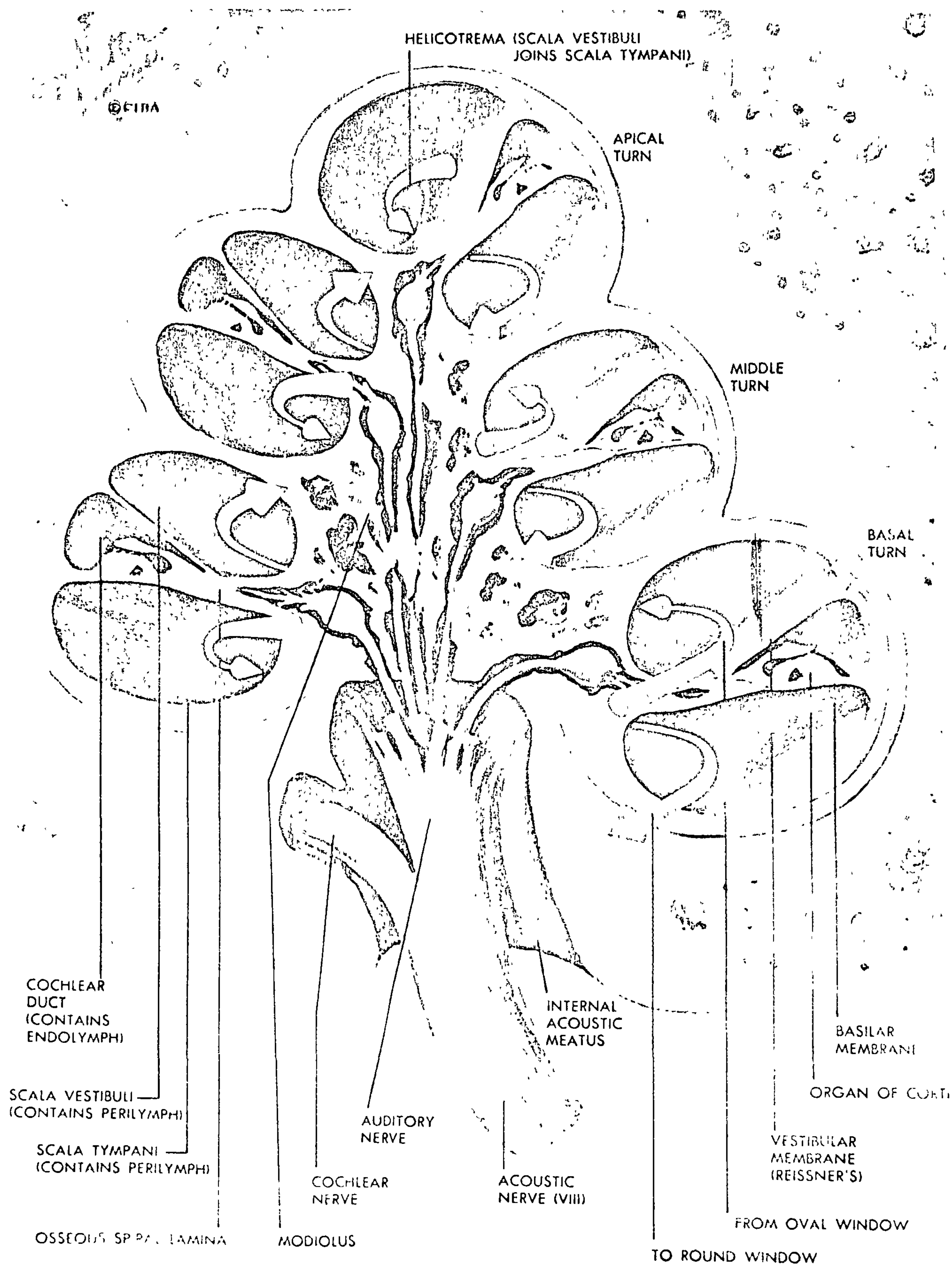

Figure 2 is a cross-section view of the cochlea.

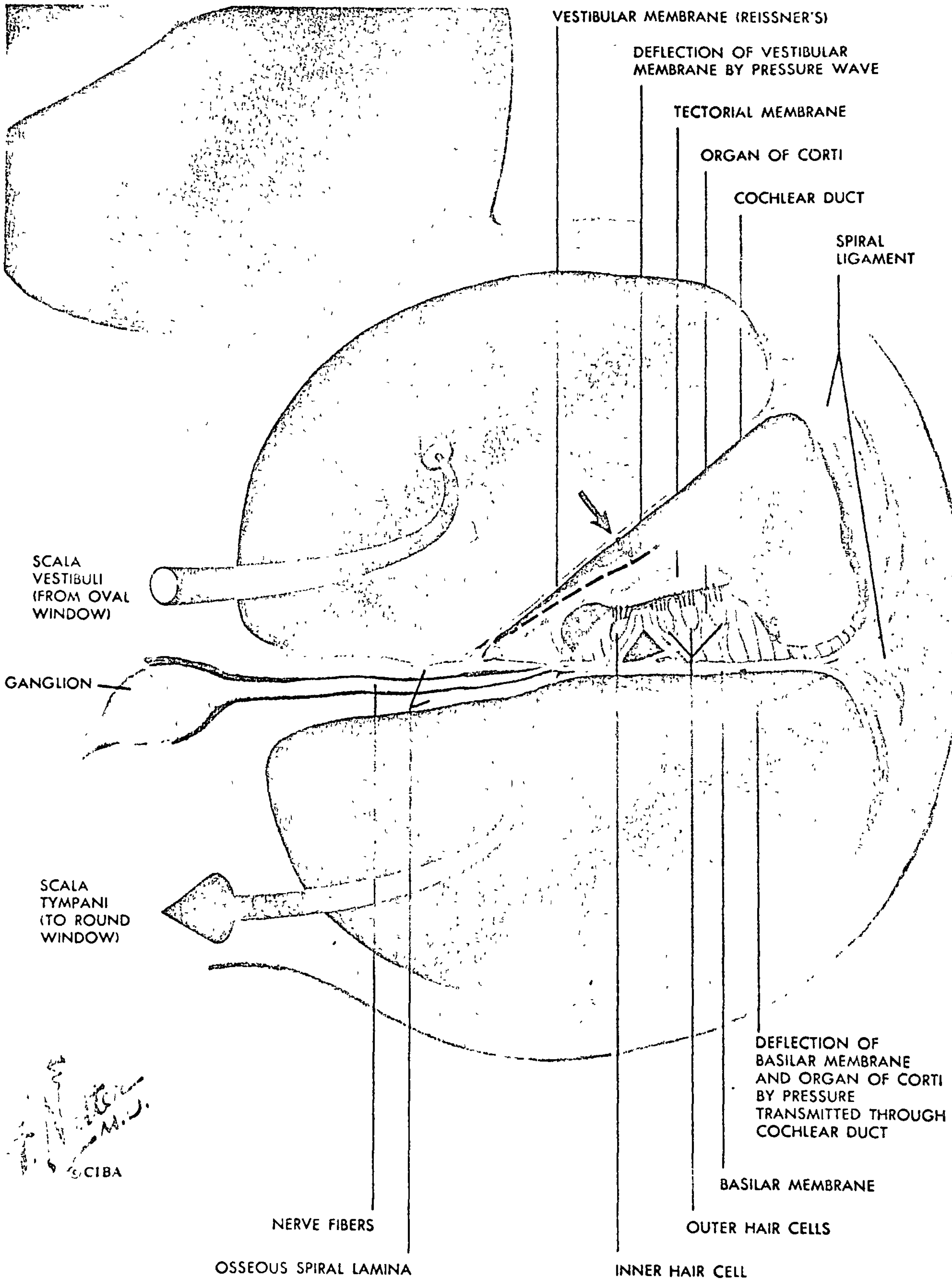

Figure 3 depicts the transmission of sound across the cochlear duct, stimulating the hair cells.

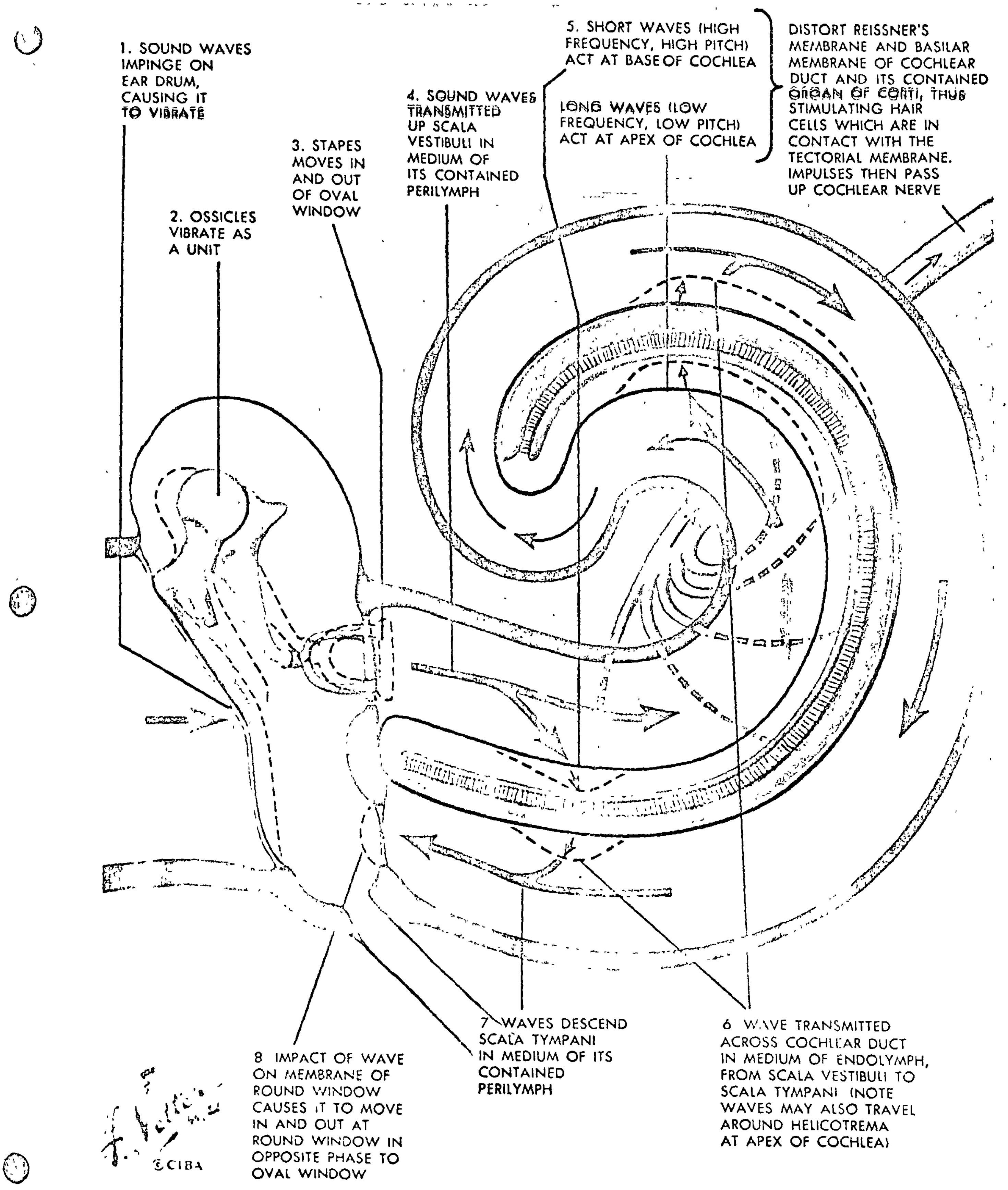

Figure 4 shows the transmission of sound vibrations from the ear drum to the cochlea.

pass *via* the cochlear nerve to the dorsal and ventral cochlear nuclei located in the pons.

From those way stations, fibers pass from the lower brain stem to the mid-brain and cerebral cortex on both sides of the brain, so that stimuli received in the two ears may be mixed and integrated. The partial crossover of neural responses to sound stimuli received by the two ears enables man to sense direction and movement of sound sources.

TABLE 1

Audiometer Zero Reference Levels—A comparison of 1951 American Standards Association (now USASI) values and 1964 International Organization for Standardization values.

Frequency	Reference Threshold Levels		
	1951 ASA	1964 ISO	Differences
125	54.5 dB	45.5 dB	9 dB
250	39.5	24.5	15
500	25	11	14
1000	16.5	6.5	10
1500	(16.5)	6.5	(10)
2000	17	8.5	8.5
3000	(16)	7.5	(8.5)
4000	15	9	6
6000	(17.5)	8	(9.5)
8000	21	9.5	11.5

The figures shown in parenthesis ( ) are interpolations.

Human Hearing Acuity

Thresholds of human hearing at various sound frequencies have been widely investigated by various experimenters. For young persons possessing good hearing, a frequency response curve of the minimum audible field (MAF) may be obtained as shown in Figure 5. The curve depicted shows the sound pressure level at which a pure tone can just be heard binaurally in an exceptionally quiet location under free sound field conditions. Three points of interest may be observed from this curve:

1) The reference pressure variation most frequently used as a basis for physical measurement of sound on a decibel scale was derived from average data obtained at 1,000 Hz. The value of this pressure variation is 20 micro-newtons per square meter (0.0002 dynes/cm²). Thus the sound pressure level at 1,000 Hz on this curve is at zero decibels.

2) The frequency at which unimpaired human hearing is most acute is at 4,000 Hz.

3) The acuity of human hearing decreases quite markedly with decreases in frequency below 1,000 Hz.

NOTE: At 50 Hz, a sound pressure level of 52 dB is required to stimulate the hearing mechanism of a typical person.

Thus from the expression:

$$dB = 20 \log \frac{P}{P_o} *$$

it may be calculated that the pressure variation required to stimulate the ear at 50 Hz is about 400 times as much as is at 1,000 Hz.

Despite the extreme sensitivity of the human ear and the delicacy of some of its component structures, it is very rugged and durable as a sound-sensing device. It can operate for more than a quarter of a century—over a range of pressure variations extending to more than 20,000 times as great as the physicist's reference pressure variation of 20 micronewtons per square meter—without any appreciable deterioration. Even with occasional exposures to sound pressure variations of more than one million times as great as that required to initiate hearing, the ear will function without damage if the duration of each exposure is limited.

When subjected to sound pressure levels greater than 140 to 145 dB, pain is experienced, as indicated by the upper curve in Figure 5. Excursions into such sound fields with unprotected ears should be strictly limited because slight but permanent

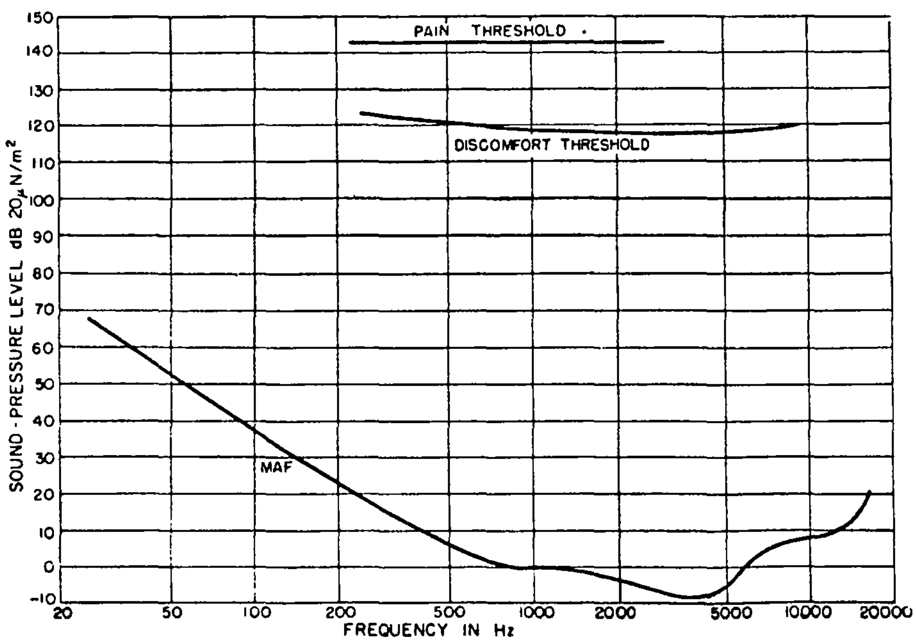

Figure 5 graphically shows the thresholds of hearing and tolerance and is reproduced here from the Handbook of Noise Measurement, published by General Radio Co., West Concord, Mass

*See "Physics of Sound," by Julian Olishifski, NATIONAL SAFETY NEWS, Vol. 98, No. 5, November 1968, pp. 67-73.

threshold shifts in hearing acuity will result from fairly short term exposures. Such noise-induced permanent threshold shifts are irreversible and cumulative.

Various methods of determining hearing acuity have been devised. Of these methods, puretone audiometry is the most widely used, and accurate, low-cost equipment is available that is especially suited to industrial hearing conservation programs.

Due to the variation in human hearing acuity, which occurs with changes in frequency or pitch, audiometer zero reference levels are different for each puretone employed. The values currently in use in the United States are shown in Table 1 The more recent 1964 International Organization for Standards (ISO) values were formally adopted by both the American Speech and Hearing Association and the American Otological Society in 1965 for use in puretone audiometric measurements. The United States of America Standards Institute (USASI) is currently considering adoption of these "zero" reference levels for audiometers.

Of the 10 puretone frequencies listed in Table 1, six tones will usually suffice to provide audiometric evaluations of human hearing thresholds in occupational situations. These are the 500, 1,000 2,000, 3,000, 4,000, and 6,000 Hz puretone frequencies.

Although the physical basis (reference pressure variation) for each of the test frequencies is different, comparison of audiometric measurements with the average values upon which they are based is greatly simplified for the practicing physician, audiologist, or industrial hygienist.

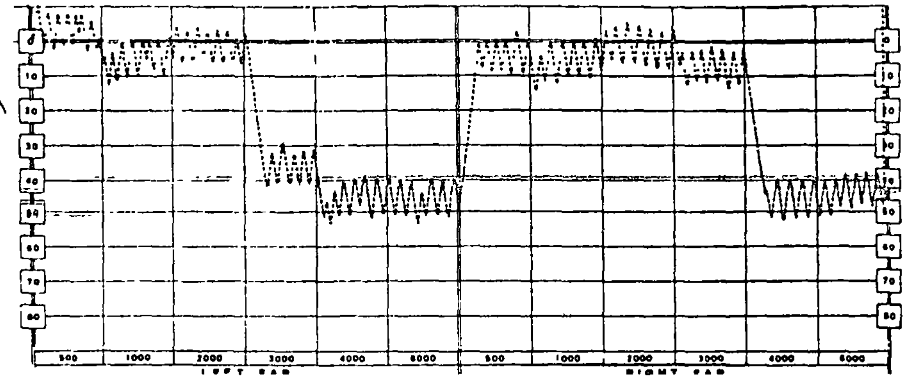

Figure 6 depicts an audiogram obtained by use of an automatic audiometer of the Békésy type as modified by Rudmose. The subject was a 40-year-old tube cleaner who was on the job for 12 years. He claims that he routinely wears ear protection.

Effects of Noise on Man

THE FACT THAT noise exposure of sufficient intensity and duration will produce sensori-neural hearing loss has been recognized for more than a century. Although hearing loss may be caused by a variety of drugs and chemical agents, by certain disease organisms, by traumatic injury, and by aging, there is little doubt that a major cause of hearing loss today is overexposure to excessive noise. It has been variously estimated that between 10 and 20 million persons in the United States have some degree of hearing impairment.

Intense sudden noise—such as that arising from an explosion—may produce severe damage to the structures of the middle and inner ear. The ear drum may be ruptured and the ossicular chain may be destroyed by the extreme pressure variation of a blast wave. Such high pressure variations may also dislocate the basilar membrane and organ of Corti. If tears in an ear drum are not too large, most perforations will heal, provided infection does not arise in the middle ear. If the ossicular chain remains intact and the ear drum heals, little or no conductive hearing loss will result. However, it is a rare ear that will survive this type of insult without some sensori-neural damage.

Noise-Induced Hearing Loss

Noise may interfere with speech communications at sound pressure levels considerably lower than those that produce noise-induced hearing loss. The concept of Speech Interference Levels (SIL) was introduced by Beranek in 1947, and has been modified and expanded since that time.[2]

Noise that masks or interferes with essential speech communications in dangerous situations constitutes an obvious hazard. Such problems do not remain unremedied for long. In many industrial situations, however, speech is not only unessential but often it is undesirable. As noise less intense than 120 to 125 dB does not produce obvious discomfort it is frequently tolerated. Generally, noise exposures less intense than 85 dB in the octave bands centered at 500 Hz and at higher frequencies will not pro-

TABLE 2
Early Loss Index—4,000 Hz Audiometry

Age Specific Presbycusis dB			ELI Scale		
Age	Women	Men	Grade	Exceed ASPV by:	Remarks
				< 8 dB	Normal—Excellent
25	0	0	A	8-14	Normal—Good
30	2	3	B	15-22	Normal—Within expected Range
35	3	7	C	23-29	Suspect noise-induced loss
40	5	11	D	30 or more	Strong indication of noise-induced loss
45	8	15	E		
50	12	20			
55	15	26			
60	17	32			
65	18	38			

duce *significant* hearing losses if limited to less than 40 hours of cumulative exposure per week—even among workers experiencing such exposures for many years. However, from a study of 1,948 persons engaged in industrial pursuits where the maximum sound pressure level of one of the octave bands covering the speech-important frequencies was 79 dB, Glorig and Davis[4] indicated that measurable shifts in hearing acuity were associated with such relatively low exposures.

Hermann[4] noted that the ultimate noise induced loss at 4,000 Hz for this body of data was only 15 dB and calculated that the rate at which this hearing decrement was reached was about 10 per cent per year. From these and other studies, it has been shown that noise-induced hearing losses tend to be self-limiting both at 4,000 Hz and at the lower speech-important frequencies.[5]

Industrial Audiometry

The proof of any industrial noise control and hearing conservation program depends upon audiometric testing in a satisfactory acoustical environment using reliably calibrated equipment, which is operated and supervised by adequately trained personnel. Valid audiometric results may be obtained using either manual or subject-controlled audiometers. The latter type is preferred by the author because it provides a direct print-out of results at the significant puretone test frequencies and has the advantage of eliminating secondary errors due to variations in procedures developed by different technicians. The Rudmose modification of a Bekesy type audiometer is particularly well suited to industrial audiometry. An example of the results obtained using such an audiometer is shown in Figure 6. The subject has good hearing in the speech-important frequencies as indicated by the threshold hearing determinations at 500, 1,000, and 2,000 Hz in both the left and right ears. The subject's hearing above 2,000 Hz in the left ear and above 3,000 Hz in the right ear is definitely poorer than normal for a 40-year-old man. As noted earlier, the frequency at which human hearing is most sensitive is originally 4,000 Hz. Logic and extensive studies have also indicated that it is most susceptible to damage near this frequency when subjected to excessive noise.

Loss of hearing with age is also quite pronounced at 4,000 Hz, and studies using large population samples were required to determine presbycusis values before the 4,000 Hz notch could be quantitatively evaluated and developed as an Early Loss Index (ELI) of noise-induced hearing loss.[5-10]

Although not pathognomonic for noise-induced hearing loss, the ELI does provide a statistical approach to the truth and is applicable to individual as well as group data. Application of this audiometric evaluation technique consists of simply determining how much an individual's hearing loss exceeds the presbycusis value indicated for his (or her) age and sex, and then using the grading scale and interpretation shown on the right side of Table 2.

Age and Sex Specific Presbycusis Values (ASPV) may be obtained by interpolation of the values given at five-year intervals—as shown on the left side of Table 2. It should be

TABLE 3

Speech Average Loss Conversational Audiometry

Grade	SAL dB	Class Name	Characteristics
A	<16 Worse ear	Normal	Both ears within normal limits no difficulty with faint speech
B	16-30 Either ear	Near normal	Has difficulty only with faint speech
C	31-45 Better ear	Mild impairment	Has difficulty with normal speech but not loud speech
D	46-60 Better ear	Serious impairment	Has difficulty even with loud speech
E	61-90 Better ear	Severe impairment	Can hear only amplified speech
F	> 90 Better ear	Profound impairment	Cannot understand even amplified speech
G	Total Deafness in both ears		Cannot hear sound

—NRC Committee on Hearing

Note: A person is graded one class lower than indicated by the above scale if, with an average loss of 10 db or more, his range of hearing thresholds in the three speech frequencies is 25 db or more in both ears considered separately.

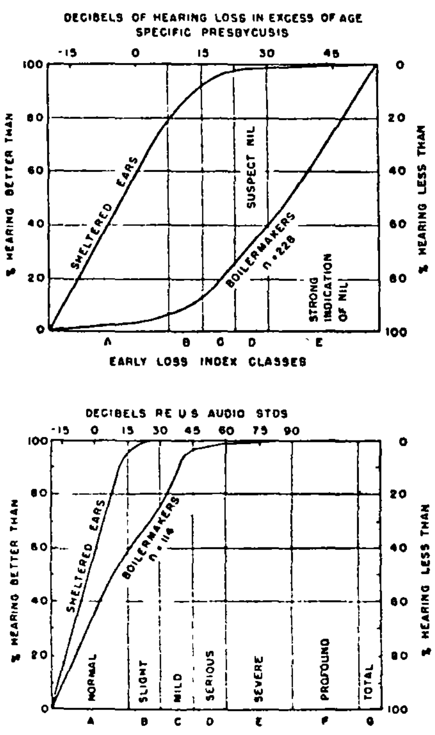

Figure 7 represents summation diagrams for comparing audiometric findings from boilermakers with those from a control group.

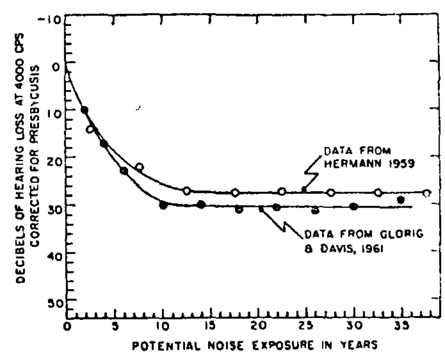

Figure 8 graphically depicts the decline of hearing acuity at 4,000 Hz as a function of noise exposure. Thresholds are in excess of age and sex specific presbycusis noted that each ear is graded separately in this procedure, and that audiometric measurements should be obtained in an acoustical environment meeting USASI standards for measuring puretone hearing thresholds.

Efforts should be made to insure that the subject has no temporary threshold shift in his hearing. A time lapse of 16 to 24 hours since the most recent excessive noise exposure is usually adequate to permit recovery from ordinary noise-induced temporary threshold shifts. If the hearing thresholds are determined by using 1964 ISO reference levels instead of 1951 ASA, six decibels should be added to the ASPVs. shown in Table 2, prior to determining any ELI grade. This compensates for the six decibel difference between audiometer calibration levels at 4,000 Hz.

Noise-induced permanent threshold shifts in the speech-important frequencies may be estimated and graded by the Speech Average Loss Method, developed by the Committee on Hearing and Bioacoustics of the National Research Council. The procedure consists of simply taking the arithmetic mean of the hearing threshold at 500, 1,000, and 2,000 Hz for each ear separately, and then obtaining an overall grade for combined hearing acuity by applying the rules noted in Table 3. A person is graded one class lower than indicated by the scale if, with an average loss of 10 dB or more, his range of hearing thresholds in the three speech-important frequencies is 25 dB or more in both ears considered separately.

The techniques outlined here have been used in a number of large industries. Notable among them was one comprehensive study of 5,000 oil refining personnel, who were classified into 14 different occupational groups ranging from female office workers having no noise exposure history, through carpenters, machinists, painters, and welders to heavily noise-exposed boilermakers.[5] An example of the statistical results obtained in this study is shown as Figure 7.

It should be noted that grades of D or E on the ELI scale are not indicative of hearing loss in the speech-important frequencies but do indicate high frequency loss and potential future impairment of hearing in the speech-important frequencies. Speech Average Loss (SAL) grades of B or lower on the scale do represent significant losses in essential hearing ability. In some states compensation awards may be made for noise-induced hearing losses as slight as grade B on the SAL scale. The much greater sensitivity of the ELI technique and the self-limiting aspect of noise-induced hearing loss should be noted from the two diagrams shown in Figure 7. Although the ability to hear and understand everyday speech is not directly related even over 4,000 Hz losses, early detection of the probability of noise-induced permanent threshold shifts among individuals or groups of people enables prescription of preventive measures before significant hearing losses have developed in the speech-important frequencies.

Hearing Loss Equations And Decay Constants

The self-limiting characteristics of noise-induced hearing loss at 4,000 Hz is illustrated by the results shown in Figure 8. The data from Glorig and Davis[3] were obtained by the testing of 5,582 ears, and that of Hermann[5] from 1,718 ears.

Both subject groups were known to be engaged in noisy occupations. It may be observed that in utilizing data obtained from a population defined by noise exposure or occupation, an ultimate 4,000 Hz hearing loss is reached and the slope of the decay curve becomes zero with passage of time. Thus a biophysical law describing hearing loss may be stated as follows:

The rate at which noise-induced hearing loss is experienced is proportional to the amount of hearing acuity remaining to be lost.

Mathematically, the detrimental effect of noise on human hearing may be expressed as a first order, first degree differential equation

$$-\frac{dL}{dt} = KL$$

in which the variables may be separated and integrated between limits to obtain

$$\ln\frac{L_t}{L_o} = -Kt \text{ or } \ln\frac{L_o}{L_t} = Kt \quad (1)$$

where L_o = the ultimate amount of hearing to be lost to noise after repeated prolonged exposures.

L_t = the amount of noise-induced hearing loss remaining at time t.

K = a constant.

H = the hearing lost ($L_o - L_t$) at time t.

When the values of L_o and K have been determined, the hearing H lost at time t may be obtained from

$$H = L_o(1 - e^{-Kt}) \quad (2)$$

which is derived by substituting (L_o − H) for L_t in equation 1 and solving for H. In these equations the units for measurement of hearing is expressed in decibels of sound pressure level, the most convenient unit of time is years, and e is the base of the Naperian system of logarithms. Values of L_o, ranging from zero to 55 dB and for K ranging from zero to 0.44 per year have been reported in a more detailed earlier publication.[4] From the decay scheme exhibited by noise-induced hearing loss, it may be hypothesized that deterioration proceeds as if noise were acting upon a single type of cell or critical structure; a monocellular decay analogous to the monatomic decay of radioisotopes or monomolecular decomposition of a chemical compound at a given temperature. If, as presently accepted, the transformation of sound stimuli from mechanical energy to electrical nerve potential is dependent upon the hair cells located in the organ of Corti, a monocellular decay scheme coincides with the known anatomy and physiology of the human ear, despite the extremely complex biophysics and biochemistry of hearing. Considering the physical size of the hair bristles, it is not unreasonable to suggest that if the amplitude of vibration of the basilar membrane becomes too large, as induced by excessive noise, the resultant severe mechanical stresses cause the hair cells or their bristles to fatigue with time and fail in a statistical manner, giving rise to monocellular decay.

Audiometric Zero

The designation of "average" hearing thresholds as zero references for puretone audiometer calibration has been the subject of much discussion and criticism in recent years. The common assumption that distributions of threshold of hearing data, expresed in decibels, are Gaussian or arithmetically normal implies that the distribution is symmetrical about the central value, and that the extremes of the distribution approach plus and minus infinity. Considering the morphology of the human ear, it must be realized that the kinetic components of the system—the ear drum, malleus, incus stapes, oval window, and cochlear fluid—all possess mass and hence inertia.

Obviously some finite sound pressure variation must be required to overcome this inertia and sustain mechanical vibration in the auditory chain. The statistical inference that the minimum threshold of human hearing approaches negative infinity is not always valid, and when sets of data obtained from persons possessing very good or hyperacute hearing are statistically analyzed, a log-normal distribution becomes apparent. In such a distribution, the variable ranges from zero to plus infinity, and the geometric mean is the most representative central value "average." In determining the lower bounds or absolute thresholds of human hearing at various puretone test frequencies, Hermann and Holzman[11] not only derived a simple equation for determining the point of origin of a log-normal distribution but provided a sound rational basis for designation of audiometric zero reference values. From a study of 197 high school students free from apparent otological abnormalities, absolute thresholds of hearing were determined for the puretone audiometric test frequencies of 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hz. These zero points were found to range from —7 to —17 decibels relative to zero decibels when $P_0 = 20\ \mu$ N/m^2 in the expression dB = 20 log (P/P_0). The significance of these absolute thresholds of hearing to puretone audiometry becomes apparent if we consider such lower bounds of hearing as being true audiometric zero points for humans. Values of the loci of absolute thresholds of hearing relative to the audiometer zero reference levels adopted by the American Standards Association (ASA) in 1951, and the International Organization for Standardization (ISO) in 1964—both of which are currently used in audiometric testing may be seen by referring to Table 4. Cognizance should be given to the fact that the ISO and ASA audiometer references were derived from average or central values of hearing data distributions, whereas the absolute thresholds of hearing were derived from determinations of the origin or zero points of hearing data distributions that were log-normal. A great deal of speculation, controversy, and discussion has taken place regarding audiometric zero because instrumental measurement of the lowest extreme of human hearing has been and still is difficult to accomplish. A large number of papers have been published on the subject and statements have even been made to the effect that there is no such thing as audiometric zero. Due to the limited size (394 ears) of the population sample selected by Hermann and Holzman in their study for determining true audiometric zero points for humans and other factors, which may have influenced the data distributions, it is likely that more representative sets of data might be employed before adopting such values to the development of standards. On the other hand, the determinations of absolute thresholds that have been made, seem to lie within a few decibels of the values indicated. Thus, it is suggested that a number such as 35 decibels be added to the 1951 ASA audiometer reference values or 24 decibels to the 1964 ISO references to provide a basis for a puretone hearing evaluation scale, which more closely proximates the truth and yet is convenient in practice and consistent with previously recommended schedules for estimation of degree of hearing impairment.

TABLE 4

Absolute Thresholds of Human Hearing Relative to 1951 ASA and 1964 ISO Audiometer Zero References for Six Puretone Test Frequencies

Audiometer Frequency (hertz)	Absolute Thresholds re 1951 ASA Audiometer Zero (dB)	Absolute Thresholds re 1964 ISO Audiometer Zero (dB)
500	—32	—18
1000	—29	—19
2000	—31	—22.5
3000	—31	—22.5
4000	—32	—26
6000	—33	—23.5

Industrial Audiometric Applications

In 1959 the American Academy of Ophthalmology and Otolaryngology (AAOO) recommended a rule for the estimation of "percentage impairment" of hearing,[12] patterned after a similar guide developed by the Committee on Medical Rating of Physical Impairment of the American Medical Association.[13] In referring to the arithmetic mean of hearing threshold measurements made at 500, 1,000, and 2,000 Hz, the AAOO rule indicated:

> *For every decibel that the estimated hearing level for speech exceeds 15 decibels by the American Standard of 1951 (the low fence), allow one and one-half per cent in impairment of hearing up to the maximum of 100 per cent.*

This rule may be formulated more generally as:

$$\%I = 1.5\ (\overline{H}\text{-}F).$$

where $\%I$ = per cent impairment of hearing

$\overline{H}$ = the arithmetic mean of hearing threshold levels at 500, 1,000, and 2,000 Hz measured in decibels (SAL for one ear).

F = a constant representing the low fence of hearing loss or beginning of impairment.

Obviously, the constant F is 15 dB for audiometric measurements referred to 1951 ASA levels. Due to the differences between the 1951 ASA and 1964 ISO audiometric references, however, the "low fence" F would become 26 dB for results referenced to 1964 ISO standards. If true audiometric zero is taken as occurring 24 dB less than the ISO or 35 dB less than the ASA standards as suggested here, the value of F becomes 50 dB. As an evolutionary step from the CHABA scale for evaluating hearing ability shown in Table 1, the Subcommittee on Hearing in Adults of the AAOO prepared a chart for classification of hearing handicap, which is shown as Table 5.

In view of the report by Davis and Kranz[14] regarding the importance of the 1964 ISO zero reference levels for pure tone audiometers and their formal endorsement by both the American Speech and Hearing Association and the American Otological Society, it would appear desirable that any new evolutionary shifts in audiometric scales be made on the basis of the 1964 ISO hearing averages rather than the 1951 ASA. Bringing the concept of absolute thresholds of human hearing or true audiometric zero into consideration as suggested here, a new list of reference threshold levels may be developed relative to the physicists zero decibel level ($P_o = 20\ \mu\ N/m^2$). These values are shown in the third, or right hand column of Table 6 for various frequencies and were obtained simply by subtracting 24 dB

TABLE 5

dB	CLASSES OF HEARING HANDICAP					
	CLASS	DEGREE OF HANDICAP	AVERAGE HEARING LEVEL (1951 ASA) 500, 1000 and 2000 C/S IN THE BETTER EAR*		ABILITY TO UNDERSTAND ORDINARY SPEECH	
−10						
0						Audiometer Zero (1951 ASA)
	A	NOT SIGNIFICANT	AT LEAST	LESS THAN 15	No significant difficulty with faint speech.	
15						"Low Fence"
	B	SLIGHT	15	30	Difficulty only with faint speech.	
30	C	MILD	30	45	Frequent difficulty with normal speech.	
45	D	MARKED	45	60	Frequent difficulty with loud speech.	
60						Educational Deafness
	E	SEVERE	60	80	Can understand only shouted or amplified speech.	
80						"High Fence"
	F	EXTREME	80		Usually cannot understand even amplified speech.	Usual Limit of Audiometer Output
100						

*If the average of the poorer ear is 25 dB or more greater than that for the better ear, add 5 dB to the average for the better ear.

This modification of a hearing evaluation chart is based on knowledge of absolute thresholds of human hearing.

from the 1964 ISO reference threshold levels.

The advantages of using these suggested "audiometric zero" reference levels are:

1) Negative thresholds of hearing are practically eliminated.

2) The horizontal straight-line reference profile of the 1964 ISO audiometer standards is maintained.

3) The AAOO rule for estimation of percentage impairment of hearing is more easily applied to data referenced to these new levels than to those referenced to the 1951 ASA or 1964 ISO standards, and in the event of compensation provides information that is conceptually easier to comprehend (How do you explain negative hearing?).

4) There is less tendency for hearing decrements only 5 to 15 dB greater than average to arouse concern in subjects, because the full range of normal hearing is included in the audiometric scale.

5) A chart for determining classes of hearing handicap may be derived from the AAOO recommended classes that utilizes the 1964 ISO audiometer standards and at the same time permits rounding of the range of each class interval to the nearest 5 dB. This has been done in Table 7.

Utilization of the hearing evaluation chart shown as Table 7 should facilitate communication, assimilation, and interpretation of audiometric results for the practitioner as well as the researcher.

The reader should be warned that more accurate determinations of absolute thresholds of hearing may be obtained by refined techniques using larger population samples of selected subjects. Certain important implications may be drawn from the information presented here. If true audiometric zero lies some 50 dB below the low fence, it is quite likely that influence will be exerted in the future to lower the low fence as a criterion of acceptable hearing level despite the difficulties presently experienced by noisy industries in limiting noise-induced hearing losses. Recognition of lower absolute boundary values for human hearing and re-evaluation of presbycusis values may give rise to lower starting points for decibel scales of noise-induced hearing losses. If such is the case, "monocellular decay constants" indicated for noise-induced hearing losses at 4,000 Hz will be somewhat greater than pre-

trum of the noise; presence or absence of strong pure-tone components; the time patterns of the noise, including rate of repetition and actual time of occurrence during the day; general background noise intensities in the residential area affected

Despite the complexity of community noise problems, various criteria, environmental codes, and noise abatement ordinances have been proposed and adopted. The best that can be said regarding solutions to community noise problems is that individual expert engineering is usually required for each case, and the most reasonable or even optimum solution to a particular problem will not be satisfactory to all parties concerned.—**End.**

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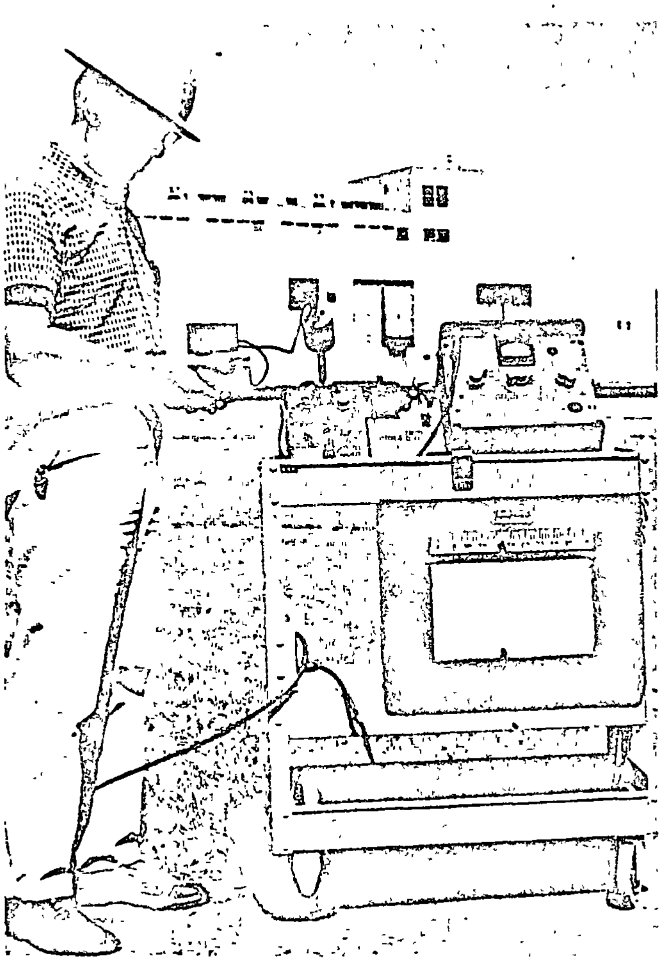
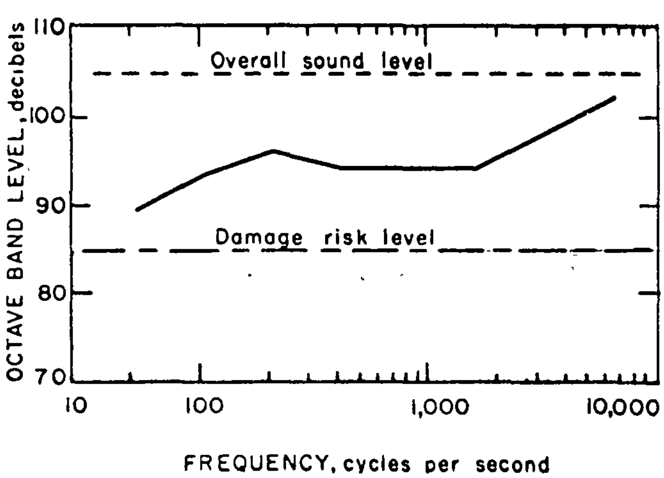
Advanced Course...Industrial Noise



Noise level is established both before and during an operation. Sound level meter and octave band analyzer give curve to solid line of graph shown below.



Analysis of sound levels is made by plotting intensity vs. frequency Octave band analysis (solid line) shows characteristic of noise; overall noise reading would show up as dashed line. (Graph is shown courtesy of Bureau of Mines, U. S. Dept. of Interior.)

This will be a one-week course, and the following subjects will be covered:

- **Physics of Sound** will include discussions on sound generation and transmission, sound pressure level, sound intensity, and sound power.
- **Instruments and Techniques of Sound Measurement** will include discussion of sound level meters, octave band analyzers, instrument specifications, auxiliary equipment, and calibration.
- **Procedure of a Sound Survey** will include an outline of the types of surveys, instrumentation, survey procedures, and a discussion of engineering surveys.
- **Anatomy and Physiology of the Ear and Effects of Noise on Man** will discuss the effects of continuous noise upon auditory mechanisms, damage risk criteria, susceptibility, effects of noise upon behavior, annoyance, and communication.
- **Hearing Measurement and Audiometry** will discuss pure tone audiometry testing rooms, technician, records, test procedures, and conservation practice.
- **Personal Protection** will take into consideration the acoustic problem, ear protector requirements, characteristics of ear protectors, and discuss ear protection programs.
- **Administrative and Human Relation Aspects of Industrial Hearing Conservation** will be offered to show that adequate education is needed to overcome resistance to protection programs.
- **Engineering Control** will include an outline of control methods, plant planning, substitution, reduction at the source, reduction during transmission, and miscellaneous methods.
- **Legal Aspects of the Industrial Noise Problem and Background for Loss of Hearing Claims** will summarize the legal, medical, and scientific and technical factors involved in workmen's compensation claims for noise induced hearing loss.

The advanced course will be open to graduates of the "Fundamentals of Industrial Hygiene" and "Training Methods" courses, or at the discretion of the director of the Safety Training Institute. The tuition will include text and other course materials but does not include housing and meals.

Enrollment will be limited to 24 students. For additional information contact: Director, Safety Training Institute, National Safety Council, 425 N. Michigan Ave., Chicago 60611.

Industrial Noise And Hearing Loss Liability

By Herbert T. Walworth

Threshold Limit Values For Noise

By Herbert T. Jones

Reprinted from National Safety News
National Safety Council, 425 N. Michigan Ave., Chicago, Ill. 60611

Industrial Noise And Hearing Loss Liability

By **Herbert T. Walworth,** Vice-President, National Loss Control Service Corporation, Chicago.

This article in the series on Industrial Hearing Conservation provides fundamental information to serve as a guide to conserving hearing and to reducing hearing loss liability.

PRIOR TO 1950, it was difficult to find references in the industrial hygiene literature concerning noise and loss of hearing. Since that time, papers on these subjects have appeared in large numbers. The first industry-wide noise survey was published in the *American Industrial Hygiene Journal* in 1953.[1] This was followed by numerous papers on the various aspects of the industrial noise problem.

Perhaps the major incident that stimulated interest in industrial noise and hearing loss in the 1950's was litigation involving the Slowinski case in New York State in 1948. In this case, the New York Workmen's Compensation Board ruled that the schedule for traumatic hearing loss applied to both accidental injuries and occupational diseases, and that Slowinski was entitled to a schedule award for partial loss of hearing even though there was no loss of wages.

Legal decisions followed in other states that further set the pattern for partial hearing loss compensation. According to a recent report,[2] 39 states and the District of Columbia permit the payment of Workmen's Compensation for partial hearing loss due to noise exposure. The maximum dollar amounts payable for hearing loss varies from $765 to $11,000 for one ear and from $4,500 to $33,000 for both ears. The methods for evaluating hearing loss under these various laws are based on medical testimony (29 states), or on the American Medical Association method. Only seven states make a deduction for existing hearing loss due to age. Thus, even though the laws may be specific in the maximum compensation allowed, the dollar value of any given loss of hearing claim will depend upon a number of factors ranging from verification of noise exposure, to hearing evaluation and interpretation of the audiogram. Reliable statistics are not available on the incidence of hearing loss claims, but fragmentary reports indicate that they are increasing moderately.[2]

In May, 1969, the Bureau of Labor Standards of the U.S. Labor Department[3] issued rules and regulations concerning permissible noise exposures for federal contractors, setting the continuous exposure limit at 90 dBA. Whether or not this development will have an impact on the future Workmen's Compensation hearing loss picture cannot be predicted. Prior to the Bureau of Labor Standards Regulations, several states already had noise regulations as shown in Table I. It can be seen that the regulations are not consistent, and most have little relationship to hearing loss prevention. There is little evidence that these regulations have been effectively enforced. However, with the federal standards now a reality, many states could adopt these new rules verbatim and pressure certain industries into action on noise evaluation and control.

Noise—An Industry Problem

There have been many significant developments in the noise problem since the first legal decision made partial hearing loss compensable. Much information has been published on the relationship of noise exposure to hearing loss, and the techniques for noise and hearing loss measurement have been developed. The number of professional people with expert knowledge in these fields has increased many fold.

Now, following the more recent regulatory developments, industry in general will need to utilize more fully the expertise available to evaluate its noise problems and to establish hearing conservation programs.

But, what is an effective industrial hearing conservation program?

What are the noise exposure standards?

How does an industry develop a satisfactory program?

To suggest that the answers to these questions are simple would be grossly misleading. This discussion will attempt to provide certain fundamental information as a guide to conserving hearing and reducing hearing loss liability.

Approaches to Hearing Conservation

Hearing loss resulting from exposure to noise is affected by such factors as 1) the magnitude of the noise exposure, 2) length of the exposure, and 3) individual susceptibility. The employer can do little to control liability resulting from individual susceptibility. There are no reliable tests to detect susceptibility. The only alternatives open is to provide a working environment relatively free of noise, provide personal ear protection, or completely ignore the problem.

Control of noise can be accomplished by engineering methods; but this is not practical in many cases. This leaves the most common alternative of personal ear protection as the most economical approach to hearing conservation. The use of ear protection offers certain problems in hearing conservation, because the devices used will be ineffective if not properly fitted or worn, or even used by the worker.

Another method of noise control open to industry, and one which will be used effectively in the future, is the purchasing of new machinery on the basis of noise specifications. This method has already been used with the result that quieter equipment has been developed. Manufacturers are also taking advantage of this development by advertising the equipment with emphasis on the quiet features. However, any major breakthrough in this area will result in more costly equipment for which industry must be willing to pay.

TABLE I

STATES WITH NOISE CONTROL REGULATIONS

State	Regulation
California	Ear protection required above following: 63 Hz — 110 dB 125 — 102 250 — 97 500 — 95 1000 — 95 2000 — 95 4000 — 95 8000 — 95
Hawaii	Control required for levels over 90 dB.
Kentucky	Risk of hearing loss exists above 85 dB in frequencies above 300 Hz. (Permissible levels higher for lower frequencies.)
Maryland	Severity of hazards determined by recognized standards.
Minnesota	(Same as California.)
Mississippi	Severity of hazard determined by recognized standards.
New Jersey	Control for certain levels, depending on frequency and exposure time per day.
Oregon	(Same as California.)
Utah	Control over 85 dB more than 5 hours per day.
Virginia	Recommended safe level—85 dB at 300-2400 Hz.
Washington	(Same as California.)
Wisconsin	Ear protection for levels over 100 dB for full day and for any exposure over 120 dB.

The longer a worker is exposed to noise, the greater the accumulated hearing loss. Again, for hearing conservation the employer has the choice of providing engineering noise control or ear protection, or limiting the number of hours of exposure per day. But what are the guidelines for the employer to follow? A commonly accepted program incorporates the following:

1) Evaluation of noise exposures, utilizing accepted methods and equipment;

2) Comparison of noise exposure data to noise criteria, for identifying noise hazards;

3) The introduction of a hearing conservation program applicable to an entire plant or to selected departments, incorporating the following:

a) Establishment of an audiometric testing program to evaluate hearing ability of all workers, and of new workers as they are employed;

b) Provide engineering controls, where practical;

c) Provide ear protection for workers in those areas where noise control is impossible or impractical;

d) Limit exposure time, if feasible.

The noise criteria selected for hearing conservation can be an important factor in the control of hearing loss liability. If an employer adopts and achieves control below the latest noise threshold limits proposed, he still will not completely eliminate hearing loss liability as will be shown later. Even at these TLV levels, some hearing damage risk still remains. Further, the high noise levels in many industries have already caused significant hearing losses in thousands of unprotected workers, who have been employed over a working lifetime. This group of workers represents significant hearing loss liability for industry as a whole.

Noise Measurement

Detailed information regarding noise measurement has been published in the *Industrial Noise Manual*[12] of the American Industrial Hygiene Association, and numerous papers have appeared in the NATIONAL SAFETY NEWS, the *American Industrial Hygiene Journal,* and other publications. The fundamentals as outlined in these publications still apply. Only the approach to evaluating the hazard has undergone change.

Prior to 1967, emphasis was placed on the need for using the *Octave Band Analyzer* for hazard evaluation. However, in that year, the Intersociety Committee on Guidelines for Noise Exposure Control[4] published a report suggesting the use of a single sound pressure level reading in dBA as a fast and convenient method of measuring noise hazard. The use of A-scale meters does not rule out the need for octave band measuring equipment, either for more precise hazard evaluation or the collection of essential data for noise control.

Noise surveys are conducted for two reasons: 1) to evaluate employee exposure to noise, and 2) to study noise sources for application of controls. Two types of surveys may be conducted. The first is the recording of sound level meter A-scale decibel readings. The second, made to supplement the A-scale data where hearing damage noise levels are recorded, utilizes the Octave Band Analyzer. A-scale measurements are made to evaluate individual employee exposures, or made on a grid pattern to define the areas of excessive noise and establish noise control or hearing conservation zones. The A-scale approach to noise hazard evaluation is relatively new. This method has made it possible to study industrial noise exposures on a larger scale than would have been possible using the octave band analyzer alone, because octave band measurements are more time consuming and require more expert personnel. The A-scale approach has created wide-spread interest in the noise problem, in noise control, and in the establishment of hearing conservation programs.

Damage Risk Criteria

According to the American Medical Association definition, hearing impairment exists when the average hearing loss at 500, 1,000, and 2,000 cycles per second (Hertz) exceed 15 decibels as measured using the 1951 ASA Reference Threshold. Thus, exposures to noise levels that cause hearing losses of 16 decibels or more are considered to be excessive. However, because of individual susceptibility, there can be no one "safe" level, which would prevent all hearing loss from noise exposure yet permit industry to operate economically.

In the 1930's, when industrial hygiene developed as a profession, little consideration was given to the industrial noise problem. Noise exposure and its relation to hearing loss was occasionally referred to in technical meetings; 90 decibels was frequently mentioned as a damage risk criteria. This reference was to 90 decibels overall, measured on the "C" scale.

As interest in the noise problem grew, investigators reported the importance of frequency, as well as noise level, and the length of exposure in the development of criteria. The first significant study designed to define the relationship of noise exposure to hearing loss was the Subcommittee Z24-X-2 report published by the American Standards Association.[5] This report related hearing loss to noise exposure levels at different frequencies. However, no recommendations were made for damage risk criteria.

In the intervening years to 1967, numerous studies were reported in the technical literature. Also, various damage risk criteria were proposed.[5,6,7,8] Most of these took frequency into consideration, and suggested that there was greater hearing damage risk from higher frequency noise. Further, the criteria indicated that a sharp line of demarcation did not exist between hazardous and non-hazardous noise.

In 1964, the Intersociety Committee on Guidelines for Noise Exposure Control[4] was formed to study the scientific literature and report its findings as an aid to industrial management in establishing hearing conservation programs. The

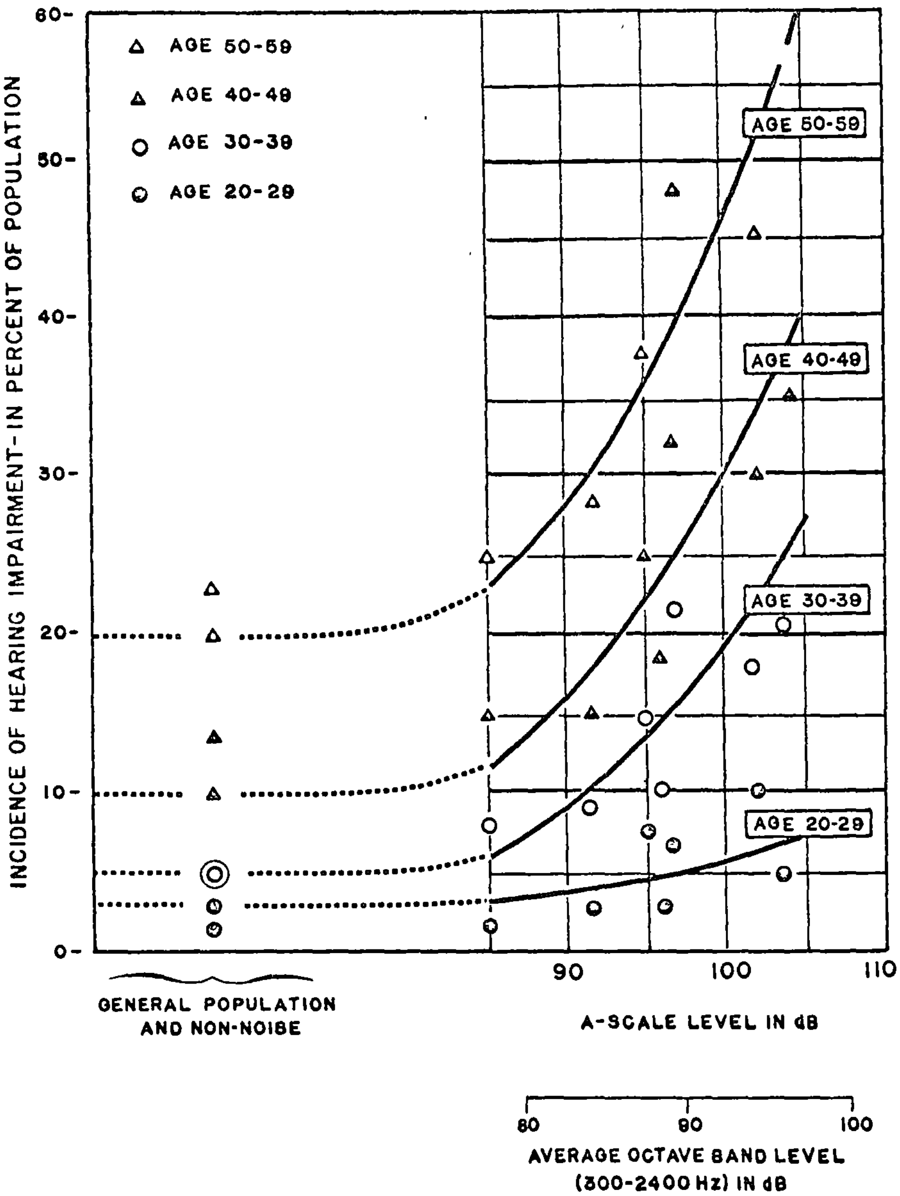


Figure 1 shows the incidence of hearing impairment in the general population and in selected populations by age groups and by occupational noise exposure. (Courtesy: *American Industrial Hygiene Association Journal.*)

committee was composed of knowledgeable representatives of five technical organizations closely associated with problems of industrial noise. The committee published its report in November 1967. In no way did this committee suggest a damage risk criteria. However, it made a number of significant contributions to knowledge in this area that later made it possible to select reliable criteria with risk. These contributions included:

1) Converting hearing loss data from various studies to equivalent levels of noise and lengths of exposure;

2) Correlating noise exposure with incidence of hearing impairment by age groups.

These data are shown in Figure I. Information presented in this graph is important to industry, for, by its intelligent use, a given plant can estimate its hearing loss liability after developing exposure data. Briefly, the graph shows that 20 per cent of the general population without industrial noise exposure have hearing impairment upon reaching the age of 50-59. However, 28 per cent of industrial workers of the same age group with 90 dBA exposure for a working lifetime, have hearing impairment. This is an increase of eight percentage points. Expressed another way, this means that of 100 workers exposed to 90 dBA noise to age 50-59, eight additional workers will suffer hearing impairment. Lifetime exposure to 95 dBA would result in 17 additional workers suffering hearing impairment.

With the Intersociety Committee Report available, the American Conference of Industrial Hygienists proposed tentative threshold limit values for noise in 1968 and adopted revised limits in 1969.[9] Essentially, the ACGIH establishes a limit of 90 dBA for eight-hour daily exposures to steady noises, and provides for increased levels of exposures for less than eight hours. Provision is also made for adding exposures of different noise levels to determine the presence or absence of a hazard. Impulsive or impact noises should not exceed 140 dBA peak sound pressure level. For steady noises, the threshold limit values adopted are as follows:

Exposure Time—Hours	dBA
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115

In May 1969, the U.S. Department of Labor[3] published safety and health standards affecting federal supply contractors. These regulations include permissible limits for noise that are the same with minor variations as the threshold limit values for noise suggested by the American Conference of Industrial Hygienists. Additionally, these rules provide a method of converting octave band noise measurements to dBA (Figure 2), and suggest a procedure for evaluating intermittent noises occurring at intervals of one second or more. The labor regulations also provide for adding noise exposures.

In analyzing these criteria, it should be mentioned that procedures for measuring impulsive or impact noises have not been correlated with duration of exposure and incidence of hearing impairment. However, industry does have its first widely accepted guidelines for evaluating the hazards of steady noises, and for estimating hearing loss liability. Reliable information is available regarding control, and for establishing hearing conservation programs. It might also be said that industry now has the economic stimulus to use these tools for hearing protection. It seems logical that the ACGIH threshold limit values or the Bureau of Labor Standards permissible limits eventually will be adopted as law or regulation by many states.

Hearing Conservation Programs

How can hearing conservation programs reduce hearing loss liability?

Through audiometric testing it is possible to establish a new employee's base line hearing level at the time of employment. In some states, any hearing loss so detected would be recognized as pre-existing and thus not the responsibility of the new employer. Some workers with hearing impairment represent a potential inherent liability, and initial audiometric testing provides a means of evaluating existing hearing loss, and periodic testing, the opportunity of detecting hearing loss progression. It should be understood, however, that the audiometric test is subjective and variations of plus or minus five decibels in the test results on the same individuals are not uncommon.

There are, of course, pitfalls in operating an audiometric testing program. Common among these are:

- Use of untrained technicians;
- Failure to provide for or maintain proper test conditions;
- Failure to maintain and to calibrate audiometric equipment;
- Failure of workers to respond properly to the audiometric test;
- Failure to make periodic assessments of the program;
- Failure to follow-up on audiometric test results;
- Testing employees with unrecognized temporary hearing loss due to noise exposures.

Periodic audiometric testing will be of limited or no value unless noise exposure control is provided. In the absence of noise control or ear protection by use of plugs or muffs, workers must be removed from the exposure for a sufficient time period to assure recovery from temporary hearing loss before a meaningful test can be conducted. Temporary hearing loss recovery may require two or three days, a week, or longer, depending upon the exposure level, the worker's hearing ability, and his age. If noise control or ear protection is provided, periodic testing can be used to detect non-compliance in wearing the protection. Thus, unless the testing and ear protection programs are coordinated, periodic testing will be of little value.

Audiometric testing programs need the same type of management attention as any other successful operation in order to attain established objectives. Important elements of the program include:

- Establishment of objectives;
- Selection of testing equipment and a testing area meeting the specifications of the American Standards Institute standard S3.1-1960.[10] Usually this will require a noise attenuating booth designed for this purpose. (In recent years, a device identified as an earphone-ear muff combination has been developed that will, under certain background noise conditions, provide a suitable environment for certain types of audiometric testing. However, at present there are not enough data available to establish the effectiveness in ordinary industrial dispensary environments, or the legality of audiometric tests performed with these devices.)
- Outline a program. The program should be specific and in sufficient detail to guide the participants

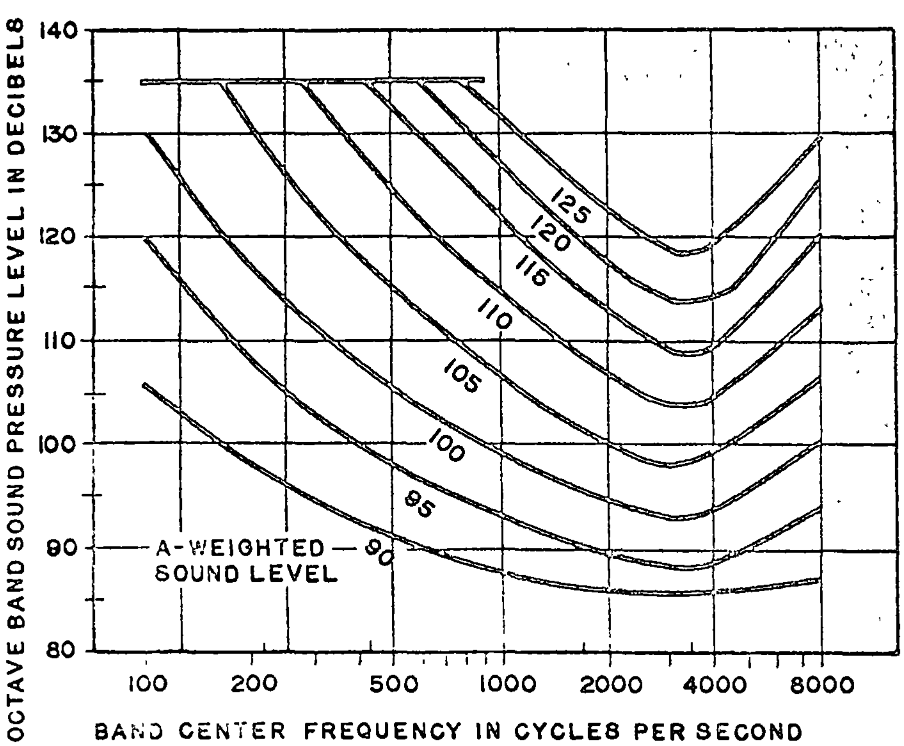


Figure 2 repr[illegible]sents [illegible] conversion of octave band pressure levels to dBA. Plot octave band read[illegible] [illegible] the highest point of penetration into the contours for the comparable [illegible]A [illegible]ing (Courtesy *Federal Register*.)

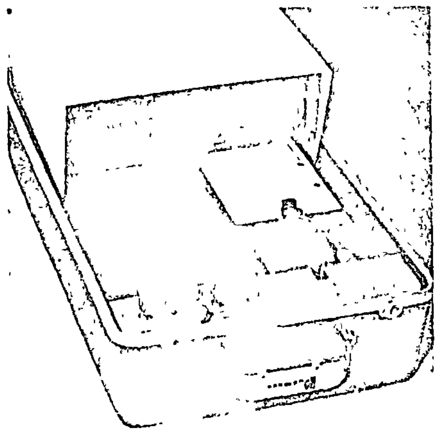


Figure 3 shows an example of an automatic audiometer.

in taking the necessary actions to meet all contingencies. For example, the program should establish what are to be considered abnormal hearing levels and the steps to be followed for various hearing loss classifications. It should specify policy in employment practices, including job placement, transfer, etc. Further, the program should specify who is to be tested and under what conditions. If the tests are not provided for the entire plant population, employees transferring in and out of noisy areas present a contingency that must be covered. A program of audiometric testing that involves only the accumulation of hearing data in employee medical files will have limited value in reducing hearing loss liability.

• Provide trained audiometer technicians. Audiometric testing may be done by a nurse or technician who has been trained in industrial audiometry. The program should be under the supervision of a physician knowledgeable in this technical area, who accepts full responsibility for the results and their accuracy. With such an arrangement, the question of the legality of the tests should be solved. In recent years, short courses in audiometry have been offered by certain colleges and universities on an intermittent basis. It is doubtful, however, that these courses as presently offered will fill the needs of industry nationwide.

• Establish a method of data handling. A uniform method of recording audiometric data should be developed.

• Provide liaison with plant supervision in matters relating to engineering control of noise and the use of ear protection.

But what of the small plant, which does not have a medical department or facilities for testing? Perhaps the most logical approach is to seek this service through local physicians or medical clinics. However, the plant manager seeking such service should have professional guidance or become sufficiently aware of the needs to outline his own requirements. While certain industrial clinics have audiometric testing facilities, it is not easy for a plant manager to evaluate the quality of the service he is purchasing. The pitfalls and omissions of an in-plant industrial program will be multiplied for the company purchasing outside services. This company will need reliable professional guidance.

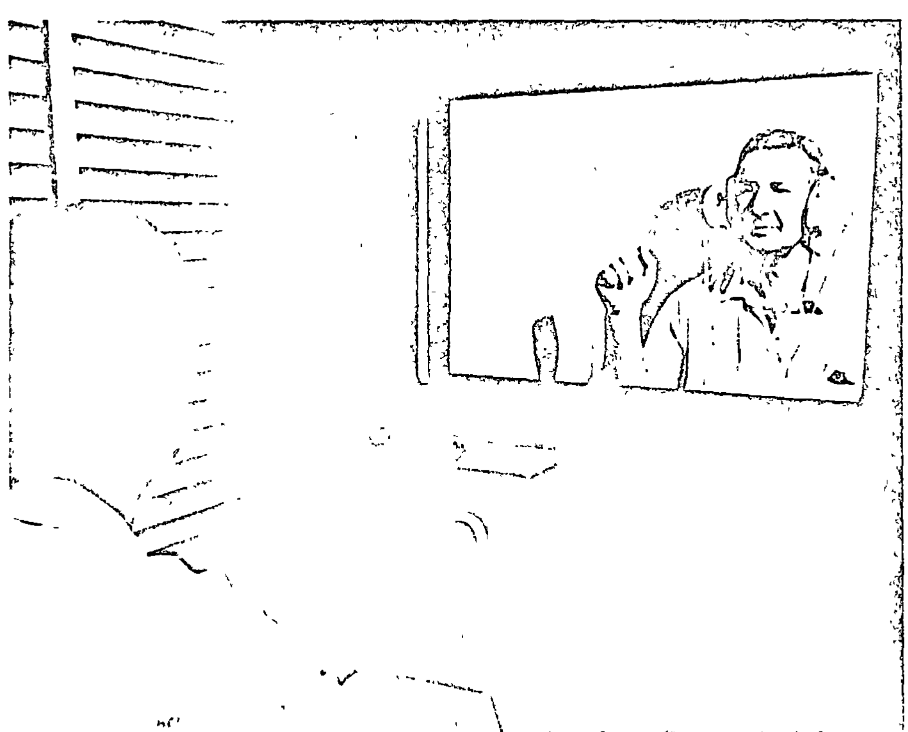


Figure 4 shows a subject in a sound attenuating booth having his hearing acuity tested by a technician, who is located outside the booth.

Personal Protection

Properly worn ear muffs or fitted ear plugs or both can provide substantial protection against hazardous noise. There are many different types of both devices on the market that can provide protection against a large percentage of the noises found in industry. All of these protectors are more efficient in attenuating high frequency than low frequency noises. For example, one ear plug is rated as providing 20 decibels of attenuation for a 500 Hz noise and almost 40 decibels of attenuation at 6,000 Hz. While the attenuation curves for both plugs and muffs will vary slightly, any of the better types will provide an average of about 30 decibels of protection for the audible frequencies of sound. Roughly speaking, this means that a worker with a properly fitted plug exposed to a 120 decibel noise would be provided protection to 90 decibels (120-30=90). However, the protection provided for a given individual at a given time may vary. Thus, from a practical standpoint, a margin of safety should be allowed. Figure 5 shows typical attenuation curves for the principal protection types available today, as reported by Hosey and Powell.[11]

There is little choice between well designed plugs and muffs, insofar as the protection provided is concerned. However, there can be great variations in their acceptability by the workers wearing them.

Some may complain that plugs are too tight and uncomfortable. Others may register complaints about muffs being too hot.

There is little question but that ear plugs and muffs are useful in protecting a worker's hearing in a noisy environment. The problem is to get workers to wear them. Merely distributing this equipment will not solve the problem. An effective program will require 1) employee education, 2) proper fitting and instructions for wearing, 3) enforcement, and 4) equipment maintenance.

The complaint is frequently made that ear plugs or ear muffs prevent workers from hearing warning signals, which are commonly used in industry. While one might believe that the use of ear protection would make communication and the hearing of industrial warning signals more difficult, the *opposite* is the case. In noise fields above 85 dB, ear protectors significantly improve one's ability to hear warning signals or speech communication.

Ear protection offers an effective way of reducing hearing loss, and thus hearing loss liability; but, an effective program for accomplishing this will require careful planning and constant surveillance.

Engineering Control of Noise

If it is assumed that the reason for controlling noise is hearing conservation, there are three basic approaches to noise control. These are, 1) ear protection, 2) reducing exposure time, and 3) engineering control. Instituting any of these methods offers problems to which there are few easy solutions. Effective ear protection involves program planning, strict supervision and administrative control. Control of exposure time involves production planning and employee utilization, both of which are related to producing products at competitive prices. Some engineering controls are complicated and expensive, and, while others may be comparatively simple, all will require periodic maintenance. Some engineering controls will interfere with production; others will not be economically feasible.

The first steps in noise control are to secure adequate quantitative and qualitative information on the nature and magnitude of the problem. This involves securing complete information regarding the

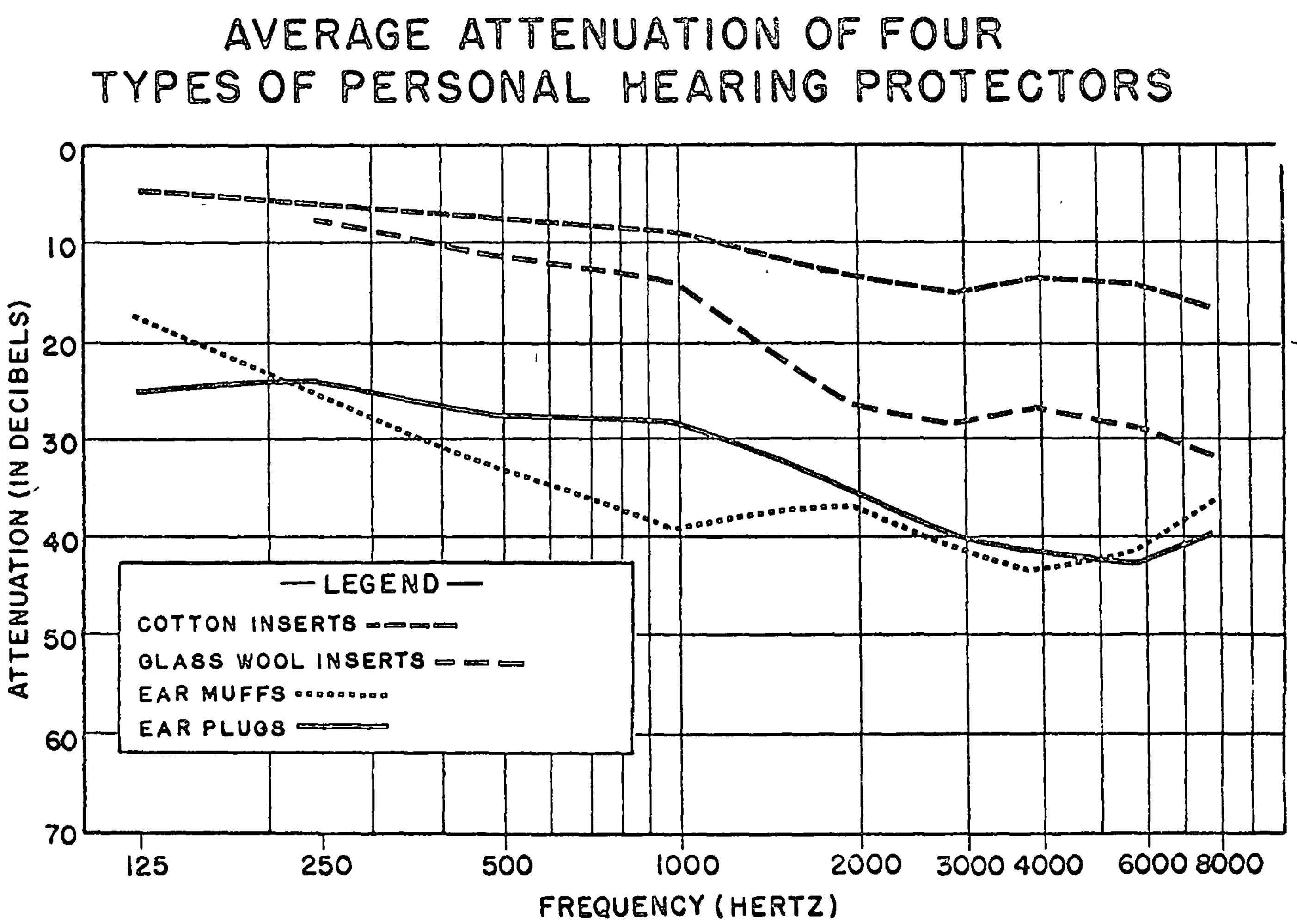


Figure 5 graphically depicts the average noise attenuation of four types of hearing protectors. (Courtesy: U. S. Public Health Service Publication No. 1572.)

noise environment and making selected noise measurements to identify hazardous noise sources and their effect on the total environment. This involves making octave band analyses, in addition to A-scale readings, and the collection of other data—such as type and duration of the noise, the number of workers exposed, etc. With this information, one can determine the degree of control necessary and then take the next logical step of evaluating the engineering control methods available.

When selecting noise control, the following should be considered:

1) Changes in plant or department layout;
   a) This will provide an opportunity for isolating noisy equipment and reducing to a minimum the number of workers exposed to the hazard.
2) Provide control of noise at the source;
   a) Redesign of machinery or equipment;
   b) Partial enclosure of the noise source;
   c) Complete enclosure of the noise source;
   d) Apply mufflers to waste compressed air lines;
   e) Substitute quieter process or machines;
   f) Reduce noise from vibrating surfaces by damping, bracing, or stiffening;
   g) Isolate machines or equipment to reduce transmission of noise;
   h) Machine maintenance;
   i) Reduce the velocity of fluid flow (compressed air jets).
3) Isolation of workers;
   a) Where operations permit, workers can be isolated in acoustically treated rooms, thus insulating them from the noise
4) Provide sound absorption materials for reflecting surfaces;
   a) This method has limited application for control of industrial noise hazards, because it reduces only the reflected noise. It does not control the direct noise from various sources.

When more than one noise source must be considered, control should be provided for the noisiest source first.

There are no magic formulas to the engineering control of industrial noise. But faced with the need for action, much can be accomplished in many industries by applying the basic principles of control just outlined. There always will be those noisy operations that, for economic or other reasons, do not lend themselves to engineering control. For these situations, personal ear protection or control of exposure time will be the only solutions.

Summary

Loss of hearing due to industrial noise has been recognized for many years, but both industry and workers have for the most part, ignored the problem. Some large industries have instituted hearing conservation programs, but the impact of these programs on the total problem is insignificant. Hazardous noise in industry is widespread. One prevailing estimate is that 30 per cent of all industrial workers have significant hearing loss (hearing impairment).

Although it is not possible to estimate the liability under existing Workmen's Compensation laws, the total figure would be substantial.

The tools for attacking the noise problem *now* are available to industry. There are at least three stimuli, which should encourage industry to take action in the near future. These are: 1) Regulations, which are here; 2) economic considerations, which for the present are largely potential, and 3) humanitarian considerations.—**End.**

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Threshold Limit Values for Noise

By Herbert H. Jones, chairman, Committee for Threshold Limit Values for Physical Agents.

THE American Conference of Governmental Industrial Hygienists for a number of years have recommended limits of exposure to chemical agents in the working environment by the setting of threshold limit values. During the past few years, a number of suggested limits of exposures for physical agents have been proposed by various organizations, but none of the limits have been accepted universally. Due to this lack of uniformity, the American Conference of Governmental Industrial Hygienists (ACGIH) in May 1967 established a Committee on Physical Agents. This Committee was directed to review the existing data on exposures of individuals to various physical agents and to recommend to the Conference safe limits of exposure.

In establishing any limit of exposure, many factors have to be considered. Among these are the types of data available and the validity of this data; methods of control of exposure and their feasibility; and of primary importance, the percentage of the group which will be protected by the established limits.

Various procedures have been suggested in the past for rating the hearing loss potential of noise. These have included "C" scale reading of a sound level meter, "A" scale reading of a sound level meter, average of the 500, 1000, and 2000 Hz octave bands, maximum limits in each of the three octave bands of 500, 1000, and 2000 Hz, and limits for each of the eight octave bands. After considering the merits of each system and their ease of application it was decided to use the "A" scale reading from the sound level meter. It must be pointed out that the "A" scale reading is used for hazard rating only, but if studies are made for the purpose of engineering control, then octave band analysis should be made of the noise.

After considering the above factors, the Committee decided to establish a limit of 90 dBA for an eight hours per day, forty hours per week exposure. Data indicates that this will protect about 90 per cent of the people exposed to this level for a normal working lifetime. As more exposure data becomes available and the cost of engineering controls are reduced, it would be desirable to revise the limit, if necessary, to protect a larger percentage of the exposed population.

For a number of years it was assumed that equal energy would produce equal damage to the ear. If this assumption were true, then each time the sound level is increased three decibels the exposure time should be reduced one-half. Laboratory data on temporary threshold shift and field data indicate that for the shorter exposure times the ear can tolerate more acoustical energy per day than for a continuous eight-hour exposure. Also laboratory data and very limited field data indicate that if the exposure is intermittent in nature, (rest periods between exposures) the ear can tolerate considerably more acoustical energy than for a single exposure to continuous noise. Considering these two factors, the limit is increased five decibels for each halving of the exposure time. Thus these limits are a compromise between the more conservative equal energy concept and the more liberal intermittent exposure concept.

At one time it was thought that limits of exposure for narrow bands of noise or pure tones should be 10 decibels lower than for broad band noise. This was then revised to only five decibels, but some of the latest data available indicated that even five decibels is too conservative. In the present limit no correction is made for pure tones or narrow bands of noise.

There is very little data available on the effects of exposure to impact or impulsive noise. Many factors possibly influence the effects, among them are: peak sound pressure level, rise time, decay time, repetition rate, time interval between impacts or impulses, number per day, and background sound pressure levels. It is known that exposure to a small number of 140 dB impulsive noises of short duration will produce a temporary threshold shift. Until additional data are available, a limit of 140 dB peak sound pressure level is recommended.

As additional data becomes available to the Committee it will be reviewed and, if necessary, revisions will be recommended to the Conference. These revisions are normally made at the annual meetings of the Conference which are held in May of each year.

Committee Members

Herbert H. Jones, USPHS, Chairman
Lt. Col. Herbert E. Bell, USAF
Dr. Gerald V. Coles, Uganda Ministry of Labor
Irving H. Davis, Michigan Department of Health
Dr. Ernest Mastromatteo, Ontario Department of Health
Fred L. Ottoboni, California Department of Health
William A. Palmisano, U.S. Army
Dr. Charles H. Powell, University of Missouri
David H. Sliney, U.S. Army
Thomas K. Wilkinson, USPHS.

Any comments or questions regarding these limits should be addressed to Herbert H. Jones, Chairman, Threshold Limits Committee for Physical Agents, American Conference Governmental Industrial Hygienists, 1014 Broadway, Cincinnati 45202.

Threshold Limit Values for Physical Agents for 1969

These threshold limit values refer to levels of physical agents and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Because of wide variations in individual susceptibility, exposure of an occasional individual at, or even below, the threshold limit may not prevent annoyance, aggravation of a pre-existing condition, or physiological damage.

Threshold limit values refer to levels of exposure for a 8-hour workday for a 40-hour work week. Exceptions are those limits which are given a ceiling value (C). They should be used as guides in the control of health hazards and should not be used as fine lines, between safe and dangerous levels of exposures.

These threshold limits are based on the best available information from industrial experience, from experimental human and animal studies, and when possible, from a combination of the three.

These limits are intended for use in the practice of industrial hygiene and should be interpreted and applied only by a person trained in this discipline. They are not intended for use, or for modification for use, 1) in the evaluation or control of the levels of physical agents in the community, 2) as proof or disproof of an existing physical disability, or 3) for adoption by countries whose working conditions differ from those in the U.S.A.

These values are reviewed annually by the Committee on Threshold Limits for Physical Agents for revisions or additions, as further information becomes available.

Ceiling Value—There are some physical agents which produce physiological response from short intense exposure and whose threshold limit is more appropriately based on this particular response. Physical agents with this type of response are best controlled by a ceiling "C" limit which is a maximum level of exposure which should not be exceeded.

Notice of Intent—At the beginning of each year, proposed actions of the Committee for the forthcoming year are issued in the form of a "Notice of Intent." This notice provides not only an opportunity for comment, but solicits suggestions of physical agents to be added to the list. The suggestions should be accompanied by substantiating evidence.

As Legislative Code—Although the Conference does not consider the Threshold Limit Values appropriate matter for adoption in legislative codes and regulations, it recognizes that the values may be so used. If so used the intent of the concepts contained in the Preface should be maintained and provisions should be made to keep the list current.

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Threshold Limit Values for Noise for 1969

These threshold limit values refer to sound pressure levels that represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech. The medical profession[1,2] has defined hearing impairment as an average hearing threshold level in excess of 15 decibels (USASI Z24.12—1952) at 500, 1000, and 2000 Hz, and the limits which are given have been established to prevent a hearing loss in excess of this value. These values should be used as guides in the control of noise exposure and, due to individual susceptibility, should not be regarded as fine lines between safe and dangerous levels.

[1] "Guides for the Evaluation of Hearing Impairment." *Transactions of the American Academy of Ophthalmology and Otolaryngology*, pp. 167-8, March-April, 1959.

[2] "Guides to the Evaluation of the Permanent Impairment; Ear, Nose, Throat and Related Structures." *Journal of the American Medical Association*, 197:489 August 1961.

Continuous or Intermittent

The sound level shall be determined by a sound level meter, meeting the standards of the United States of American Standards Institute and operating on the A-weighting network with slow meter response. Exposure shall not exceed that shown in table below.

These values apply to total time of exposure per working day regardless of whether this is one continuous exposure or a number of short-term exposures but does not apply to impact or impulsive type of noises.

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

$$\frac{C1}{T1} + \frac{C2}{T2} + \ldots \frac{Cn}{Tn}$$

exceeds unity, then, the mixed exposure should be considered to exceed the threshold limit value, C1 indicates the total time of exposure at a specified noise level, and T1 indicates the total time of exposure permitted at that level. Noise exposures of less than 90 dBa do not enter into the above calculations.

Impulsive or Impact Noise

It is recommended that exposure to impulsive or impact noise should not exceed 140 decibels peak sound pressure level "C" (ceiling limit). —End.

Permissible Noise Exposures

Duration per day Hours	Sound Level dBa*
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
¾	107
½	110
¼	115-C**

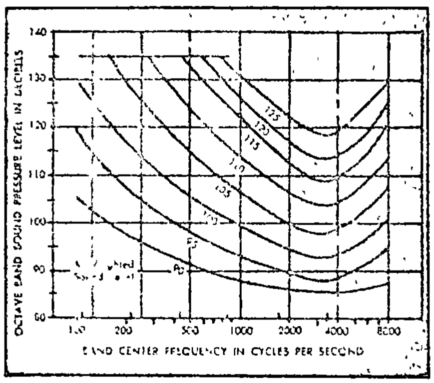
*Sound level in decibels as measured on a standard level meter operating on the A-weighting network with slow meter response.

**Ceiling Value

Copies may be obtained from Secretary-treasurer, ACGIH, 1014 Broadway, Cincinnati 45202

Walsh-Healy Occupational Noise Exposure Regulation

a) Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table I of this section when measured on the A scale of a standard level meter at slow response. When noise levels are determined by octave band analysis, the equivalent A-weighted sound level may be determined as follows:



Octave band sound pressure levels may be converted to the equivalent A-weighted sound level by plotting them on the illustrated graph and noting the A-weighted sound level corresponding to the point of highest penetration into the sound level contours. This equivalent A-weighted sound level, which may differ from the actual A-weighted sound level of the noise, is used to determine exposure limits from Table I.

b) When employees are subjected to sound exceeding those listed in Table I of this section, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of the table, personal protective equipment shall be provided and used to reduce sound levels within the levels of the table.

c) If the variations in noise levels involve maxima at intervals of one second or less, it is to be considered continuous. In such cases, where the duration of the maxima are less than one second, they shall be treated as of one-second duration.

d) In all cases where the sound levels exceed the values shown herein, a continuing, effective hearing conservation program shall be administered.

Exposure to impulsive or impact noise should not exceed 140 dBC peak sound pressure level fast response.

TABLE I

Permissible Noise Exposure[1]

Duration per day, hours	Sound level Slow response dBA
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115

[1]When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: C1/T1 + C2/T2 . . . Cn/Tn exceeds unity, then, the mixed exposure should be considered to exceed the limit value. Cn indicates the total time of exposure at a specified noise level, and Tn indicates the total time of exposure permitted at that level.

An Industrial Hearing Conservation Program. The introduction to a series of articles, based on the NSC Safety Training Institute's course on Industrial Noise, provides the basic concepts.
8 pp 111 17-37 (August 1968)

Physics of Sound. A review of the basic physics of sound provides the background for minimizing, limiting, or preventing excessive exposure to noise. Includes a Glossary of Terms. (Second in a series of articles based on the NSC Safety Training Institute course on Industrial Noise.)
8 pp. 111.17-42 (November 1968)

Instruments and Techniques of Sound Measurement. The third article in a series on the fundamentals of industrial hearing conservation discusses sound-level meters, octave band analyzers, and auxiliary equipment plus calibration techniques.
10 pp. 111.17-44 (December 1968)

Procedures of a Sound Survey. Types of noise, types of sound surveys, the equipment needed, and survey procedures are outlined.
12 pp. 111.17-46 (January 1969)

Ear Anatomy and Effects of Noise on Man. The physiology of the ear helps explain the effects of noise on behavior, communication, and hearing.
16 pp. 111.17 47 (February 1969)

Personal Ear Protection. Discusses requirements of ear protectors in regard to the acoustic problems and describes types of personal ear protection devices available.
12 pp. 111.17-48 (March 1969)

Hearing Measurement and Audiometry and Audiometer Room Criteria. Discusses procedures for measuring employee hearing acuity and thresholds. Audiometric equipment is explained and a program for its care and maintenance is discussed. Criteria for sound pressure level of background noise in test rooms is given.
12 pp. 111.17-49 (April 1969)

Administration and Human Relations Aspects of Industrial Hearing Conservation and Getting Employees to Wear Hearing Protection. Discusses how the safety specialist can motivate employees to wear hearing protectors.
12 pp. 111.17-50 (May 1969)

Engineering Control of Noise and Engineering Noise Control Effectively. Discusses basic principles of controlling industrial and occupational noise hazards through engineering.
12 pp. 111.17-51 (June 1969)

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Engineering Control Of Noise

By Charles L. Cheever, Industrial Hygiene Engineer, Argonne National Laboratory, Argonne, Ill.

The ninth article in a series on industrial hearing conservation discusses the basic principles of engineering for the control of industrial and occupational noise hazards

NOISE CONTROL in industry is important to the *worker* because it can affect his well-being. No one wants permanent impairment of hearing that occurs from continued excessive exposure to high noise levels. In addition, noise is objectionable because of interference with speech or audible signals. In this respect it may be a contributory cause of accidents. Excessive noise may also be an annoyance factor and a source of fatigue.

Noise control is likewise important to *management* because of its responsibility for safeguarding the health and well-being of its employees. It is management's obligation to prevent occupational hearing loss. The provisions for more stringent control of industrial noise in the Walsh-Healy Act, along with the setting of noise exposure limits by other governmental agencies, will add impetus to noise control or hearing conservation programs in industry. In some cases noise may have an adverse affect on the morale of the work force. There have been bitter complaints concerning undesirable noise conditions.

Noise control is important to the *safety professional* because both the worker and management seek his know-how and advice for protecting the worker Safetypros need to be knowledgeable concerning the hazardous aspects of noise. Besides giving advice, the safetypro is the logical one to initiate action for the control of noise.

Initial noise control effort should be at the origin, and secondarily by interfering with the transmission of noise. Engineering control will be treated here as the reduction of sound energy. (In some special cases, noise control may involve *adding* rather than *reducing* sound energy. An example is where office noise levels are very low and conversation is transmitted from one office to another. To remedy this, an increase in background noise will mask out the intruding conversation.)

Approach to noise control

Careful consideration should be given to minimizing noise problems in the initial stages of planning a new plant, a building addition, or a new work procedure in an existing operation. Consideration at those times may eliminate subsequent unnecessary expense for noise control measures. For example, heavy air handling and compressor equipment should be located away from critical speech communication spaces such as conference rooms and private offices. Heavy equipment areas are advantageously located on grade level to minimize vibration and noise transmission to other areas of the building. Where the advantage of distance and buffer zones between noisy and quiet spaces is not available, special construction and precaution will be required to provide desired noise conditions.

Plant layout, construction materials, equipment selection, and equipment installation are all factors affecting an industrial noise condition. In planning new facilities, advantage may be taken of *distance, isolation,* and *absorption* for the control of noise.

Many noise sources are somewhat directional in nature. It may be practical to locate and orient sources so that the direction of maximum noise radiation is least objectionable — possibly taking advantage of sound absorbing materials. The most desirable and most economical control of noise can be obtained through knowledgeable preplanning in the blue print stage.

The article, "A Clean, Well-Lighted, and Quiet Foundry,"[1] describes the special construction features used in a General Motors foundry for isolation and control of noise. Architects frequently utilize acoustical engineers for review and consultation in the early stages of planning buildings.

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In one facility where this wasn't done, noise has been a troublesome problem from the start. A number of changes were made during construction, prior to building occupancy, to reduce ventilation noise levels, and additional work has gone into this problem but noise levels at this location are still considered unsatisfactory. The noise problem could have been greatly reduced or avoided in the planning stages. Now, the expense involved in making the desired changes is considered economically prohibitive.

The approach for control of existing noise problems is to first gather qualitative and quantitative information on the conditions. Obtain *sound pressure level* measurements within desired frequency bands at the locations of interest. (Previous articles in this series discussed proper sound pressure level measurement techniques and instruments.)

Other pertinent information concerning the noise problem should also be collected. This may include information on the sources of noise, the number of people affected, the nature of the problem, room measurements, and acoustical features of the environment. In many cases the various sources of noise and paths of noise transmission must be studied in detail. Figure 1 shows paths of noise transmission from noise sources. Noise and vibration measurement instruments and frequency analyzers may be used to study the noise flow paths. The next step is to compare measured noise levels to criteria for noise control. To protect against noise-induced hearing loss, the criteria selected may be an 85 dB* limit in the 300 to 4,800 Hz** octave bands, the Walsh-Healy Act exposure limit, or other recommended damage risk criteria.

In the case of speech interference or annoyance, the *Noise Criteria Curves* and suggested limits for various applications may be used as guidelines. The book, *Noise Reduction*, by L. Beranek[2] is one source of this information.

After determining the amount of noise reduction needed by comparing noise level measurements to selected criteria, alternate or multiple methods of noise control should be considered. (The various engineering control methods available will be discussed in detail.)

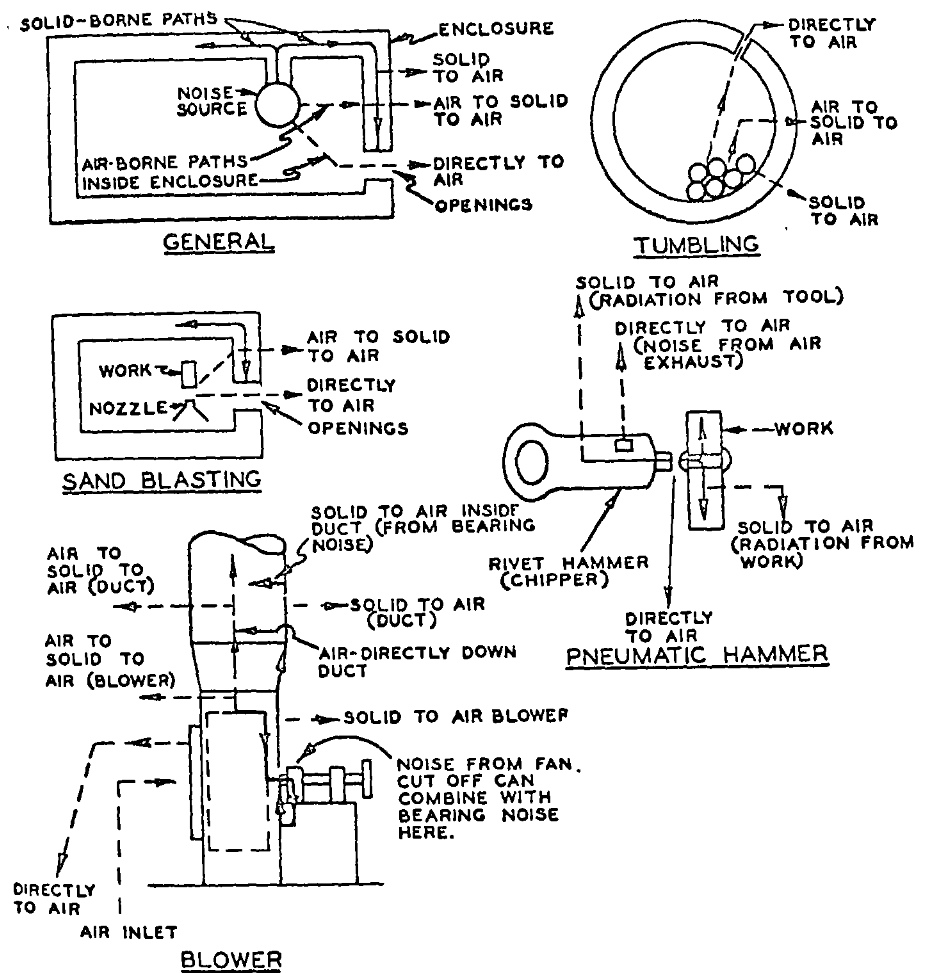


Figure 1 depicts noise flow diagrams. (Source: F. G. Tyzzer, "Reducing Industrial Noi American Industrial Hygiene Association Quarterly, Vol. 14, No. 4, December 1953.)

Reduction of noise at the source, along the transmission path, and at the receiver should be considered from the standpoint of effectiveness, desirability, cost, and maintenance. Often the way to progress is to use the experimental or cut and try approach to noise control following basic principles.

A total *system analysis* approach is needed because reducing one component of noise far below another doesn't reduce the total noise appreciably. For example, if each of two adjacent machines independently produce noise levels of 80 dB, the combined noise level—the result of adding the levels of the two machines—is 83 dB when both machines are running simultaneously. Therefore, a drastic reduction, or even elimination, of noise from one of the machines will produce only a three decibel overall reduction in the total noise level if the other machine continues to produce 80 dB.

In many cases, the engineering control of noise to attain desired levels may be economically unfeasible. Where there is a potential hearing loss hazard, an effective hearing conservation program will have to consider other means of noise attenuation—personal protection. While ear protectors are classed as personal protection devices, they may also be considered as providing control of noise *at the receiver*.

Selected noise control measures are next implemented or put into effect. Then, as a final step, the resulting noise levels are measured to determine whether the controls have attained the desired attenuation or condition or not. As some control measures may deteriorate with time, it is advisable to check noise levels

* The decibel (dB) sound pressure reference level used throughout this article is .0002 dynes/cm².

** Hertz (Hz) is equivalent to cycles per second (cps).

periodically and to make corrections where necessary.

Noise specifications

Noise problems may often be nipped in the bud by the use of noise specifications in the process of selecting equipment. While other factors, such as cost and performance of equipment, weigh heavily in the selection process, noise should also be a routine consideration. Many equipment manufacturers emphasize relatively low noise levels for sales appeal. They may also advertise, or at least should be able to supply, noise level ratings for their equipment. Sound power levels or sound pressure levels in octave or one-third octave bands are given for a specified acoustic environment, equipment operating conditions, reference levels, and methods of testing.

Practical considerations must enter into specifications of equipment noise limits. It is impractical to specify noise limits that none of the equipment manufacturers can meet. It is also costly to pay a premium needlessly for noise control. For example, specifying a sound pressure level of 70 dB on the A scale for prescribed equipment operation and measurement conditions would be foolish if the equipment is to be located permanently where the existing noise level is 90 dBa.

It is a good practice to send noise level specification forms along with inquiries about potentially noisy equipment. An example equipment noise specification form is shown as Figure 2. In many cases, it may become necessary to purchase equipment that produces noise levels higher than those desired. However, in such cases, the specifications serve the useful purpose of obtaining the degree of subsequent noise control needed.

Noise control specifications should be incorporated also into architectural or constructional specifications. Buildings can be designed using materials that reduce noise levels if knowledgeable planning and appropriate specifications are utilized. Specifications for appropriate vibration isolation mounts, equipment inertia blocks, mufflers, etc., can play an important role in the control of noise. It would be well for the purchasing and engineering personnel of a company to take advantage of the use of specifications for noise controls.

Control Measures

Substitution

Reduction of noise at the source should be the first consideration in engineering control of noise. In certain cases, it may be feasible to substitute quieter equipment or a quieter operation. Examples given in the *Industrial Noise Manual*[3] of effective substitutions that reduced noise levels are shown in Table I.

Reduce vibration forces

Noise may be produced by forces causing either structural or air vibrations. In equipment the vibration forces are commonly due to reciprocating motion or to imbalance in rotary motion. In air, vibration forces are created by turbulence or pressure pulses. Vibration forces are transferred back and forth between the air and structural materials.

The following measures can reduce troublesome vibration forces:

EQUIPMENT NOISE SPECIFICATION

1 GENERAL

1.1 This Specification is a means of establishing the limiting value of noise (unwanted sound) generated by equipment to be installed in an industrial plant. It also provides a uniform method of conducting and recording noise tests to be made on such machinery.

1.2 Application of Specification. This Specification describes limits and methods of measuring sound emission in the purchase of equipment. Tests are to be made by the vendor and witnessed by purchaser unless otherwise specified. Confirming or additional measurements by purchaser shall be permissible.

1.3 American Standards Association. Noise measurement sections 2 and 3 of this Specification are based on ASA Z24.7-1950.

2. INSTRUMENTS

2.1 A Sound Level Meter as specified in ASA S1.4-1961 when used alone measures over-all noise levels only.

2.2 An Octave Band Analyzer, as specified in ASA Z24.10-1953 is the preferred instrument for measuring broad band noise by this Specification, used in conjunction with a sound level meter.

2.3 A Narrow Band Analyzer in conjunction with a Sound Level Meter is used to identify Narrow Band or Pure Tone sounds.

2.4 Instruments shall be calibrated as recommended by the instrument manufacturer. Over all calibrations of the instruments, including the microphone and internal calibration of the meters, shall be made before and after the test of each piece of equipment.

3. NOISE TESTS

3.1 Ordinarily the test will be made at the factory or in a test room provided by the vendor at his expense. The test room should preferably provide conditions free of extraneous sounds and minimize the conveyance and reverberation of sounds emitted by the equipment under test which tend to increase the sound level in the test environment.

3.2 Ambient sound levels within the test room should be 5 dB or more below the sound level that prevails when the tested equipment is in operation.

3.3 Unless otherwise specified equipment tested should be at full load.

3.4 The placement of the microphone during the test should be such as to protect it from air currents, vibration, electric or magnetic fields, and other disturbing influences that might affect the readings obtained. Positioning of the microphone at ear level and a horizontal distance of 3 feet from the nearest major surface is usually satisfactory. The entire area surrounding the equipment should be explored to insure that the maximum noise levels are measured.

3.5 Measurements shall be made at a minimum of 6 points approximately 60 degrees apart in the plane specified in paragraph 3.4, starting with the line of maximum noise level. Additional readings will be specified when a directivity pattern is to be established. When multiple similar units are to be purchased, tests on more than one might be requested.

4 RECORDS

4.1 Records of tests for each piece of equipment shall include the information and readings called for in this specification.

4.2 Test results are to be reported to the purchaser for analysis and acceptance before equipment is shipped unless otherwise specified.

5 SOUND LEVEL SPECIFICATIONS

5.1 The location and orientation of the microphone for measurements of total (ambient plus machinery) and ambient noise levels shall be identical. If either the machine or ambient noise levels fluctuate appreciably, maximum levels shall be recorded. If the difference between total and ambient readings is less than 3 dB the ambient level is unsatisfactory for measuring the noise produced by the machine. If the difference is 10 dB or more the higher readings are essentially the noise levels generated by the machine. For differences of 3 to 10 dB, the machinery noise levels shall be determined by applying the correction values indicated below.

5.2 Unless otherwise specified octave band analysis will be used to measure equipment sound levels. Maximum levels suitable for the application intended shall be specified by purchaser for each purchase. Sound level specifications for equipment to be installed in various environments are to be supplied by purchaser.

5.3 Over-all Levels. When the relation between the over-all noise level and frequency band analysis of a machine is known the over-all noise level measured with the sound level meter only may be sufficient. This decision will be at the discretion of the purchaser. If frequency analyzing instruments are not available, the more stringent requirements of 85 dB maximum over-all noise level (C scale flat response) shall be used.

6 SPECIAL REQUIREMENTS

6.1 Equipment or locations which create special noise problems not covered by these specifications (such as neighborhood noise) require special consideration and can be provided for by including supplementary specifications in respect to

a. Noise levels as stated in paragraph 5.2

b. Load or load range during test as stated in paragraph 3.3

c. Microphone positions as stated in paragraph 3.4.

d. Number of readings as stated in paragraph 3.5.

Correction Values Allowed for High Ambient Sound Levels

Difference between Total and Ambient Noise Levels dB	Correction to be Subtracted from Total Sound Level dB
3	3
4–5	2
6–9	1
10	0

EQUIPMENT NOISE SPECIFICATION

TYPE OF EQUIPMENT ____

MANUFACTURER ____ VENDOR ____

VENDOR'S NOS-ORDER ____ SERIAL ____ SHOP ____

PURCHASER'S PROJECT ____ MACHINE NO. ____ ORDER ____

EQUIPMENT SPECIFICATIONS: MODEL NUMBER ____ SERIAL NUMBER ____

SIZE ____ CAPACITY ____

SPEED ____ HORSEPOWER ____

MACHINE LOAD – % CAPACITY ____

TEST ROOM–DIMENSIONS LENGTH ____ WIDTH ____ HEIGHT ____

MATERIAL FLOOR ____ WALL ____ CEILING ____

NOISE DESCRIPTION CONTINUOUS ____ INTERMITTENT ____ IMPACT ____

DOES NARROW BAND NOISE EXIST YES ____ NO ____

NARROW BAND ANALYSER USED YES ____ NO ____

OCTAVE BAND ANALYSER USED MAKE ____ SERIAL NUMBER ____

SOUND LEVEL METER MAKE ____ SERIAL NUMBER ____

MICROPHONE TYPE MAKE ____ SERIAL NUMBER ____

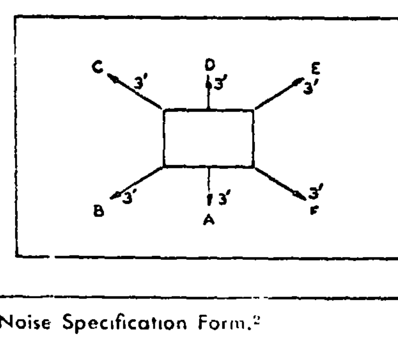
MICROPHONE CABLE USED YES ____ NO ____

READING CORRECTED YES ____ NO ____

METER SPEED USED FAST ____ SLOW ____

LOCATION OF MICROPHONE

INDICATE ON THE SKETCH BELOW THE POSITION OF THE EQUIPMENT AS PLACED IN THE ROOM AND ORIENT THE MACHINE BY SOME IDENTIFYING FEATURE. NOTE THE SOUND LEVEL READINGS AT APPROPRIATE LOCATIONS SUCH AS A-F



OUTLINE OF TEST ROOM. INDICATE TOTAL AREA OF OPEN WINDOWS AND DOORS.

Figure 2 shows the two sides of an Equipment Noise Specification Form.[2]

TABLE I

Substituting quieter equipment or quieter operations are effective engineering controls for noise.*

Substitute	Previous Noise Source
Belt Drives	Gear Drives
Punch press mechanical parts ejector	Punch press air ejector
Diamond face core drill	Star drill and air hammer
Hydraulic press riveter	Pneumatic hammer riveter
Proper size weld peening tool	Oversized weld peening tool
Pneumatic air cylinders	Electric solenoids
Pneumatic rotary shear	Pneumatic chisel
Welding	Riveting
Grinding, Arcair metal removal or flame gouging	Chipping

* Source: Industrial Noise Manual.[2]

1) Reduction of equipment operating speed;

2) Reduction of imbalance through the proper alignment and balancing of the rotating equipment —balancing should be done preferably under dynamic load conditions;

3) Replacement of worn parts —such as bad bearings;

4) Provision for proper lubrication to reduce frictional forces;

5) Reduction of peak forces by extending the force application time —an example is the use of stepped punches so that the total work isn't done at one instant;

6) Reduction of flow velocities of gases and liquids — turbulence and vibration increase as flow rate increases;

7) Reduction of turbulence in the flow of gases and liquids by streamlined design — for example, fans with airfoil blades provide reduced turbulence and noise;

8) Reduction of impact forces by the use of resilient materials — an example is the use of rubber liners in castings tumblers;

9) Tightening of loose parts because increased forces may be produced when motion isn't adequately restricted.

10) Proper assembly of parts—impact or frictional forces may result from improper assembly.

Reduce vibration response

Reducing the response to vibration forces is an aid for control of many noise problems. This may be brought about through the use of vibration isolators or the use of damping materials. Examples of various types of vibration isolators are shown in Figure 3. Commercially available isolators are, in some cases, a combination of basic types. Isolators are chosen on the basis of the load supported and the deflection needed to reduce transmission of vibration by the desired amount. They are also selected on the basis of cost, resistance to deterioration, expected service life, and damping characteristics.

The natural frequency of a machine, which is supported by vibration isolators, is the frequency at which the system will vibrate if displaced and then released to vibrate freely of its own accord. It is a function of the static deflection of the isolators. As static deflection is increased, the natural frequency of the system decreases and in general transmission of vibration energy decreases.

The application of periodic impulses can cause a machine or machine part to vibrate with a frequency that may or may not be the natural frequency of the vibrating body. When the period of the forced vibration is the same as that of the free vibration, the two effects reenforce each other and large amplitudes of the vibrating body result in a condition that is called resonance.

There are instances where machinery cannot be operated at certain speeds because the frequency of the applied impulse at such speeds corresponds to the natural frequency of some vibrating member.

The natural frequency is also the frequency at which resonance occurs. When the frequency of the driving force coincides with the natural frequency, transmission of vibration force is increased rather than reduced by the isolators. To counteract resonant vibration, damping is added to many isolators to increase energy dissipation. This is done with some sacrifice in the effectiveness of the isolator at other frequencies.

Materials that are commonly used for vibration isolation are cork, felt, rubber, and steel springs. The cork, felt, or rubber may be coated with another resilient material to add resistance to deterioration. They are most effective against high frequencies. The large deflections, which can be attained with steel springs, make them the isolator of choice for low frequency vibration from heavy equipment such as reciprocating compressors. For heavy equipment and large vibration forces, the ef-

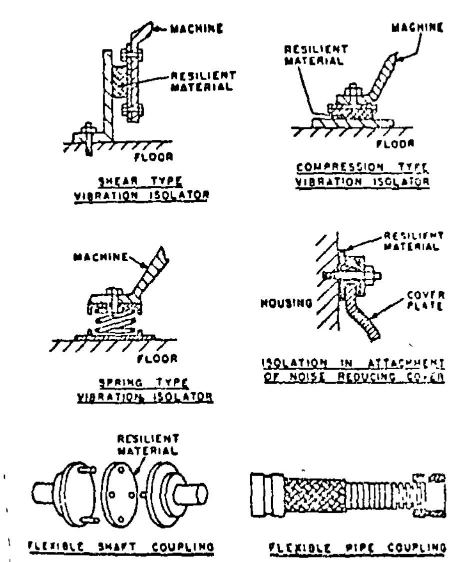


Figure 3 shows six types of devices used for isolation of vibration.[2]

fectiveness of isolation is improved by mounting the equipment on concrete inertia blocks to increase the weight and inertia of the system by a factor of about three or more. It is also important in these cases for the isolator supports to be located in the plane of the center of gravity of the system. Information regarding selection of isolators for a specific application can be obtained from manufacturers of these devices. It is advisable to consult a specialist in this field to obtain expert engineering advice in nonroutine applications.

Other example applications of vibration isolators are the use of canvas or rubber flexible connectors between ductwork and fans to reduce the transmission of fan vibration. Spring-type hangers are used to support steam lines near pressure reducing valves to reduce transmission of vibration to the building structure.

Vibration isolators reduce the transmission of vibration to adjacent structural members and thereby reduce the surface areas radiating significant noise. Even with very effective vibration isolators in use, airborne noise can produce structural vibrations and transmission of noise to other areas. A combination of measures to reduce both structure-borne and air-borne vibrations may be needed for effective control.

Vibration damping

The term "damping" is used to describe the conversion of resonant vibration energy of structures into heat energy. It is an effective mechanism for noise control, because once converted to heat the vibration energy is no longer available for generation of airborne noise. There is some inherent damping in all materials, but most structural materials—such as metal panels—require damping treatment for noise reduction purposes. In materials such as aluminum or steel, the flexural vibrations persist at various resonant frequencies. Most of the vibration energy in these materials is stored in the bending action and acts as the force to produce repeated vibrations.

In mastic materials the vibrational energy is quickly dissipated because they resist motion. Asphalt base mastic materials with various solid additives have long been used as a damping material. An example is their application to automobile door and body panels to reduce noise from resonant vibrations. Without damping treatment the automobile would be described as tinny and noisy. As asphalt base materials vary widely in their damping effectiveness, it is necessary to obtain damping ratings for the specific material and conditions of use. Damping ratings may be expressed as vibration decay rates in decibels per second at 160 Hz at room temperature for the particular type and thickness of damping treatment applied to a test panel. The thick plate test panel is a ¼-inch thick, 20- by 20-inch cold rolled steel plate. Vibration is measured as sound pressure at a microphone placed a few inches away from the center of the panel. In general, damping becomes more effective as the vibration frequency increases.

Asphalt impregnated felts are also used as damping materials. When a fibrous material, such as felt or glass fiber blanket, is applied with a septum attached to it, a very high level of damping occurs. The high level of damping is affected by the crushing and flexing of the fibrous material between the septum and the vibrating surface. Care must be taken to avoid any solid connection between the septum — *e.g.* sheet metal, and the vibrating surface.

Many other damping materials and ingenious techniques can be used to reduce resonant vibrations for noise control. Prefabricated panels of a laminated construction with a layer of visco-elastic material, provide an effective new integral approach to damping of resonant vibrations. As costs are not great, damping treatments can be used in trial applications to evaluate their effect. A technique for indicating the presence of resonant vibrations and the need for damping is to vary the speed of equipment from well below to well above normal speed. Listen for increased noise at certain speeds and for changes in pitch. Either may indicate that resonances are occurring and that damping treatment may be a useful measure for noise reduction. Sophisticated instrument measurement techniques may also be used to determine vibration levels and node patterns.

Reduce transmission

In some cases the practical solution to a noise problem will be to enclose the noise source with a sound attenuating barrier. It is necessary that the enclosure be made of non-porous material to prevent the direct transmission of the air sound pressure waves. The enclosure walls should have sufficient

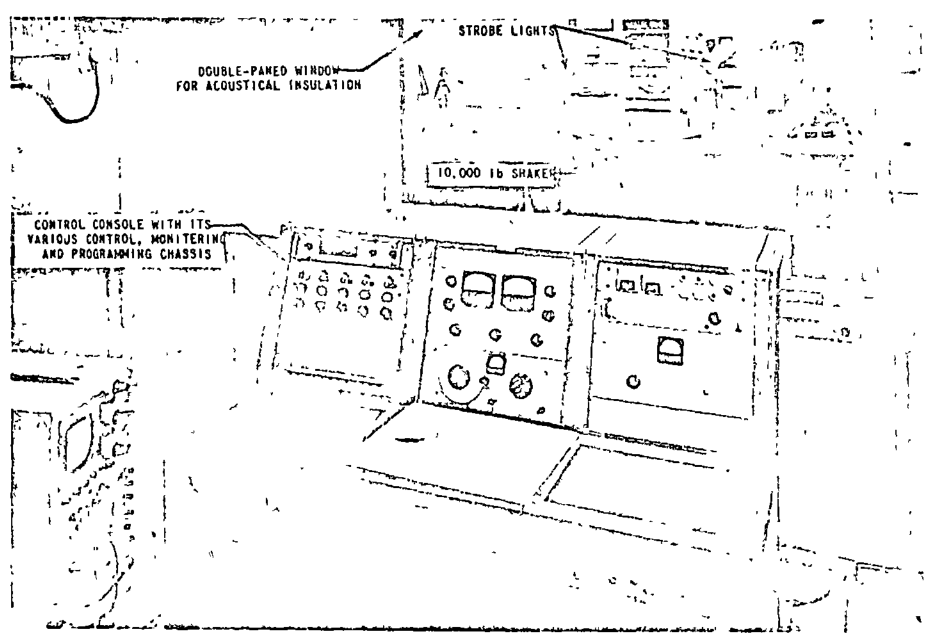


Figure 4 provides a view of a test setup from a control room and shows a noise barrier partition, which includes a double-paned window for acoustical insulation. (Picture courtesy Argonne National Laboratory) mass to counteract the driving force of the airborne noise. Sound absorbing materials should be installed inside enclosures to reduce the buildup of reflected sound energy.

Special enclosures may be constructed around the noise source or a noisy area may be partitioned off. An example of a partition used for noise attenuation at Argonne National Laboratory is shown in Figure 4. This partition has a large double pane window for easy viewing of the shaker apparatus. With the shaker operating at 800 Hz, and 90 times the acceleration due to gravity, the sound pressure level at the control console was 71 dBa as compared to 95 dBa in the shaker room. The partition allows the shaker operators to work without wearing ear protectors. A more massive partition, without penetrations, would provide a much greater noise reduction.

Transmission loss (TL) is defined as the number of decibels reduction in the transmission of sound energy, of random incidence, through a partition. It is frequency dependent. When a single value is given it should refer to the average of the transmission losses at 125, 175, 250, 350, 500, 700, 1,000, 2,000, and 4,000 Hz. Figure 5 shows the transmission loss and weight in pounds per square foot of various structural materials. Mass theory states that transmission loss should increase by six decibels for each doubling of partition weight. However, for practical application experimental transmission loss values are used. These are obtained from testing laboratories where full size partitions are tested. In certain cases, special construction techniques—such as decoupled double-wall construction—can provide increased transmission loss. Relatively low transmission losses result when the frequency of sound energy is coincident with resonant partition vibrations.

The following discussion adapted from "Industrial Noise," P.H.S. Publication 1572, illustrates the use of transmission coefficients.

The fraction of incident sound energy transmitted through a partition is called its *transmission* coefficient (τ).[4] It is related to the transmission loss of a partition by the equation:

TABLE II

Noise Insulation Factor of a Room

	Area Square Feet (S)	T.L. dB	τ	τS
Ceiling — four-inch concrete slab one-inch acoustical tile	800	50	0.0000100	0.0089
Walls — four-inch cinder block with plaster (both sides)	1,200	45	0.0000320	0.0384
Floor — four-inch concrete slab plus floor covering	800	50	0.0000100	0.0080
3/16-inch glass windows	60	28	0.001600	0.0960
Two 1½-inch hardwood doors (close fit)	36	20	0.010000	0.3600

(A = Total room absorption ft² = 718) (See Table 2)   Total transmittance (T)=0.5113

$$\text{Noise insulation factor} = 10 \log_{10} \frac{A}{T} \text{dB} = 10 \log_{10} \frac{718}{0.5113} = 31.5 \text{ dB}$$

(Adapted from *Industrial Noise*.[4])

$$\text{T.L.} = 10 \log_{10} \frac{1}{\tau} \text{ dB}$$

The boundaries of most rooms or enclosures are constructed of a number of sections having different areas of varying transmission coefficients. If it is assumed that each element of construction has sound of the same level incident upon it, the average transmission coefficient $\bar{\tau}$ is given by:

$$\bar{\tau} = \frac{\tau_1 S_1 + \tau_2 S_2 + \tau_3 S_3 \ldots \tau_n S_n}{S} = \frac{T}{S}$$

Where τ_1, τ_2, τ_3, and τ_n are the transmission coefficients of the different parts of the boundary; S_1, S_2, S_3, and S_n are their corresponding surface areas; S is the sum of all these areas. T is the transmittance.

The transmittance and the total number of units of absorption in a room are the principal factors in establishing a figure of merit for the noise-insulative properties of its boundaries. Such a rating is given by the noise-insulation factor of a room.[4] This factor is expressed by:

$$\text{NIF} = 10 \log_{10} \frac{A}{T} \text{ dB}$$

An example of the uses of this formula is given as Table II to illustrate the importance of eliminating small areas that have relatively large transmission coefficients if good noise insulation is required.[4] Consider a room 20 by 40 by 10 feet with plastered ceiling and walls. If the windows are replaced by double windows with a transmission loss of 40 dB ($\tau = .0001$), the noise insulation factor would be increased to 32.3 dB. On the other hand, if the windows were open ($\tau = 1.0$), the noise insulation factor would be only 11 dB. It is obvious from these examples that little would be gained by an increase in the insulation value of the walls because most of the sound is transmitted through the windows and doors. Also, it should be pointed out, there should be no openings in enclosures around doors, services, etc. In the situation where double windows were used, if there had been an opening of .42 square feet, this would have permitted the transmission of as much sound energy as the balance of the room even though this represents only 0.015 per cent of the area.[4]

Sometimes misguided attempts are made to reduce noise levels by wrapping or enclosing noise sources with porous sound absorbing materials such as fiberglass blankets. The results are very disappointing because sound energy passes quite freely through the porous covering. Sheet lead is now frequently used as a noise barrier. For this application it has the excellent properties of high density and low stiffness. Its ease of installation, including cutting and fitting tightly around obstructions, makes it competitive with cheaper materials.

Small openings in sound barriers may greatly reduce their effectiveness. For example, a one-inch diameter hole will transmit slightly more sound energy than the entire surface of a four- by 12-foot sheet lead barrier rated at 40 dB transmission loss. Door crack openings and ventilation transfer grilles are often noise transmitters. Both commercially available special rubber seals for doors and acoustically treated air transfer grilles may be used to avoid excessive noise leaks. Where heat buildup in an enclosure is excessive, a fan and lined ducts or package attenuators may be required to provide ventilation without breeching the noise barrier.

Enclosures may be placed around the receiver rather than around the source of noise. For example, closed booths or partitioned-off office-type work stations are utilized in the spacious noisy areas of steel-rolling mills. Also, closed air conditioned crane cabs provide substantial noise reduction.

Partial enclosures are not nearly as effective as total enclosures for reducing noise levels. However, they can be satisfactory where only a small amount of noise reduction is required. Noise reduction may be improved by lining the partial enclosures with sound absorbing materials. They are most effective in reducing high frequency noise, and may provide no significant attenuation at low frequencies. An example given in the *Industrial Noise Manual*[3] is the installation of a safety glass shield between the operator of a punch press and the parts air ejector. The noise reduction afforded the operator was nearly 10 dB. This was due to reduction at the higher frequencies. In the octaves below 600 Hz the reduction was 2 dB or less.

Barrier walls show the same effect as the safety glass shield. They provide a noise shadow effect for the high frequencies but are ineffective for the long wavelength low frequency noise. They are most effective when either the noise source or the receiver or both are close to the barrier wall.

Absorption of sound energy

Sound absorbing materials may be used to reduce the reflection or reverberation of sound energy. These materials are porous in nature. They cause sound energy to be degraded to heat energy by producing frictional shear forces in the air. Air molecules in motion in a sound wave are slowed down by friction at surfaces within the absorbing materials. These materials aren't effective as sound barriers as they transmit air motion and have a low mass per unit of thickness.

Sound absorbing materials are rated by the ratio of the sound energy absorbed to the energy of the incident sound. This ratio is expressed as the absorption factor or coefficient. Absorption varies with the angle of incidence of sound energy and coefficients are generally related to random incidence by reverberant room testing. As absorption varies with the frequency of the sound, the absorption coefficient is commonly listed at six frequencies — 125, 250, 500, 1,000, 2,000, and 4,000 Hz. A single value termed noise reduction coefficient (NRC) of acoustical materials is the average of the absorption factors at 250, 500, 1,000, and 2,000 Hz. The use of the noise reduction coefficient for calculating noise reduction due to the installation of acoustical materials is simpler but less exacting than using the coefficients for the various frequencies.

Absorption coefficients of acoustical materials are affected by the type of mounting. The most effective transfer of sound energy to heat energy occurs at the maximum velocity of air molecules in a sound wave. This molecular motion is at a minimum at the reflecting or boundary surface. It passes through a maximum, ¼ wave length from the point of reflection. For most efficient absorption the acoustical material needs to be mounted so that the maximum molecular velocity occurs within its matrix. In the case of low frequency noise, *e.g.*, 125 Hz, a quarter wave length corresponds to 2.2 feet. That is why suspended ceiling-type mounting of acoustical tile provides better absorption of low frequency noise than does surface mounting.

TABLE III

Noise Reduction Computation With Acoustical Absorption Materials

	Surface area (S) In square feet	Absorption Coefficient (α)	Absorption Units (Sabins)
Floor	800	0.04	32
Walls	1,200	0.03	36
Ceiling (before treatment)	800	0.03	24
Equipment			50
	Total absorption before treatment		142 (A_1)
Ceiling (after treatment)	800	0.75	600

Total absorption after treatment (600 + 32 + 36 + 50) = 718 (A_2)

$$\text{Therefore: } NR = 10 \log_{10} \frac{A_2}{A_1} = 10 \log_{10} \frac{718}{142} = 10 \times 0.7 = 7 \text{ dB}$$

(Adapted from *Industrial Noise* [4])

The optimum density of an acoustical material occurs where the sound energy reflected from the surface of the material equals the sound energy coming from the material after reflection from the backing surface. A denser material reflects too much of the incident energy while a less dense material doesn't absorb the sound energy as effectively.

The sound absorption in a space is expressed as equivalent square feet of total absorption. One square foot of total absorption (equivalent to one square foot of open window area) is called a *sabin*. The square feet of surface area times the absorption coefficient gives the number of sabins absorption for that area. Adding together the number of sabins of all surface areas gives the total room absorption in sabins. The reverberant noise level in a room decreases 3 dB for each doubling of the total absorption. In most applications, installation of acoustical materials provides less than 10 dB of noise reduction. This is obviously not a cure-all for noise problems. Treatment of 20 to 50 per cent of the boundary surface area is a practical approach. Installation of acoustical tile on the ceiling or as a false ceiling is a common practice. It is impractical to treat more than 50 per cent of the room surface area because noise reduction gained going beyond this amount is slight.

In a simplified example, the average sound pressure level in a room can be calculated from the sound power level of the noise source and the absorption of the room. With a single noise source producing .01 watt of sound power in a 10- by 20- by 10-foot room with an average absorption coefficient of

$$\bar{\alpha} = .2,$$

the calculation is:

$$\text{Average SPL} = \text{PWL} - 10 \log_{10} S\,\bar{\alpha} + 16.5 \text{ dB}$$

SPL = Sound pressure level, (reference level = .0002 dynes/cm²)

PWL = Sound power level, (reference level = 10^{-12} watts)

S = Boundary surfaces, feet² (walls, ceiling, and floor)

$\bar{\alpha}$ = Average sound absorption coefficient

TABLE IV

Absorption Coefficients of Mounted Mineral Fiber Tile

Mounting	Frequency (Hz) 125	250	500	1,000	2,000	4,000
Cemented directly to ceiling	.10	.26	.79	.93	.86	.80
Mounted on special metal supports	.64	.70	.72	.83	.90	.85

Therefore:

$$\text{SPL (average)} = 10 \log_{10} \frac{10^{-2}}{10^{-12}} - 10 \log_{10} 1{,}000\,(.2) + 16.5$$
$$= 100 - 23 + 16.5 = 93.5 \text{ dB}$$

A small amount of sound energy can cause problems as indicated by this hypothetical case.

A convenient means for predicting the effectiveness of proposed absorbing treatment is the calculation of noise reduction that such a treatment would provide.[4] The far field noise reduction at a given frequency can be expressed in terms of total room absorption as follows:

$$NR = 10 \log_{10} \frac{A_2}{A_1}$$

A_1 = Total room absorption before treatment in sabins.

A_2 = Total room absorption after treatment in sabins.

An example[4] of the computation of noise reduction for the use of acoustical absorption materials would be made as follows:

> A room 20- by 40- by 10-feet with plastered ceiling and walls has a sound absorption coefficient, α, of 0.03 at 1,000 Hz. For the floor, $\alpha = 0.04$ at the same frequency. The equipment in the room has an absorption of 50 sabins. The ceiling is to be treated with a material having an α of 0.75 at 1,000 Hz., (see Table III).[4]

There is a wide selection of acoustical materials that can be purchased and used satisfactorily if their capabilities and limitations are understood. They reduce noise in the reverberant sound field but don't alter direct noise emission. The sound pressure level at the position of the operator of the noisiest machine in a room will likely be unchanged because the operator is in the direct sound field. Other employees, at a distance from the machine, will be benefited by a reduced noise level because they will be in the reverberant or reflected sound field. Selection of acoustical materials should, in addition to absorption properties, take into account fire resistance, cost, esthetic qualities, light reflection, susceptibility to physical damage, and ease of maintenance.

Acoustical tiles are available in various sizes, compositions, surface textures, and styles. They are standardized to ½, ¾ or one inch in thickness. A fissured mineral fiber tile ¾-inch-thick and mounted as indicated will provide average absorption coefficients as shown in Table IV.[2]

The absorption is much greater than for hard reflecting surfaces such as plaster, smooth concrete, metal surfaces, or tile floors. The hard reflecting surfaces generally have absorption coefficients of .01 to .05. Mineral fiber tile is preferred to cellulose tile because of fire safety. Properly designed perforated metal facings or thin plastic membrane facings allow transfer of sound energy into acoustical absorbing materials. These facings protect the fibrous sound absorbing materials and are easily maintained. The sound absorption coefficients must be for the specific materials and mounting methods used. With any of the acoustical materials it is important to avoid loss of absorption properties due to plugging of porous openings by dirt loading or by repainting. Repainting may be accomplished without bridging over the void spaces if proper techniques are used—such as light spray painting.

Sprayed-on mineral fiber acoustical coatings may also be used effectively for noise absorption. They have the advantage of conforming to irregular surfaces. However, they have the disadvantage of being easily damaged and they are difficult to clean.

Space absorbers (preformed acoustical units that are hung from wires) have the advantage of providing relatively good low-frequency sound absorption because they are mounted away from the sound reflecting surfaces. Another advantage is their potential for reuse by simply taking them down and rehanging them in another area. They may be in the form of baffles or various geometric shapes. They should be rated in terms of sabins or equivalent square feet of total absorption for a given installation spacing. Their effectiveness is similar to that of the equivalent number of square feet of acoustical tile mounted at the ceiling.

Acoustical materials applied inside of equipment enclosures reduce reverberant buildup of noise levels and thereby reduce the amount of noise energy generated into the surrounding space. Fan noise transmitted through duct systems is frequently reduced by lining the ducts with fiberglass blankets or by installing package attenuators in a section of the ductwork. The package attenuators are convenient to install and provide an appreciable reduction in noise level. They are commercially available, normally in two- to eight-foot lengths, and are sized for relatively low pressure drops at rated flow. For example, a five-foot-long unit that was installed in one laboratory supply air system was rated at 5,000 cfm, .25 inches of water pressure drop and from 17 to 47 dB attenuation in the octave bands of interest. Anyone selecting such units should be aware that the manufacturer's noise reduction ratings may relate to a static test. Under air flow conditions, some noise may be regenerated due to air turbulence at the discharge.

Mufflers

Discharge of compressed air, such as from pneumatic tools, compressors, or engines, may produce a noise exposure hearing loss hazard. Either dissipative or reactive type mufflers can be used for control of this noise problem. Dissipative mufflers are lined with sound absorptive materials and provide moderate reduction of noise over a broad frequency range. Ventilation ducts lined with glass fiber blankets and the package duct attenuators may both be termed dissipative mufflers. In some applications, the absorptive liners in these mufflers may have to be replaced due to particulate loading.

Reactive mufflers make use of reflection of sound energy and resonance phenomenon. They may have very high noise reduction characteristics over a relatively narrow frequency range. Therefore, a series of reactive components are often incorporated to broaden out the effective frequency range.

In review

More extensive treatment of the principles and applications of engineering control of noise may be found in the bibliography. Reduction of noise at the source through substitution or modification should be the safety professional's first consideration. When that isn't practical or is inadequate, the various means for reducing transmission of noise from the source to the employee are considered. If noise can not be reduced to safe levels through preferred engineering controls, then the employee must wear personal hearing protectors.

By being well informed about noise hazards and controls, the safety professional is better equipped to recognize noise control needs and to make better use of the services of specialists in the field.—**End.**

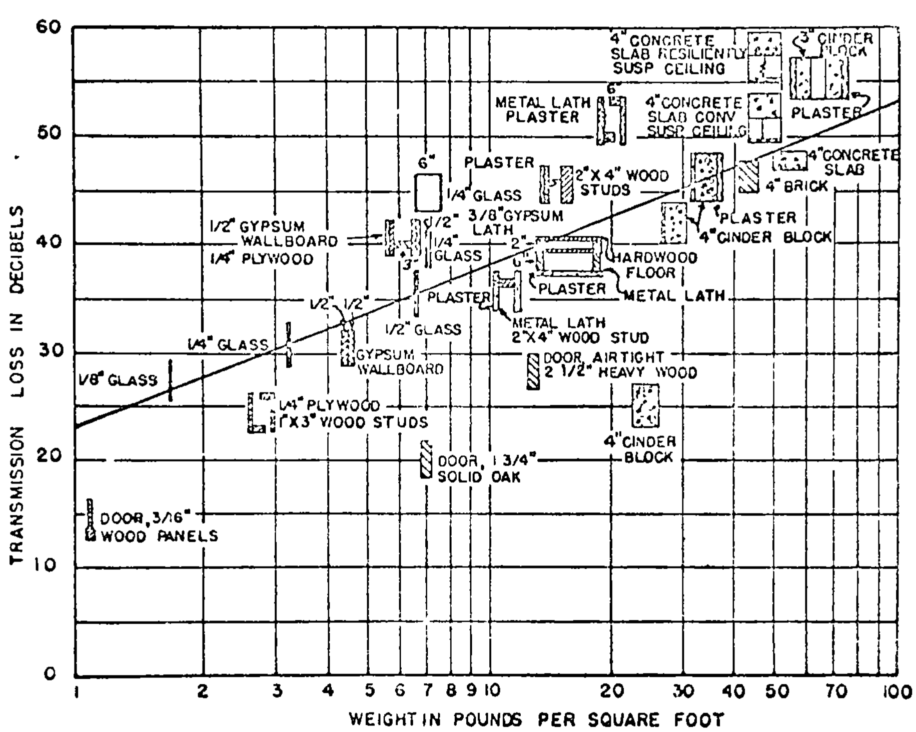


Figure 5 plots the noise barrier transmission loss in decibels for various materials according to their weight in pounds per square foot.[4]

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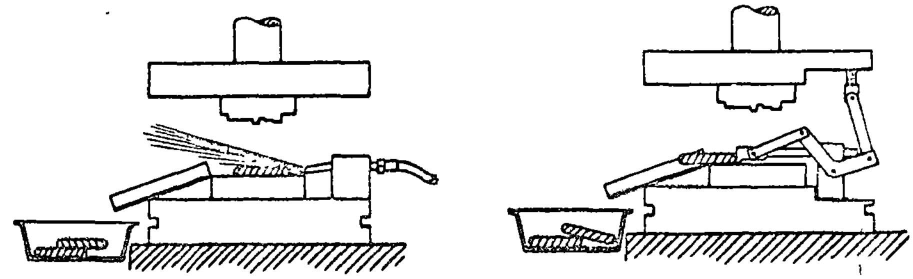
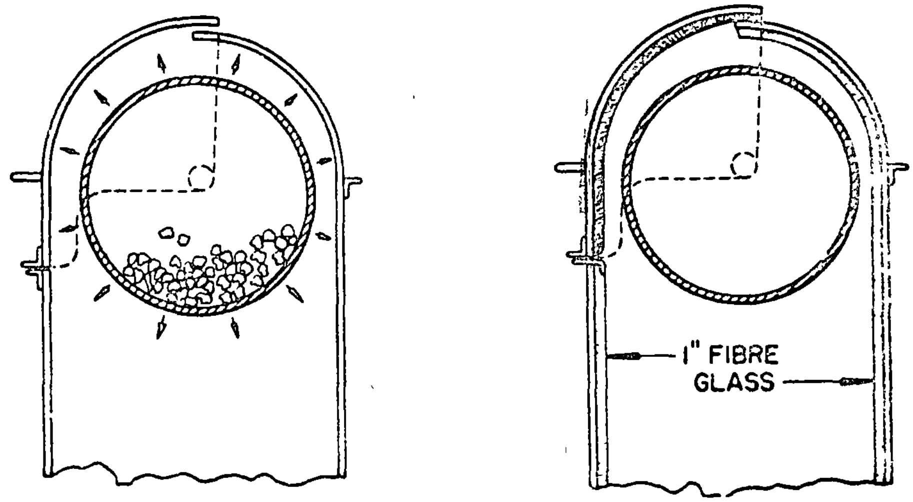
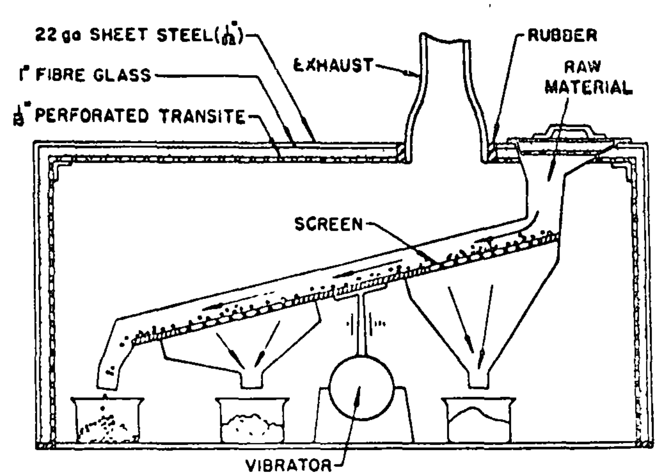
Some Practical Examples of Engineering Noise Control



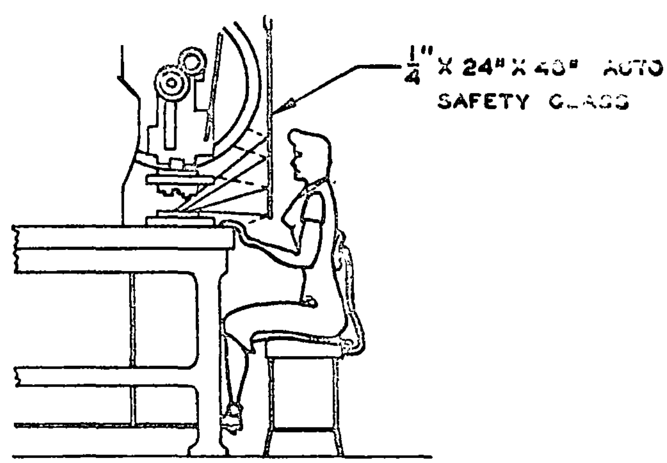
In the use of quieter equipment, the illustration on the left shows the noisy air ejection method while the figure on the right shows quieter mechanical ejection.



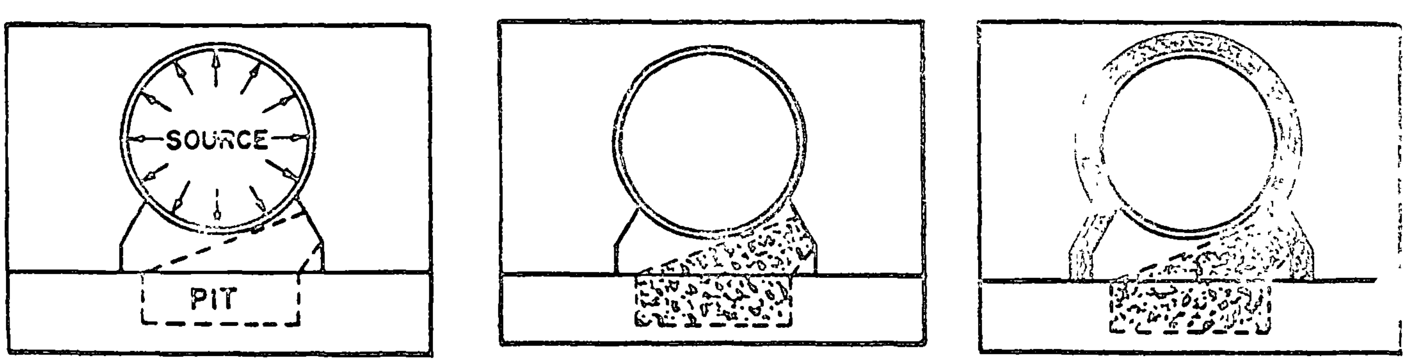
An enclosure house for a tumbler barrel was lined with fiberglass inside and the inside of door was coated with an underseal.



A total enclosure for a screen sifter proved to reduce noise effectively in the case shown.



Shown here is a safety glass shield that has been placed between the operator and the punch press as a sound barrier.



In reducing vibration — a source of noise at a pulp refinery — the illustrations show: on the left the original condition; center, the pit filled in with an acoustical material to minimize reverberation buildup; on the right, the entire machine has been sprayed with an acoustical material and covered with asphalt.

Engineering Noise Control Effectively

AFTER THE PROPER SURVEY of existing noise levels for various environments and machines has been made, and after the measuring instruments have shown that an area is too noisy for comfort, what steps can the safetypro take to reduce noise levels for employees working in those areas?

There are two approaches:

1) The environment and the machines can be redesigned so that the over-all noise level is reduced—noise reduction at the source;

2) Where it is impossible or not feasible to reduce noise to a comfortable or safe level, individuals can be provided with protective devices designed to reduce possible aural injury.

The general principles used to reduce structure-borne sound are:

- *Isolate* the source of vibration from a sound-radiating surface;

- *Place a sound barrier* between the noise source and the equipment or machine exterior;

- *Damp* the amplitude of vibration of the sound radiating surface.

Vibration isolation materials make use of a resilient mounting to separate the energy source from the vibrating surface. Products that reduce transmission of sound by conduction include: high-density glass wool materials; steel springs; elastomers; cork; felt.

Sound barriers utilize a material capable of retarding airborne sound transmission. They can be air-impervious materials and include: glass wool blankets with impervious facings, paper-cellulose or asbestos; asphalt-treated gypsum board, hardboard or plywood; plastic sheeting; lead-loaded vinyl sheeting and metal sheet or heavy foil.

Panel damping consists of the application of a material with high internal damping properties. The effect of such treatment is to reduce the ring or tinny sound of a metal surface. To decrease the amplitude of vibration of panels, the following may be used: asphalted felt, applied by adhesive; damping adhesives; damping tapes.

Vibration isolators break the path of vibration because they are resilient and act as springs.

With sound barriers of the air-impervious sheet type, the incident sound waves set the sheet into vibration, and the sheet generates new sound waves of reduced intensity on the other side. The effectiveness of a barrier increases directly with its weight per square foot. For sound barriers of the faced glass wool type, in addition to the barrier action of the facing, the sound energy is absorbed in passing through the porous layer of glass wool material and is converted into heat.

Vibration dampeners are heavy, limp materials with high internal friction, which reduces the vibration of the panel.

Certain physical principles of noise control methods must be considered. For example, the property of resonance is basic to control by engineering methods. When a small object—such as a watch or a piano wire—is isolated, it produces relatively little sound. But, when it is in contact with a large acoustic conductor—such as the sounding board of a piano—there is a transfer of sound energy that results in considerable amplification. Machinery and equipment act the same way if insulators or isolators are not provided to prevent the noise from being transmitted and considerably amplified.

In some cases, it is possible to substitute quiet operations or devices for more noisy ones. Welding can be substituted for riveting in some operations without loss of strength or efficiency to the resulting product. Also, in many noisy environments, flasher lights instead of bells may be used as signals.

Likewise, one material may be substituted for another to cut down the noise of operations. In stamping operations, for example, mild steels, brass, copper, or aluminum may be used in place of the harder steels, where possible, with consequent reduction of impact noise.

Too often, the rattles, squeaks, and thumps of machinery indicate that maintenance has been neglected. Frequently, considerable noise can be eradicated through a good housekeeping program, which includes regular inspection, tightening of loose connections, and periodic lubrication of equipment, together with the installation of proper damping to reduce unnecessary vibration of parts.

Although proper maintenance is an extremely important phase of noise reduction, machinery eventually becomes too worn to accomplish properly the task for which it was designed. When that state of obsolescence is reached, substitution of more modern equipment, together with a complete survey of plant layout and operations, can often mean lower noise levels and increased safety and production (see Table II).

When new construction is necessary, both sound and air conditioning of the new area should be considered. When both types of conditioning are utilized, the walls of the room should be constructed of materials of high density and mass and low elasticity, as compared to air. The result is low sound transmission. Combined with a layer of absorbent material, it provides good insulation for efficient air conditioning. The two types of conditioning then work together to isolate the individual from unnecessary noise.

Where the walls produce a high degree of sound reflection and there is no absorption, the echoes from a sound source do not have a chance to die away before another increment of sound is added. Under such conditions, the installation of acoustic materials on walls or ceilings can be of great benefit in bringing over-all sound levels down to a safe exposure point.

Engineering control of airborne noise can be summed up in three words: *absorption; isolation; substitution.*

Current practices include the installation of mechanical barriers that absorb noise within an area or prevent its movement from one area to another.

Absorbent materials reduce reflection or echoing, and may be acoustic wallboard, glass fiber, panels, or any other building material that combines high porosity and resistance to air flow. Numerous types of absorbent materials are available, and more are continually coming on the market.

When isolation is the method used, noisy machines may be separated from one another so that their noise output is not so great within a single area; or, they may be enclosed in highly absorbent housings with impervious outer walls. If neither of these methods is practical, a study of the over-all operation may lead to changes that, together with better maintenance, will reduce the noise level.

In order to have good sound isolation between two spaces, it is necessary to separate them by a heavy, impervious material—such as sheet metal, masonry, lead, or wood. The heavier the material, the more difficult it becomes for the incident sound wave to produce any vibration of the wall. It is the vibration of the wall that causes sound to be radiated into the adjoining space.

Studies within rooms enclosed by a sound isolating partition show that the reflected sound is almost as intense as the incident sound. The reflections on one side of the partition will cause a reverberant field to be built up. The increase in the intensity at the partition over that shown for a wall covered with absorbing material will cause unnecessary vibration of the partition.

Better sound isolation between two rooms can be obtained if the reverberant buildup in the first room is eliminated. A partition that combines the advantages of an absorbing material to reduce reverberation and a heavy, impervious panel to reduce the transmission of sound can obtain the optimum sound isolation possible with a single-wall construction. Double-wall construction may be necessary to control some industrial noise problems.

This combination of sound absorbing and isolating materials is the basic component of most designs for the control of airborne noise. Often a protective facing is placed in front of the absorbing material to protect it from damage. Usually, this facing will be a perforated material such as sheet metal, press board, or mineral board; sometimes a thin plastic or glass wool bag may cover the absorbing material. A properly protected wall structure will find wide application to noise control problems.

In constructing an isolating partition, it is mandatory that no leaks —no matter how small—be permitted. In noise control, enclosure means that all cracks and openings are sealed so that the resulting structure is completely air tight.

To illustrate this point, an opening one inch in diameter in a concrete block wall 10 feet square would, in the mid-frequency range, transmit as much sound as the entire remainder of the wall. Similarly, a door placed in this wall that has a crack between it and the jamb of only a few thousandths of an inch will, in the same frequency range, transmit as much sound as the rest of the wall.

Therefore, all cracks should be sealed with an elastic caulking compound. Openings for ducts, conduits, piping, and control cables should have tight-fitting gaskets. Doors should be sealed with an extruded rubber gasket, made in the form of a hollow tube. The enclosure should be inspected and reinspected so that all leaks will be eliminated permanently.

It is often impossible to enclose a noise source and still maintain any production. In such a case, the smallest tolerable opening should be used. If an opening is much too large, and there is no absorbing material on the inside of the structure, there will be an increase in the noise at the operator's station.

A method of noise control that will permit operation may provide only a few decibels of quieting in the important frequency range. In many cases, this reduction may be sufficient to eliminate effectively the hazard or annoyance. If not, it may be necessary to utilize some method of remote automatic feeder control, and to enclose the noise source. Surprisingly enough, remote control will often be less expensive than redesign of the machine to reduce the noise at the source.

The approach to a noise control problem can best be summed up as follows: 1) Consider the source. Can a quieter machine be substituted? Can the noise energy be reduced (lower rpm)? Can a useful change be made in the directivity pattern? Can resilient mounts be used to reduce vibrations? Can a muffler be used? 2) Consider the path from the source to the listener. Can the source or the listener be readily moved to reduce the noise level? Is acoustic treatment of the ceiling or walls a useful solution? Should sound barriers be erected? Is a total enclosure required? Is personal protection required?—**End.**

TABLE II

Changes in machinery that produce changes in vibration levels are countless, and include or are a result of the following:

∘ Wear ∘ Erosion ∘ Corrosion ∘ Aging ∘ Inelastic behavior ∘
∘ Loosening of fastenings ∘ Broken or damaged parts ∘
∘ Incorrect or inadequate lubrication ∘ Foreign matter ∘
∘ Environmental changes ∘ Chemical changes in materials ∘

When maintenance of proper performance or acceptable noise and vibration levels is the goal, symptoms are used as a guide to discover the source of any trouble that may develop and to decide on the remedy. It is helpful to keep in mind the many ways that machine performance is affected by changes that occur with time. A systematic classification of the sources of these changes should serve to point up the many possibilities that exist (Adapted from Handbook of Noise Measurement, General Radio Co., West Concord, Mass.)

"Quiet Please" Doesn't Work Any More

by Clifford R. Bragdon

The earliest city noise ordinances in the United States usually restricted street activity, but the provisions generally were non-quantitative and consequently unenforceable The first ordinances containing specific permissible noise levels regulated industry and other activities fixed to the land as well as automobiles and trucks operating on the roadways. Today noise ordinances are becoming more comprehensive. Their impact varies with quality, content, and administration.

Since the beginning of western civilization, there has been noise control. Chariot use was restricted in the Roman Empire. Medieval towns tried to hush both mobile and stationary noise sources. Iron-wheeled carts were not permitted to move on paved market streets due to associated noise. There were nighttime restrictions on noisy commercial and industrial activities including blacksmith operations.[1]

The earliest noise regulations in the United States were municipal ordinances dating back to 1850[2] Not until the early 1900's did national concern for noise control begin to develop As late as 1930 there were fewer than 20 American cities with laws regulating noise, and the legislation in existence was poorly defined and non-quantitative.

Several historic events shaped evolution of community noise ordinances. These include.

(1) Publication of *City Noise*, prepared by the Noise Abatement Commission for the New York City Department of Health in 1930[3]

(2) Adoption of a motor vehicle control ordinance by the city of Memphis, Tennessee, in 1938.[4]

(3) Publication of the National Institute of Municipal Law Officers (NIMLO) model ordinance prohibiting unnecessary noise in 1948[5]

(4) Adoption of a performance zoning ordinance by the city of Chicago, Illinois, in 1955, as developed by the Armour Research Foundation.[6]

(5) Enforcement of the noise control sections of the Motor Vehicle Code by the California Department of Highway Patrol in 1967.[7]

(6) Adoption of a noise ordinance by the city of Inglewood, California, in 1969[8]

(7) Publication of a revised NIMLO model noise ordinance in 1970.[9]

(8) Adoption of a revised noise ordinance by the city of Chicago in 1972.[10]

New York Mayor Jimmy Walker gave approval to the Commissioner of Health to establish a Noise Abatement Commission for studying urban noise and recommending solutions. Appointed in 1929, this was the first such commission ever assembled Their report, *City Noise*, has been widely circulated and was the first definitive statement about city noise problems. The noise control laws recommended for New York were subsequently adopted by many cities.

Basic provisions included muffler requirements for motor vehicles and other internal combustion engines, building restrictions in residential areas from 5.00 p m. until 8 00 a m.; prohibitions on use of horns and whistles, regulation of peddlers, hawkers, and vendors; and a ban on excessive noise from mechanical or electrical sound-making or sound-reproducing equipment. Both stationary and mobile noise sources were identified, but the report did not discuss industrial noise in any detail.

Table 2 – Noise Violations in Memphis, Tennessee [1,16]

Year	Type of Violation	Citations
1966	Improper Muffler	5,760
1971		1,099
1966	Horn Blowing	360
1971		150

Memphis, Tennessee – proclaimed America's quietest city – borrowed several provisions from the New York document for the 1938 Memphis ordinance regulating vehicle noise[4] Noise is regarded as a nuisance and regulated as such Maximum permissible sound levels are not specified in decibels. Usually this type of non-quantitative noise control fails, but an active enforcement program in Memphis has made this particular ordinance one of the most successful regulations in the country.

Recognizing that municipalities establishing noise ordinances needed guidance, the National Institute of Municipal Law Officers (NIMLO) in 1948 prepared a research report, *Municipal Control of Noise – Sound Trucks – Sound Advertising Aircraft – Unnecessary Noises – Annotated Ordinances.*[5] This report, containing the "NIMLO Model Ordinance Prohibiting Unnecessary Noises," has shaped most noise ordinances in the United States. A study conducted for the U. S. Environmental Protection Agency showed that 29 of 83 local jurisdictions (35%) had enacted the NIMLO model The NIMLO Model was a refinement of ordinances existing at the time, but it did not include quantitative noise limits.

In 1955 the most influential building ordinance restricting noisy land use became law.[6] Chicago regulated noise by setting limits in decibels for various octave bands This was a new approach to zoning. Restrictions were placed not on the type of industry – e g. light or heavy manufacturing – but rather on industrial performance in terms of noise For the first time industry was regulated according to specific acoustical criteria rather than vague nuisance provisions It was required that sound-measuring instruments be used for property line measurement. Initially the Chicago ordinance was not very well enforced, but other jurisdictions began to adopt similar provisions for zoning

In 1952-53 a few cities established vehicle noise restrictions expressed in decibels – e g. Seattle, Washington,[12] and Cincinnati, Ohio[13] Not until 1967 was an effective vehicle noise control law and program established by a government agency. The California Vehicle Code was the first to regulate noise quantitatively for new vehicles sold as well as for existing vehicles operating on highways[7]

California again took the lead in 1969 when Inglewood established the first comprehensive community noise ordinance program[8] Many elements of the Inglewood program have been emulated by other jurisdictions.

In obvious response to the need for enforceable noise ordinances, NIMLO in 1970 modified its earlier model and proposed decibel provisions as an alternative.[9] Included now are noise limits for use in districts – e g. residential, manu-

(continued on page 24)

Table 1 – City Noise Control Regulations in January 1973

Location	1970 Population	Nuisance	Zoning	Building	Vehicle	Aircraft
ALABAMA						
Birmingham	300 910	+	—	—	—	—
ALASKA						
Anchorage	48,081	—	—	—	A	—
Juneau	6 050	+	—	—	—	—
ARIZONA						
Flagstaff	26 177	+	—	—	+	—
Phoenix	581 562	+	—	—	+	—
Tucson	262 933	A	A	—	—	—
ARKANSAS						
Little Rock	132 483	+	—	—	—	—
CALIFORNIA						
Alhambra	62 125	A	—	—	—	—
Anaheim	166 704	+	—	—	—	—
Beverly Hills	33 416	A	—	—	—	—
Burbank	88 871	—	—	—	—	+
El Segundo	15 620	A	A	—	—	—
Fremont	100 869	+	—	—	—	—
Hemet	12 252	+	A	—	—	—
Inglewood	89 985	A	A	—	—	A
Los Altos Hills	6 865	—	—	—	A	—
Los Angeles	2,816 061	+	A	A	+	—
Sacramento	254 413	+	—	—	—	—
San Clemente	17 063	+	—	—	—	—
San Diego	696 769	A	—	—	—	—
San Francisco	715 674	+	A	—	A	—
San Jose	445 779	—	—	—	—	+
Santa Barbara	70 215	+	—	—	—	A
Santa Monica	88 289	—	—	—	—	+
Torrance	134 584	—	A	—	—	+
COLORADO						
Aspen	2 404	A	A	—	A	—
Boulder	66 870	+	A	—	—	—
Denver	514 678	+	A	—	—	—
Dillon	182	—	—	—	+	—
Lakewood	92 787	+	A	—	A	—
CONNECTICUT						
Hartford	158 017	+	—	+	—	—
New Haven	137,707	+	A	—	—	—
DISTRICT OF COLUMBIA	756 510	+	A	—	A	—
DELAWARE						
Wilmington	80 386	+	—	—	+	—
FLORIDA						
Coral Gables	42 494	+	A	—	—	—
Fort Lauderdale	139 590	+	+	+	—	—
Madeira Beach	4 342	—	—	—	—	—
Jacksonville	528 865	—	A	—	—	—
Miami	334 859	+	+	—	—	—
Orlando	97 565	—	—	—	—	A
GEORGIA						
Atlanta	497 421	+	—	—	—	—
College Park	18 203	+	A	—	—	A
Lake City	2 306	+	—	—	—	—
Macon	122 423	+	+	—	—	—
Waycross	18 996	+	—	—	—	—
IDAHO						
Pocatello	40 036	A	A	—	A	—
ILLINOIS						
Chicago	3 369 359	+	A	—	—	—
Decatur	90 397	+	—	—	—	—
Des Plaines	57 239	—	A	—	A	—
Park Ridge	42 466	A	A	—	—	A
Peoria	126 963	A	—	—	A	—
Northbrook	27 297	—	—	A	—	—
Urbana	32 800	A	A	—	—	—
INDIANA						
Indianapolis	745 739	A	—	+	—	—
IOWA						
Des Moines	200 587	+	—	—	+	—
KANSAS						
Wichita	276 534	+	—	+	+	—
KENTUCKY						
Covington	52 535	A	—	—	—	—
Louisville	361 472	A	A	—	A	—
LOUISIANA						
New Orleans	593 471	+	+	—	—	—
MARYLAND						
Baltimore	905 759	A	A	—	—	—
MASSACHUSETTS						
Acton	14,770	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Boston	[illegible]	+	A	—	A	—
Pittsfield	57,020	+	A	—	A	—
Springfield	163,905	+	A	—	—	—
MICHIGAN						
Ann Arbor	99,797	+	A	+	A	—
Detroit	1,512,893	+	—	—	—	—
Grand Rapids	197,649	A	—	—	—	—
Wyoming	56,560	A	—	—	—	—
MINNESOTA						
Bloomington	81,970	—	A	A	—	—
Minneapolis	434,400	+	A	+	—	—
MISSISSIPPI						
Jackson	153,968	+	—	—	—	—
MISSOURI						
Independence	111 662	—	A	—	—	—
Kansas City	507,330	+	—	—	A	—
St Louis	622,236	+	—	—	—	—
MONTANA						
Billings	61,581	+	—	—	—	—
Helena	22,730	—	—	A	+	—
Missoula	29,497	—	—	—	+	—
NEBRASKA						
Scottsbluff	14,507	+	—	—	+	+
NEVADA						
Las Vegas	125,787	+	—	—	+	—
NEW HAMPSHIRE						
Manchester	87 754	+	—	—	+	—
NEW JERSEY						
Absecon	6 094	+	—	—	—	—
Asbury Park	16 533	+	—	—	—	—
Bayonne	72,743	+	—	—	—	—
Belleville	34 643	A	A	—	—	—
Bloomfield	52 059	+	—	—	—	—
Boonton	9 261	A	A	—	—	—
Bordentown	4,490	+	—	—	—	—
Brigantine	6 741	+	—	—	—	—
Burlington	11,991	+	—	—	—	—
Camden	102,551	+	—	—	—	—
Cape May	4 392	+	—	—	—	—
Clifton	82,437	A	A	—	—	—
Clinton	1,742	+	—	—	—	—
Corbin	258	+	—	—	—	—
Dover	15 039	+	—	—	—	—
East Orange	75 471	+	—	—	—	—
Elizabeth	112 654	+	A	—	—	—
Fair Lawn	37 975	+	A	—	—	—
Gloucester City	14 707	+	A	—	—	—
Guttenberg	5 754	+	—	—	—	—
Hammonton	11 464	+	A	—	—	—
Hanover	10 700	—	A	—	—	—
Harrison	11 811	+	—	—	—	—
Hawthorne	9 173	—	A	—	—	—
Hoboken	45 380	—	A	—	—	—
Irvington	59,743	—	A	—	—	—
Jersey City	260 545	+	—	—	—	—
Long Branch	31,774	+	—	—	—	—
Margate	10 576	+	—	—	—	—
Morristown	17 662	+	—	—	—	—
Newark	382 417	+	—	—	—	—
Newton	7 297	+	—	—	—	—
North Wildwood	3 914	+	—	—	—	—
Nutley	32 099	+	—	—	—	—
Ocean City	10 575	+	—	—	—	—
Orange City	32 566	+	—	—	—	—
Paterson	144 824	+	—	—	—	—
Perth Amboy	38 798	+	—	—	—	—
Plainfield	46 862	+	—	—	—	—
Pleasantville	13 778	+	—	—	—	—
Princeton	12 311	A	A	—	—	—
Rahway	29 114	+	A	—	—	—
Ridgefield Park	14 453	+	A	—	—	—
Salem	7,648	+	—	—	—	—
Secaucus	13 228	+	—	—	—	—
South Amboy	9,338	+	A	—	—	—
Summit	23 620	+	—	—	—	—
Trenton	104 638	+	—	—	—	—
Vineland	47,399	+	—	—	—	—
Westfield	33,720	+	—	—	—	—
West Orange	43 715	+	—	—	—	—
Wildwood	4 110	+	—	—	—	—
Woodbridge	78 846	A	—	—	—	—
NEW MEXICO						
Albuquerque	243,751	+	+	—	+	—
NEW YORK						
Albany	115,781	—	+	—	—	—
Binghamton	64,123	A	—	—	—	—
Buffalo	462,768	+	—	—	+	—
New York	7,895,563	+	A	A	—	—
Rochester	296,233	+	—	—	—	—
White Plains	50,125	+	—	—	+	—
New Rochelle	75 385	+	—	—	+	—
NORTH CAROLINA						
Greensboro	144,076	+	—	—	+	—
Raleigh	123,793	+	—	—	—	—
NORTH DAKOTA						
Bismarck	34,703	+	—	—	—	—
OHIO						
Akron	275 425	+	—	—	—	—
Cincinnati	452,524	+	—	—	A	—
Cleveland	750,903	+	—	—	+	—
Columbus	540,025	+	A	—	—	—
Dayton	243,601	+	A	—	—	—
Toledo	383,818	+	—	—	—	—
University Heights	17,055	+	—	—	—	—
OREGON						
Medford	28,454	+	—	—	+	—
Portland	380,620	+	+	—	—	—
OKLAHOMA						
Oklahoma City	368,856	+	A	—	—	—
PENNSYLVANIA						
Philadelphia	1,950,098	+	—	—	—	—
Pittsburgh	520,117	+	—	—	+	—
Scranton	103,564	—	—	—	+	—
RHODE ISLAND						
Warwick	83 694	—	A	—	—	—
SOUTH CAROLINA						
Columbia	113,542	+	—	—	—	—
SOUTH DAKOTA						
Sioux Falls	72,488	—	+	—	+	—
TENNESSEE						
Memphis	623 530	+	—	—	—	—
Nashville	448 003	—	A	—	+	—
TEXAS						
Dallas	844 401	—	A	—	—	—
El Paso	322 261	+	—	—	+	—
Houston	1,232,802	+	—	—	—	—
Irving	97,457	—	A	A	—	—
Killeen	35,507	+	—	—	+	—
San Antonio	654,153	+	—	—	—	—
UTAH						
Ogden	69,478	—	—	—	+	—
Salt Lake City	175,885	A	—	—	—	—
VIRGINIA						
Norfolk	307 951	+	—	—	—	—
Richmond	249 621	+	+	—	—	—
WASHINGTON						
Seattle	530,831	+	—	—	A	—
WISCONSIN						
Madison	173 258	+	—	—	+	—
Milwaukee	717,372	+	—	A	—	—
Totals:						
176 Cities	**47,200,593**	24	53	8	15	7
		124	9	4	27	6

A Regulation includes acoustical criteria.
\+ Regulation does not include acoustical criteria.
— No regulation.

*(**Quiet, Please** continued from page 12)* facturing, and commercial—as well as for motor vehicles.

Chicago's fully revised 1972 noise ordinance is currently the most comprehensive in existence.[10] The program has attracted national attention and is becoming a yardstick to which other jurisdictions are compared.

The influence of Chicago—and to a lesser extent NIMLO—is only beginning to be noticed. Government and professional associations are in the midst of preparing guidelines to help municipal and state agencies enact technically responsible laws and programs. The American National Standards Institute (Working Group S3-50: Outdoor Evaluation of Community Noise) is preparing guidelines for a model noise ordinance,[14] while EPA is working with the Council of State Governments to prepare model state enabling legislation in regard to noise.[15]

Kinds of Ordinances

The constitutionality of regulating noise for the protection of public health, safety, and welfare has been upheld. A municipality—that is, a city government—may use police power to regulate nuisances. A nuisance is anything that endangers life or health, gives offense to the senses, violates laws of decency, or obstructs reasonable and comfortable use of property. The majority of municipal noise ordinances in the United States are based upon nuisance law.

Municipalities in nearly every state have adopted noise regulations, but the number of citizens protected by noise regulations is only 47 million—23% of the total U. S. population. The majority of city governments have no noise ordinances, and many existing ordinances are vague. (See Table 1.)

Ordinances may be classified as either nuisance or performance regulations. Performance regulations are based upon specific acoustical criteria. Nuisance regulations are not. Nearly 85% (148 out of 175) of the regulations listed in Table 1 are the nuisance type.

Nuisance Regulations

The nuisance type of noise ordinance typically prohibits unreasonably loud, disturbing, or unnecessary noise. There is usually no attempt to define noise acoustically. Most ordinances of this type are similar because they are based upon the NIMLO model. Banned activities usually include

- Sounding of horns or other signaling devices except in case of emergency.
- Operating radios, phonographs, or other sound-producing devices in such a manner as to disturb the peace, quiet, and comfort of people nearby.
- Constructing or repairing buildings between the hours of 6 p.m. and 7 a.m. except in cases of urgent necessity or under permit.
- Street vendors' disturbing peace and quiet to direct attention to their wares, trade, or calling.
- Vehicles' causing unnecessary noise because of defects, improper loading, or inadequate mufflers.
- Animals' causing frequent or long-continued noise that disturbs people's comfort or repose.
- Operating construction equipment so as to cause loud or unusual noise between the hours of 10 p.m. and 7 a.m.

In addition, quiet zones often are specified for institutional land use. Unnecessary noise is restricted near schools, hospitals, and churches—during periods of time when buildings are occupied.

With few exceptions enforcement of nuisance regulations is ineffective. Nuis-

(continued on page 26)

Table 3—Fixed-Source Noise Levels Allowable at Residential Boundaries

*National Institute of Municipal Law Officers Model Noise Ordinance

A-WEIGHTED SOUND LEVEL IN dB(A)	DAY	NIGHT	BOTH
60	Boston, Mass; Fair Lawn, N J; College Park, Ga		Anaheim, Cal
	Baltimore, Md.		
	Dallas, Tex		Dayton O
55	Miami, Fla.; Lakewood, Colo.; Los Angeles, Cal; San Francisco, Cal	Fair Lawn, NJ	Minneapolis, Minn; Tucson, Ariz; Chicago, Ill
	Peoria, Ill.	Baltimore, Md	
		Miami, Fla	Columbus O
	Warwick, R.I.		
50	NIMLO*	Boston, Mass; San Francisco, Cal; College Park, Ga; Lakewood, Colo.	Hemet Cal
		Dallas Tex	
		Peoria Ill	
		Warwick, RI	Springf[illegible]
45		Los Angeles Cal	Binghamton N.Y.
		NIMLO*	
40			Beverly [illegible] Cal

LA INSTRUMENTACION APLICADA A LA EVALUACION DE LA VIBRACION MECANICA.

Ing. Miguel Medina

INTRODUCCION:

El propósito de ésta platica es contribuir en la técnica de medición del ruido y la vibración mecánica, asumiendo una actitud modesta, debido a que el campo es bastante amplio y a la vez despertar el interés y la motivación en las nuevas generaciones que actualmente se enfrentan a un mundo de rápidos cambios tecnológicos siendo necesario una agil readaptación a las nuevas áreas de conocimientos.

La mayor preocupación del Ingeniero de mantenimiento en la Industria es la conservación del equipo o maquinaria que le ha sido dado a su cuidado.

Si una máquina en la Industria digamos un soplador presenta severas vibraciones al simple tacto, nuestro ingeniero se preocupa y con razón, debido al inesperado y no programado paro repentino que puede sufrir la unidad repercutiendo en los costos de la productividad.

DEFINICION DE VIBRACION:

Todos los cuerpos en la naturaleza poseen propiedades físicas tales como elasticidad y masa cualidades que los hacen capaces de vibrar al ser sometidos a una excitación de tipo impulsivo ejem. Un automóvil que viaja por carretera y es golpeado por un bache producirá un vaiven en el sentido vertical originando con esto una vibración, en otras palabras la vibración es la variación de la configuración de un sistema con respecto al tiempo, alrededor de una posición de equilibrio estable.

VIBRACION FORZADA:

Nombre dado a la vibración resultante en una máquina que generalmente es la mezcla de diferentes fuentes de vibración producidas en la misma unidad. La vibración forzada en maquinaria normalmente es de naturaleza periódica esto es, cuya configuración física se repite a intérvalos de tiempo constante llamado periódo.

ANALISIS DE FOURIER:

Fourier descubrió que cualquier onda no importando su forma cuadrada, triangular, diente de sierra etc. Siempre y cuándo sea periódica, puede descomponerse en funciones armónicas Ver formulas.

$$f(t) = f_o' + \sum_{1}^{\infty} f_n' \cos n w_o t + \sum_{1}^{\infty} f_n'' \operatorname{Sen} n w_o t$$

Dónde $w_o = \frac{2\pi}{T}$

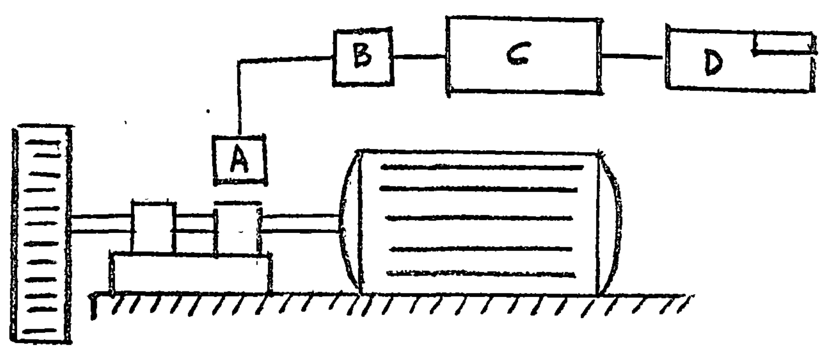
$$f'_o = \frac{1}{T}\int_o^T f(t)\, dt.$$

$$f'_n = \frac{2}{T}\int_o^T f(t)\, \cos n\, \frac{2\pi t}{T} dt.$$

$$f''_n = \frac{2}{T}\int_o^T f(t)\, \mathrm{Sen} n\, \frac{2\pi t}{T} dt.$$

Las vibraciones producidas en una máquina por ejemplo el soplador mostrado- en la figura son de carácter complejo y la única particularidad que tiene - es la periodicidad, es decir que si conocemos la forma de la onda y su período podríamos utilizar las relaciones matemáticas arriba anotadas, lo cuál- sería muy complicado para el ingeniero en la práctica.

Es necesario utilizar aparatos que hagan todo éste trabajo engorroso y nos- den la información necesaría para localización de fallas.(Ver diagrama de - block)



UNIDAD SOPLANTE

A.- Transductor.

B.- Preamplificador.

C.- Analizador de frecuencias.

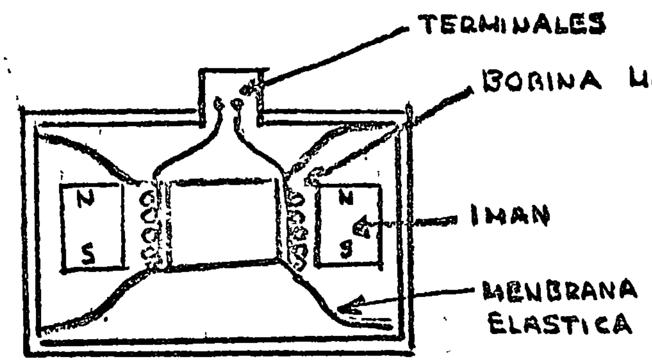
D.- Registrador Gráfico.

El proceso de evaluación con los aparatos mostrados se le llama análisis de vibración.

A.- Transductores: Son los dispositivos que transforman la vibración mecá - nica en señal eléctrica existen en la práctica dos tipos comunes.

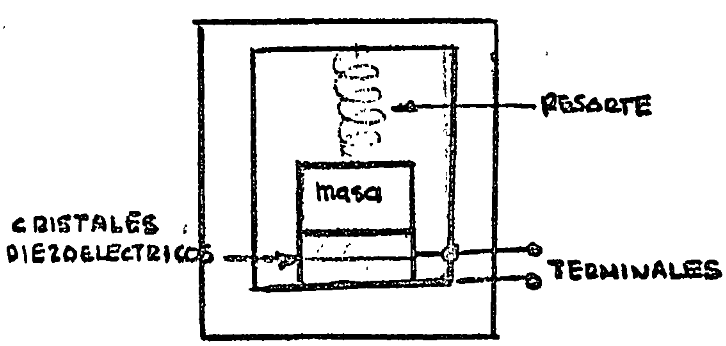
I.- Electrodinámicos.

Los transductores electrodinámicos consisten en una bobina móvil suspendida por membranas de acero que funcionan cómo resorte, la bobina al ser excitada por la vibración se mueve y corta líneas magnéticas de un iman vecino (Principio electrodinámico) y se genera -- un voltage que es proporcional a la velocidad de la vibración, la ventaja de este aparato es que tiene alta sensibilidad pero limitada respuesta de frecuencia no más de 1000 ciclos por segundo, y no soporta altas temperaturas.



2.- Acelerómetro.

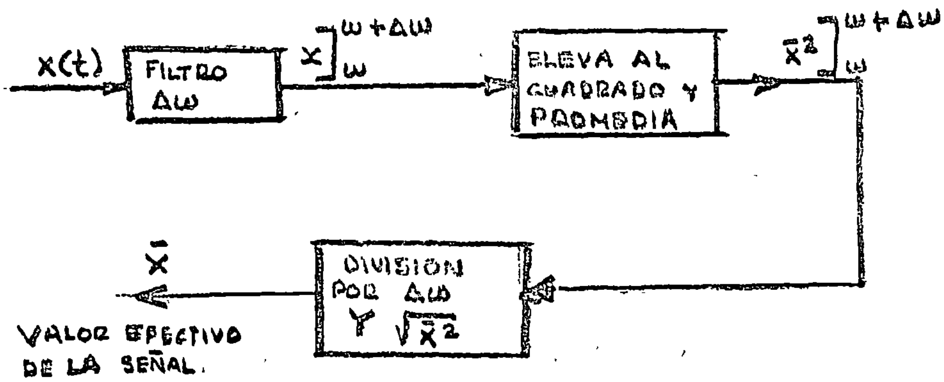
Este dispositivo funciona bajo el principio del cristal Piezo eléctrico que al ser sometidos a presiones y tensiones se genera en las caras del mismo un voltage proporcional a la aceleración y es procesado en un aparato indicador.
Las ventajas de éste dispositivo es de peso ligero soporta altas temperaturas, humedad, y tiene alta respuesta en frecuencia hasta 20,000 ciclos por segundo, la desventaja es que tienen poca sensibilidad y necesitan forsozamente un preamplificador.



B.- Preamplificador: La señal eléctrica de salida del acelerómetro es muy débil y es necesario amplificarla con la minima distorsión posible, recordando que la señal del acelerómetro es proporcional a la aceleración para obtener la velocidad y el desplazamiento de la vibración magnitudes necesarias que dan un panorama más completo de información, es escencial que dicho preamplificador tenga dentro del circuito dos redes-integradoras.

C.- Analizador de Frecuencias: El objetivo principal de este aparato es el-de romper la vibración compleja que viene de la máquina en sus equiva - lentes armónicos en otras palabras, el aparato que substituye y realiza la ardua tarea de resolución matemática de Fourier.

Procedimiento: El aparato contiene los siguientes pasos en el circuito-para procesar la señal.



La señal x(t) de entrada al instrumento pasa por un circuito de fil -- trado de ancho de bamda lo más angosto posible dentro del rango de -- frecuencias $\omega+\Delta\omega$ y procurando no atenuar la señal, después pasa por - un paso que eleva al cuadrado y promedia todas las señales que están - dentro del mismo rango, enseguida pasa por el paso que divide por $\Delta\omega$ - y al mismo tiempo sacando raíz cuadrada para obtener finalmente el va-lor eficaz de la señal, esta puede leerse en indicador o pasar a otro-aparato llamado graficador.

Es necesario observar que existe dos tipos o procedimientos de filtra-do, uno es en el porciento de Banda con relación a la frecuencia cen - tral, que algunos aparatos tienen un rango desde 6 a 29%, estos son -- los más adecuados para realizar análisis de vibración de maquinaria.

El otro tipo de filtrado es el de filtros fijos de rangos en octavas - y tercios de octavas (una octava abarca un lapso de doble frecuencia - por ejemplo una frecuencia de 100 C.P.S. la siguiente octava es de 200 C.P.S.) Este sistema es muy adecuado para medir ruido por contener me-nos frecuencias discretas dentro de su espectro.

D.- Graficador: El registrador gráfico consiste en imprimir la señal en -- papel para su estudio, este debe tener buena sensibilidad y amplio rango de frecuencias.

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COMPENDIO PRACTICO DE ACUSTICA APLICADA.
José Pérez Miñova.

INTRODUCCION A LA TEORIA DE VIBRACIONES MECANICAS.
De F. Lafita Babio, H. Mata Cortés.

INSTRUMENTACION APLICADA A LA EVALUACION DE RUIDOS

N T R O D U C C I O N:

El ambiente moderno tiene frecuentemente actividades generadoras de ruido y transmisoras del medio y las causas más frecuentes del ruido son:

1. Vehículos de motor
2. Instalaciones productoras de ruido (Maquinaria en general)
3. Construcciones
4. Ruidos varios.

Los efectos del ruido determinan no solo fatiga en la audición sino tambien disminución de la eficiencia en el trabajo y trastornos psicológicos - serios. Entre los efectos mas frecuentes del ruido existen los siguientes:

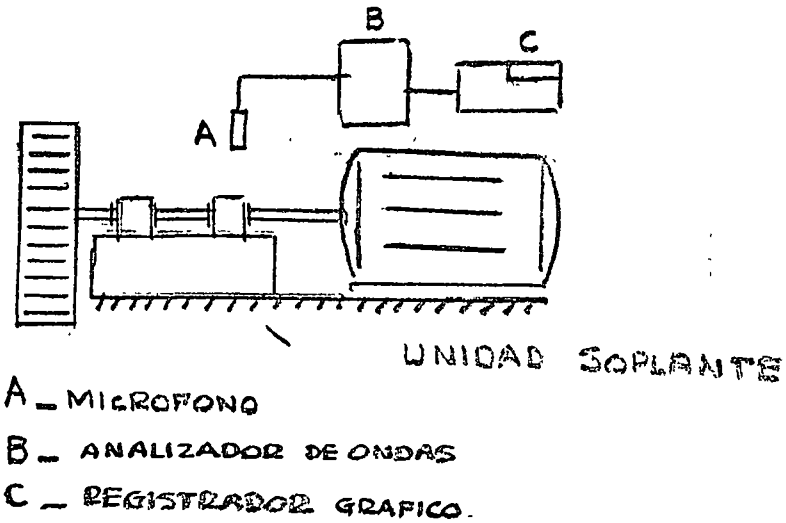
1. Fatiga mental producida por el esfuerzo para percibir correctamente una voz humana o un sonido dentro del ambiente ruidoso.
2. Errores de comunicación así como la interpretación debido a trastornos de la percepción acústica.
3. Alteraciones en el equilibrio psicológico y por consiguiente aumento en la problematica de comunicación humana.
4. Fatiga de las cuerdas vocales debido a la necesidad de hablar fuerte por el ruido ambiental existente.
5. Lesiones auditivas que pueden ser desde mínimas con disminución de la audición hasta máximas y permanentes como la sordera total que puede observarse en personas que están en contacto con ruidos en forma crónica.

D E F I N I C I O N D E R U I D O:

El ruido es un conjunto de sonidos que producen molestia y alteración de la salud en el ser humano. Ejem.:

Cuando un soplador presenta vibraciones violentas, las partes en movimiento actuan como generadores de ruido; pues perturbarán las moléculas de aire vecinas originándose las fuentes de ruido.

Para evaluar las características físicas tales como el nivel de presión sonora (Decibelios) y las **frecuencias** preponderantes del ruido mencionado es necesario utilizar los aparatos descritos en diagrama de block.



M I C R O F O N O S:

El sonido se genera debido a una perturbación, vibración mecánica transmitida a través de un medio gaseoso (aire) un dispositivo capaz de transformar estas oscilaciones mecánicas en oscilaciones de una corriente eléctrica, recibe el nombre de microfono, este dispositivo es el equivalente electroacústico de nuestro organo auditivo (el oído).

Las características que expresan el funcionamiento de un microfono y que determinan su correcta aplicación, son las siguientes:

1. Sensibilidad o rendimiento.
   Queda determinada cuando se conoce la tensión eléctrica producida por unidad de presión acústica recibida. Cuanto mayor sea la tensión eléctrica generada, tanto mayor es la sensibilidad.

2. Curva de respuesta.
   Si para una potencia sonora de recepción fija, se anotan sobre las ordenadas los distintos niveles de salida obtenidos segun las diferentes frecuencias, llevadas sobre el eje de las abscisas, por conveniencia a escala logarítmica, de esta manera se tendrá la curva de respuesta del microfono en cuestión. (ver fig. 1).

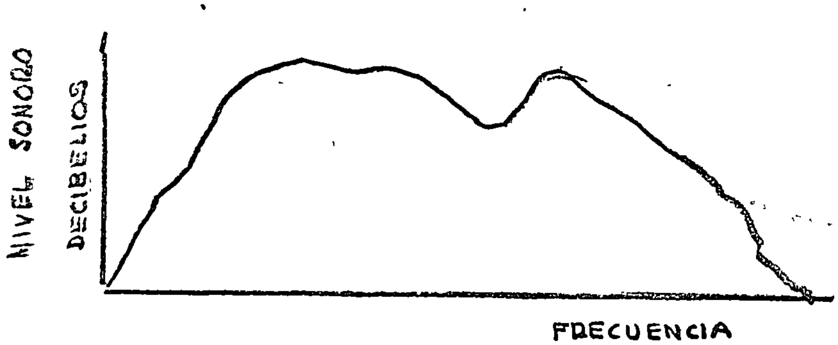


FIG. 1

3.- Fidelidad.

Es la exacta reproducción de todas las frecuencias. La fidelidad supone una curva de respuesta en forma de una recta paralela al eje de abscisas (Resp8esta plana), siendo imposible conseguir en la práctica, como máximo, es posible obtener una curva de respuestas que para ciertas frecuencias tenga variaciones $\pm$ un decibelio considerando este resultado como de gran fidelidad.

4. Distorción.

Cuando la tensión eléctrica de salida de un microfono no reproduce exactamente las frecuencias que registra, sino que las deforma, se dice que existe distorción.

La distorción puede ser de tres tipos:

a) Distorción no lineal. Si a la frecuencia fundamental se le agregan frecuencias extrañas en forma de armónicos de la misma, el sonido inicial quedará convertido en un desarrollo de Fourier:

A_1 Sen w_1 t + A_2 Sen w_2 t + A_3 Sen W_3 t.

El cuarto y quinto armónico y los demás se desprecian por considerarse mínimo su valor.

Se entiende por coeficiente de distorción D La expresión:

$$D=\sqrt{\frac{A_2^2 + A_3^2}{A_1^2}}$$

Cuyo valor indicará la importancia de la distorción, el cual deberá estar dentro de tolerancia.

5. Ruido de Fondo.

Se llama así al sonido propio que tiene todo sistema electroacústico. Aunque el microfono no reciba ningún sonido, genera un pequeño voltaje motivado por el movimiento de electrones como consecuencia del calentamiento del circuito (ruido eléctrico).

Debe tenerse en cuenta que al amplificarse la salida del microfono, el ruido de fondo también será amplificado.

6. Direccionalidad.

La sensibilidad de un microfono varía también según el angulo de incidencia que forma con su eje geométrico el sonido recibido; esta sensibilidad es muy desigual según los diversos tipos de microfono, hay 3 tipos principales: unidireccionales, Bidireccionales y Omnidireccionales.

a) Unidireccionales.

Cómo su nombre lo indica, son los que presentan una diferencia de sensibilidad muy notable en determinada dirección, siendo máxima cuando el foco sonoro se encuentra sobre la prolongación de su eje, decreciendo rápidamente a medida que aumenta el ángulo de incidencia siendo muy pequeña cuándo éste valga 90° y nula (no registrando sonido) cuándo el sonido llegue por la parte posterior del micrófono. La fig. 2 muestra la respuesta de éste tipo de micrófono.

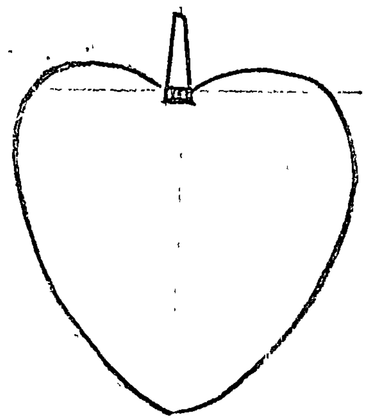


FIG. 2

b) Bidireccionales.

Presentan las anteriores características de direccionalidad por ambas caras, tal cómo indica fig. 3. El micrófono no tiene respuesta en un plano perpendicular al eje de simetria.

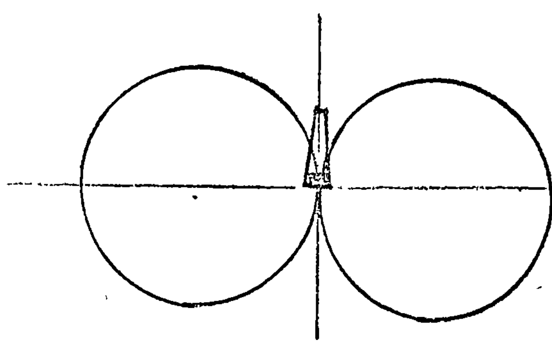


FIG. 3

c) Omnidireccionales.

Presentan una sensibilidad constante cualquiera que sea la dirección por dónde les llegue el sonido. Ver fig. 4

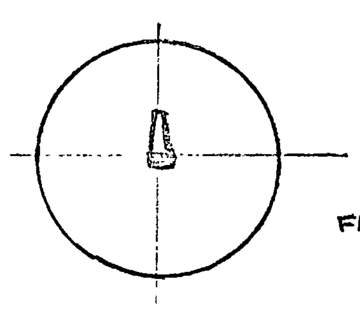


FIG. 4

C L A S I F I C A C I O N D E M I C R O F O N O S.

I. Micrófonos electrostáticos, también llamados de condensador debido a que su funcionamiento se basa en las variaciones de capacidad de un condensador Ver fig. 5

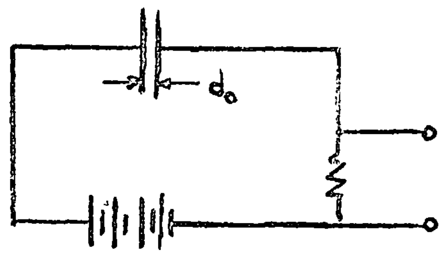


FIG. 5

Fisicamente el micrófono de condensador consiste en una placa fija y la otra movil de un material ligero de Duraluminio que puede vibrar ligeramente de acuerdo con la vibración sonora recibida estas fluctuaciones cambian la capacidad Dielectrica del condensador.
Un estudio más detallado de éste micrófono se centrará en la siguiente figura. 6

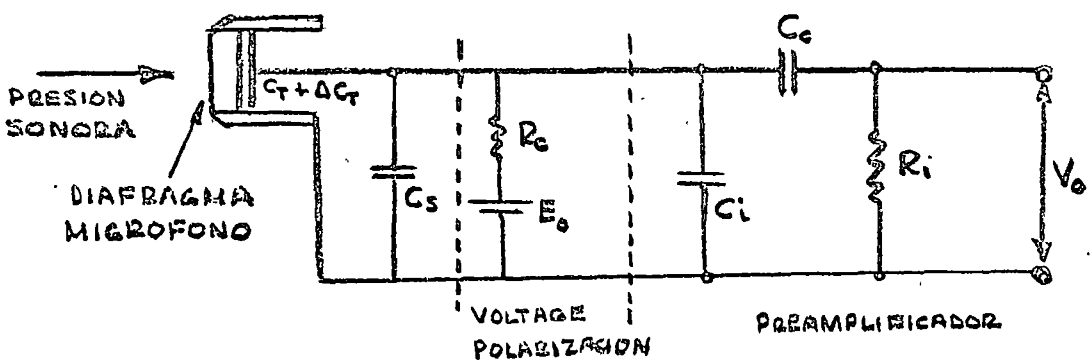


Diagrama de un circuito simplificado de un micrófono de condensador y su preamplificador.
Un micrófono de condensador tiene un valor muy pequeño de capacitancia y requiere la preamplificación cómo es mostrado en fig. 6

$$V_o = \left[\frac{AC\ (t)}{C_t} \right] E_o \cdot \frac{jwRC}{1 + jwRC} \qquad (1)$$

E_o = Voltage de polarización.

C_t = Capacitancia del micrófono.

AC (t) = Variación de capacitancia debido a la presión sonora.

C_s = Capacitancia interna del circuito.

C_c = Capacitancia de acoplamiento.

C_i = Capacitancia de entrada al amplificador.

$C = Ct + C_s + C_i$.

R_c = Resistencia de carga.

R_i = Resistencia entrada al preamplificador.

$R = \frac{Ri\ Rc}{Ri+Rc}$

Pero Cc Mayor que C el cuál puede ser despreciado en el circuito equivalente fig. 7

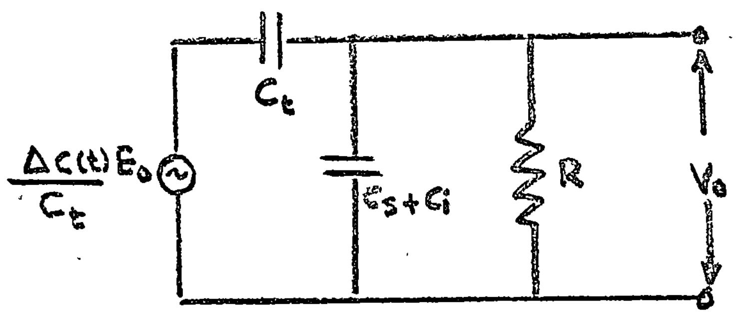


FIG. 7

Circuito equivalente del micrófono de condensador y preamplificador.

De ecuación 1 se observa que el voltage de salida V_o es proporcional a el voltage de polarización E_o pero inversamente proporcional a la capacitancia total C por lo tanto ésta última debe ser de un valor minimo posible, detalle que hace necesario un diseño especial dónde el preamplificador está construido dentro del mismo micrófono.

Conclusión.

Las ventajas del micrófono de condensador es de alta fidelidad y amplia respuesta Ver fig. 8 de frecuencia, unicamente se debe tener cuidado con la humedad y utilizar los micrófonos adecuados para ambientes humedos.

Micrófonos Piezo eléctricos. Conocido es el fenómeno de Piezo electricidad que presenta el Cuarzo, consiste en transformar las presiones y tensiones mecánicas que actuan en cargas eléctricas. La sal de Rochela y la Turmalina poseen también esta propiedad Ver fig.9

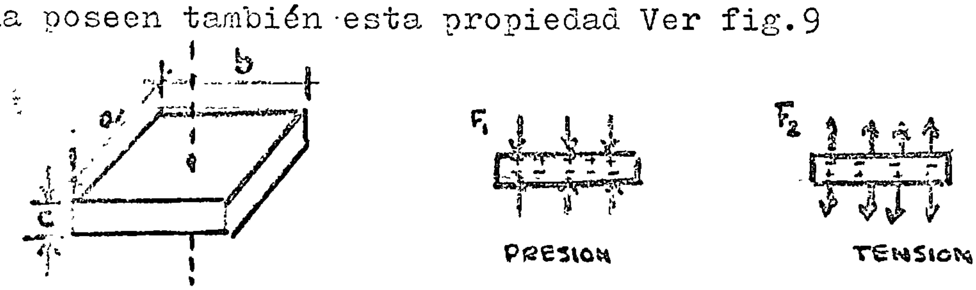


Fig. 8 y 9

Un dispositivo dotado con un cristal de cualquiera de estos elementos , sera capaz de transformar las presiones que recibe en potenciales elec - tricos. La pieza sustancial será, por tanto, un cristal Piezo eléctrico, a este tipo de micrófonos también se les llama de cristal.

Si en la fig. 9 el cristal es de cuarzo y si se aplica una fuerza de com- presión F. La presión unitaria será de $\frac{F_1}{a \times b}$ y la cantidad de electricidad culombs. que aparecerá en sus caras será $Q_1 = \frac{F_1}{a \times b} \cdot K\, a \times b = KF_1$ siendo K la constante Piezo eléctrica del cristal.

Si se aplica una tensión F_2 al cristal la cantidad de electricidad será - $Q_2 = F_2 K$ pero los signos de las cargas tendrán signos opuestos.

La fig. IO muestra un esquema de un micrófono de cristal.

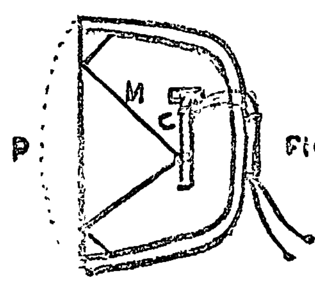
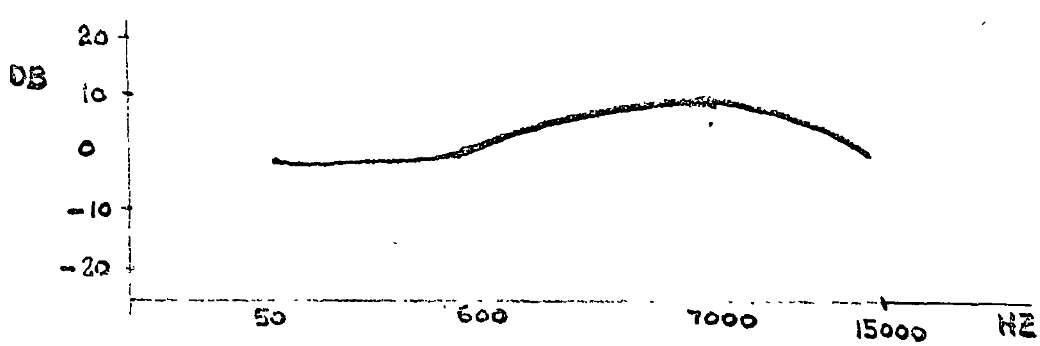


FIG. 10

Microfon de cristal que consiste protección P membrana M y cristal C, la presión sonora incide sobre la membrana y esta comunica el movimiento me- cánico al cristal generando una señal eléctrica.

Los micrófonos de cristal no son de buena calidad y tienen pobre respues- ta de frecuencia Ver fig. II



Curva de respuesta de un micrófono de crital Roselson.

FIG. 11

Atte. Ing. Miguel Medina Villanueva.

#73-193

Background Noise Study in Chicago

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DEPARTMENT OF ENVIRONMENTAL CONTROL

CITY OF CHICAGO

BACKGROUND NOISE STUDY IN CHICAGO

by C. Coccavari and H. Schechter

Outdoor noise levels in large metropolitan areas are a complex mixture of noise from transportation, factories, machines, and people. An effective noise abatement program is difficult to establish without a knowledge of the types of noises, the level or intensity of the noise, the characteristics of the noise, the time of day of the occurrence and, lastly, the activity or area where the noises are produced. All of these factors will govern the emphasis and direction of urban noise abatement programs.

Even with a knowledge of the many variables which can subjectively affect the reactions to noise, a simple, straightforward measurement and analysis technique is not readily available to the concerned environmentalist. Methods of isolating individual sources in composite noise levels are difficult, tedious and often not accurate in predicting subjective reactions to changes in urban noise levels.

The Chicago Department of Environmental Control has begun a program to establish "baseline noise" levels within the City of Chicago. The technique which has been adopted is one which is currently in use in both the United States and Europe. The procedure provides a 24 hour noise signature in dB(A) at each preselected location and also can be expanded to depict a statistical plot of the noise for every 15 minutes of the 24 hour period. A more detailed discussion of the procedure and presentation of data will be covered later on in this paper.

Briefly, it should be stated that the data findings were valuable to the Department of ıvironmental Control for several reasons:

1) The data clearly presents the variation in dB(A) levels over a typical 24 hour period.

2) It indicates the maximum noise levels that occur and the time of day they occur.

3) It provides a comparison of background noise levels within the city, e.g., manufacturing, business, commercial, and residential districts.

4) It relates the types of noise to zoning areas within the city.

5) Most important - they establish "baseline" reference levels for future comparison in evaluation or judgment of noise abatement goals.

6) It provides an evaluation of urban noise monitoring systems.

7) The background noise levels can be utilized for the prediction of building occupant acceptancy.

The results of the study have confirmed several major points concerning noise in an ban setting.

First, the major source of noise and the dominating factor in affecting community back- ound noise levels are transportation noises, e.g., trucks, autos, trains, rapid transit, buses, rcraft, and motorcycles. Only in isolated instances do other sources dominate the urban ise level.

Second, it was learned that the background noise level in certain areas of the city never crease to the property line noise restrictions as set forth by the Chicago noise ordinance. An ample of this is the downtown district. At 3:00 am (which is the quietest period during the hours) the background noise decreased to 63 dB(A). The noise ordinance requires all tionary sources on buildings to be limited to 62 dB(A) at the property line in business or mmercial districts. Obviously, enforcement of the ordinance would be difficult in these eas due to the masking effect of background noise.

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The sources of background noise in the downtown area varies 13 decibels over the 24 hour period. During the day local traffic such as cars and buses dictates noise levels. However, at night the noises reaching the loop are from distance expressway traffic several blocks away.

Third, the background noise level in residential districts can decrease to as low as 40 dB(A) at night. Due to the many major expressways and arterial streets in Chicago, it was anticipated that higher nighttime levels would be recorded in residential districts. However, test data substantiate that quiet residential areas are a reality in a large metropolitan city such as Chicago.

A complete noise inventory of the City of Chicago would prove costly and involve many man-hours. At the present time, it is felt that the random selection of typical community areas are adequately represented by this study. In the future, as new, simpler, more accurate measurement sampling techniques are developed, they can be utilized to expand a program of this type. For the present this study does provide the type of information needed to evaluate and aid in directing the current noise abatement program in the City of Chicago.

INSTRUMENTATION AND DATA ANALYSIS

Instrumentation selected for any measurement program must have the flexibility of being apable of extending over a preset as well as wide range of interest. In the case of the baseline" survey, the equipment chosen had to be capable of achieving the following:

1) A constant 24 hour operation without breakdown.

2) A power supply (120 volt AC) as well as battery operation in low voltage or remote areas.

3) Be light enough to carry into buildings or onto sites where the flexibility of the equipment may be well tested.

4) Be able to separate transducer from main body of equipment through use of interconnecting cable. This tends to put less strain on criterion number 3 above.

5) Accurate measurements to within one-half dB with minimum 50 dB dynamic range so that further analysis of the data will achieve an accurate picture of the noise levels in each area.

6) The measurement system should be compatible with other community surveys to provide comparative results.

Other factors which enter into selection were availability and maintenance of the equipment as well as the cost of such instrumentation.

Ideally a complete eight channel transducer system would have been preferable such that octave band (63 Hz to 4000 Hz) as well as weighted scale readouts could be achieved simultaneously. Due to cost as well as physical non-reliability, the department settled for a single readout setup with the noise picture presenting an A-weighted characteristic of the ambient level in each location.

As such the available equipment included the following:

1) Bruel and Kjaer 2204 Sound Level Meter (SLM).

2) One hundred foot cable to interconnect above with 1" B & K Condensor Microphone mounted on a six foot long pole.

3) Power supply for above to be used wherever AC power is readily available. It should be noted that where battery operation is necessary, the batteries must be changed every six hours.

4) Bruel and Kjaer Graphic Level Recorder.

5) Bruel and Kjaer 4420 Statistical Distribution Analyzer.

6) For complete portable locations a power inverted system taken off a Dodge van could be used.

It should be noted that whenever such portable AC generating equipment is used, the internal noise output of such apparatus must be below the lowest ambient level recorded during the 24 hour period as measured at the microphone location.

The noise evaluations were then designed to incorporate the above equipment in such a manner to provide useful and accurate data over a preselected scope of the program.

A block diagram of the instrumentation system is shown (Figure 1).

The transducer and pole combination was positioned so that a typical ambient field for each site would be "seen" by the microphone. This was achieved by use of the six foot pole to position the microphone as far as possible from reflecting surfaces such as building walls, or the ground below.

Other factors pertinent to choosing the proper microphone position on a site were:

1. Ascertaining the lack of steady noise sources inherent to the building wherein the test equipment was located. This was to insure that the microphone "heard" the entire neighborhood sound field and not just a single source.

2. Attaining proper height for the microphone from the ground in order to be assured that any nearby street traffic (either expressway or smaller arterial) would have typical acoustic access to the transducer.

3. Last and, perhaps, most important attaining a position for the microphone in order that curiosity seekers would neither be tempted nor persuaded to "get themselves taped".

Upon achieving proper microphone positioning, the transducer "package" is then connected to the recording system. A preliminary check of ambient level will usually reveal what dB range to choose on the SLM so the peak level will not overload the top line on the chart recorder. Once proper dynamic range is achieved, the study should progress smoothly for the following 24 hour period except for the recording of the distributed sound pressure level counts from the B & K 4420 statistical distribution analyzer.

The Department of Environmental Control noise section chose the fastest possible sampling rate with a 10,000 count duration for its 24 hour studies. This assured a sampling of sound intensity every 18 minutes with the ability to divide the counts into the 60 dB dynamic range in five dB increments (one 5 dB increment for each of the 12 counters). Starting times for each 18 minute segment were recorded above the 12 counter readout in each column of the data sheets.

The foregoing data was analyzed using a Wang 7000 Minicomputer. The 12 counter readouts for each 18 minute period were fed into this computer and through use of statistically oriented programs, the mean dB level of each sampled period would be fed to a typewritten printout device. The standard distribution was similarly printed and through use of the formula $L_{10}-L_{90}=2.56 \times$ (standard deviation) the L_{10}, L_{50}, L_{90} loudness levels were achieved.

It must be noted that L_{10} as well as in one instance L_1 levels had to be estimated due to the fact that a 10,000 count was chosen for the period selection; such "guesswork" was not as difficult as one might expect. For future analyses, a more elaborate computer system could be used which might use actual counting techniques to achieve automatic readout of L_1, L_{10}, L_{50}, L_{90} and L_{99} levels. The Wang 7000 does not have adequate "core space" for such a program but minicomputers with 8,000 bit capacity are available and future studies may make use of the larger unit.

SITE SELECTION AND DATA PRESENTATION

Since the planned noise inventory in the City of Chicago was limited by cost and ersonnel, the selection of acceptable measurement sites was critical. Several basic guidenes were set forth to provide a spectrum of sites which were typical of urban settings; sites hich would not have a noise problem unique to only a few residents. The purpose of this riteria was to obtain noise data during the test which was unaffected by the single air onditioner, exhaust fan or other mechanical equipment, the level of which would not change uring a 24 hour period.

Rather the sites were selected to be representative of a typical residential, business or ommercial, or manufacturing district. Sites were selected in proximity to major expressways nd also representative of communities distant from expressway systems to provide a broad omparison on the effects of expressway noise on urban areas at all hours of the day.

Other practical considerations limited the site selection because each location required AC power for the measurement equipment and in some cases housing for observers working on he program. Table II lists the sites utilized for the study and the zoning boundary in which t was situated.

Twelve sites were used for the study; six in residential districts, three in business or commercial districts, and three in manufacturing districts. The sites are tabulated Table 1 o present the actual locations in the city, the zone in which it is situated, and the traffic conditions on streets closest to the measurement location. Only the highest and lowest raffic volumes are presented. The maximum traffic conditions exist between 7 and 9 a.m. and between 5 and 7 p.m.

RESIDENTIAL DISTRICTS

A wide variety of urban conditions was selected in our range of measurements within residential districts.

a) The first residential district selected was in a triangular residential area with a railroad switchyard forming one side of the triangle. On the second side was a railroad paralleled by an elevated expressway, and the last side was three blocks from a main arterial street (Figure 2).

Figure 3 presents the measurements recorded over the 24 hour period. The top curve is a continuous readout of the noise on the graphic level recorder for the 24 hour period. An obvious characteristic of this type of environment is the narrow range of the noise over the 24 hour period (approximately 6 dB). The noise level actually never went below 59 dB(A) at any time during the measurement period. It should be mentioned that the Chicago noise ordinance limits noise from stationary sources to below 55 dB(A) at the lot line. Enforcement of the city noise ordinance would be very difficult in this area.

b) The second area selected was within 125 feet of a residential district on one boundary and well displaced from main arterial streets (one-fourth mile from a railroad switchyard and manufacturing district (Figure 4)). The data shown on Figure 5 indicates noise levels approximately 10 decibels below that shown in the previous test. This indicates the strong influence of expressway noise on urban background noise. Although the predominant noise in this residential area was due to traffic noise, it was much more distant and at lower speeds.

c) The next location was very similar in characteristics to the previous test with one major exception - a heavy trafficked street was within 600 feet of the single family dwelling (Figure 6).

The effects of the roadway are noticeable on the graph (Figure 7). The data in this case indicates that 50% of the noise is above 53 decibels. Again enforcement of the noise ordinance would be difficult.

d) The last residential survey we will present was conducted in an area far removed as possible from main arterial streets in a city as populated as Chicago (Figure 8). Note on the figure that the home is surrounded by residences, an elementary school, and several parks. This area proved to be the quietest district during the total study. Noise levels dropped to 40 decibels between 10 p.m. and 4 a.m. This indicates that even in a large metropolitan area, quiet can be accomplished (Figure 9).

The final graph presented represents a composite curve of the residential community to indicate the range of background noises which can be found in highly populated urban communities (Figure 10). The spread of the field test data is approximately 10 dB as compiled from six locations. Later in the report the data will be compared to measurementd made in other residential areas.

BUSINESS AND COMMERCIAL DISTRICTS

The second category of measurements included business and commercial districts. Three of these tests will be presented.

a) The survey would not be complete without noise measurements taken at the corner of one of the busiest streets in Chicago - State and Madison (Figure 11). The noise levels for 50% of the time were above 63 dB(A) even during the Loop's quietest hour - 3 a.m. (Figure 12). Daytime levels reached 75 to 77 dB(A) during peak traffic conditions. During the night the back ground noise in the downtown district was dominated by an expressway one-half mile west of the microphone location. At this location the noise ordinance limits stationary sources to 62 dB(A). Again enforcement on building mechanical equipment would be difficult.

This set of curves includes an evaluation of the L_1, or the level above which the noise was exceeded for 1% of the time during the 24 hour period. The additional analysis was comple to determine one aspect of the effectiveness of our noise enforcement program. Namely, the cur ing of horn blowing in the downtown district. This is accomplished by repeating the 24 hour survey a second time a year later.

Data from the second test completed a year later at State and Madison Streets is shown fo comparison in Figure 13. It indicates a negligible change in the L_{10}, L_{50} and 90 curve. Yet L_1 curve (Figure 14) reveals approximately a five dB decrease for most of the 24 hour period. Th change can be attributed to the noticeable reduction in horn blowing offenders in the downtown district.

b) The second commercial or business district selected for the measument was on the outskirts of the downtown district (Figure 15). The major noise sources in this area are street traffic on Wacker Drive and the elevated on Wells Street. The data (L_{50}) varied over a 13 dB range during the 24 hour period (figure 16). The lowest level reached (2:00 am) was 60 dB(A). The peak level occurred at 8:00 am. The river adjacent to the site provided an open path for noise to reach the microphone.

c) The last business district to be discussed was selected because area residents indicated that large truck volumes utilized Pulaski Road (Figure 17). The data corresponds to the previous two business studies with very little variation. A composite graph is presented to indicate the range of noise measured in the various business districts (Figure 18).

MANUFACTURING DISTRICTS

The last test series included noise measurements recorded in manufacturing areas-both of which were situated within one-half mile of a major expressway. The individual plots are not presented since there was very little deviation between the two sets of data. Rather a plot of the range of the noise is presented (Figure 19). Note the slight spread between the two sets of data as well as the almost flat response of the noise over the 24 hour period. The distant express-ways serve as a uniform line source throughout the measurement session.

CONCLUSION AND SUMMARY

A "baseline" noise study is essential to a community embarking on a noise abatement program. The study can provide the needed guidelines to set up and direct the program toward the more serious noise sources. Later as the program is developed, the information can be used to evaluate the effectiveness of the program.

One of the major concerns with an urban noise study is that the data can be related to other communities of equal or smaller size. Other noise studies were reviewed to provide comparative data for evaluating the effectiveness, predictability, and relationships to other surveys. A 24 hour study conducted in Medford, Massachusetts* provided useful noise measurements in residential districts and in areas adjacent to major expressways. The range of background noise in Chicago has been compared to the "quiet" Massachusetts area and compared with the lower range of background noise in Chicago residential district (figure 20). The relationship between the two curves is within one or two decibels for most of the 24 hour day. The variations occur during early morning "rush hour" traffic conditions when the Chicago noise levels are slightly higher.

A comparison of the upper limit of residential background noise levels indicate a greater deviation between the two studies both related to expressway noise. The noise levels in Chicago are due to the Chicago skyway which is heavily trafficked at an elevation above 40 to 50 feet above the dwellings with no acoustical shielding. Therefore we would expect a more serious and noisy situation.

*"Community Sound Levels (A Comparison of Measured and Estimated Data)" by Harvey B. Safeer, July, 1971.

Although the current program as discussed does not encompass the total city, it provided valuable insight into the direction and needs of the urban dweller to achieve a t environment. The study has brought out several important aspects of noise and rcement.

1. It conclusively proves that transportation noise dominates our daily outdoor life.
2. Maximum background noise levels in an urban area occur during morning and evening traffic rush hours.
3. Minimum background noise levels occur during the night between 2:00 a.m. and 3:00 a.m.
4. Background noise levels in residential districts in a large metropolitan area can decrease to 35-40 dB(A) during nighttime hours.
5. Typical background level representing the various zoning districts were obtained which will be useful for future studies. Such data can be effective in dictating the type of exterior wall construction necessary to meet occupant acceptancy due to the background noise.
6. Last, it provides a valuable tool in determining the effectiveness of an enforcement program.

We realize that the study does not provide all of the answers to the many complex noise ations which can exist in an urban area. It is a beginning. A goal cannot be reached without tart. Chicago has begun, and with education and cooperation of the people we should dually realize decreases in urban noise from all sources.

ACKNOWLEDGMENTS

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TABLE 1

TRAFFIC AND ZONING CHARACTERISTICS
OF 24 HOUR MEASUREMENT SITES

ADDRESS	ZONE	TRAFFIC PEAK	TRAFFIC LOW
1. 2100 S. Jefferson	M2	—	—
2. 5000 N. Kimberly	M1	—	—
3. 3332 S. Emerald	R	879 @ 5-6pm	10 @ 2-3 am
4. 2624 E. 94th Street	R	1954 @ 5-6 pm	—
5. 7410 N. Talman	R	184 @ 2-3 pm	1 @ 2-3 am
6. 6500 S. Kilpatrick	R	431 @ 5-6 pm	2 @ 3-5 am
7. 1340 W. Morse Ave.	R	3018 @ 5-6 pm	—
8. 6100 N. Sheridan Rd.	R	4974 @ 8-9 am	—
9. 5500 N. Sheridan Rd.	R	2377 @ 5-6 pm	—
10. 3950 W. Jackson Blvd.	B	2523 @ 5-6 pm	—
11. 325 N. Wells St.	B	3358 @ 2-3 pm	—
12. State & Madison Sts.	B	1365 @ 8-9 am	146 @ 3-4 am

(B & K = Bruel & Kjaer)

A. B & K Type 4145 Condenser Microphone
B. B & K Type UA 1096 Gooseneck Preamp
C. B & K Type 2204 Sound Level Meter
D. B & K Type 2305 Graphic Level Recorder
E. B & K Type 4420 Statistical Distributor Analyzer
F. B & K Type F6-220 3/4 A.C. to D.C. power supply
G. B & K Type AU-0029 100ft. cable
H. B & K Type 4220 Pistonphone Calibrator

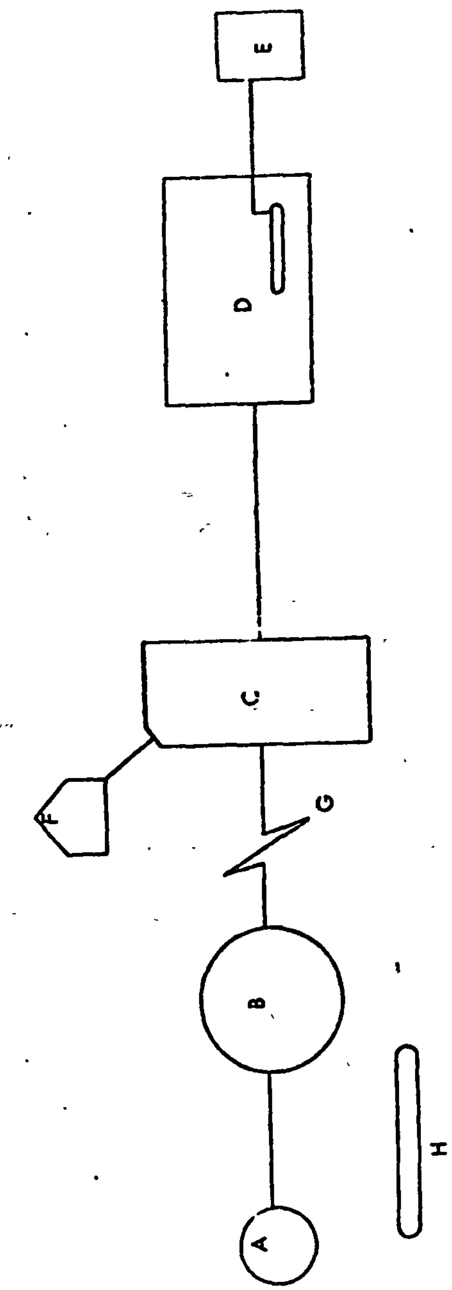


Fig. 1 BLOCK DIAGRAM OF MEASUREMENT INSTRUMENTATION FOR 24-HOUR NOISE STUDY

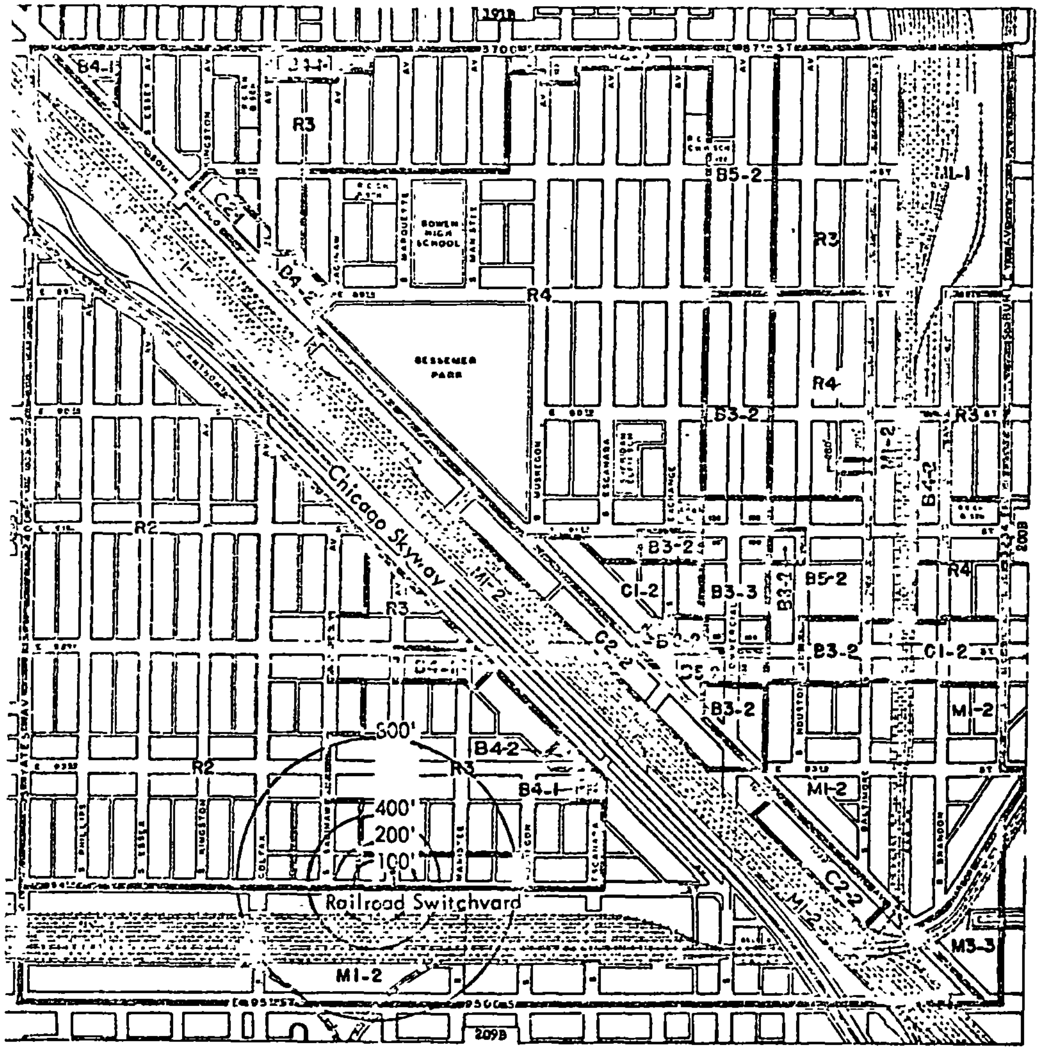
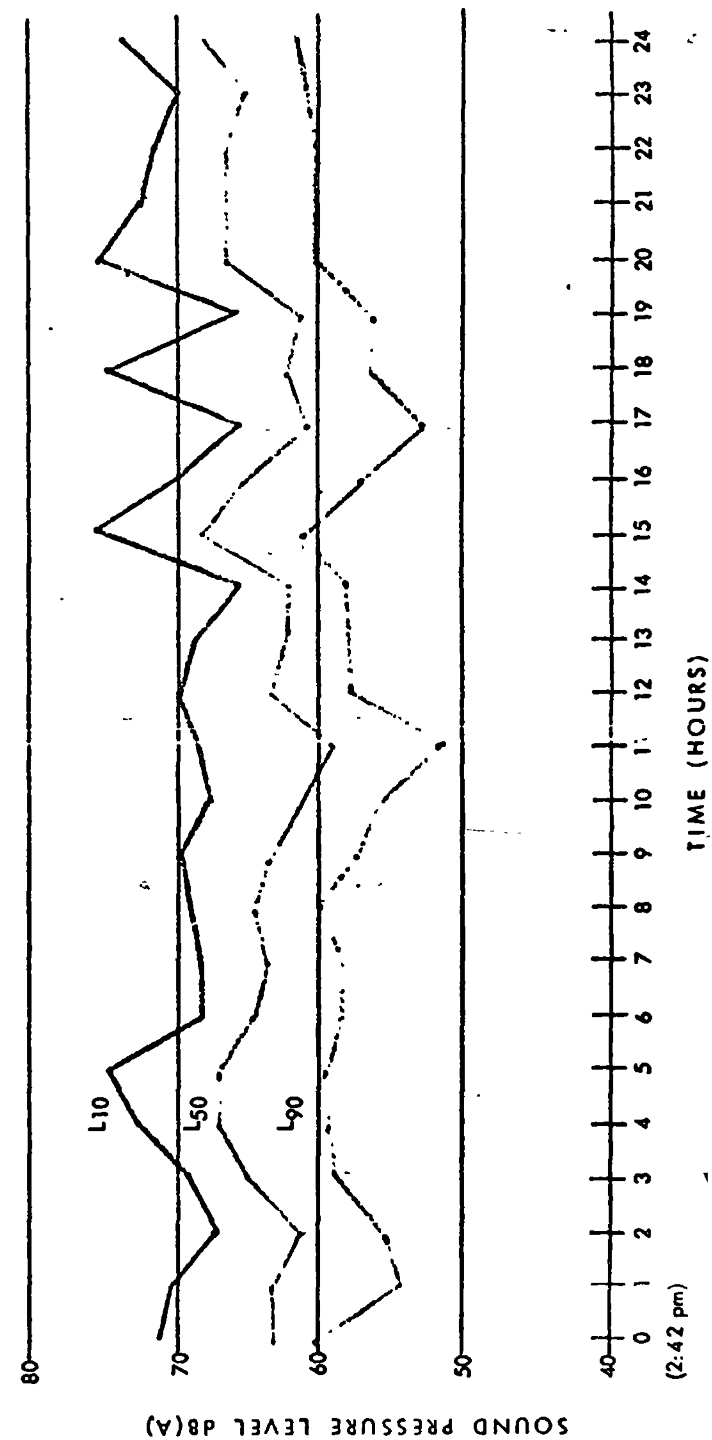
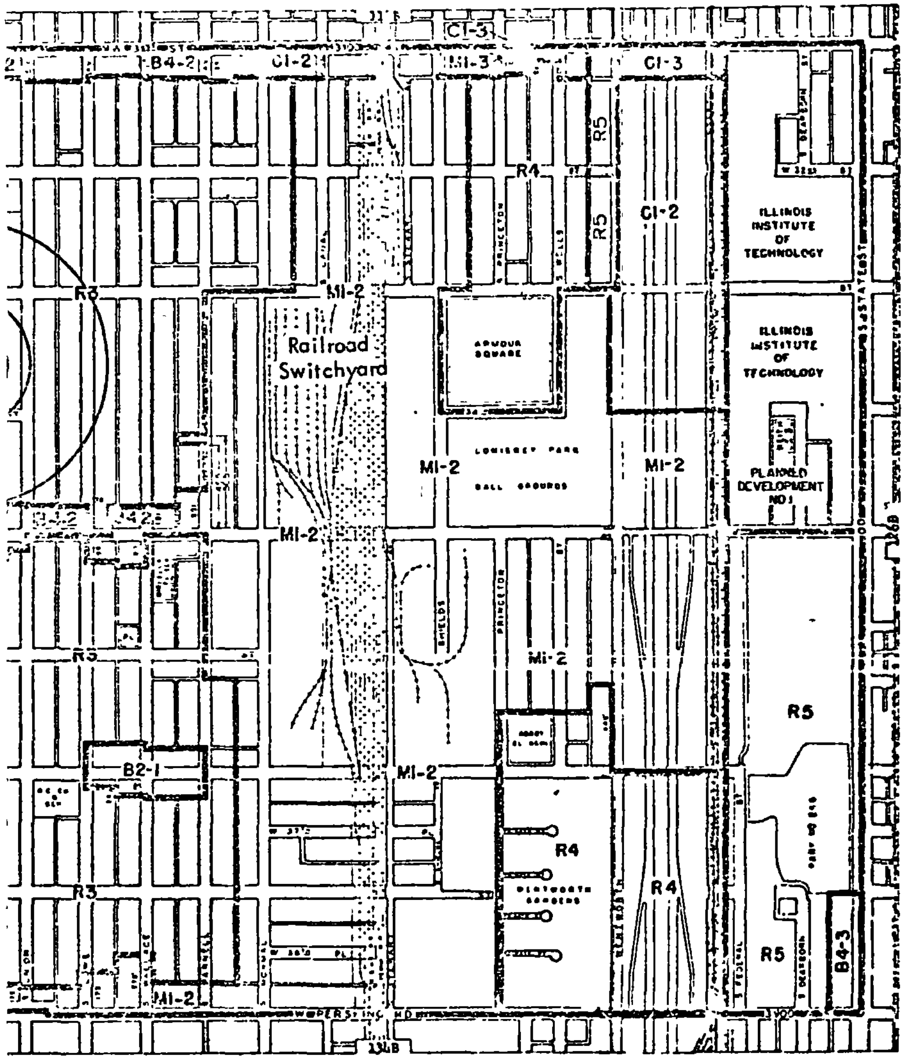


Fig. 2. MICROPHONE LOCATION IN RESIDENTIAL DISTRICT AT 2662 EAST 94th STREET



73-193



MICROPHONE LOCATION IN RESIDENTIAL DISTRICT AT 3332 S. EMERALD AVENUE

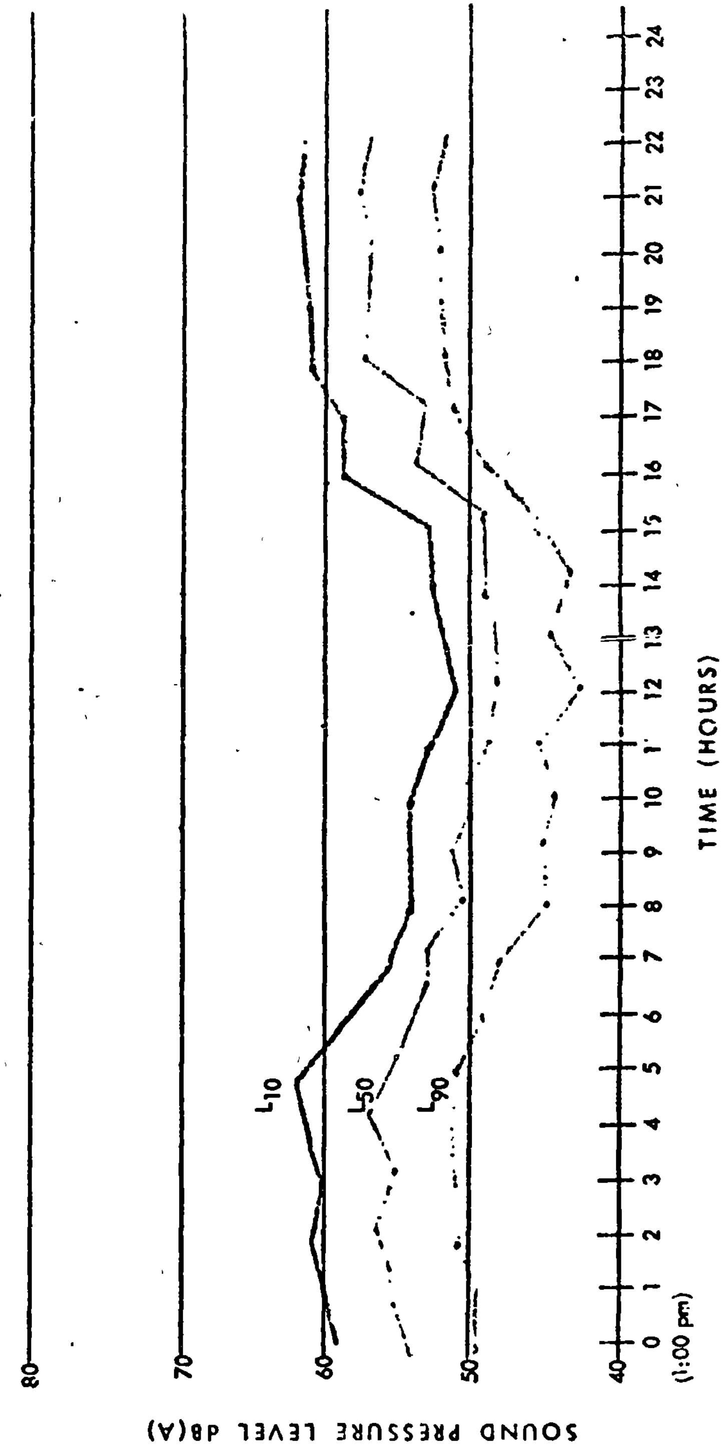


Fig. 5 BREAKDOWN OF BACKGROUND NOISE LEVELS IN A RESIDENTIAL DISTRICT. (33rd & EMERALD) MAY 1-2, 1972

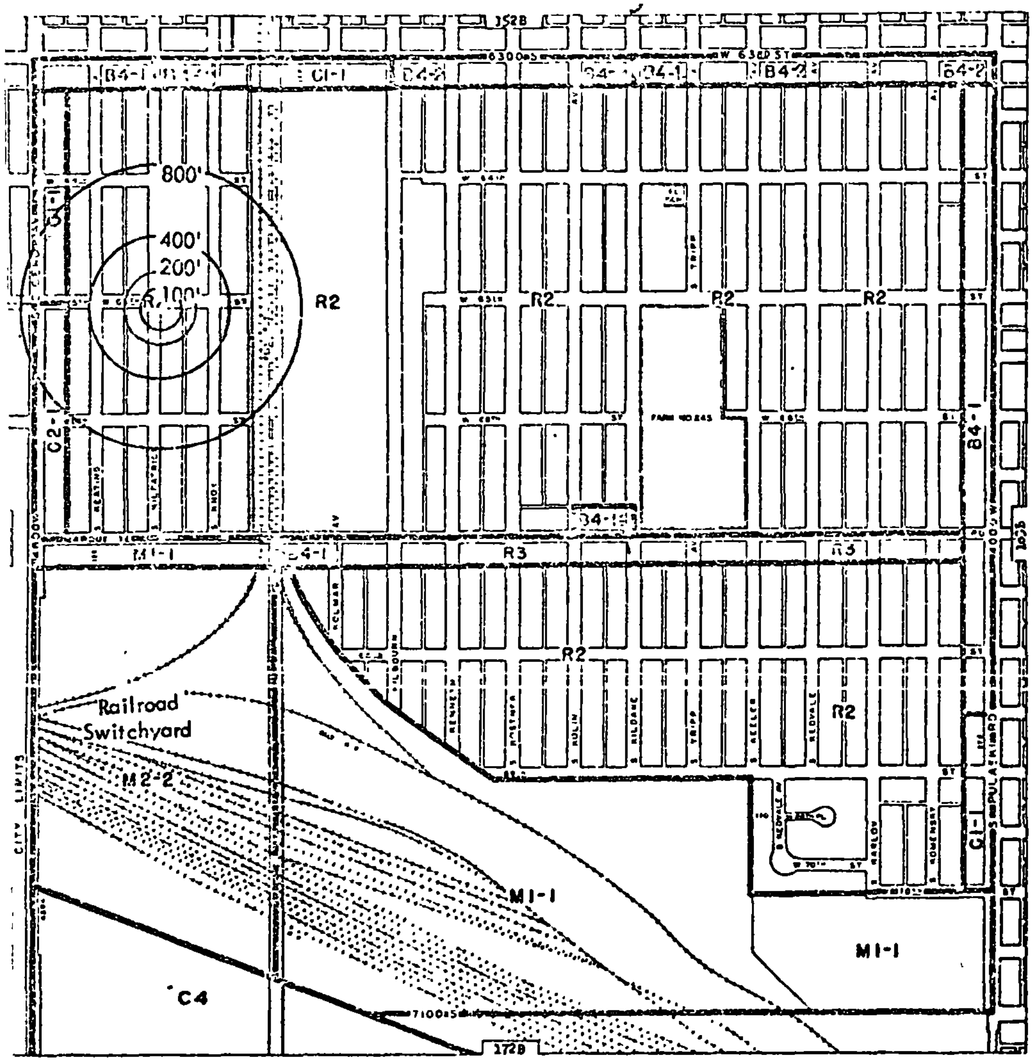
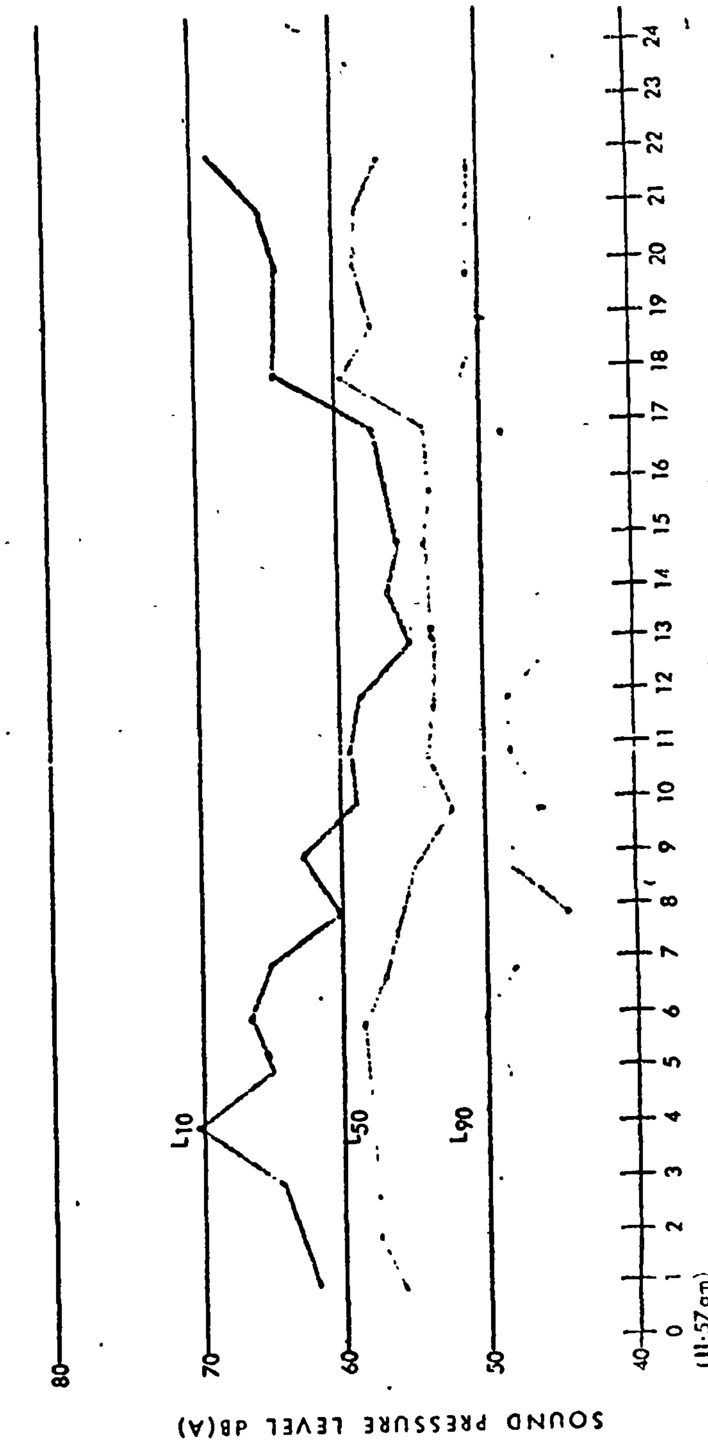
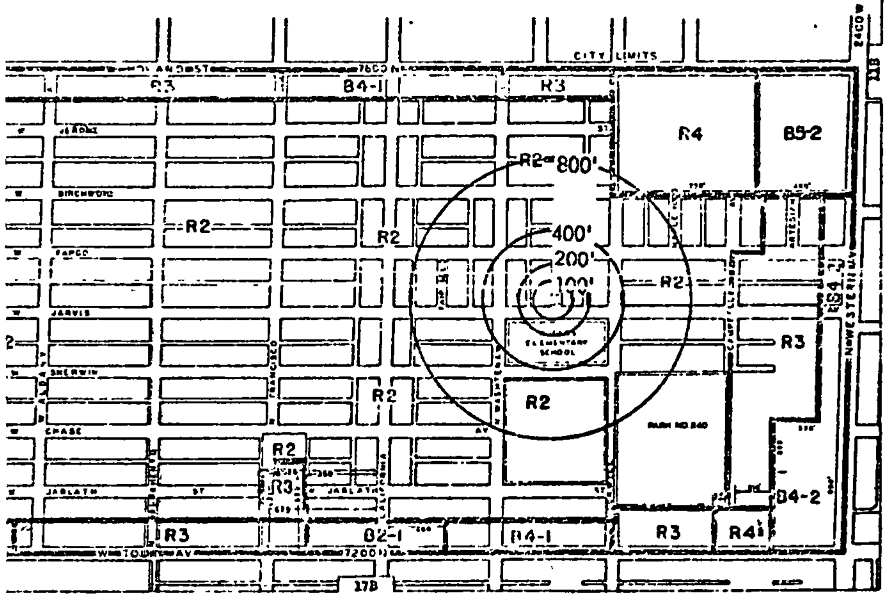


Fig. 6. MICROPHONE LOCATION IN RESIDENTIAL DISTRICT AT 6500 S. KILPATRICK AVENUE





CROPHONE LOCATION IN RESIDENTIAL DISTRICT AT
6 N. TALMAN AVENUE

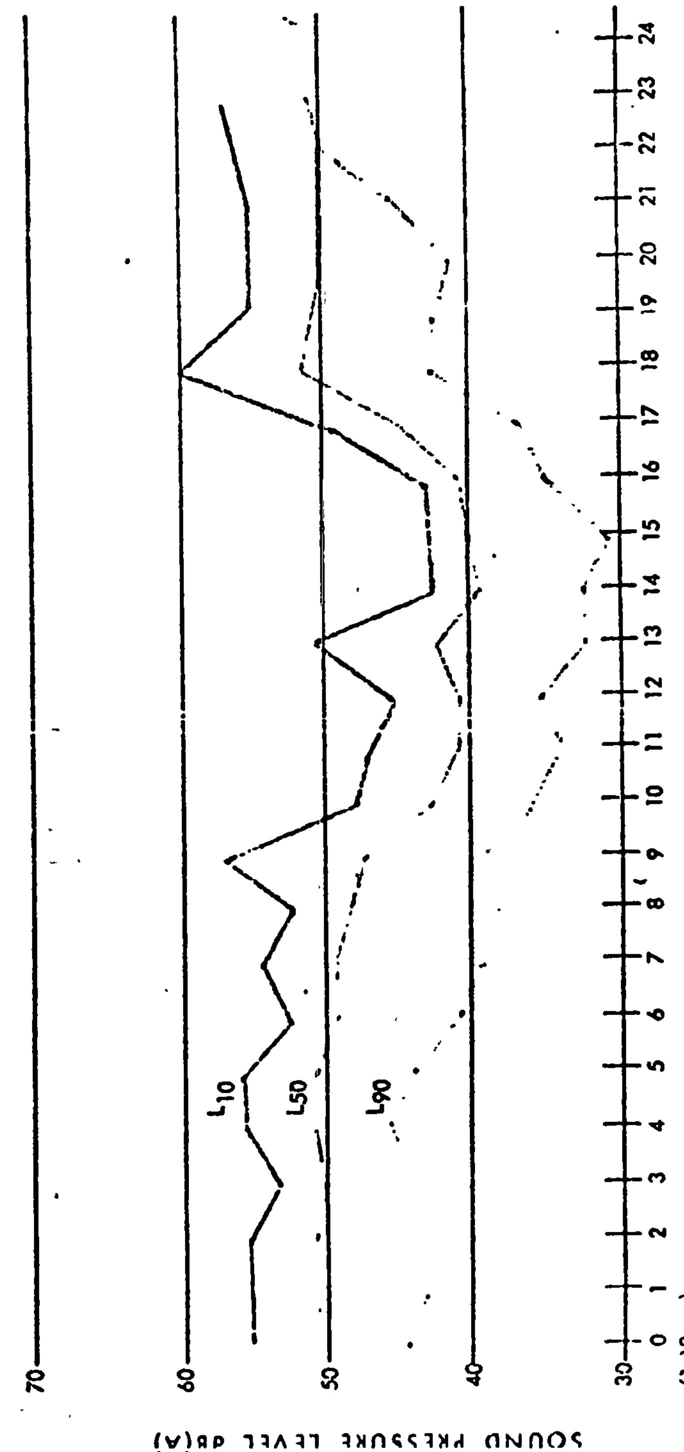


Fig. 9 BREAKDOWN OF NOISE LEVELS IN A RESIDENTIAL DISTRICT. (9400 N. TALMAN) DECEMBER 21-22, 1971

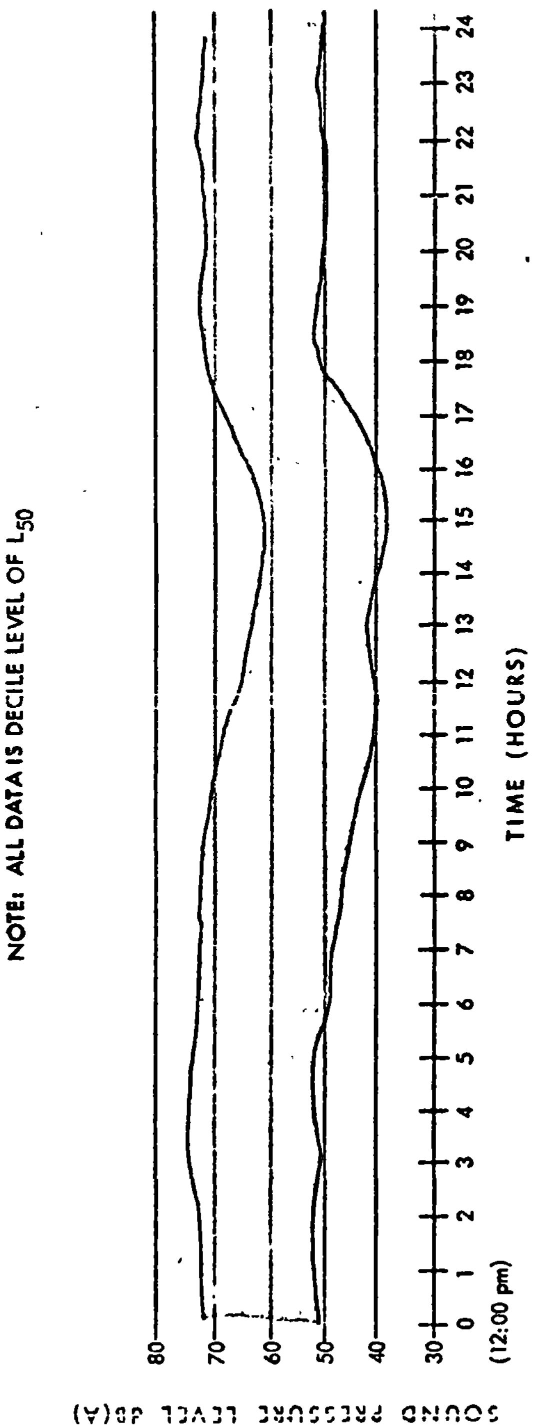


Fig. 10 RANGE OF BACKGROUND NOISE LEVELS IN RESIDENTIAL DISTRICTS. (1971-1972)

73-193

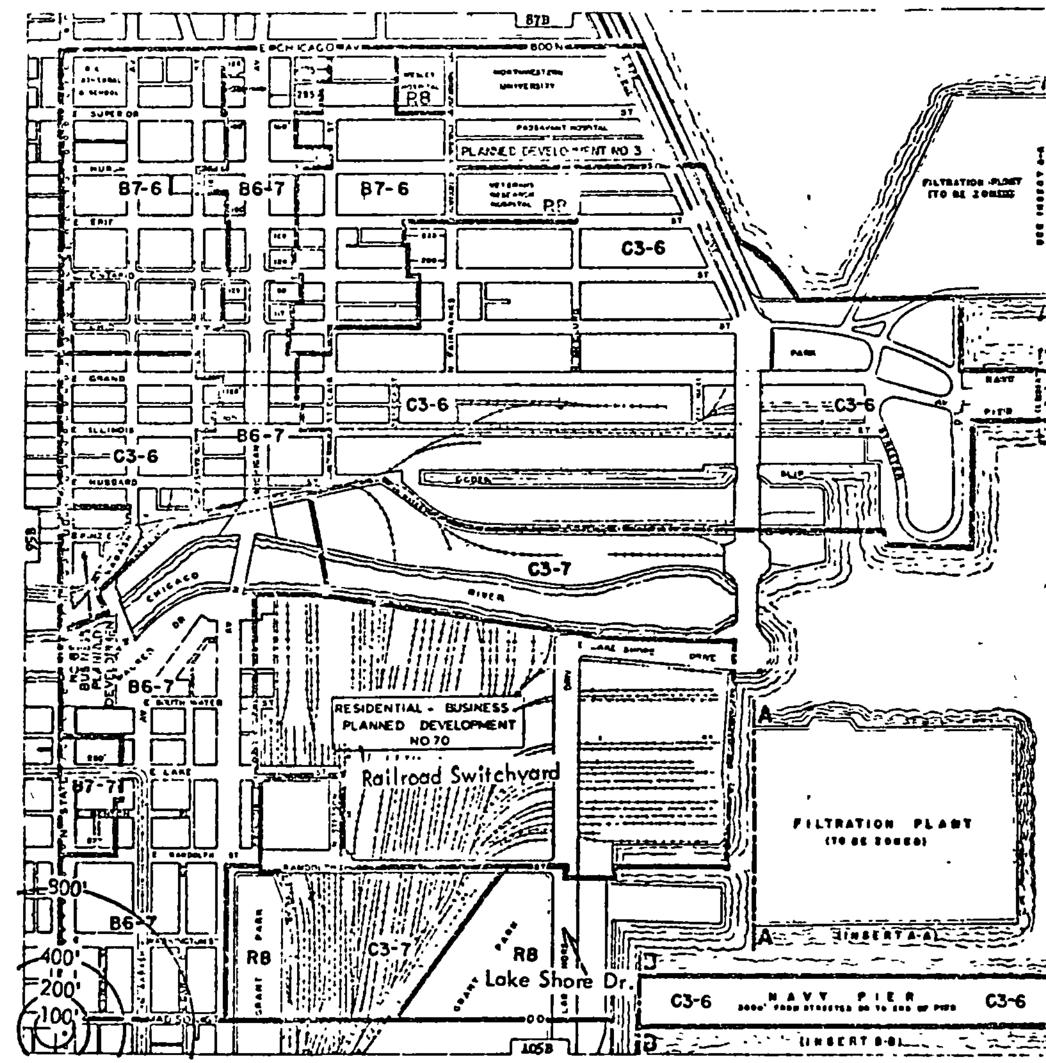


Fig. 11. MICROPHONE LOCATION IN BUSINESS DISTRICT AT CORNER OF STATE & MADISON STREETS

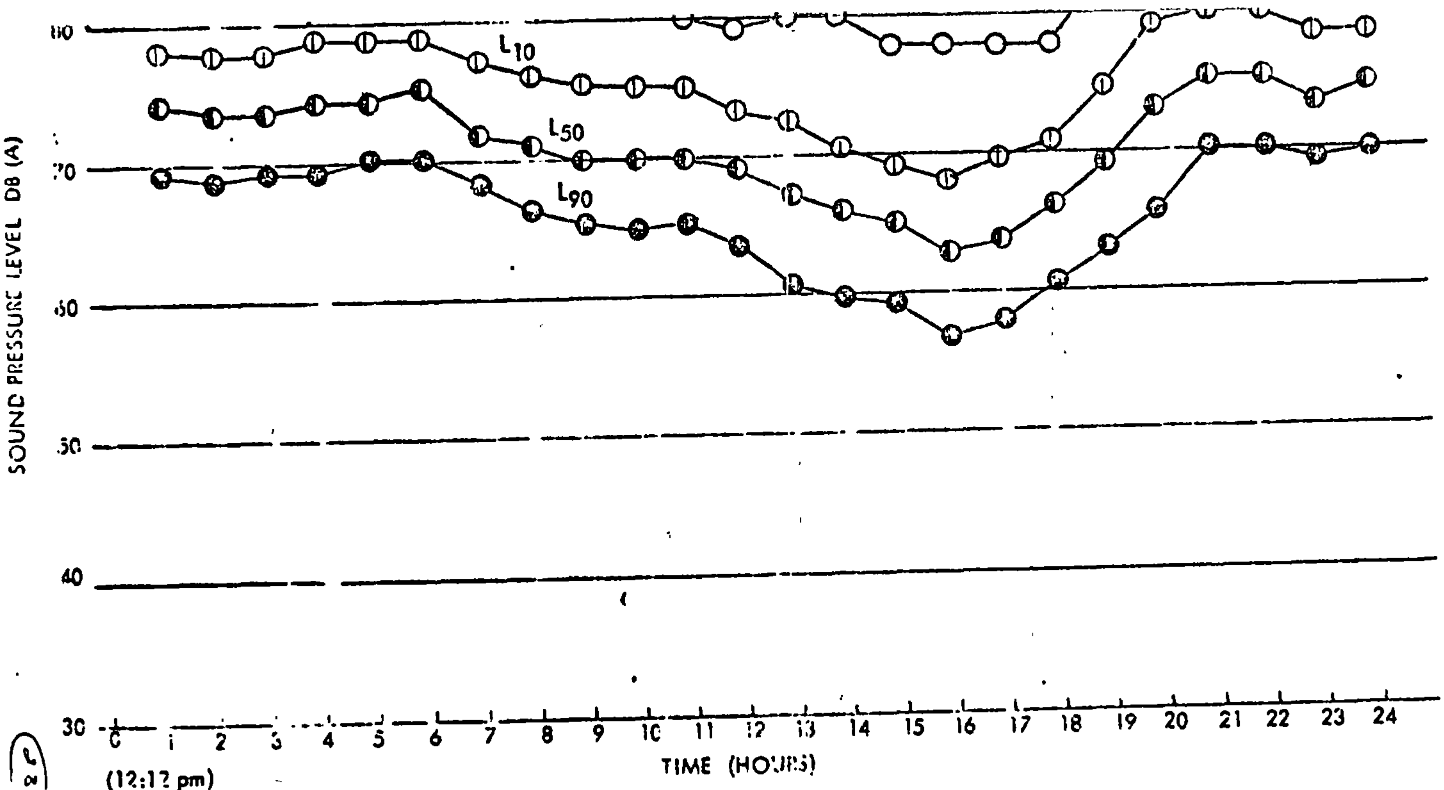


Fig. 12 BACKGROUND NOISE LEVELS IN A BUSINESS DISTRICT. (STATE & MADISON) JANUARY 30-31, 1972

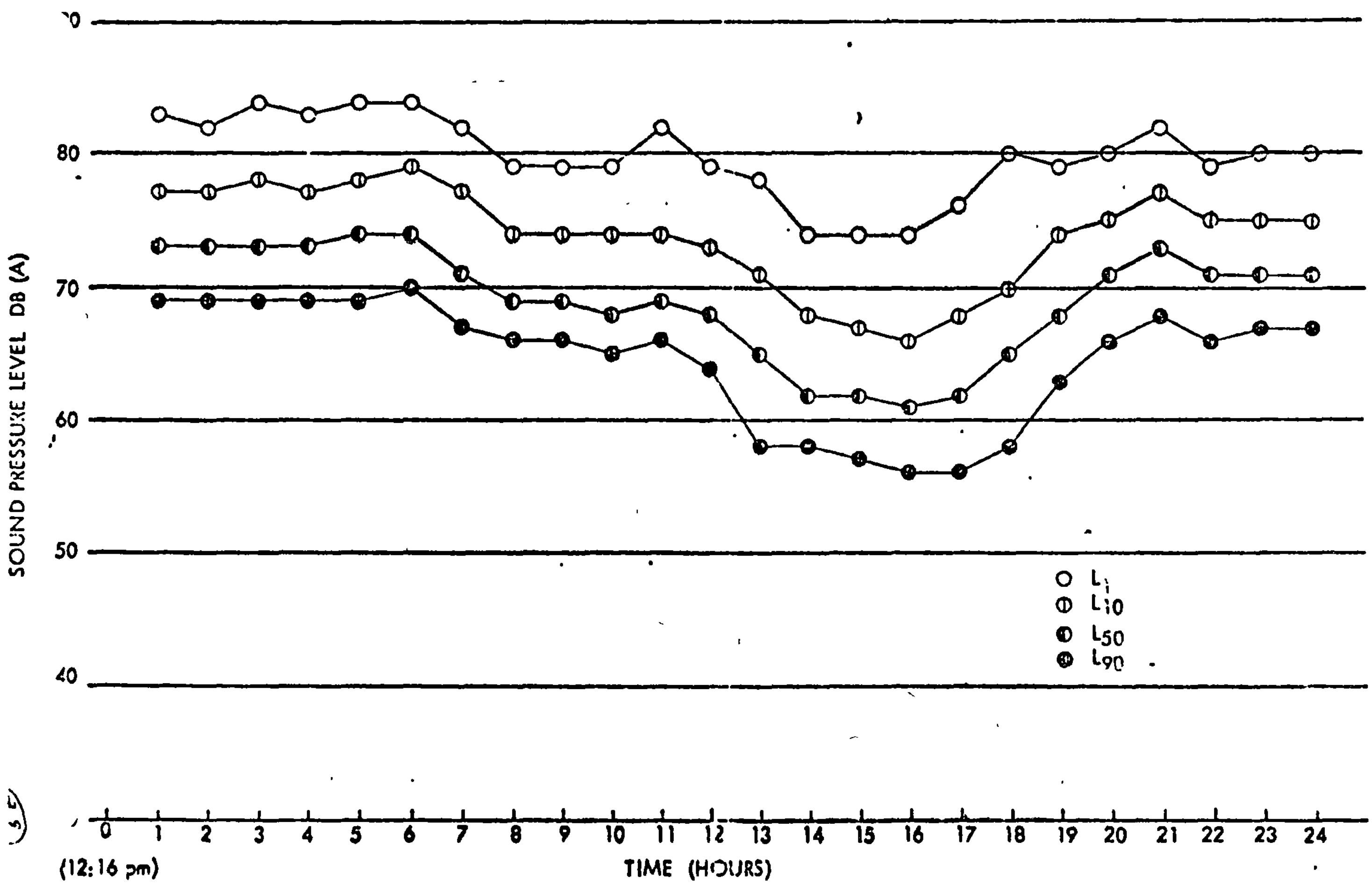


Fig. 13 BREAKDOWN OF NOISE LEVELS IN A BUSINESS DISTRICT. (STATE & MADISON) FEBRUARY 7-8, 1973

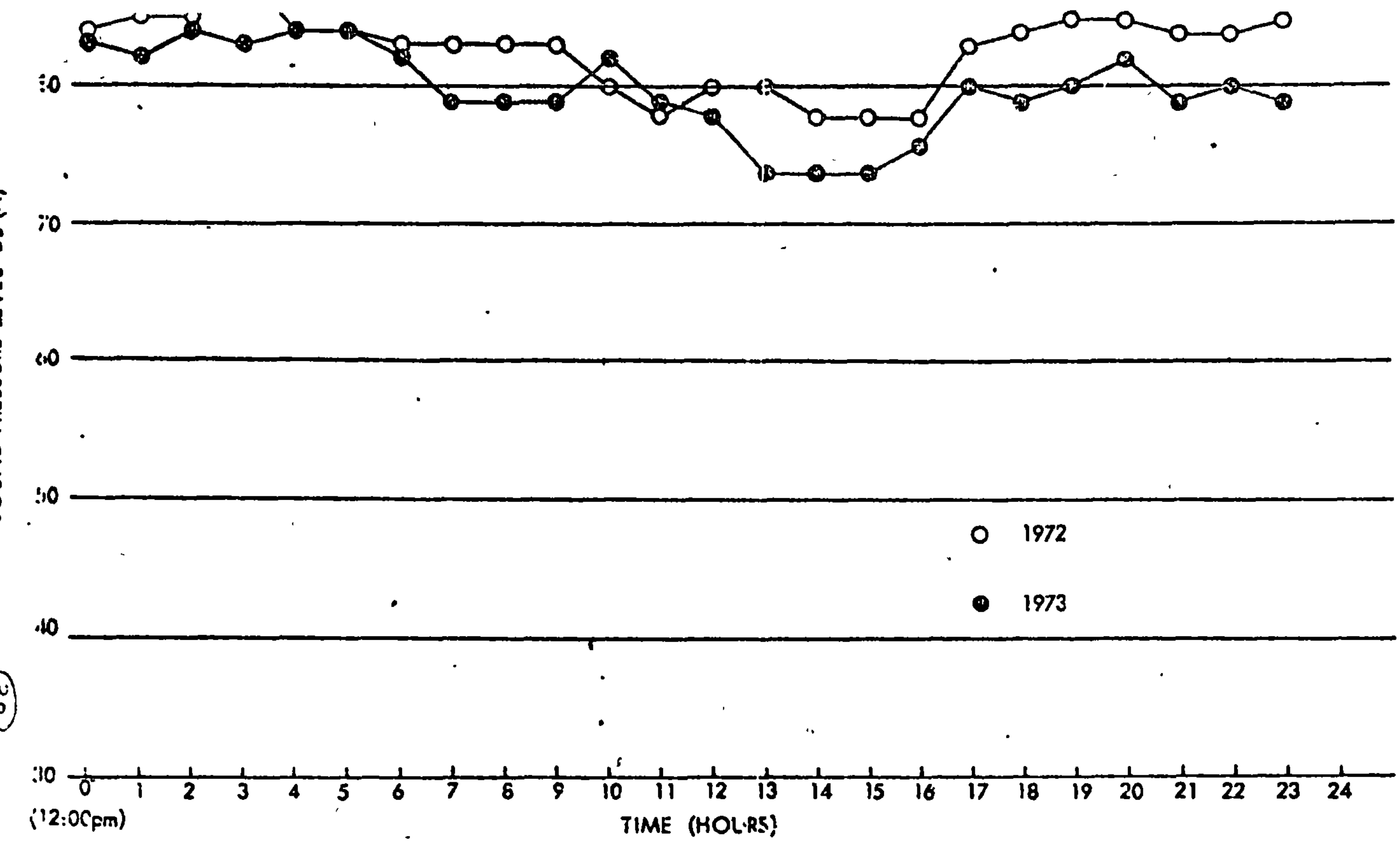


Fig. 14 ONE PERCENT NOISE LEVELS FOR STATE & MADISON. COMPARISON OF 1972 and 1973

(30)

73-193

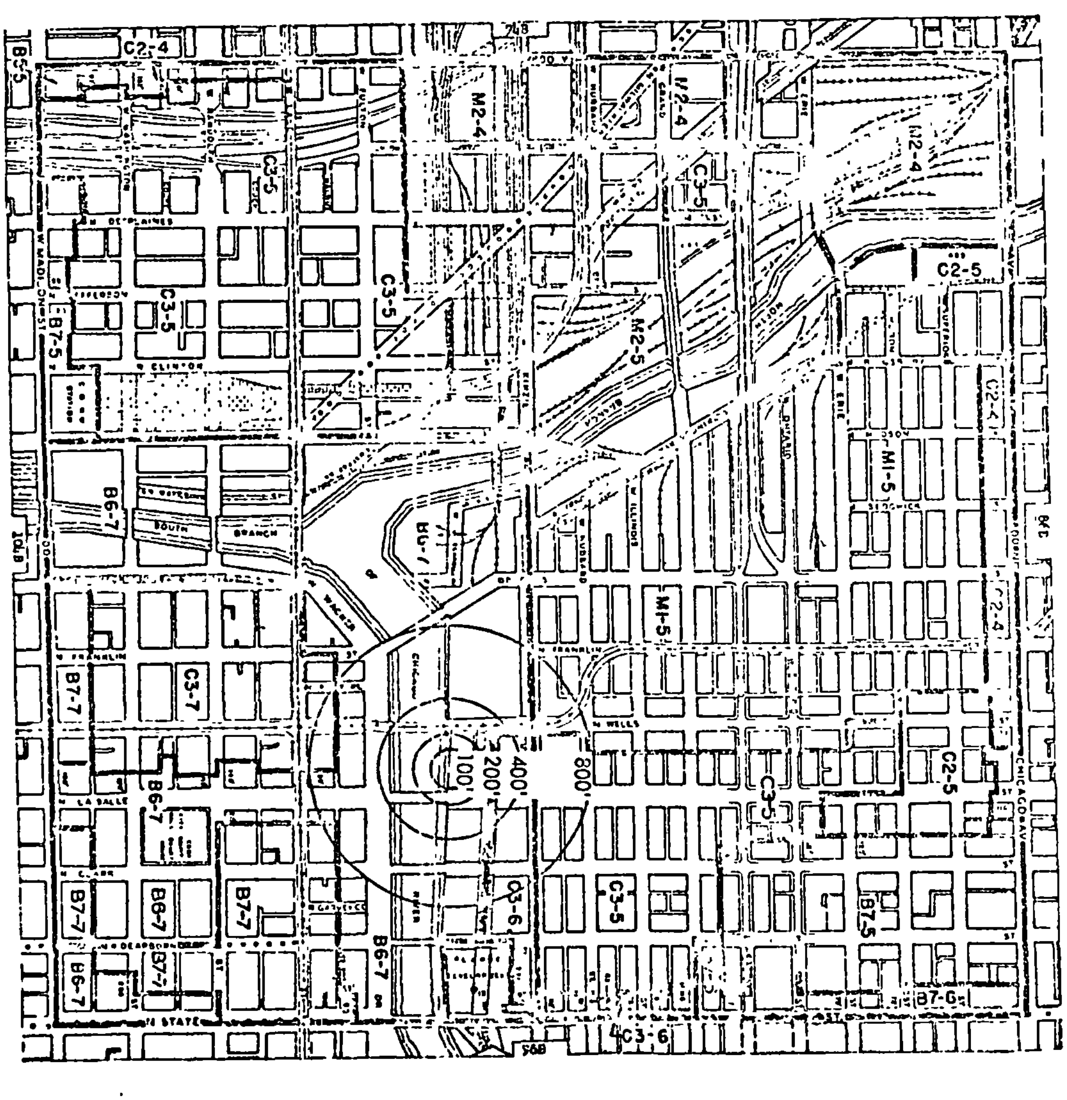


Fig. 15. MICROPHONE LOCATION IN BUSINESS DISTRICT AT 325 N. WELLS STREET

(31)

73-193

73-193

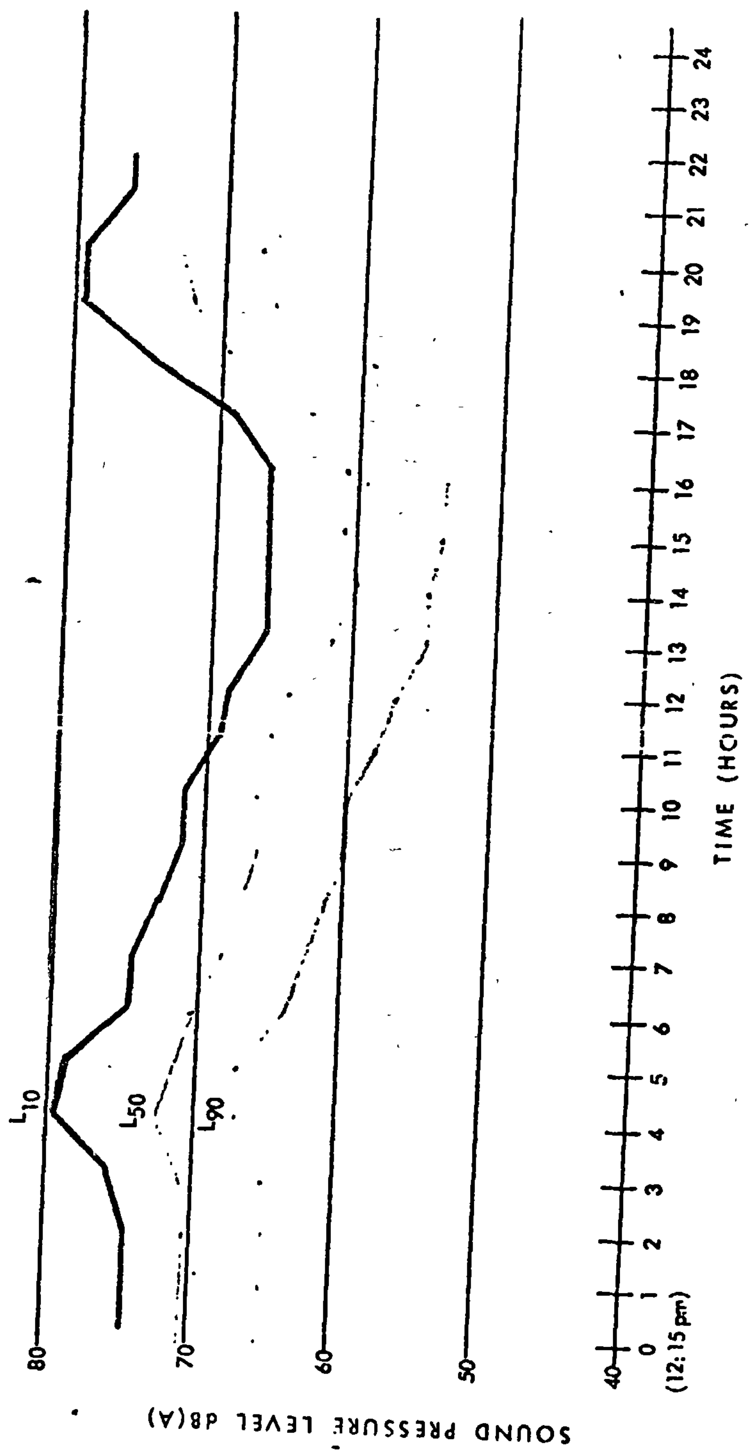


Fig. 16 BREAKDOWN OF NOISE LEVELS IN A BUSINESS DISTRICT. (325 N. Wells) DECEMBER 16-17, 1971

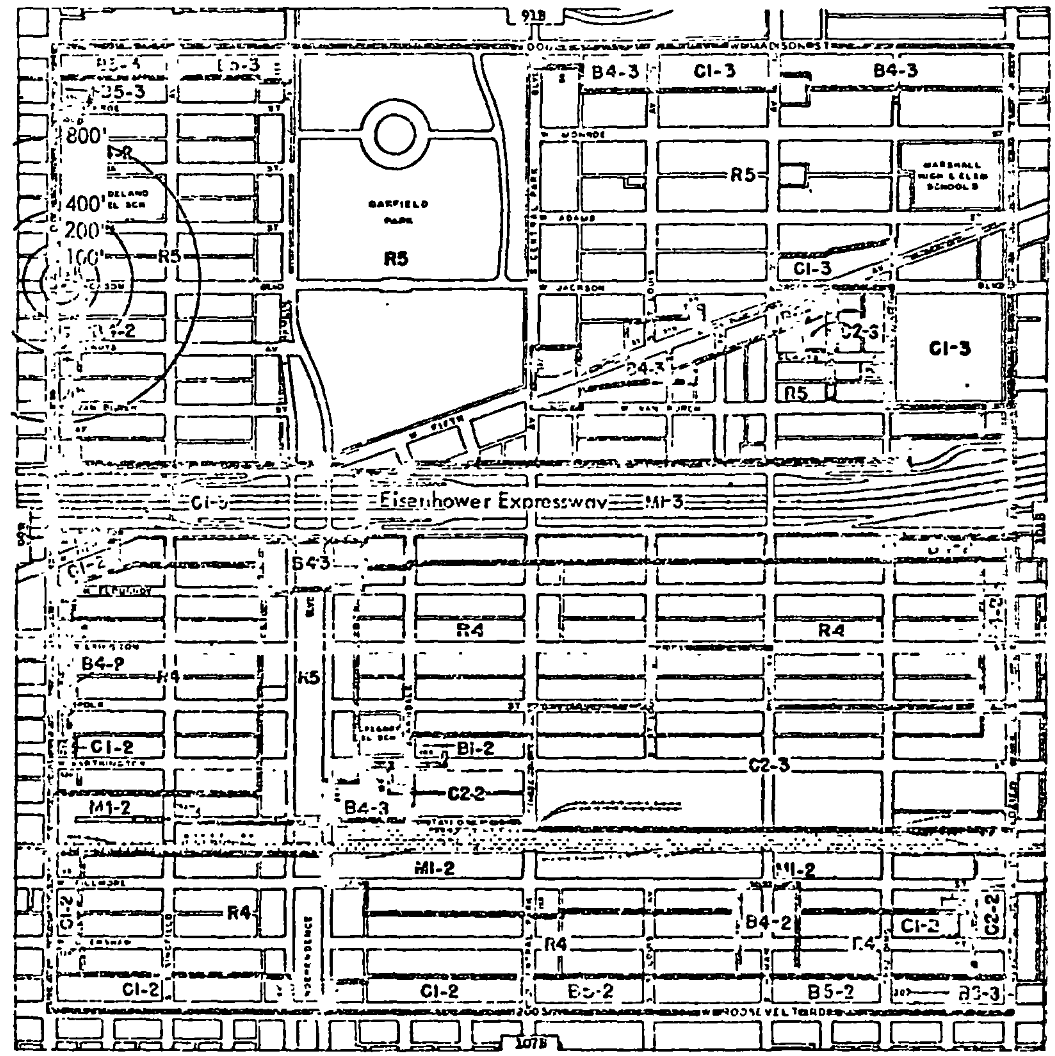


Fig. 17. MICROPHONE LOCATION IN BUSINESS DISTRICT AT 3952 WEST JACKSON BLVD.

NOTE: ALL DATA IS DECILE LEVEL OF L_{50}

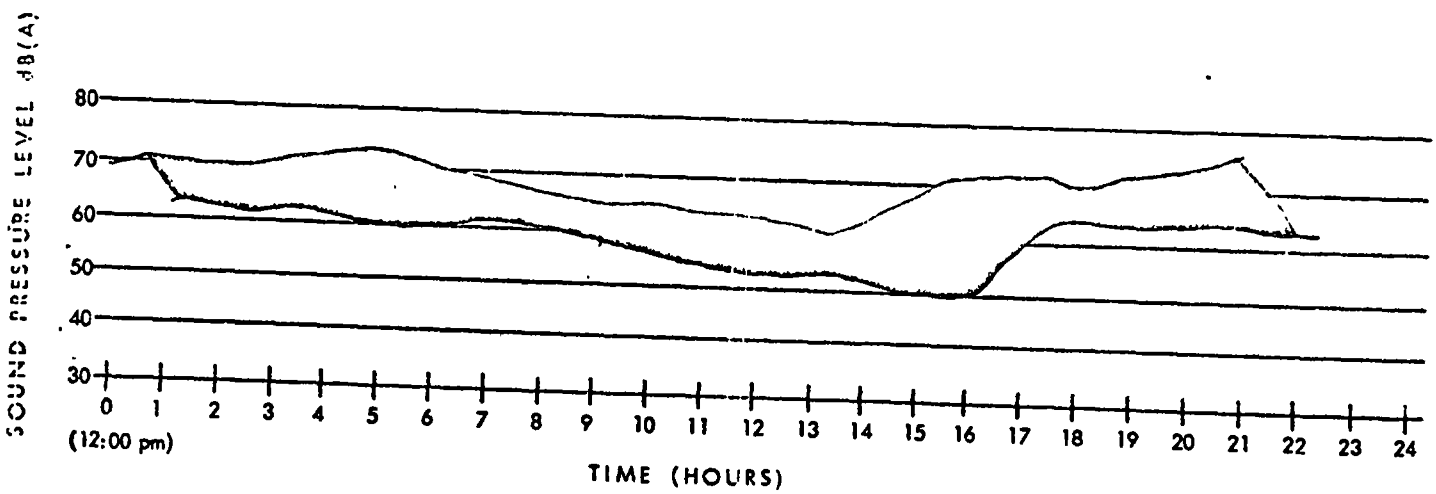


Fig. 18 RANGE OF BACKGROUND NOISE LEVELS IN A BUSINESS DISTRICT. 1971

34

73-193

NOTE: ALL DATA IS DECILE LEVEL OF L_{50}

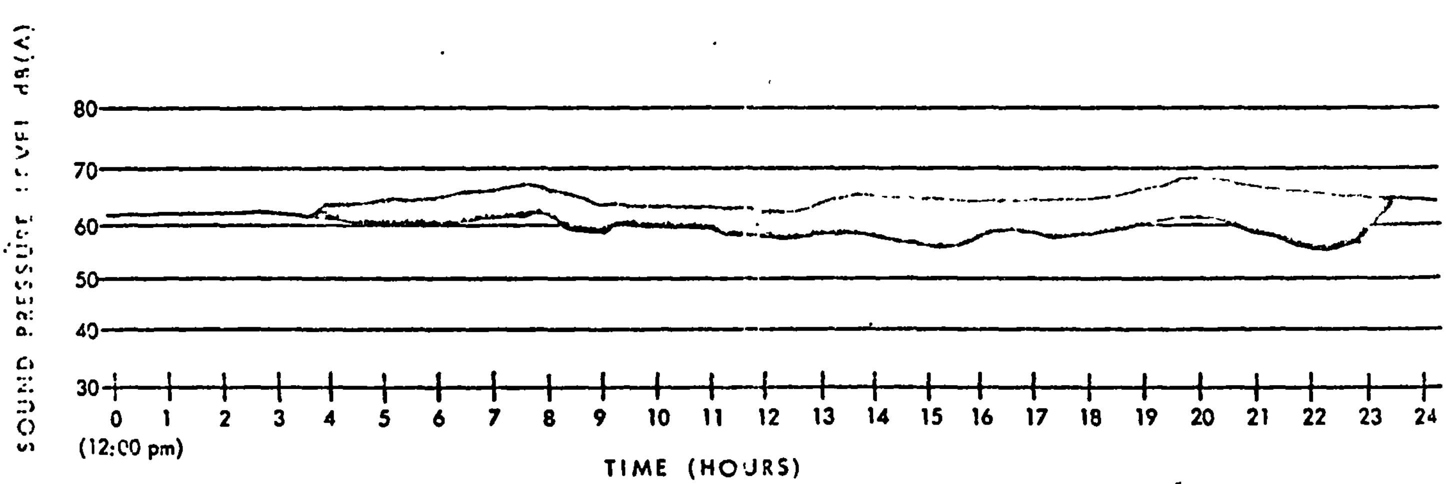


Fig. 19 RANGE OF BACKGROUND NOISE LEVELS IN A MANUFACTURING DISTRICT. 1972

35

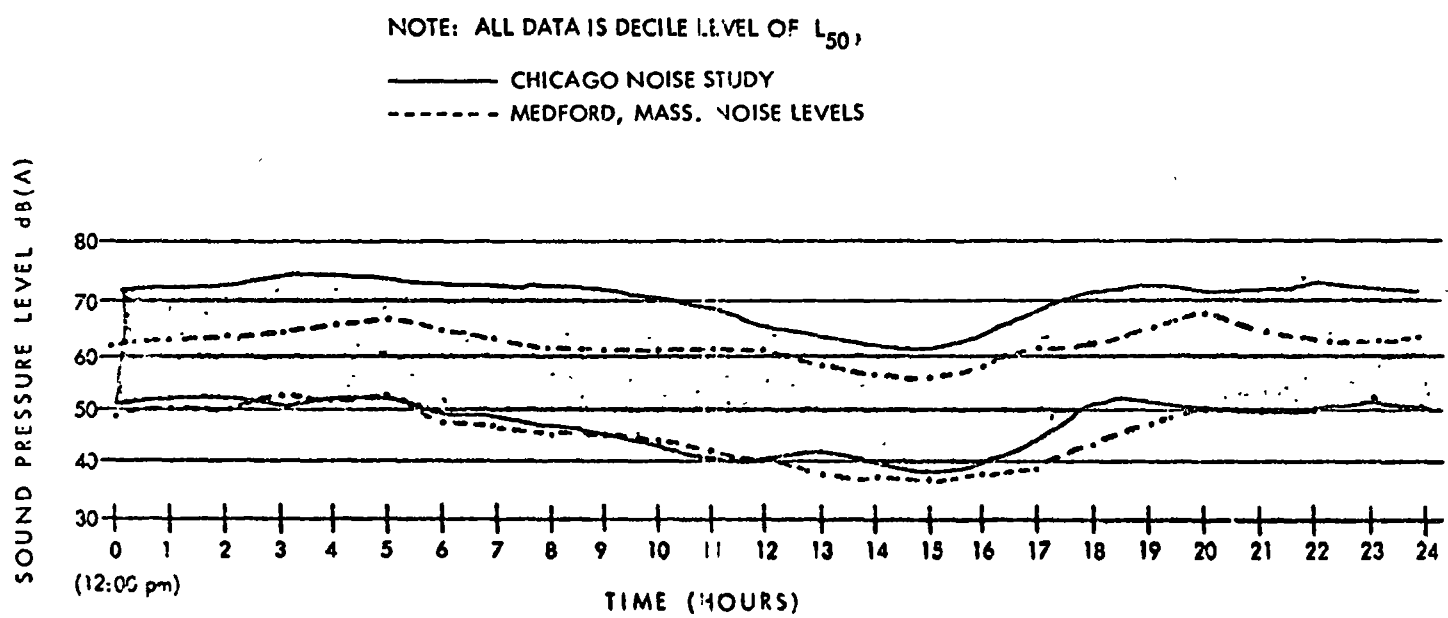


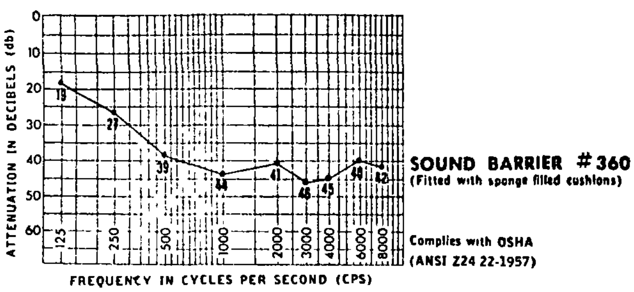
Fig. 20 COMPARISON OF BACKGROUND NOISE LEVELS IN RESIDENTIAL DISTRICTS.

360 Convertible Sound Barrier® Ear Muffs

The 360 is the most versatile Sound Barrier yet. It can be worn comfortably in any position on the head, even under the chin (a feature women will appreciate to protect their hair styles). The unique configuration of the ear cups of this 360° rotation model enables the new Sound Barrier to be worn with hats and caps and welding helmets.

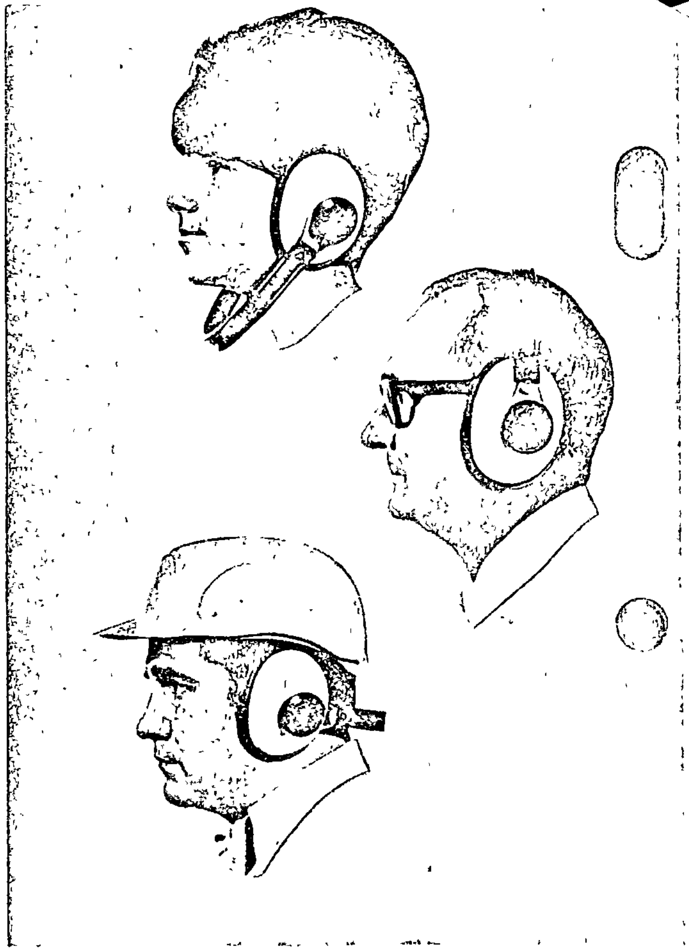
The ear cups are made of tough thermoplastic. Durable vinyl-covered sponge cushions on the 360 provide comfort plus good attenuation. The 360A is standard with fluid filled cushions. Both style cushions are replaceable.

The headband is made of a strong, flexible stainless steel, cushioned with a soft plastic cover. It is lightweight and fully adjustable. All these features insure one of the most versatile, efficient and attractive ear muff-type hearing protectors on the market today.



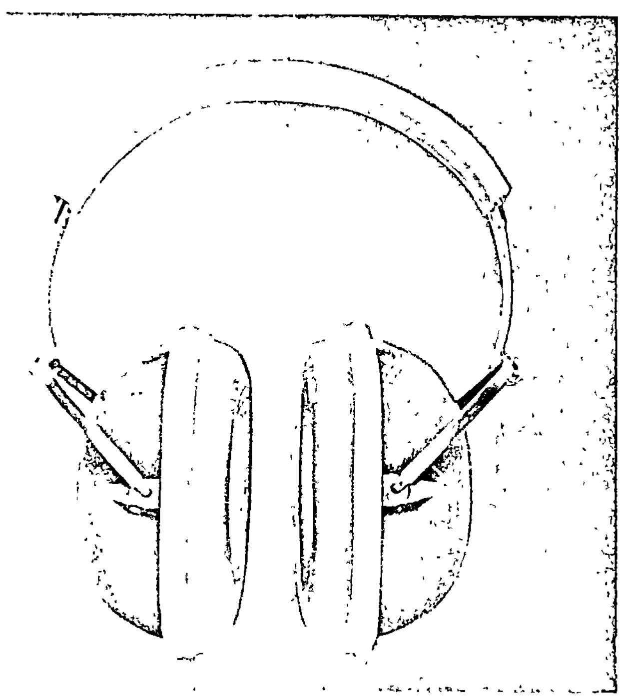
360 —Sound Barrier with sponge filled cushions

360A—Sound Barrier with fluid filled cushions

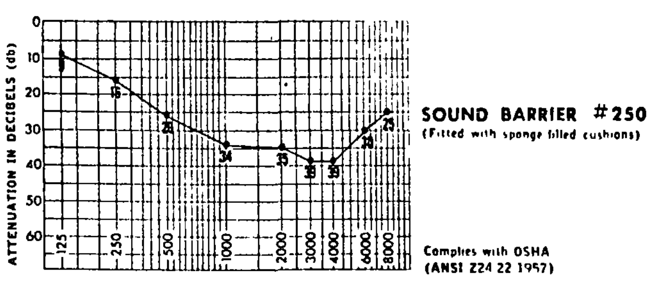


Outstanding protection against the effects of high-level noise at moderate cost

The Model 250 Willson SOUND BARRIER offers excellent hearing protection against high-level noise even when it is accompanied by extreme vibration. It is scientifically designed to attenuate the many high-frequency noises encountered in industry and by the military. Yet, low-level sounds such as spoken voices and warning signals can be easily heard by the wearer. When worn properly in high-frequency-noise situations, the 250 gives protection against the serious hearing impairments and deafness which can result from continued exposure to high-frequency noise. It is insurance not only against such impairments but also against the absenteeism and reduction of personnel efficiency which are so often the result of hearing deterioration.



The 250 attains its attenuation effectiveness through the use of sponge-filled vinyl covered cushions. Considering the effectiveness of the 250, its price is moderate. Distinctively modern in appearance with tough, durable plastic cups, vinyl sponge filled cushions and an extruded vinyl head frame cover. The adjustable headframe is made of steel. Optional are patented fluid-filled vinyl cushions.

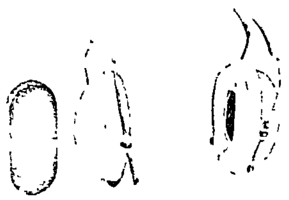


HOW TO ORDER

250 —Over-the-Head Type Ear Muff Sound Barrier (Sponge-Filled Cushions)

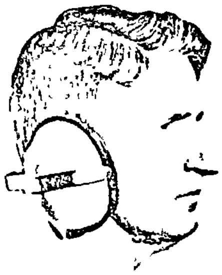
250A—Over-the-Head Type Ear Muff Sound Barrier (Fluid-Filled Cushions)

All items on this page are Standard Warehouse Products.



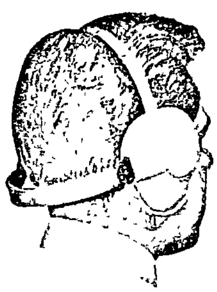
#150 Sound Barrier

Attractive unit with molded slim line earcups mounted on plastic cushioned spring wire headframes. Same, equipped with Willson Fluid-Filled Ear Cushion, specify #150-A.



#151 Sound Barrier With Nape Strap

For extra convenience, nape strap and cutaway earcups that fit under safety hats and caps. Same, with Willson Fluid-Filled Ear Cushion, specify #151-A.

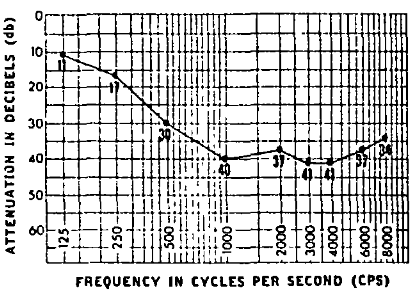


#155 Sound Barrier With Nape Strap

This model, with its triangular-shape earcups and soft 3/4" nylon crown strap was designed especially to provide greater comfort when worn with safety hats and caps and "bump" caps. The sponge cushions are vinyl covered. An outstanding mechanical feature of the #155 model is the patented tension adjustment knob on each earcup. By permitting adjustment for variations in head shapes and contours, it increases wearing comfort.

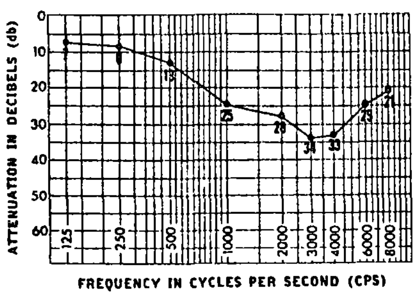
*#155 Sound Barrier with Sponge Filled Cushions.

*#155-A Sound Barrier with Fluid Filled Ear Cushions.



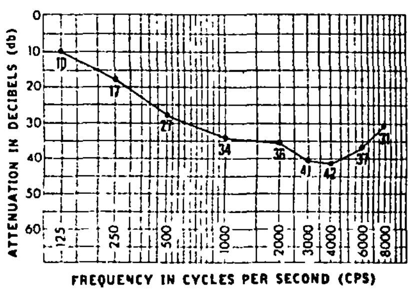
SOUND BARRIER #150
(Fitted with sponge filled cushions)

Complies with OSHA (ANSI Z24.22-1957)



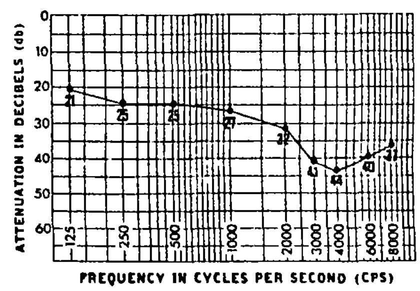
SOUND BARRIER #155
(Fitted with sponge filled cushions)

Complies with OSHA (ANSI Z24 22-1957)



SOUND BARRIER #151
(Fitted with sponge filled cushions)

Complies with OSHA (ANSI Z24 22-1957)



SOUND SILENCER EP100

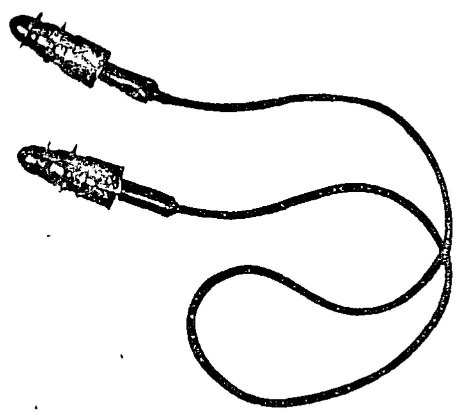
Complies with OSHA (ANSI Z24 22-1957)

WILLSON SOUND SILENCER® EAR PLUGS

Air cushioned insert ear plugs fit everyone comfortably.

Its special design makes Willson Sound Silencer the first insert ear protector soft enough and sufficiently comfortable to be worn all day without irritation. Attenuation tests prove Sound Silencer to be as effective in reducing damaging noises as many ear muff types. It features a unique air cushion and three-flange design that's unusually effective in sealing ear openings to sounds, despite head and jaw movements. Flexible construction permits Sound Silencer to fit everyone without special fittings by medical personnel. Just two sizes to stock.

EP100



EP101B

ORDERING INFORMATION

***EP100** —Flesh Color Sound Silencer ear plugs with carrying case. Specify EP100G for green color.

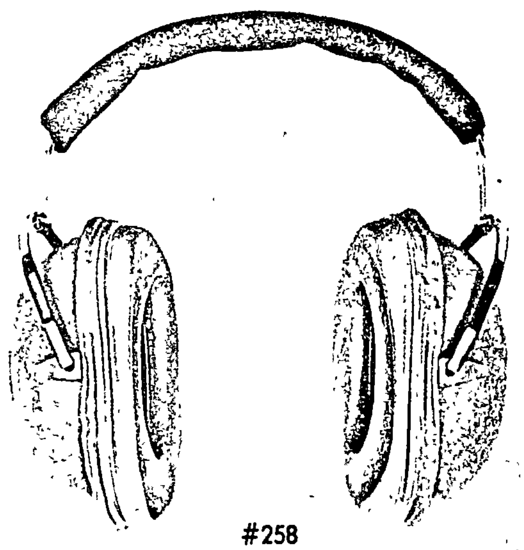
***EP100S**—Small size flesh color Sound Silencer ear plugs with carrying case. Specify EP100SG for green color.

***EP101B**—Sound Silencer Assembly—a pair of black Sound Silencer ear plugs connected with a chemically bonded 30" nylon cord. The nylon cord can be draped around the worker's neck and the ear plugs are inserted into the ear canal in the usual manner. In the course of the worker's movement, should the ear plug fall from his ear the cord keeps the plug in easy reach. Specify EP101SB for small size.

**Standard Warehouse Product*

WILLSON® HEARING PROTECTION

Sound Barrier® Equipment Designed for Utmost Comfort



#258

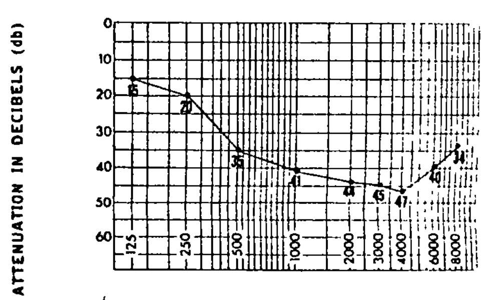
You'll work confidently and communicate freely when wearing Willson equipment because it assures positive hearing protection under the most trying conditions. Don't take chances. Safeguard yourself against the damaging effects of noises present throughout business and industry. Ask for Willson Hearing Protection Equipment, scientifically designed to keep you more comfortable as well as fully protected.

WILLSON #258 SOUND BARRIER EAR MUFFS protect against harmful high-level noises while permitting the wearer to hear low-level sounds such as voices and warning signals. This unit is a basic piece of equipment in the Willson Sound Barrier System. To #258 ear muffs can be added microphones, earphones, and even a complete communication system to protect hearing while permitting normal communication.

SUPERIOR DESIGN AND CONSTRUCTION FEATURES

- **Tough, Noise-Deflecting Earcups**
- **Soft, Sound-Absorbent Sponge Earcup Insert**
- **Fluid-Filled Ear Cushion**
- **Adjustable Nickel-Plated Beryllium Copper Headframe**
- **Headframe Pad for Complete Comfort**
- **Easily Disassembled. Entire ear muff can be taken apart without tools for cleaning and sanitizing. All parts are replaceable.**

SOUND BARRIER #258
Standard Warehouse Product

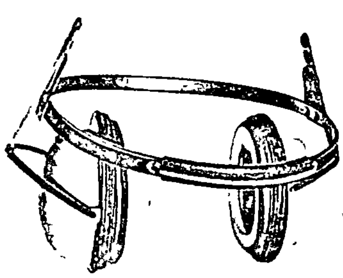


FREQUENCY IN CYCLES PER SECOND (CPS)

Complies with OSHA (ANSI Z24.22-1957)

In addition to individual ear muffs, Willson units are available for use with head protection equipment.

#283 Sound Barrier With Kwik-Klip® Headgear



These specially built earcups can be attached quickly to any make of safety cap by means of Willson's patented Kwik-Klip headgear. The exclusive Kwik-Klip has a spring-tension band that holds entire unit on the cap by slight pressure, without needing alterations to cap.

#284 Sound Barrier For Safety Cap

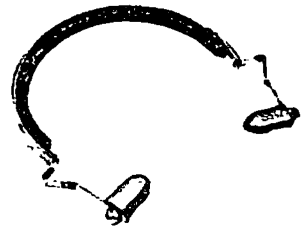
Features notched earcups and brackets for permanent mounting on any safety cap. #284 combines effective hearing protection with comfortable head protection. Specially designed spring-jointed clip permits earcups to be moved both vertically and laterally . . . even swing out of the way when not needed. Does not include cap.

SOUND-BAN™ HEARING PROTECTOR

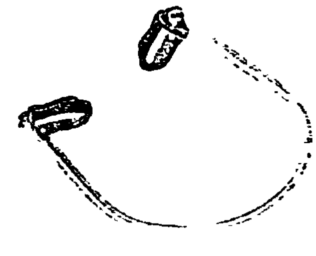
The Sound-Ban™ is a hearing protector to meet the needs of the user who requires more than ear plugs but does not need as much protection as our Sound Barrier ear muffs. The pads for the Sound-Ban can be cleaned or replaced, which makes it a cleaner, more sanitary hearing protection.

#10 Sound-Ban—This model has a metal headband which fits close to the head and is adjustable. A foam cushion padding makes the headband non-slip, and adds to the comfort when worn.

#20 Sound-Ban—The headband is not adjustable but can be worn under the chin or behind the head and is constructed of plastic tubing. This unit is lighter in weight.



#10



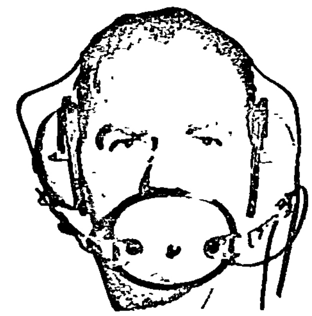
#20

WILLSON SOUND BARRIER® UNITS WITH COMMUNICATION

600 OHMS IMPEDANCE

Willson Sound Barrier hearing protection equipment can be furnished with receivers and microphones, permitting their use with a wide variety of communication systems. This equipment can be used with your present direct wire transmission system or with radio transceiver equipment. The 600 ohms impedance equipment is economically priced, standard on airlines, and in many in-plant systems.

#259 Sound Barrier with Receivers



#260C-2 Sound Barrier with Receivers and Mouth Cup Microphone

WILLSON SOUND BARRIER IN-PLANT COMMUNICATIONS EQUIPMENT

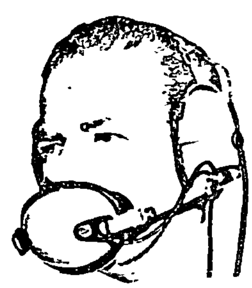
65 OHMS IMPEDANCE

Ideal for use between departments in high-noise-level areas, and for communication between test stations, control rooms or personnel working under severe noise conditions in the same room. Only two microphone units, a master amplifier, and auxiliary amplifier and connecting cords are required to set up a complete portable or permanent communications system that also safeguards hearing.

#265 features Receivers with Lip Microphone, recommended for areas with noise levels under 120 decibels.

WILLSON SOUND BARRIER WITH SOUND POWERED COMMUNICATION

No power line plug-in nor batteries are needed with this Willson Sound Barrier hearing protection plus communications system. The only power needed is the human voice. Infinitesimal A.C. current relays spoken messages clearly for distances up to 30 miles. All you need for a complete two-station system are two Sound Barrier headsets and a 100′ #EM-39 Extension Cord. To add stations, a junction box (#EM-107), headset and cord are needed. The system is easily set up in plant or at remote locations.



#271 equipped with Microphone Toggle Switch.

WILLSON

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WILLSON PRODUCTS DIVISION

ESB INCORPORATED

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P.O. BOX 622, READING, PENNSYLVANIA 19603

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12. ING. JORGE JAIME PRADO BARRAGAN Av. Alvaro Obregón No. 115 Col. Roma México 7, D. F. Tel: 5-11-55-27	DIRECCION GENERAL DE AEROPUERTOS, S.O.P. Xola No. 1755 México, D. F. Tel: 5-30-30-53
13. ING. FLORENTINO PRIEGO VILLANUEVA López 50 No. 304 México 1, D. F. México, D. F.	D.D.F. DIRECCION GENERAL DE SERVICIOS URBANOS. Estación del Metro Colegio Militar México, D. F. Tel: 5-41-06-36
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5.0 PSYCHOACOUSTICS

The hearing mechanism, shown in cross section in Figure 20 can be divided into three parts: the external ear, the middle ear, and the inner ear. The external ear consists of an external appendage, called the pinna, and the ear canal, which is closed at the inner end by the eardrum. The middle ear contains three tiny bones or ossicles which transmit vibrations from the eardrum to the inner ear. These bones -- the hammer, anvil, and stirrup -- constitute a lever mechanism that communicates the vibrations of the drum to the membrane of the oval window, which is the entrance to the inner ear. Since the oval window is only about one twentieth as large as the eardrum, the pressure of the vibrations communicated through the oval window to the liquid in the inner ear is increased. Thus the action of the middle ear is that of an efficient mechanical transformer, coupling vibrations in the air to the liquid in the internal ear. The inner ear has two distinct functions: (1) the maintenance of body equilibrium, accomplished by the vestibular portion of the ear, which is made up principally of three semicircular canals; and (2) the perception of sound which is accomplished by the cochlea and its associated apparatus.

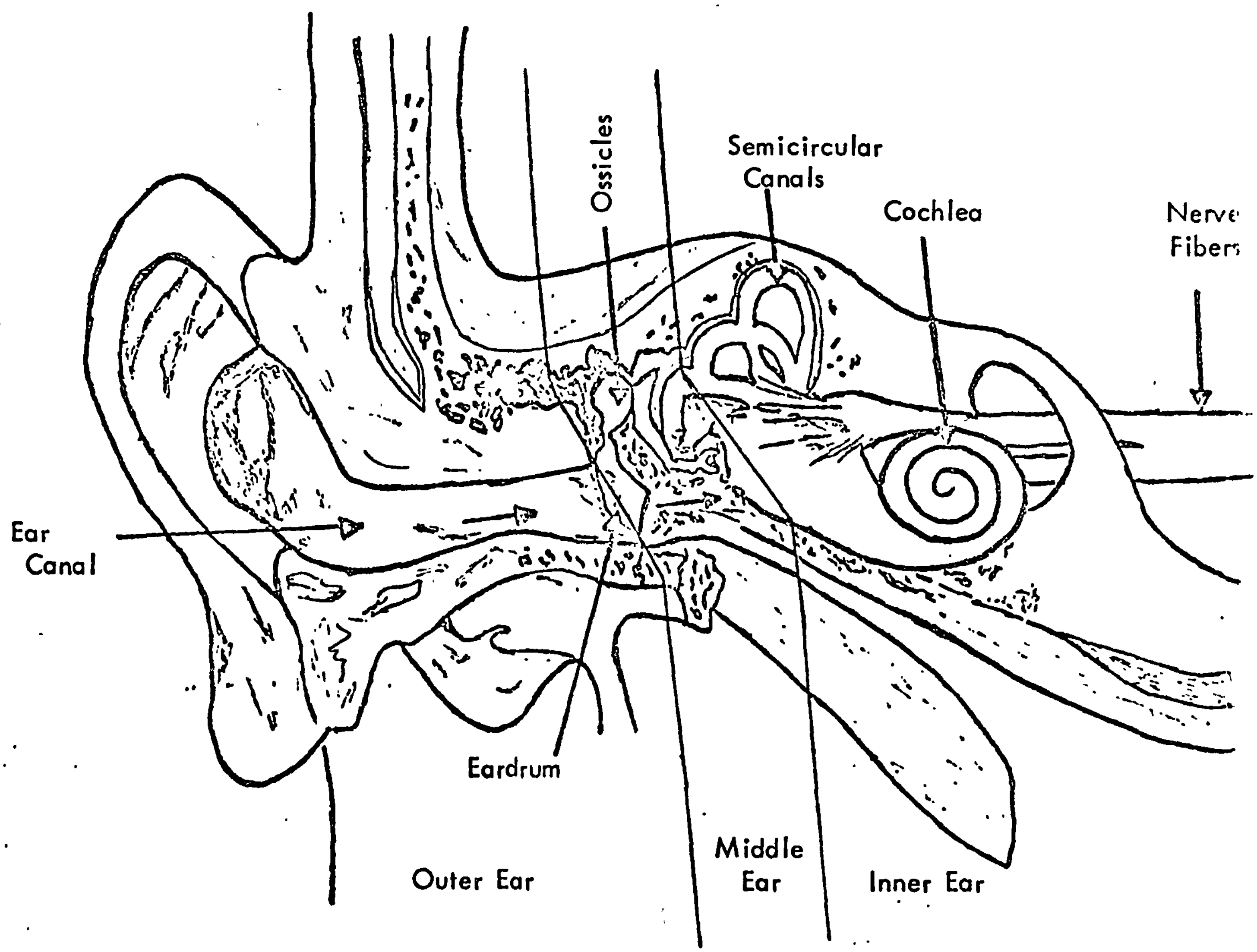

FIG. 20 CROSS-SECTIONAL DRAWING OF THE HEARING MECHANISM

The cochlea is a liquid-filled spiral canal, subdivided along its length into two canals by a bony structure and a rough membrane. The end of one of these canals is closed by the oval window. It is through this window that the vibrations of ossicles is transmitted to the liquid in the cochlea. Sensitive nerve endings, associated with tiny hair cells in a third canal, are excited by the vibration set up in the cochlear liquid, and they send impulses to the brain by way of the nerve fibers. It is believed that the rate at which the total number of these nervous impulses are communicated to the brain determines the loudness. This rate depends on the number and activity (pulsing rate) of the nerve endings stimulated. It increases with the sound pressure of the wave striking the ear. The pitch of the sound sensation is determined principally by the location of the nerve endings that are most excited by the resonant vibration of various sections of the basilar membrane; however, at low pitch the frequency of arrival of the nervous impulses at the brain may be the chief determinant. Tonal quality is determined largely by the number, location, and extent of the excited nerve endings and is complexly related to the wave form and pressure of the sound wave striking the ear. A more detailed explanation of the functioning of the ear follows.

5.1 Physiology of Hearing

Major interest in this section will be given to the structure and function of the ear as related to the hearing process and its impairment due to excessive noise exposure. The brain mechanisms underlying the hearing process will be largely ignored since noise-induced hearing loss seems to be primarily a peripheral as opposed to a central-type of disorder.

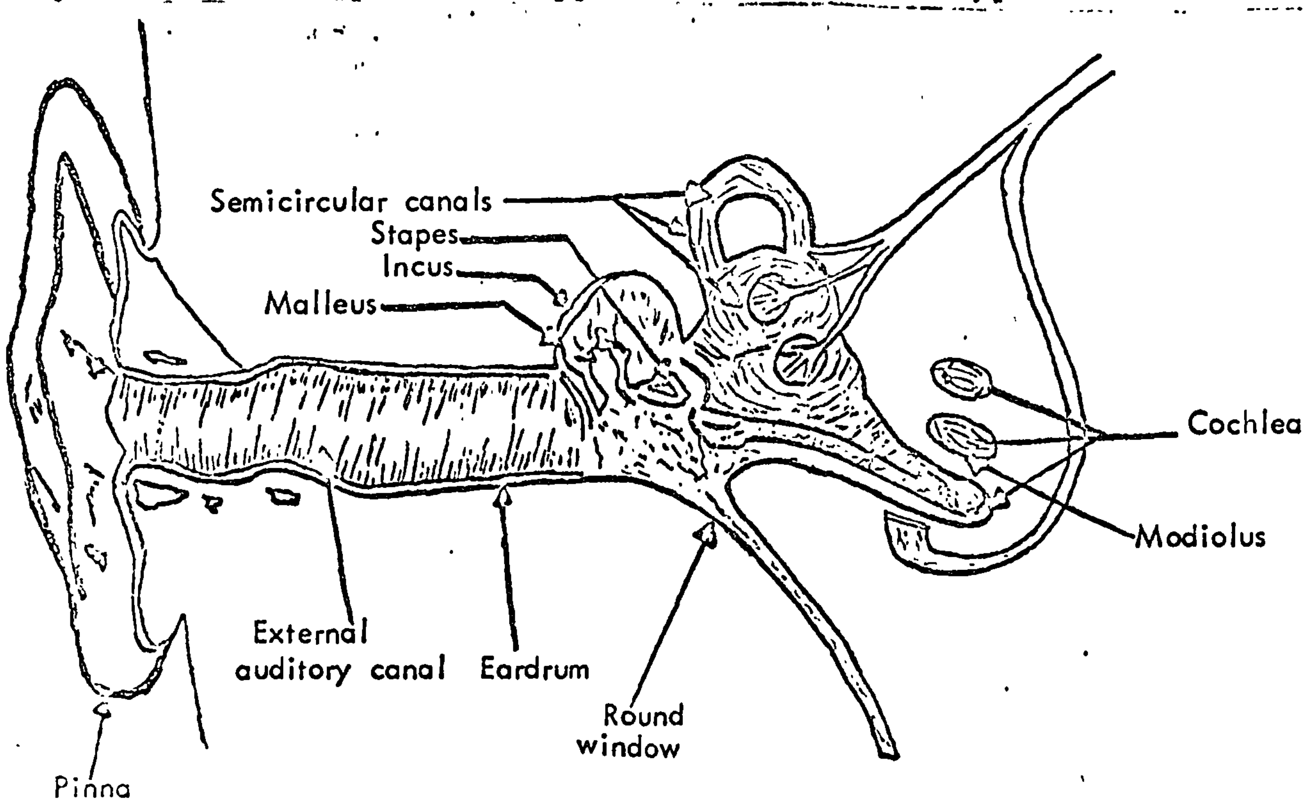

FIG.21 DRAWING OF THE HUMAN EAR SHOWING THREE SUBDIVISIONS IN CROSS-SECTION

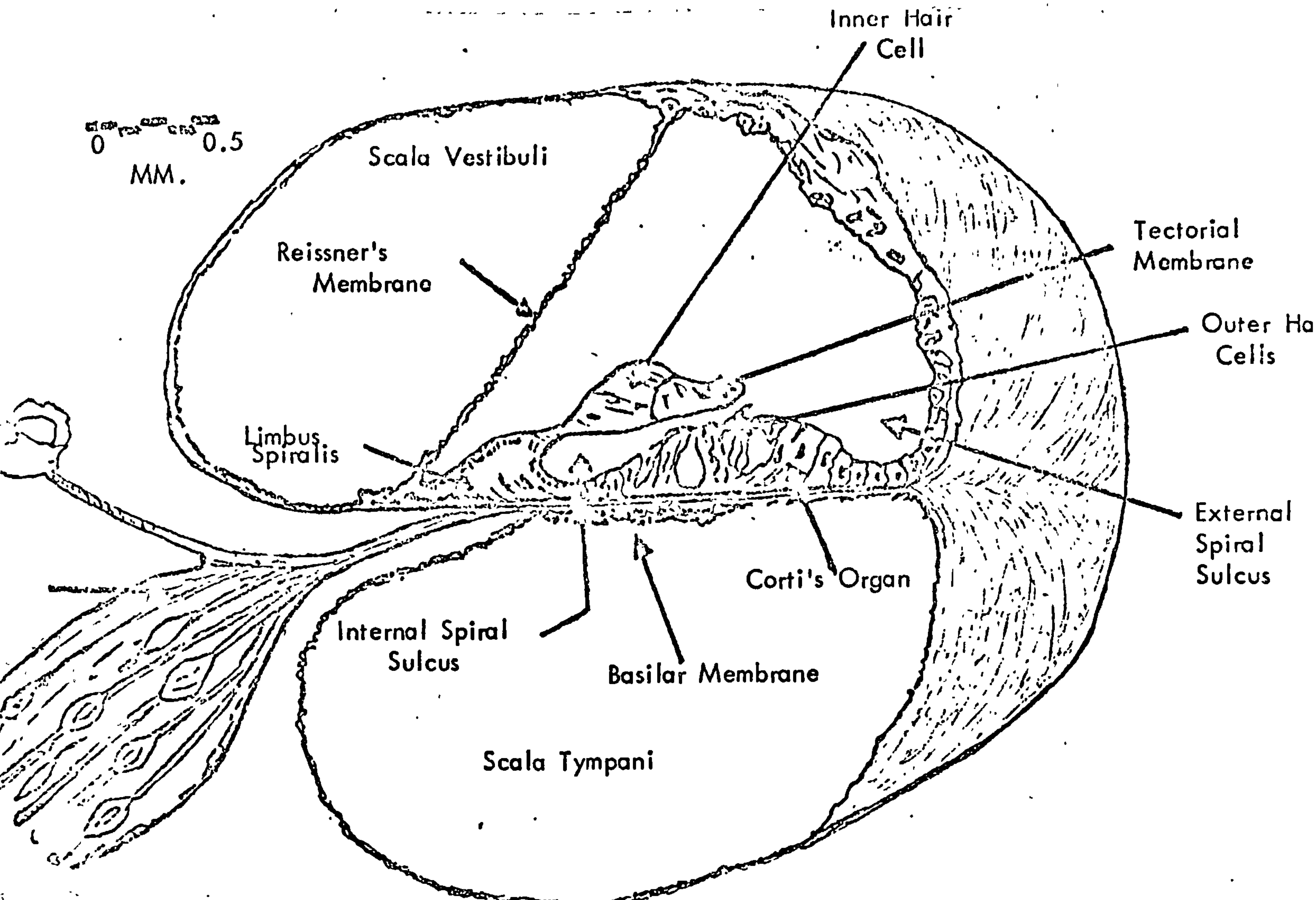

Fig. 22 Enlarged cross-section drawing of the cochlea

5.1.1 Ear Anatomy and Physiology - Anatomically, the ear can be divided into three subdivisions called the external, middle and inner ears (see Fig. 21). The external and middle ear functions are principly to collect and transmit sound stimuli to the inner ear where the sensory receptors for sound sensation are located. The pinna of the external ear funnels sound inward through the external ear canal to the tympanic membrane or eardrum. The incoming sound waves strike the eardrum and set it into vibration. Behind the eardrum is the middle ear, an air-filled cavity containing three small bones or ossicles referred to as the malleus, incus and stapes. The handle of the malleus is attached to the eardrum and articulates with the incus, which, in turn, is joined to the stapes. The footplate of the stapes fits snugly in the oval window which is one of the two covered openings between the middle and inner ears. The other opening lies just below the oval window and is called the round window. Functionally, the three ossicles form a chain which carry the sound-produced vibrations of the eardrum through the middle ear to the inner ear.

Also located in the middle ear are the intra-aural ear muscles consisting of the tensor tympani and the stampedius. The tensor tympani is attached to the malleus and, when contracted, places the eardrum under greater tension. The stampedius muscle is fastened to the stapes and upon contraction pulls this bone in a donward and outward direction therein affecting the movement of the stapes footplate in the oval window. The contractile state of these muscles can be produced by the onset of these muscles can be produced by the onset of intense sound and, in effect, reduces the amount of sound energy that is conducted by the ossicular chain to the inner ear. This action is considered protective in nature since it minimizes the potentially damaging effects of high intensity sounds on the hearing receptors in the inner ear.

Another middle ear feature is the Eustachian tube, a passageway leading from the middle ear cavity to the back of the nose and throat. The purpose of the tube is to equalize air pressure on both sides of the eardrum. Equalization in pressure is necessary to make the eardrum more capable of responding to and transmitting the sounds impinging upon it.

Just behind the oval and round windows is the inner ear which consists of three sections known as the vestibule, semicircular canals, and cochlea. Of these, the cochlea is the most important for hearing. The human cochlea is essentially a triple canal coiled up spirally around a bony axis, the modiolus, which is channeled to form the pathway for the auditory branch of the VIIIth cranial nerve. The larger turns of the spiral are at the The three canals comprising the cochlea are formed by two partitions (see Figure 22). One partition is composed of a ledge of bone, the spiral lamina, which winds around the modiolus like the thread of a screw and the basilar membrane which extends from the projecting tip of the spiral lamina to the outer wall of the cochlea. The second partition is formed by Reissner's membrane which stretches from the upper surface of the spiral lamina to a point on the outer wall of the cochlea, a short distance above the attachment of the basilar membrane. The canal, which lies below the basilar membrane, is called the tympanic canal (scala tympani); the canal enclosed between the basilar membrane and Reissner's membrane is called the cochlear duct (ductus cochlearis), and the canal lying above Reissner's membrane is referred to as the vestibular canal (scalavestibuli), The vestibular and tympanic canals contain perilymph fluid and communicate with one another through a tiny opening at the apex of the cochlea. The base of the vestibular canal is sealed by the oval window into which the footplate of the stapes is lodged. The lower termination of the tympanic canal is sealed by the membrane-covered round window. The cochlear duct contains endolymph fluid and also the tectorial membrane which is attached at one end to the spiral lamina with the other end floating freely in the endolymph just above the basilar membrane.

The basilar membrane is narrowest at the base of the cochlea (i.e., near the oval window) and becomes progressively wider as it extends towards the apex. This is in contradistinction to the dimensions of the total cochlear structure which becomes smaller as the apex is approached. Distributed in four rows (one inner row, three outer rows) along the entire length of the basilar membrane are hair cells which project upward toward the underside of the tectorial membrane. These hair cells are the sensory receptors for hearing which together with supporting cells constitute the Organ of Corti, the auditory sense organ. The hair cells are innervated by nerve fibers which pass through small openings in the spiral lamina and enter the modiolus of the cochlea where their cell bodies are grouped to form the spiral ganglion. Axons from this ganglion collect at the base of the cochlea and pass out from the bottom of the coil as the auditory branch of the VIIIth cranial nerve. These axons end upon nerves in the medulla, which, in turn, pass axons to different and higher nerve centers in the thalamus and cerebellum. Axons from these centers finally lead to the temporal lobe of the cerebral cortex.

Although knowledge is still lacking, cochlear function underlying the hearing process has become clearer in recent years. As a physical system the cochlea has been described as an enclosod collumn of fluid bounded at one end by the stapes footplate in the round window and at the other end by the membrane covering the round window. Since fluid is incompressible, the vibrations transmitted by the stapes footplate, similar to a plunger action, cause mass movements of fluids in the cochlear canals. In this process every inward movement of the stapes footplate causes the round window to bulge outward, and every stapes outward movement causes the round window to move inward. The fluid movements in the cochlear canals cause structural displacements along the basilar membrane which take the form of a traveling wave whose crest along the membrane depending upon the frequency of sound stimulation. Generally, the locus of the crest or peak displacement for high frequency sounds is in the basal section of the basilar membrane, the peaks for lower frequencies becoming progressively shifted toward the apex of the basilar membrane.

As a result of the wavelike motions of the basilar membrane, a shearing action develops between the basilar membrane and the tectorial membrane leading to bending and squeezing of the hair cells found on the upper surface of the basilar membrane. This hair cell deformation causes electrical and/or chemical changes which are believed to trigger nerve impulses in the nerve fibers associated with the hair cells. The pattern of neural impulses arising within the cochlea provides the basis for auditory sensation and is transmitted to the cerebral cortex for interpretation.

5.1.2 Sensitivity of the Ear - A sound wave must have a certain minimum value of pressure in order to be heard by an observer. This value for selected observers, who have good hearing, who are facing the source of plane progressive waves and listening with both ears, is called the minimum audible threshold for a free field. It is shown in the lower curve of Fig. 23. Frequency is indicated along the horizontal axis; and the pressure level of the plane progressive sound wave

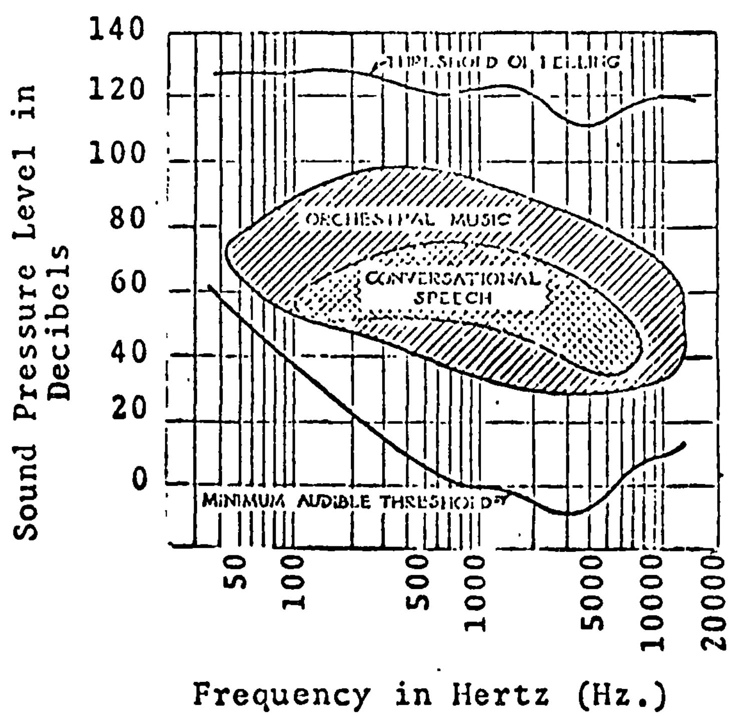

Fig. 23. CHART SHOWING THE MINIMUM AUDIBLE THRESHOLD VS. FREQUENCY, AND THE THRESHOLD OF FEELING

that is just barely audible is indicated along the vertical axis. One notes that the sensitivity of hearing varies enormously for sounds of different frequencies. Fortunately, the ear is most sensitive in the frequency range that is most important for the intelligibility of speech sounds. Since, in the evolution of man, speech and music were developed later than the sense of hearing, it appears that speech and music have developed in such a manner as to be well adapted to the sensitivity characteristics of the ear.

An observer in the field of a free plane progressive wave will notice that, as the pressure of the wave is increased, the resulting sound becomes louder and louder until it attains a level at which the sound can be felt (a sort of tingling sensation) as well as heard. This level is called the threshold of feeling. Above this threshold, the observer experiences a mixed sensation of sound, feeling, and pain. Figure 23 shows that, unlike the minimum audible threshold, the threshold of feeling varies relatively little with frequency. The minimum audible threshold curve, if extrapolated at both ends, will intersect the threshold of feeling curve at two points which determine the lower and upper frequency limits of audibility; namely, at about 20 cycles for the lower limit and at about 20,000 cycles for the upper limit. These are the average values for young persons with good hearing. The upper frequency limit, along with the sensitivity for the higher frequencies, generally decreases with increasing age.

The ability of the ear to differentiate small changes of sound·pressure or frequency is of importance in the hearing of speech and music. Anything that interferes with this function of the ear renders the understandability of speech or music more difficult. It is therefore of interest to inquire about the ear's capability in this respect. The minimum perceptible increment of sound-pressure level of a pure tone varies with both pressure and frequency, but, for levels greater than about 40 db above the threshold of audibility and for frequencies between 200 and 700 cycles, the minimum perceptible increment in pressure level varies from one qu rter to three quarters of a decibel. The smallest perceptible change in frequency that the ear can detect is different for different pressure levels and frequencies, but, for pure tones more than 40 db above threshold and for frequencies greater than 500 cycles, it is of the order of 0.3 per cent for monaural listening with an earphone.

5.2 Thresholds of the Ear

One of the simplest measurements that can be made of our hearing ability is to determine the manner in which the minimum perceptible intensity level varies with frequency. The acoustic intensity that can be barely detected at any particular frequency is known as the threshold of hearing or threshold of audibility for that frequency. Measurements have been made of this threshold by numerous observers. As is to be expected, the results vary to a considerable extent from one individual to another, even when all have what is commonly considered normal hearing, and the threshold intensity is also a function of the age of the listener, a progessive loss in sensitivity at the higher frequencies being customary with increasing age. In addition, the exact shape of the threshold curve varies with the manner in which the incident sound level is measured, i.e., at the pinna of the ear or in the free sound field, the observe's head being absent. It also depends on the direction of the incidente of the sound and on whether the listening is done with both ears or with only one ear. Figure 24 shows a typical response for both ears, the level being measured in a free sound field of random horizontal direction. It is to be noted that a logarithmic frequency scale has been used and that the reference intensity level is 10^{-16} watt/cm^2, which corresponds to an rms reference pressure of 0.0002 dyne/cm^2.

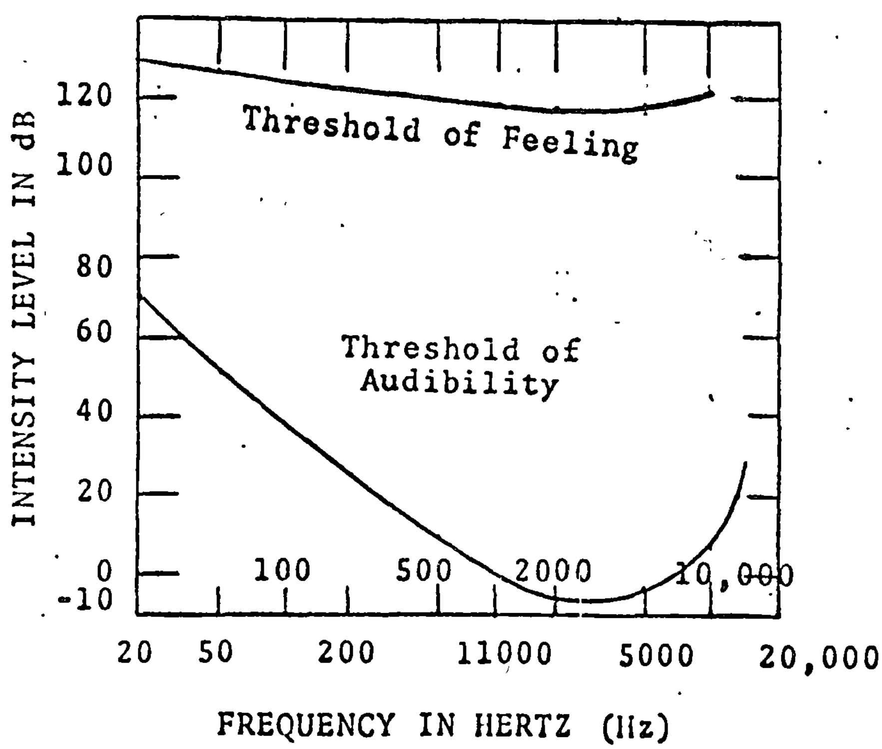

Fig. 24. THRESHOLDS OF THE EAR (0db=10^{-16}WATT/CM^2)

The frequency of maximum sensitivity is in the vicinity of 300 cycles/sec for normal ears. To some extent this is accounted for by resonance in the auditory canal, but other factors are undoubtedly of greater importance. The threshold curve crosses the 0 db level at about 1000 cycles/sec and rises in a regular manner with decreasing frequency, the minimum power required to produce an audible sound at 50 cycles/sec being nearly a million times as great as it is at 3000 cycles/sec. This fact serves to emphasize the problems involved in developing loudspeakers designed to radiate both low-frequency and high-frequency sounds. Measurements of the threshold curve below about 30 cycles/sec. are quite unreliable, as the required intensities become so great that it is difficult to avoid the presence of small percentages of harmonics in the source. Since the pitch-discriminating ability of the ear is relatively poor in this frequency range, the harmonics may be mistaken for the fundamental. Even when the source is known to develop a strictly pure sine wave, nonlinearity in the hearing mechanism itself may give the illusion of hearing a fundamental that is actually inaudible.

For high frequencies the threshold curve also rises, the rate of increase near the upper limit being often so rapid as to constitute a sharp cut-off. It is in this frequency region that the greatest variability is observed between different listeners, particularly if some of them are over thirty years of age. The cut-off frequency for a young man or woman may be as high as 20,000 or even 25,000 cycles/sec, but people who are forty or fifty years of age can seldom hear frequencies in excess of 15,000 cycles/sec. and in some the cut-off is below 10,000 cycles/sec. In the range below 1000 cycles/sec, the threshold is essentially independent of the age of the observer.

The sensitivity of the human ear to sounds of low intensity is quite phenomenal. In the range from about 1000 to 5000 cycles/sec, the minimum perceptible sound intensity is less than 10^{-4} micro-microwatt/cm^2, about one-tenth the diameter of a hydrogen molecule. Calculations show that in this frequency range the changes in pressure due to the thermal agitation of the air molecules are very nearly as great as the minimum audible acoustic pressures, so that any appreciable increase in the sensitivity of our hearing mechanism would also result in our observing a background of thermal noise, a hissing or rushing sound that would interfere with the perception of low-intensity acoustic waves. It is consequently improbable that there are any animals whose hearing is more acute than ours in this frequency range, for they too would be susceptible to the masking produced by thermal noise. On the other hand, it is well known that many animals, such as dogs, are readily capable of perceiving sounds of appreciably higher frequency than can human beings.

As the intensity of the incident acoustic waves is increased, the resulting sound grows louder and eventually reaches a level at which it produces a tickling sensation, or one of pain, rather than a sensation of hearing. This level, which is also shown in Fig. 24 is less dependent on frequency than is the threshold of audibility and has a value of approximately 120 db. It is called the threshold of feeling or the threshold of pain. As with the lower threshold, it varies somewhat from individual to individual but not to so great an extent. Prolonged stimulation at appreciably higher intensities causes permanent damage to the hearing mechanism.

5.2.1 Loudness - In elementary treatments of acoustics it is often stated that the subjective characteristic of a sound which is commonly known as its loudness is determined by its intensity. When properly interpreted, this statement is strictly correct, but it is somewhat misleading, for it may appear to imply that loudness and intensity are synonymous. An inspection of Figure 24 shows immediately that this is not true. For example, a pure tone having an intensity level of 20 db and a frequency of 1000 cycles/sec is plainly audible, whereas one having the same intensity but a frequency of 100 cycles/sec is well below the threshold of audibility and cannot be heard at all. The loudness of such a tone is therefore a function not only of its intensity but also of its frequency.

Although our hearing mechanism is not well adapted to making quantitative measurements of the relative loudness of different sounds, there is fair agreement between observers as to when two pure tones of different frequency appear to be equally loud. It is therefore possible to plot contour curves of equal loudness, such as those shown in Figure 25. The data for these curves are obtained by alternately sounding a reference tone of 1000 cycles/sec. and a second tone of some other frequency. The intensity level of the second tine is then adjusted to the value that makes the two tones

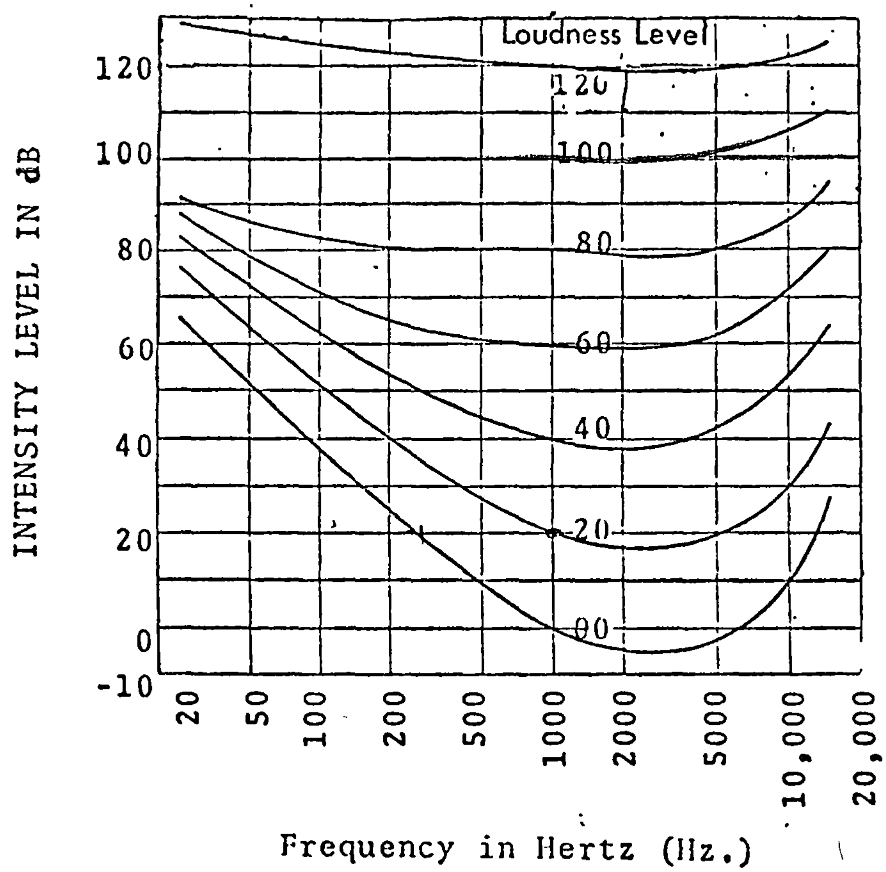

Fig. 25. EQUAL LOUDNESS LEVEL CONTOURS (0db = 10^{-16} WATT/CM^2)

appear equally loud. The unit of loudness level is the phon, the loudness level (in phons) of any sound being taken as numerically equal to the intensity level in decibels of a pure 1000-cycle tone that is judged by the average observer to be equally loud. For example, a pure tone having a frequency of 100 cycles/sec and an intensity level of about 50 db sounds as loud as a pure 1000-cycle tone whose intensity level is 20 db, and hence the loudness level of this 100-cycle tone is by definition 20 phons. It should be noted that the reference intensity level used in defining the phon is that of Figure 24, i.e., zero decibels corresponds to a 1000-cycle intensity of 10^{-16} watt/cm^2.

5.2.2 Pitch - From a subjective point of view, a continuous sound has in general three different characteristics that distinguish it from other continuous sounds. One of these characteristics, its loudness, has been discussed in the previous section. The second subjective characteristic is its pitch. Pitch, like loudness, is a complex characteristic and is not dependent on any single physical quantity, the pitch of a musical sound being determined primarily by its frequency but being also a function of its intensity and wave form. For example, if a pure tone having a sinusoidal wave form and a frequency of about 100 or 200 cycles/sec is first sounded at a moderate and then at a high loudness level, nearly all observers will agree that the louder sound has a lower pitch, in spite of the fact that its frequency remains unchanged. Experiments of this type show that the most pronounced decrease in pitch with increasing loudness of such a tone is increased from a level of 10 to one of 100 phons it may be necessary to increase the frequency by as much as 10 per cent in order to maintain the pitch at a constant value. There has been some disagreement as to the exact frequency at which this change in pitch with loudness is most apparent, one set of experiments having indicated a frequency of about 100 and another 200 cycles/sec, but both groups of observers are in agreement that it occurs at a low frequency and that it is most apparent for pure sinusoidal tones. For frequencies between about 1000 and 5000 cycles/sec, i.e., over the range for which the ear is most sensitive, the pitch of a pure tone is relatively independent of its intensity; at still higher frequencies an increase in loudness produces an increase, rather than a decrease, in pitch.

It should be emphasized that the appreciable changes in pitch with loudness that have just been discussed are characteristic only of pure tones. For ordinary musical tones, such as those produced by violins, clarinets, trumpets, etc., the changes in pitch are much smaller, usually not more than one-fifth as great. This is to be expected, since Fourier's theorem shows that the complex acoustic waves produced by these instruments may be resolved into a fundamental frequency and a series of harmonics, some of which have amplitudes that are quite large, and may even exceed that of the fundamental. Consequently, even if the fundamental lies in the frequency range where a pure tone shows a large decrease in pitch, the harmonics will have frequencies for which the pitch changes very little, or increases with increasing loudness, so that the ear judges the entire series of components as remaining at essentially the same pitch.

Several different approaches have been employed in an attempt to establish a relationship between our subjective sense of pitch and the physical property of frequency. One method is to present alternately to an observer two pure tones of the same loudness level, usually 40 or 60 phons, and to require the observer to adjust the frequency of one of the tones until its pitch appears to be exactly half that of the other. The experiment is then repeated for a series of frequencies covering the entire audible range. As is to be expected, the agreement between different observers is by no means exact, but the average results show clearly that pitch and frequency are not proportional. For example, the frequency that is judged to be half as great as one of 200 cycles/sec is about 120 cycles/sec, but the frequency that sounds half as high as 5000 cycles/sec is less than 2000 cycles/sec. It should be clearly understood that in making tests of this type the two frequencies are presented alternately, and not at the same time. If a pair of tones that are judged to have a pitch ratio of two to one are sounded simultaneously the result is in general very discordant, so that if the tones had originally been presented together the observer would have instinctively adjusted the lower frequency to exactly half that of the upper, i.e., to an octave below, and would thus have avoided the discord.

5.3 Hearing Loss Due to Noise

Deafness may be classified into three basic types, namely, conductive, perceptive (neural) and functional. Conductive hearing loss is caused by a disorder in the external and/or middle ear which prevents the normal amount of sound energy from reaching the inner ear. This pathology may vary from excessive wax being formed in the external ear canal to a bony sclerosis or hardening of tissue around the footplate of the stapes in the oval window (called otosclerosis). Most conductive-type impairments are amenable to treatment and can be corrected. Perceptive deafness refers to disorders in the inner ear and/or along the VIIIth cranial nerve. Such pathology may range from disturbance in the cochlear fluids to degeneration of the hair cell receptors and nerve supply. These types of loss are not capable of being restored through surgical or other medical means.

Functional deafness is applied to a hearing loss that has no organic basis. In other words, the individual does not fully utilize his hearing capacity despite the fact that there is no actual damage to his hearing mechanism.

Hearing loss from noise exposure can be either conductive or neural in nature. Occasionally, it may even be a combination of the two. Noise-induced hearing loss of a conductive type, termined acoustic or blast trauma, can result from an explosion which may rupture the eardrum. The inner ear is infrequently damaged in such instances, but the ossicular chain may be dislodged. The perceptive type of noise-induced hearing loss results from prolonged exposure to excessive amounts of noise such as may be found in industry. The eardrum or ossicular chain is rarely affected in these cases, the site of this disorder is in the cochlea. Initial exposure to excessive industrial-type noise produces a temporary loss in hearing which is recovered after a short time away from noise. With repeated or prolonged exposure for months or years, the likelihood of the ear recovering all of its temporary noise-induced loss is diminished. The residual or non-recovered part of the loss constitutes a permanent hearing impairment due to noise.

The mechanism responsible for deafness from noise exposure remains to be more fully determined. One author suggests that since the Organ of Corti has no direct blood supply, its capacity for rapid exchange of cell nutrients and waste products is quite limited. Thus, even short periods of acoustic overstimulation can cause cellular depletion with consequent decreased cell sensitivity. It is this effect that seems manifest in temporary hearing loss or temporary threshold shift (TTS). While in this lowered physiological state, continued acoustic overstimulation will cause still more cellular depletion to a point where complete recovery cannot take place. The result is reflected as a permanent loss in hearing sensitivity.

Histological studies have shown that the regions of cellular injury due to excessive noise exposure are localized on the basilar membrane, the location and width of such regions depending on the characteristics of the overstimulating sound. Generally speaking, however, the cellular areas of the membrane mediating high frequency sensitivity (more basal in direction) show more vulnerability to noise-induced damage than do those receptor regions underlying low frequency sensitivity (more apical in direction). There are several reasons for this differential finding. Among these are: (1) the high frequency membrane regions give higher amplitudes and more sharply concentrated patterns of response to incoming stimulation; (2) the middle ear reflex shows less attenuation (hence, less protection) for high frequency as compared with low frequency sounds; and (3) the resonant frequency of the external ear canal will give added amplification to high frequency relative to low frequency sounds.

Regardless of the site of the basilar membrane, the process of noise-induced damage is essentially the same. Damage occurs first to the outer hair cells and their supporting structures. The inner hair cells seem generally to be the last sensory structure damaged. The final irreversible stage of the process is the complete dissolution of the Organ of Corti, leaving a denuded section of the basilar membrane. Subsequently, these damaged sections are replaced by a layer of epithelial cells.

As already mentioned, perceptive-type deafness is not curable. Noise-induced losses of the perceptive-type can be prevented, however, and all feasible efforts must be taken to insure such prevention.

5.3.1 Audiometry - Hearing losses can be measured by a pure-tone audiometer which describes threshold intensity levels for hearing different frequency sounds relative to intensity values representing the average hearing of a normal listener population. (Note: These reference settings are not to be confused for sound pressure level measurements. Actually, the reference values for normal hearing on the audiometer are different for different test frequencies.) Pure-tone air conduction audiometry is most commonly used in hearing testing although bone conduction and other more elaborate tests (e.g., noise-masked thresholds or pure-tone discrimination) are also used for purposes of diagnosing a given hearing disorder.

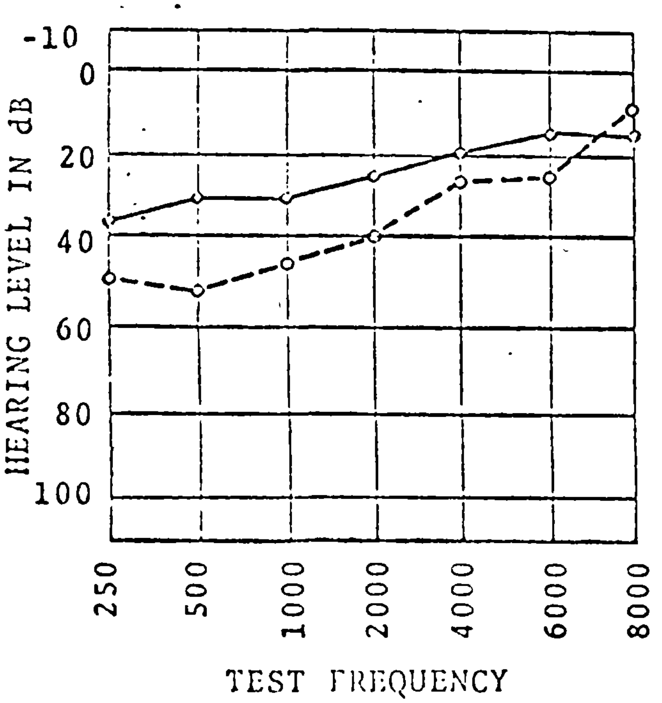

Fig. 26. A DIAGRAM SHOWING CONNECTIVE HEARING IMPAIRMENT

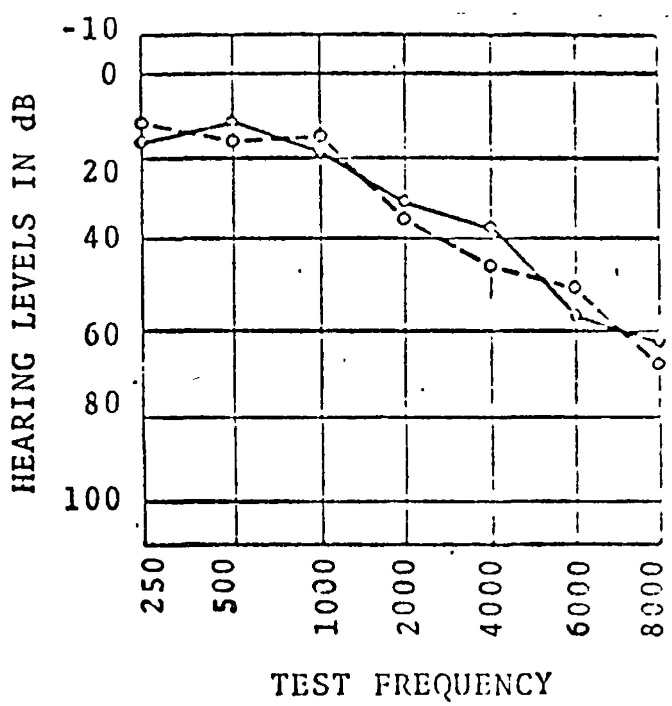

Fig. 27. A DIAGRAM SHOWING PERCEPTIVE TYPE HEARING IMPAIRMENT

Figures 25 and 26 above show typical audiograms for ears with conductive and perceptive hearing losses, respectively. Note that in the conductive case (Fig. 26) the losses for low frequency sounds are greater than those for the higher frequencies. In contrast, the perceptive hearing disorder (Figure 27) shows relatively greater losses at the higher frequencies. Figure 28 describes the development of permanent noise-induced hearing loss as a function of exposure time to excessive industrial noise. Early in the development, the losses

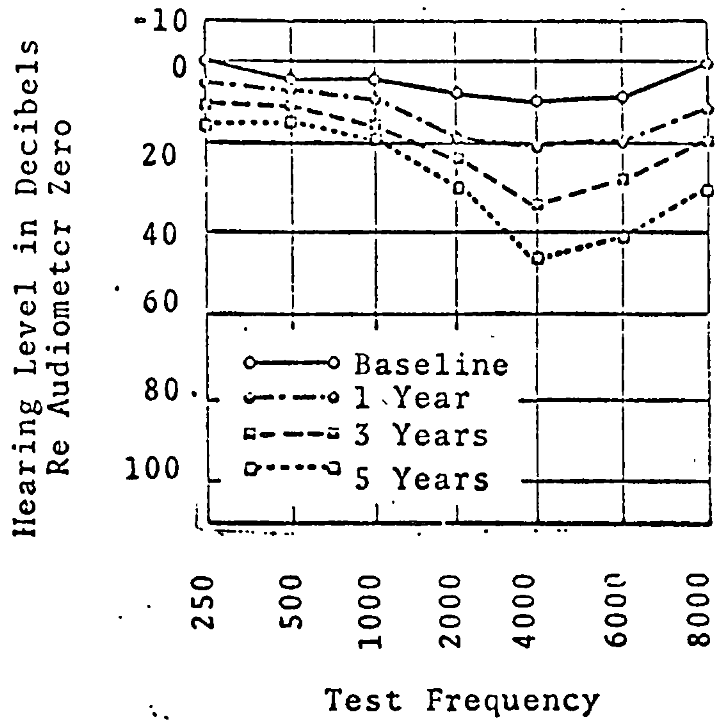

Fig. 28. HEARING LOSS FROM NOISE AS A FUNCTION OF EXPOSURE TIME

are most prominent for frequencies of 3000 to 6000 cps and show a peak of 4000 cps. With continued exposure significant losses appear at other neighboring frequencies as well as increases still further in the 3000-6000 cps range. Deafness due to aging (presbycusis) also shows losses in the audiogram at those frequencies severely affected by noise exposure. This raises the problem of how much of a given hearing loss at a test frequency is due to noise and how much is due to age. Hearing data acquired from noise-free population of listeners, classified by age, are presently being used to estimate the extent of hearing loss due to the age factor only. Such losses are deducted from audiometric measurement on noise-exposed individuals, leaving a value which is believed to more accurately reflect the extent of the noise-induced loss. In actuality, however, their procedure may give invalid results since age and susceptibility to noise-induced hearing loss may be subject to unique interactions.

5.3.2 Levels Producing Damage to Hearing - An important consideration in most industries is that the noise levels in factory spaces be low enough so that no damage should occur to the hearing of employees who are exposed to the noise over a long period of time. Tentative criteria have been established for no damage to hearing based on an analysis of all reliable information on the subject in the literature.

TABLE 11

DAMAGE RISK CRITERIA

Frequency, Hz	Pure Tone Levels or Critical Band Levels of Continuous Noise	Octave-Band Frequencies, Hz	Octave-Band Levels of Continuous Noise	Half-Octave-Band Frequencies, Hz	Half-Octave-Band Levels of Continuous Noise	Third-Octave-Band Frequencies, Hz	Third-Octave-Band Levels of Continuous Noise
50	110	37.5- 75	110	37.5- 53	108	45- 57	107
100	95	75- 150	102	75- 106	100	90- 114	99
200	88	150- 300	97	150- 212	94	180- 228	93
400	85	300- 600	95	300- 425	91	360- 456	90
800	84	600-1200	95	600- 850	91	720- 912	90
1600	83	1200-2400	95	1200-1700	91	1440-1824	90
3200	82	2400-4800	95	2400-3400	91	2880-3648	90
6400	81	4800-9600	95	4800-4680	91	5760-7296	90

Table 11 above is a listing of various frequencies and their relative intensities showing the maximum permissible levels for various octaves and octave bands.

5.3.3 Thresholds of Audibility - A threshold of audibility for a specified signal is the minimum effective sound pressure of that signal that is capable of evoking an auditory sensation (in the absence of any noise) in a specified fraction of the trials. It is usually expressed in decibels re 0.0002 microbar. The threshold of audibility varies with a great many factors. It is different from person to person. Even for the same person, it varies from day to day and hour to hour. After exposure to even a moderate noise level, temporary, though slight, deafness occurs which shifts the threshold upward. One of the principal factors affecting the threshold of audibility is age. In Figure 29 we show the results of studies of progressive loss of aural sensitivity with increasing age.

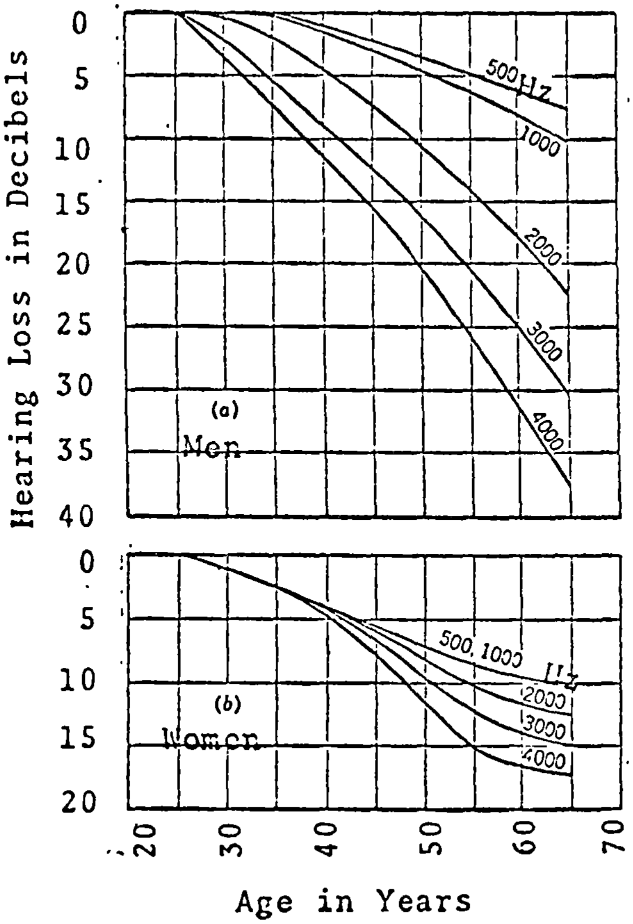

Fig. 29. SHIFT IN AVERAGE THRESHOLD OF HEARING WITH AGE AS A FUNCTION OF FREQUENCY FOR MEN AND WOMEN

A loss in actuity of hearing is manifested by the required increase in the sound level at which a pure tone is just audible. Furthermore, it has been shown that this shift in threshold is a fairly good measure of the loss of ability to understand speech. By definition, the hearing loss of an ear at a given frequency, expressed in decibels, is the difference between the threshold of audibility for that ear and the normal threshold of audibility at the same frequency. The normal threshold of audibility is the modal value of the minimum audible threshold of a large sample of the general population in the United States.

The relationship between the hearing loss and various inabilities to hear has been investigated by the U. S. Public Health Service. In its survey, nearly 9000 persons were asked to classify their hearing ability into one of the five following groups:

(1) Normal hearing; no noticeable difficulty.
(2) Unable to understand speech in a public place such as a church or theater.
(3) Unable to understand speech from a person speaking two or three feet away.
(4) Unable to understand speech from a telephone.
(5) Total deafness; unable to understand speech under any condition.

The hearing loss in the speech-frequency range of those in each of the above groups was measured. The average results are shown in Figure 30. It will be seen, for example, that the group reporting an inability to understand speech in a typical church or theater shows an average hearing loss of about 25 db.

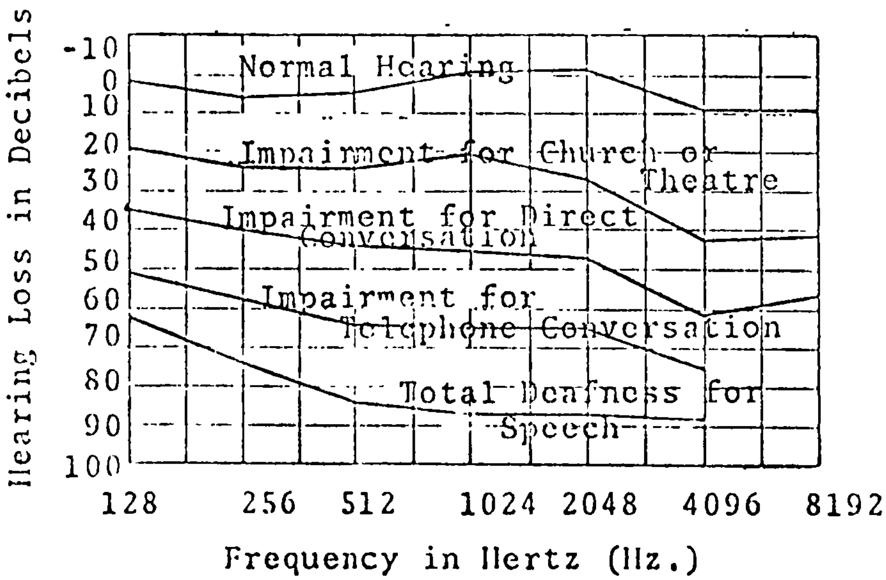

Fig. 30. AVERAGE AUDIOGRAMS FOR GROUPS REPORTING DIFFERENT DEGREES OF HEARING

It is of interest to know what percentage of a group of people have various degrees of hearing loss. Such data may be obtained from the comprehensive survey conducted on a large sample of the population -- visitors to the 1939-1940 World's Fair in New York and San Francisco. A series of curves (Figure 31) has been constructed from these data by Steinberg, Montgomery, and Gardner. The curves give the percentage of the

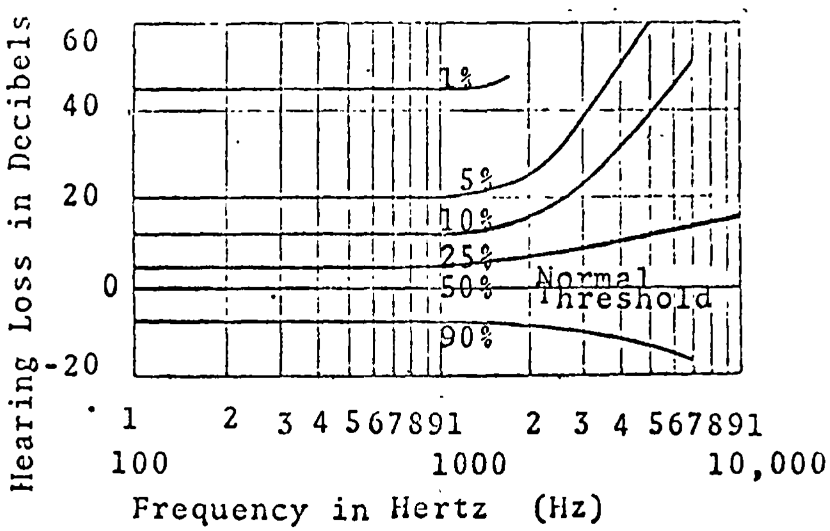

Fig. 31. PERCENTAGE OF POPULATION HAVING A HEARING LOSS AT LEAST AS GREAT AS THAT INDICATED BY THE CONTOUR LINES. (BASED ON DATA OF J. C. STEINBERG, H. C. MONTGOMERY, AND M. B. GARDNER.)

population having a hearing loss of at least 20 db for frequencies below 1000 cycles. In other words, for a pure tone to be just audible for this five per cent of the populat-on, it would be necessary to raise the level of the tone at least 20 db above the level required for a person with "normal" hearing. The loss in the acuity of hearing generally increases with age. This is shown in Table 12. It gives the percentages of the population, according to age groups having a hearing loss of at least 45 db at the several frequencies indicated; these frequencies are representative of the important frequency range for the proper reception of speech. For example, sixteen per cent of the male population between the ages of 40 and 49 has a loss of 3520 cycles of 45 db or more. Note that, in a given age group, the loss at the higher frequencies is greater for men than it is for women.

The loudness of a sound as discussed before depends not only on the pressure of the sound but also on its frequency spectrum. As we have seen, loudness can be described quantitatively in terms of another subjective characteristic of sound, the so-called loudness level, which itself is defined in terms of the sound level, which itself is defined in terms of the sound pressure and frequency of a pure tone; see Figure 32.

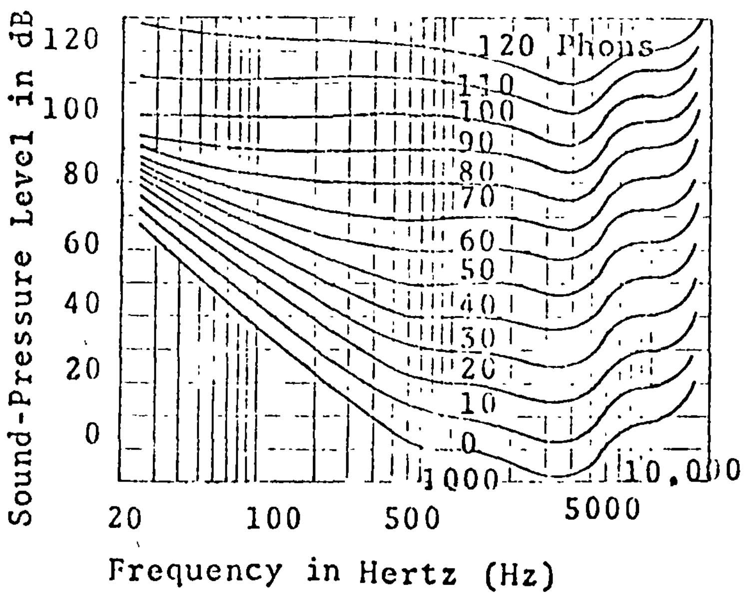

Fig. 32. CONTOURS OF EQUAL LOUDNESS.

Notice that at loss frequencies a given change in sound level produces a much larger change in apparent loudness than does the same change in sound level at higher frequencies. It should be emphasized that the curves in Figure 32 are contours of equal loudness for pure tones and may not apply to continuous sound spectra like room noise. This is one of the reasons why sound-level meters do not measure the loudness level of such sounds correctly.

Table 12

PERCENTAGE OF THE POPULATION HAVING
A HEARING LOSS OF AT LEAST 45 dB

AGE GROUP	LOSS IN DECIBELS		
	FREQUENCY		
	880 Cycles	1760 Cycles	3520 Cycles
10-19			
Men	0.6	0.6	1.8
Women	0.6	0.4	0.3
20-29			
Men	0.1	0.3	2.7
Women	0.4	0.3	0.7
30-39			
Men	0.3	0.6	6.0
Women	1.2	0.8	1.6
40-49			
Men	1.4	2.6	16.0
Women	2.1	1.5	3.0
50-59			
Men	2.6	6.0	27.0
Women	4.0	3.0	7.0

It should be clearly understood that although two sounds having the same loudness level in phons appear to the average observer to be equally loud, this does not imply that the apparent loudness of a sound having a level of 60 phons will seem to be twice as loud as one whose level is 30 phons. The agreement among different observers as to when one sound is just twice as loud as a similar one of lower level is not too satisfactory, but even simple experiments of this type prove conclusively that apparent loudness is not directly proportional to loudness level. More exact determinations made by various indirect methods also show that loudness ratios are not proportional to the increment in loudness level, as might be expected from the logarithmic nature of the definition of the phon. For example, increasing the loudness level by 10 phons from 10 to 20 phons increases the apparent loudness by a factor of approximately 6, whereas a similar increase from 50 to 60 phons increases the loudness by a factor of only about 2.

In a true loudness scale doubling the number of loudness units should double the subjective loudness. Similarly increasing the number of loudness units by a factor of 10 should increase the subjective loudness by the same factor, etc. One indirect method of establishing such a scale depends on the assumption that a sound heard by both ears will appear to be exactly twice as loud as the same sound heard by only one ear. A sound of relatively low level is introduced through telephone receivers to both ears of an observer and is alternated with the same sound introduced into a single ear to such a value that it appears as loud as the sound entering both ears. When this has been accomplished it is assumed that, if these two levels were listened to alternately by both ears, they would appear to have a subjective loudness ratio of 2 to 1. The experiment is then repeated at successively higher and higher initial levels throughout the intensity range of hearing.

5.4 Effects of Noise on Other Physiological Responses

Aside from damage to the hearing mechanism, noise conditions found in industry are not considered to produce any other physiological impairments. Recent reports, however, suggests a tie-up between noise, hearing loss, and cardiovascular disorders although the inter-relationship between these variables is still unclear. Even moderate levels of noise appear to cause constriction in peripheral blood circulation. The significance of such changes to health has not been determined. Individuals working under intense mpose conditions (ball-bearing manufacturing plants) showed some functional disturbances of the cardiovascular system uncluding instability of arterial pressure, slowed heart beat (bradycardia). A fatty diet appears to be associated with both circulatory disorders and hearing loss. Perhaps hearing loss is due to a reduction in nutriment to the hearing sense organ resulting from noise-induced constriction in blood flow or from a cardiovascular disorder of another origin. Obviously, there is a need for more research in this area.

It should be mentioned that intense noise of sudden onset will cause marked physiological changes including a rise in blood pressure, increase in sweating, changes in breathing, and sharp contractions of muscles in the body.

These changes are generally regarded as an emergency reaction of the body, increasing the effectiveness of any muscular exertion which may be required. Although perhaps useful in emergencies, these changes may be harmful for long periods since they would interfere with other necessary activities or produce undue amounts of fatigue. Fortunately, these physiological reactions subside with repeated presentations of the noise.

It has often been stated that in order for performance on a task to remain unimpaired man must exert greater effort in a noisy environment than necessary under more quiet conditions. Measu-es of energy expenditure, e.g., oxygen consumption, pulse rate, muscle potential, do show changes in the early stages of work under noise conditions which are indicative of increased effort. With continued exposure, however, these responses return to their normal level.

Intense (or extremely high) levels of sound (over 140 dB) are capable of causing dizziness or loss of equilibrium since the balancing organs (semi-circular canals) are stimulated. Such high intensity exposures may also cause alternations with other types of sensory behavior, and will definitely cause pain, perhaps even traumatic damage in unprotected ears. Examples of such extreme noise conditions are few; possibly in jet engine test cells would these high levels be reached.

5.5 Impairments in Performance Efficiency

Contrary to popular thinking, there is little evidence to support the notion that noise degrades performance. Laboratory studies of this problem have shown that tasks involving simple, repetitive operations are not affected by noise. Although efficiency in more complex tasks may be initially decreased by noise, such effects tend to vanish as exposure time and/or practice on the task increases. There have been reports, however, which show noise to cause significant losses on vigilance-type tasks. Such tasks require the subject to keep a constant watch over a number of dials or indicators so as to report changes that may occur on any dial at any time. Noise-related losses in vigilance performance are important because of their implications for automated jobs which involve the monitoring of control panels with many indicators displaying information about an ongoing machine process. This finding also has practical importance for jobs requiring the inspection of items passing on a conveyor belt. In such situations a single item must be viewed within a short period of time before passing on to the next.

Field studies concerned with efficiency changes associated with reductions in noise have yielded data that are suspect. Some investigators have noted increased output consequent to noise control treatment in select work areas. This improved performance level was maintained, however, with the restoration of the original noisier conditions. The effects on performance in these cases are probably due to morale changes. That is, the workers see that an interest is being taken in them or their working conditions and respond with increased effort, leading to greater output. The fact that field studies cannot control factors such as morale, motivation, worker attitudes toward job or supervisor makes it difficult to obtain valid and reliable data reflecting the effects of manipulation of the occupational noise conditions upon performance. For the same reasons, it is difficult to establish cause and effect relationships between industrial noise conditions and accident rate, absenteeism, and employee turnover.

5.6 Noise and Annoyance

Perhaps the most widespread reaction to noise is that it is annoying. Whether annoyance types of noise conditions constitute a hazard to health is not known. It has been stated that residents of communities surrounding airports develop hypertension, ulcers, undue anxiety and nervous disorders as a result of the aircraft flyover noise exposure. These effects, however, have never been verified. In fact, stu of communities impacted by aircraft noise show complaints to be motivated by factors that do not bear directly on the health status of the exposed population, e.g., interruption in voice conversation (telephone use) and TV reception, personal grievances against the airport management. Such studies, however, have not included a survey of the health of the residents in the impacted area and so do not rule out the possibility that physiological or mental type disorders may stem from such noise conditions.

In any event, judgments of noise-annoyance are complicated by many non-acoustical considerations. Some of these considerations are cited below with examples to illustrate each of them.

1. Factor: The sound has unpleasant associations.

Example: The annoyance caused by the intrusion of aircraft noise into communities around airports is based, in part, upon the residents being fearful of the planes crashing into their homes.

2. Factor: The sound is inappropriate to the activity at hand.

Example: Music tolerated during waking hours may be annoying during the hours of sleep.

3. Factor: The sound is unnecessary.

Example: People may complain of the noise made by the neighbor's pets, but not by the delivery trucks in the same neighborhood.

4. Factor: The sound has an advantage associated with it.

Example: The comforts derived from air conditioning outweighs the noise of such units. Similarly, the economic value of nearby plants to a community may balance out the noise produced by the plants; annoyance due to military aircraft noise may be offset by the assurance against surprise attack by an enemy.

5. Factor: Individual tolerance to noise.

Example: Some individuals complain about all kinds of noise as well as other types of nuisances.

As for the stimulus itself, there appear to be some basic characteristics of sound which can be considered as more annoying than others. These characteristics are as follows:

1. Loudness - the more intense and consequently louder sounds are more annoying.

2. Pitch - a high pitch sound, i.e., one containing high frequencies is more annoying than a low pitch sound of equal loudness.

3. Intermittency and irregularity - a sound that occurs randomly in time and/or is varying in intensity or frequency is judged more annoying than one which is continuous and unchanging.

4. Localization - a sound which originates from several sources or locations is less preferred than one which originates from a single source.

At the present time, extensive interest is being directed toward identifying which measure or measures of noise best correlates with annoyance reactions.

For office conditions, speech-interference-level values and loudness-level determinations (these values represent the decibel level of a 1000 cps tone judged equal in loudness to the sound or noise in question) correlate well with subjective ratings of annoyance.

A new measure called perceived noisiness in decibels (PN^{dB}) (22) has been found to agree well with subjective ratings of the acceptability of flyover aircraft noises. This measure takes into account the octave band intensity levels of the noise in question and adjusts them in terms of data showing equal annoyance judgments for different bands of noise. Some noise criteria for airport operations are specified in terms of PNdB. John F. Kennedy Airport (formerly Idlewild), for example, has a noise ceiling of 112 PN^{dB} for all aircraft operations as measured under the flight path of outgoing or incoming aircraft at one-fourth mile from the end of the runway.

Besides PNdB computations, still other procedures have been proposed to convert the physical measurements of a noise into numerical expressions of annoyance level: Specifically, conversions to loudness measures in sones or phons as developed by Stevens or by Zwicker's technique are quite popular for noise annoyance quantification. The assumption in using loudness formulations for rating noise-annoyance is that loudness is the chief determinant in annoyance judgments. Also A-scale sound-level values read directly off a conventional sound pressure-level meter have been frequently used to provide numerical expressions of noise-annoyance conditions. Inherent to the A-scale readings as well as the conversion procedures noted are weighing schemes which reflect, in various ways, established relationship between the physical dimensions of sound (primarily frequency and intensity) and associated auditory reactions, both psychological and physiological. (A discussion of the relationships underlying the various conversion procedures is found in References.)

It must be emphasized again that the procedures noted above can give only limited prediction of community noise nuisance because they consider only the physical characteristics of the noise stimulus itself. Other factors -- social, personal, economic -- must also be taken into account in making such predictions. Several models now exist which consider the physical characteristics of the noise together with known social and psychological factors in estimating the complaint potential of a noise to a community or neighborhood. One of these models is described in Section N-5. The accuracy of the prediction made by this and other models has still not been sufficiently determined.

SUMMARY

Adverse effects of noise on man include temporary and permanent hearing loss, speech disruption, loss in performance capacity, and annoyance. Factors believed critical in evaluating a potential noise hazard to hearing are the noise, total exposure duration, time and frequency distribution of short term exposure periods, and susceptibility of an individual's ears to noise-induced hearing loss. Specifications for valid damage risk crit for noise exposure must take account of these factors. Measures for predicting speech interference of noise are available and have been used as a guide for establishing limiting noise conditions in rooms hwere effective speech communication is needed. Performance changes and non-auditory physiological changes due to noise have been reported but will require further substantiation. Annoyance reactions to noise are based upon both acoustic and non-acoustic considerations. Models and measures for predicting noise-nuisance are available, but require validation.

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INTRODUCTION TO ACOUSTICS

1.1 Introduction

In this discussion of noise and vibration, it is intended to move quickly into the use of acoustical terms and to become acquainted with some of the elementary acoustical procedures without necessarily knowing or comprehending all the acoustics background that goes into the development of this material. Textbooks or reference books in acoustics may be studied for a more detailed discussion and technical understanding of this material.

Sound is defined by the United States of America Standards Institute (USASI) (formerly the American Standards Association) as an oscillation in pressure, stress, particle displacement, particle velocity, etc. in a medium with internal forces (e.g., elasticity, viscosity) or the superposition of such propagated oscillations, or as an auditory sensation evoked by the oscillations described above. The term "sound wave" could be used for the first concept, and "sound sensation" for the second concept.

Sound may also be defined in two ways- objectively and subjectively. Objectively, sound is a form of wave motion due to pressure alteration or particle displacement in an elastic medium.

Subjectively, sound is a sensory experience in the brain.

It is a moot point, for example, whether a sound is produced when a giant tree crashes to the ground in an uninhabited forest. This, of course, is just a matter of definition. In this manual, the word sound will be used to denote a physical disturbance, an alteration or pulsation of pressure, capable of being detected by a normal ear. (In accordance with this definition, the falling tree does generate sound.) In general such a disturbance reaches the ears by traveling through air. In any case, a medium possessing inertia and elasticity is needed to propagate it. Sound waves do not travel through a vacuum.

The auditory sensation produced by sound waves will be called sound sensation. The crashing tree produces a sound sensation only when an ear hears it.

[Sounds are frequently classified into three types: noise, music, and speech. However, this classification is not always clear-cut. It is sometimes questionable, for example, whether a sound should be classified as music or noise. In general, noise may be defined as unwanted sound. Thus, if one is listening to a concert in an auditorium, a conversation in the next row may be regarded as noise. On the other hand, if one is trying to converse on the telephone while "Junior's Dixieland Four" is holding forth in the living room, this music, as far as the person on the telephone is concerned, very definitely falls under the classification of noise.

Sound may also be classified as ordered or disordered. In an ordered sound the instantaneous pressure follows a regular pattern. Furthermore, a frequency analysis of such sound will show a definite overtone structure; that is, the sound can generally be resolved into a fundamental frequency and a series of overtones, the latter having frequencies that often are integral multiples of the fundamental frequency. Overtones possessing this simple relationship of frequencies are called harmonics. On the other hand, the peaks of acoustic power in disordered sound (for example, the background noise in a large auditorium) occur more or less at random. In such sound, practically all audible frequencies, from the lowest to the highest, are present. The periodic qualities of ordered sound are lacking.]

1.2 Basic Definitions

Frequency - The number of complete to-an-fro vibrations that the source, and hence the particles in the medium, makes in 1 second is called the frequency of vibration. A string that undergoes 256 complete oscillations in 1 second ("middle C") produces a vibration of the same frequency in the surrounding air and in the eardrum of an observer in the sound field. This assumes that the source and the observer are at rest with respect to the medium- the usual assumption in room acoustics. Frequency is a physical phenomenon; it can be measured by instruments, and it is closely related to,

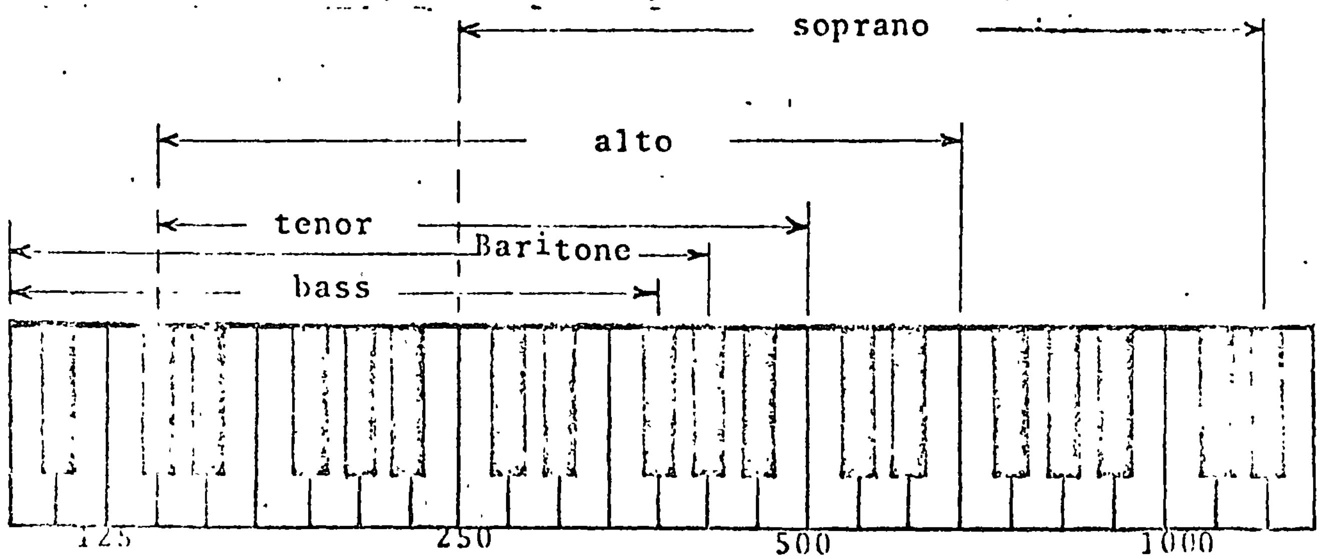


Fig.#1
PIANO KEYBOARD SHOWING HUMAN VOICE OCTAVE RANGES

but not the same as pitch -- a psychological phenomenon. Frequency is usually designated by a number followed by cycles per second (abbreviated cps)*. Figure 1 shows the piano keyboard and the relative ranges in frequency of male and female voice types.

Loudness and Pitch - Two of the various characteristics that distinguish one sound from another are loudness and pitch. Loudness is a measure of the quantity of sound that reaches the listener's ear. Pitch is a measure of the quality of a pure tone. Some sounds are pure tones and others a combination of several tones, but many sounds are neither. Instead, they can be described as "broad band" sounds. Even without distinctive tones the sounds may have a characteristic quality that identifies the source to the average listener.

We will be discussing pitch and loudness in greater detail later on in this section on Acoustics.

Propagation of Sound - Sound has its origin in vibrating bodies. A plucked violin string or a struck tuning fork can actually be seen to vibrate. In the sounding board of a piano and the paper cone of a loudspeaker, as in most other sound sources, the amplitude of vibration is too small to be observed visually but often the vibration can be felt with the finger tips.

Consider the tuning fork in Fig. 2 vibrating in air. As it moves in an outward direction it pushes a "layer" of air along with it; this layer of air is compressed, and its density and temperature are correspondingly increased. Since the pressure in this layer is higher than that in the undisturbed surrounding atmosphere, the particles (that is, the molecules) in it tend to move in the outward direction and transmit their motion to the next layer, and this layer then transmits its motion to the next, and so on. As the vibrating body moves inward, the layer of air adjacent to it is rarefied. This layer of rarefaction follows the layer of compression in the outward direction, and at the same speed; the succession of outwardly traveling layers of compression and rarefaction is called wave motion. The speed of propagation is determined by the compressibility and density of the medium -- the less the compressibility of the medium and the less its density, the faster will the wave motion be propagated.

(*) Frequency, Hz and CPS (With the recent trend in U.S. and international standards to recognize the early men in science, many new names for old units are being adopted. The traditional unit for frequency in the U.S. has been "cycles per second", abbreviated "cps", The new international unit for frequency, recently adopted by U.S. standards groups, is "Hertz", abbreviated "Hz". Throughout the remainder of this manual the new unit "Hz" will be used; it has the same meaning as "cycles per second".

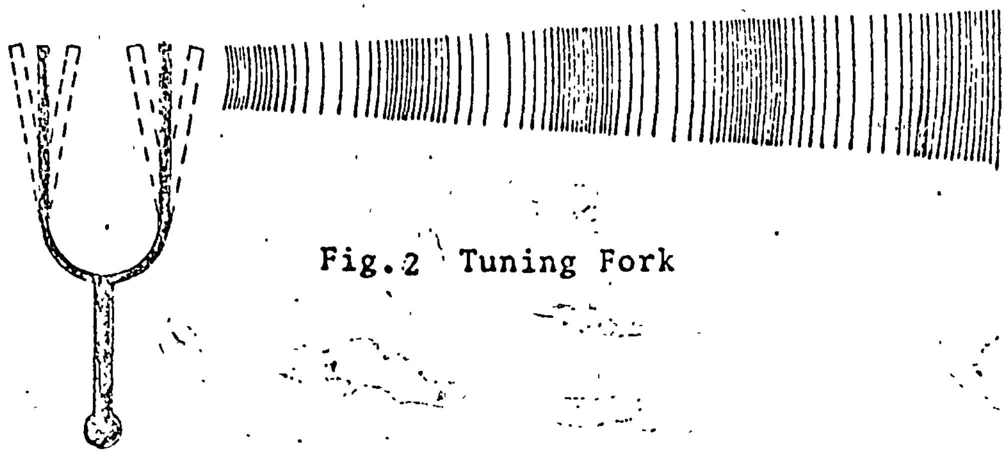


Fig. 2 Tuning Fork

In acoustics, the term "level" is used whenever a decibel quantity is expressed relative to a reference value, as in "sound pressure level" (referred to the reference value of 0.0002 microbar) and "sound power level" (referred to the reference power of 10^{-12} watts).

Sound Pressure Level - The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of the sound to the reference sound pressure. Unless otherwise specified, the effective (rms) pressure is to be understood. The reference sound pressure is 20 $\mu N/m^2$.

Sound Level (Noise Level) - For air-borne sound, sound level (noise level) is a weighted sound pressure level, obtained by the use of metering characteristics and the A-weighting as specified in the referenced standards. When the A-weighting is employed, it must be indicated.

1.3 Sound Pressure Level

The ear is sensitive to sound pressure. Sound waves represent tiny oscillations of pressure just above and just below atmospheric pressure. These pressure oscillations impinge on the ear and we hear the sound.

A "sound level meter" is also sensitive to sound pressure. When a sound level meter is properly calibrated, it relates the sound pressure of an incident sound wave to the standard reference pressure (0.0002 microbar) and it gives a reading in decibels relative to that reference pressure. "0 dB" on this scale means 0 dB above the reference pressure, which, of course, is the same as the reference pressure. This reference pressure, or 0 dB sound pressure level, represents approximately the weakest sound that can be heard by the average young human ear in the frequency region of highest sensitivity.

A simple but expressive definition of "noise" is that it is "unwanted sound"; so "noise level" is often used synonymously with "sound pressure level." Both terms have the same reference pressure and are used interchangeably in this manual. The reference to 0.0002 microbar may be and frequently is omitted when it is clearly understood that the dB quantity is a sound pressure level. Hence one might say that "the noise level in the City is about 75 dB."

1.4 Analogy Between Light and Sound

Sound pressure and sound power can be illustrated simply with an analogy between light and sound. Suppose first that a room is illuminated with a bare 15-watt electric lamp. Even in a room with white painted walls and ceiling, this normally would be considered as a weak light source. If the room had only dark, unreflecting surfaces, the general room illumination would be very poor. Now a bare 150-watt lamp would give good general illumination if the walls are white, or light-colored, or highly reflecting (and depending, of course, on the size of the room and the distance to the lamp). However, the same 150-watt lamp might not give adequate room illumination if the walls and ceiling were black, or dark-colored or non-reflective. Thus, it is reasonably obvious that the intensity of the general room illumination depends not only on the power rating of the lamp, but also on the light-reflecting (or absorbing) properties of the room surfaces, on the size of the room, and on the distance to the light source. Further, if the lamp had a lamp-shade or if it were recessed in a flush-mounted ceiling receptacle, the light would be brighter in some directions than in others.

All the same factors apply to sound in a room! "Sound pressure level" is somewhat analogous to room illumination; "sound power level" is somewhat analogous to the power rating of the lamp. A "weak" sound source would produce low sound levels while a "stronger" sound source would produce higher sound levels. A constant sound source that would produce one sound level in a hard-walled bare room would produce a different sound level in the same room surfaced with a large amount of soft, fluffy acoustic absorption material.

The sound source would produce a higher sound level a few inches away than it would several feet away. It might radiate higher sound levels from one side than from another side. It would produce different sound levels in a large room than it would in a small room. Thus, the sound level in the room depends not only on the sound source (actually its "sound power"), but also on the sound absorption properties of the room surfaces, on the size of the room, the distance to the sound source, and also the directional characteristics of the sound source. In effect, the sound pressure levels heard by a person in the room are determined both by the sound power radiated by the source and by the "acoustic characteristics" of the room. All of this is merely leading up to the fact that (1) there is need for a way of rating a sound source that is independent of the environmental surroundings, and (2) there is need for a way of describing the "acoustic characteristics" of the room that is independent of the sound source. Then, with these two independently determined bits of information, any known, definable room or space and the sound field or "sound pressure level" ("SPL") about the room can be determined, remembering that it is the sound pressure level to which people respond in their living and working environments. Just as the 150-watt lamp may produce relatively poor to good illumination in a given room, so also will a sound source produce relatively low or high sound pressure levels in a given room. Further, just as electric lamps are rated by a power rating, so also sound sources are rated by a power rating.

1.5 Decibels

Just as "inches" are used to measure distance and "degrees" are used to measure temperature, "decibels" are used to measure sound intensity. As in electrical engineering, decibels are used to express in logarithmic terms the ratio of two powers; i.e., if there are two electrical or acoustical powers P_1 and P_2, the ratio of those powers expressed in decibels would be

$$10 \log P_2/P_1$$

If the power P_1 were some accepted standard reference power, such as a watt or some other basic unit of power, the decibels could be standardized to that reference value.

In acoustics, the decibel (abbreviated "dB") is used to compare both sound power and sound pressure. When describing the sound power of a sound source, the basic reference power is 10^{-12} watt. When describing the sound pressure in a sound field, the basic reference pressure is 0.0002 microbar, and a particular area might be stated as having a "sound pressure level" of, say, 90 dB re 0.0002 microbar.

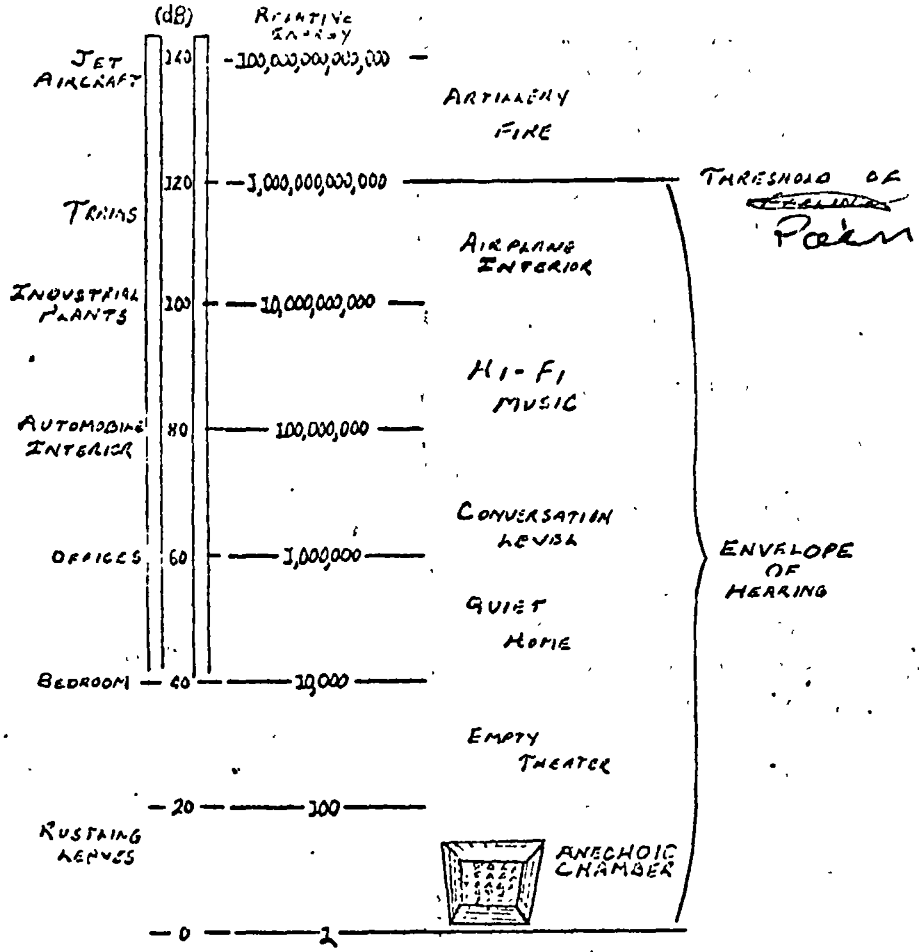


Fig. 3 LOGARITHMIC VARIATIONS

The figure above displays the logarithmic aspect of the decibel scale. Further discussions of decibel nomenclature appear in Part "C" of this section

Sound Power - Sound power waves travel away from the vibrating object in all directions in the form of spherical waves. These waves will continue to travel until they are absorbed by the air, or reflected by some object. The acoustic power passing through a unit surface area decreases as the distance from the source increases.

1.6 Sound Power Level

The quantity "sound power level" (PWL) expresses, in decibels relative to the reference power of 10^{-12} watt, the total amount of sound power radiated by a sound source, regardless of the space into which the source is placed. As suggested above, if the power level of a sound source is known and if the "acoustic characteristics" of a space are known, it will then be possible to estimate or calculate the sound pressure level in that space. Ultimately it is the SPL that usually must be determined because it is on that basis that people judge an acoustic environment.

A microbar is equal to one dyne per sq. cm. or 0.1 newton per sq. meter and is very nearly equal to one millionth of a standard atmosphere. It is likely that in a few years the reference pressure 0.0002 microbar will come to be known as $2x10^{-5}$ newton per sq. meter. If this comes, it will be in the interest of international standardization of terminology and units.

1.7 "Overall" Frequency Range and Octave Bands of Frequency

In order to represent properly the total noise of a noise source, it is usually desirable or necessary to break the total noise down into its various frequency components; that is, how much of the noise is low frequency, how much high frequency and how much is in the middle frequency range. This is essential for any comprehensive study of a noise problem for two reasons: (1) people react differently to low frequency and high frequency noise (for the same sound pressure level, high frequency noise is much more disturbing and is more capable of producing hearing loss than is the case for low frequency noise); and (2) the engineering solutions to reduce or control noise are different for low frequency and high frequency noise (low frequency noise is more difficult to control, in general).

It is conventional practice in acoustics to determine the frequency distribution of a noise by passing that noise successively through several different filters that separate the noise into 8 or 9 "octaves" on a frequency scale. Just as with an "octave" on a piano keyboard, an "octave" in sound analysis represents the frequency interval between a given frequency (such as 250 Hz) and twice that frequency (500 Hz in this illustration).

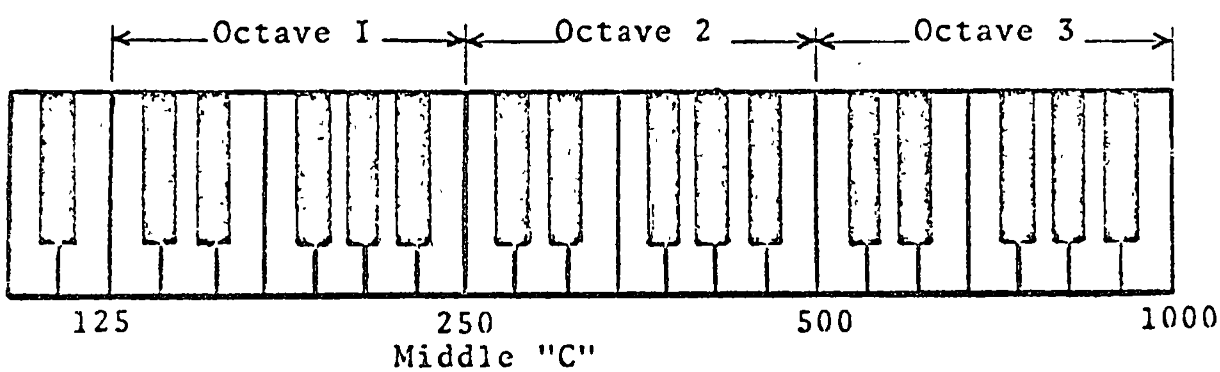


Fig. #4
PIANO KEYBOARD SHOWING #3 OCTAVE RANGE

In conducting noise studies it is often necessary to determine the distribution of sound pressure with frequency because hearing loss, annoyance, speech interference, sound absorption, etc., all vary with frequency. This can be done by measuring the sound pressure in frequency bands of various widths. Those most commonly used are the octave, half-octave, and third-octave bands. An octave band is a frequency interval in which the upper frequency is twice the lower frequency, such as 150 to 300 cycles per second or 1200 to 2400 cycles per second.

The frequency bands in use in the U.S. before adoption of the bands listed above are as follows: 20-75, 75-150, 150-300, 300-600, 600-1200, 1200-2400, 2400-4800 and 4800-10,000 Hz. Most of the literature in acoustics before about 1963 will refer to these "old" frequency bands. The "new" international standard frequencies (sometimes called "preferred frequencies" in current literature) are used in this manual. Essentially the "old" and "new" frequency bands may be considered as being equivalent, with a few exceptions that will not be significant to the material in this manual. A set of filters used to separate a complex sound into octave bands is commonly referred to as an "octave band analyzer."

When a sound <u>pressure</u> level or a sound <u>power</u> level includes all the audio range of frequency, the resulting value is called the "overall" level. When the level refers to the sound in just one specific octave frequency band, it is called an "octave band level" and the frequency band is either stated or clearly implied.

For some special situations, a noise spectrum may be studied in finer detail than is possible with octave frequency bands. In such cases one-third octave bands might be used or even narrower filter bands might be used, for example to separate one particular frequency from another one if it is desired to separate the causes of a particular complex noise. The bandwidth and the identifying frequency of the band should always be specified.

The normal frequency range of hearing for most people extends from a low frequency of about 20 Hz up to a high frequency of 10,000 to 15,000 Hz, or even higher for some people. By virtue of U.S. adoption of a recent international frequency standard in acoustics, most octave-band noise analyzing filters now cover the audio range of about 22 Hz to about 11,200 Hz in nine octave frequency bands. These filters are identified by their geometric mean frequencies; hence 1000 Hz is the label given to the octave frequency band of 700-1400 Hz. The nine octave bands of the "new" international standard are as follows (the numbers are frequently rounded off):

Octave Frequency Range (Hz)	Geometric Mean Frequency of Band (Hz)
22-44	31-1/4
44-88	62-1/2
88-175	125
175-350	250
350-700	500
700-1400	1000
1400-2800	2000
2800-5600	4000
5600-11,200	8000

The term "overall" designates the full frequency coverage of all the octave bands, hence 22-11,200 Hz, or in some cases, 44-11,200 Hz when the 31 Hz band is omitted.

1.8 Weighting Networks: A-, B- and C- Scales

Sound level meters are usually equipped with "weighting circuits" that tend to represent the frequency characteristics of the average human ear for various sound intensities. Hence, "overall" readings are sometimes taken with "A-scale" or "B-scale" or "C-scale" settings on the meter. The "A-scale" setting of a sound level meter filters out as much as 20 to 40 dB of the sound below 100 Hz, while the "B-scale" setting filters out as much as 5 to 20 dB of the sound below 100 Hz. The "C-scale" setting is reasonably "flat" with frequency, i.e. it retains essentially all the sound signal over the full "overall" frequency range. A plot of the frequency response of the electrical system of a sound level meter meeting USASI (U.S.A. Standards Institute, formerly American Standards Association) standards for the A-, B- and C- scale weighting networks is shown in Figure 5. For several years the A- scale and B- scale readings were held in disfavor because they do not provide any knowledge of the frequency distribution of the noise, but there is a revival in the use of A- scale readings as a single-number indicator of the relative loudness of a sound as heard by the human ear. It is very important, when reading A-, B- or C- scale sound levels, to positively identify the scale setting used. The resulting values are called "sound levels" and are frequently identified as dB(A), or dB(B) or dB(C) readings. Note that these readings do not represent true "sound pressure levels" because some of the actual signal has been removed by the weighting filters.

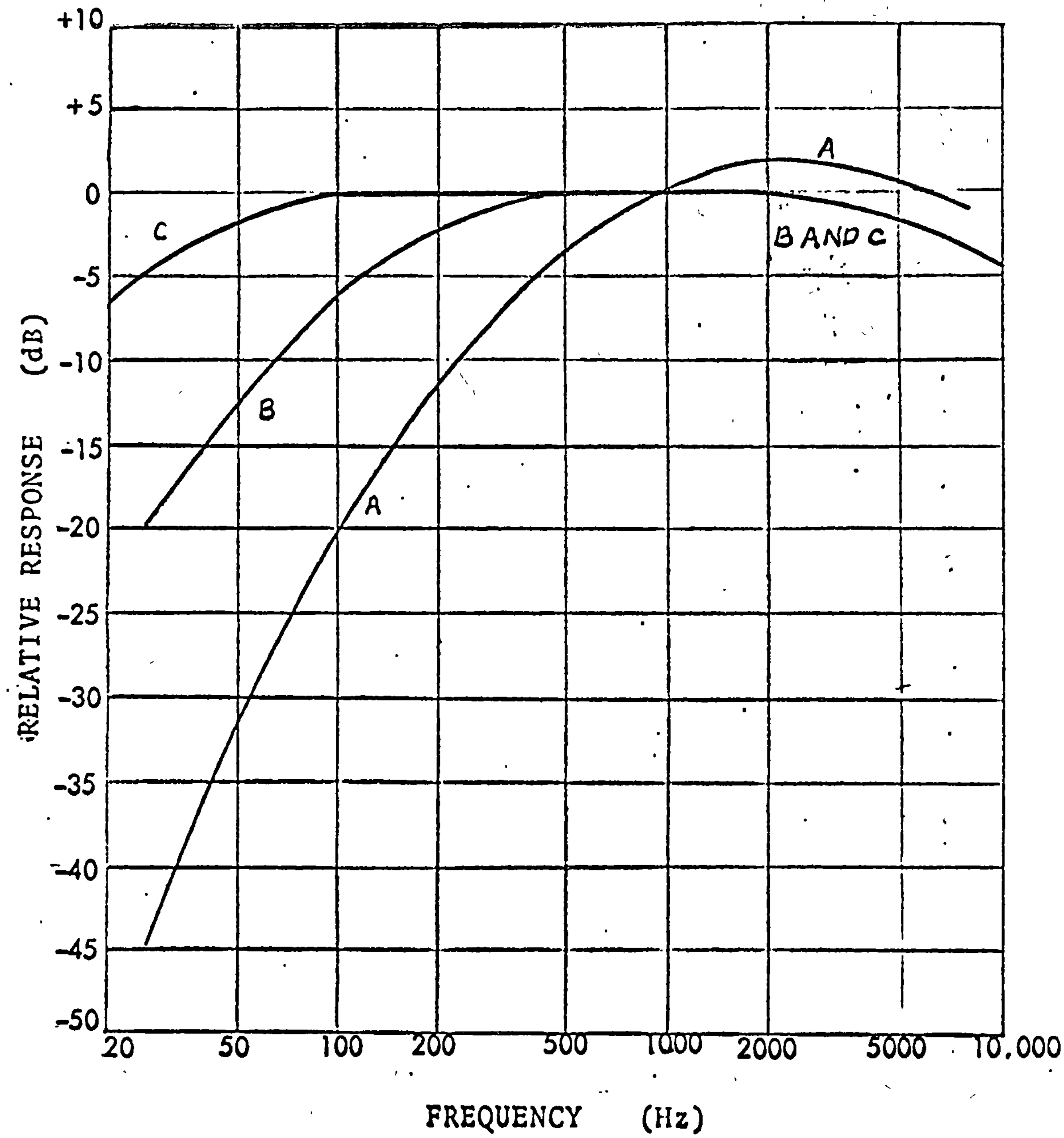


Fig. 5 WEIGHTED SCALES

For most acoustic applications the octave frequency band readings are the most useful. It is always possible to construct A-, B- or C- scale readings from all the octave band readings, but it is never possible to exactly construct the octave band readings from the weighting scale readings.

2.0 Waves

If a stone is dropped into a quiet pool of water, a disturbance is created where the rock enters the liquid. However, the disturbance is not confined to that place alone but spreads out so that it eventually reaches all parts of the pool. (Fig.6)

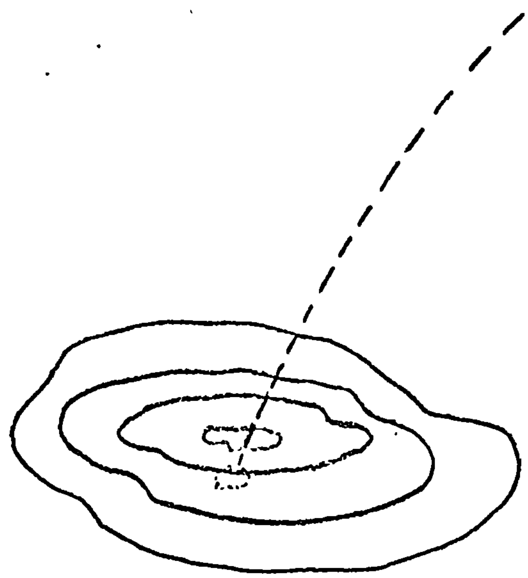


Fig 6. ROCK IN POND

When the stone enters the water, it sets into motion the particles of water with which it comes in contact. These particles set into motion neighboring particles. They in turn produce similar motion in others and so on until the disturbance reaches particles at the edge of the pool. In all this disturbance no particle moves far from its initial position. Only the disturbance moves through the water. This behavior is characteristic of all wave motions. The particles move over short paths about their initial positions and as a result a wave moves through the medium. A wave is a disturbance that moves through a medium. The medium as a whole does not progress in the direction of the wave.

As another example of this compression and rarefaction effect, Fig. 7 shows a piston at one end of a long tube filled with a compressible fluid. The vertical lines represent certain layers of molecules which are equally spaced when the medium, such as a fluid, is at rest. In our discussion we shall ignore the random thermal motion of the molecules for the time being at least. If we push the piston forward, the layers of fluid in front of it are compressed. These layers will in turn compress layers farther along the tube, and a compressional pulse travels down the tube. If we then quickly withdraw the piston, the layers of fluid in front of it expand and a pulse of rarefaction travels down the tube from layer to layer. These pulses are similar to transverse pulses traveling along a string, except that the particles of the medium are displaced along the direction of propagation (longitudinal) instead of at right angles to this direction (transverse). If the piston oscillates back and forth, a continuous train of compressions and rarefactions will travel along the tube (Fig. 7).

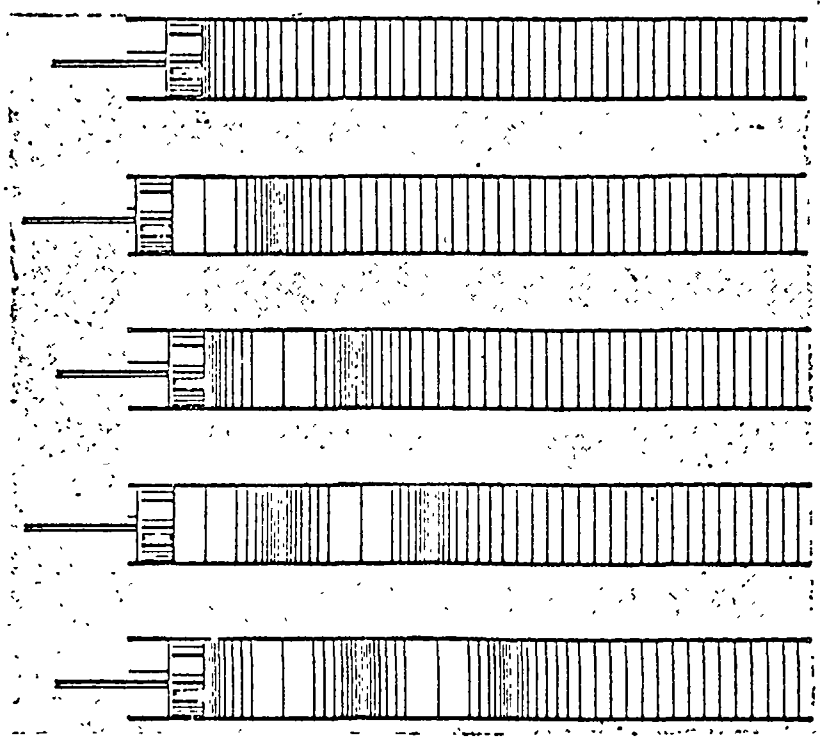


Fig. 7. SOUND WAVES BEING GENERATED IN A TUBE BY AN OSCILLATING PISTON SHOWING COMPRESSIONS AND RAREFACTIONS

2.1 Air and Sound Pressure

2.11 Weather Systems

a. All forms of energy tend to flow from regions of higher concentrations to lower concentrations. Thus, high pressure weather systems follow low pressure systems in an attempt to balance the forces of nature.

b. The barometric pressure is the scale by which the meterologist can determine the relative changes of high and low air systems over a period of time.

2.2 Audible, Ultrasonic, and Infrasonic Waves

Sound waves can be propagated in solids, liquids, and gases. The material particles transmitting such a wave oscillate in the direction of propagation of the wave itself. Actually, there is a large range of frequencies within which longitudinal mechanical waves can be generated. Sound waves are confined to the frequency range which can stimulate the human ear and brain to the sensation of hearing. This frequency range spreads from about 20 Hz. to about 20,000 Hz. and is called the audible range. A longitudinal mechanical wave whose frequency is below the audible range is called an infrasonic wave, and one whose frequency is above the audible range is called an ultrasonic wave.

Infrasonic waves of interest are usually generated by large sources, earthquake waves being an example. The high frequencies associated with ultrasonic waves may be produced by elastic vibrations of a quartz crystal induced by resonance with an applied alternating electric field (piezoelectric effect). It is possible to produce ultrasonic frequencies as high as 6×10^8 cycles/sec in this way; the corresponding wavelength in air is about 5×10^{-5} cm.

Audible waves originate in vibrating strings (for example, violin, human vocal cords), vibrating air columns (for example, organ, clarinet), and vibrating plates and membranes (for example, drum, loudspeaker, xylophone). These vibrating elements alternately compress the surrounding air on a forward movement and rarefy the air on a backward movement. (Fig. 8). The air transmits these disturbances outward from the source as a wave. Upon entering the ear, these waves produce the sensation of sound. Waveforms which are approximately periodic or consist of a small number of approximately periodic components give rise to a pleasant sensation, as for example musical sounds. Sound whose waveform is very irregular is heard as noise. Noise can be represented as a superposition of periodic waves, but the number of components is very large.

The generation of sound is probably most easily described by using a vibrating object as the source. While the vibrating object is moving in one direction, there is a buildup of pressure as the air molecules are pushed together, which continues

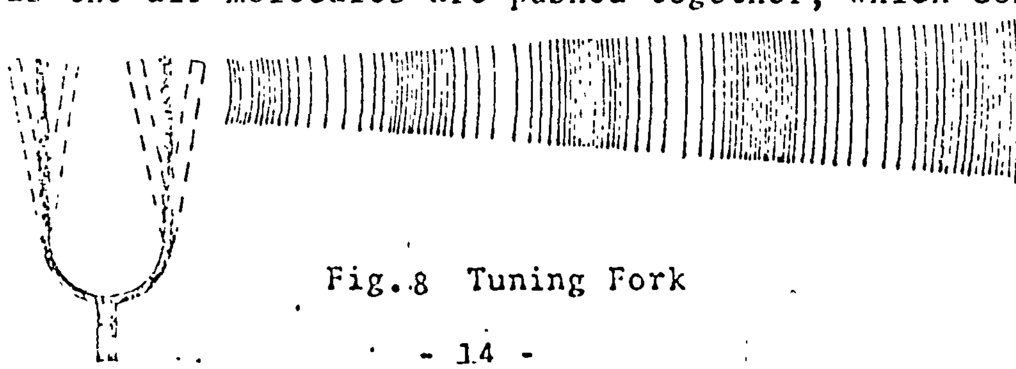


Fig. 8 Tuning Fork

until the object reverses direction. This region of higher pressure is a pressure wave which moves out in all directions from the object. As the object moves in the opposite direction, the air molecules move further apart and a region of reduced pressure is created. This region of reduced pressure is forced out from the vibrating object by the next pressure wave. As the vibration continues, waves of increased and decreased pressures are set up. One complete vibration of the object corresponds to one complete cycle of pressure change. The number of object vibrations or pressure cycles per unit time defines the frequency of the sound wave.

The speed of a sound wave in air does not vary appreciably with frequency in the audible range. Furthermore, the speed does not change with intensity except for very intense waves. For a powerful source of sound such as an air-raid siren, the speed of the sound within a few inches from the source increases slightly with increasing intensity.

The speed with which sound waves travel is a function of the elasticity of the air is equal to a constant times the static pressure of the air, i.e., atmospheric pressure. The constant is equal to the ratio of the specific heat of air at constant pressure to the specific heat at constant volume, which at the temperatures normally encountered would be equal to 1.4. Thus, the speed of sound (c) can be computed from the equation

$$c = \sqrt{\frac{1.4 P_o}{\rho_o}}$$

where P_o = atmospheric pressure

ρ_o = the density of the air

Since a sound wave involves compression and expansion of some material, sound can be transmitted only through a material medium having mass and elasticity. No sound can be transmitted through a vacuum. This fact can be demonstrated experimentally by mounting an electric bell under a bell jar and pumping the air out while the bell is ringing. (Fig. 9)

As the air is removed, the sound becomes fainter and fainter until it finally ceases, but it again becomes audible if the air is allowed to reenter the jar.

Sound waves will travel through any elastic material. We are all familiar with sounds transmitted through the windows, walls, and floors of a building. Submarines are detected by the underwater sound waves produced by their propellers. The sound of an approaching train may be heard by waves carried through the rails as well as by those transmitted through the air. In all materials the alternate compressions and rarefactions are transmitted in the same manner as they are in air.

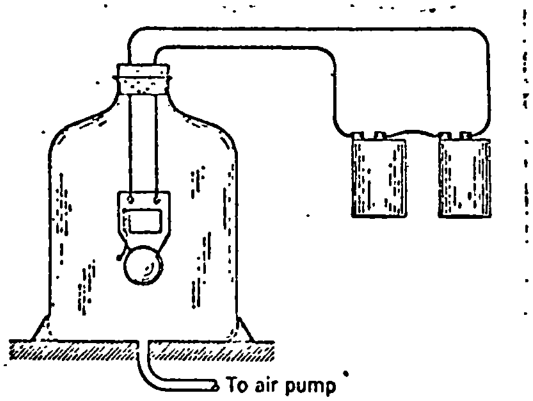


Fig. 9. BELL JAR

Airborne sound refers to rapid pressure variations; that is, alternate increases and decreases in normal atmospheric pressure produced by a vibrating object or turbulence within the air.

Sound travels much faster in liquids and solids than it does in air. Thus the speed in water is about 5000 feet per second; in hard wood it is about 13,000 feet per second along the fibers and only 1000 feet per second across them: and in stone it is about 12,000 feet per second.

Some typical values for the speed of sound are given in Table I below:

TABLE I
Speed of Sound

Medium	Temperature °C	ρ Mass	Speed Meters/sec	Speed Ft/sec
Carbon Dioxide	0	2.0 g/l	258.0	846
Air	0	1.3 g/l	331.3	1,087
Hydrogen	0	0,9	1,286	4,220
Oxygen	0		317.2	1,041
Water	15		1,450	4,760
Lead	20		1,230	4,030
Aluminum	20		5,100	16,700
Copper	20		3,560	11,700
Iron	20		5,130	16,800
Extreme values				
Granite			6,000	19,700
Vulcanized rubber	0		54	177

2.2.1 Absorption of Sound in Air - It is well known that every type of wave motion, including sound, loses part of its energy as it is propagated through a ponderable medium such as air. The attenuation of sound is due to viscosity, heat conduction, radiation, scattering, and molecular absorption. The attenuation of sound waves having pressures ordinarily associated with speech and music depends principally on the frequency of the sound wave, relative humidity, wind factor temperature, and other environmental variables.

The wind and temperature variations in the atmosphere may greatly modify the distribution of energy about a sound source by bending the sound rays from their usual rectilinear paths. These effects on the propagation of sound in the atmosphere, as well as the absorptive properties of the air itself and the influence of sound-absorptive surfaces in the sound field, are discussed in the following paragraphs of this section.

2.2.2 Effect of Wind Upon the Propagation of Sound - It was shown in Table I that the speed of sound in still air, at a given temperature, is constant, and equal to about 1130 feet per second.

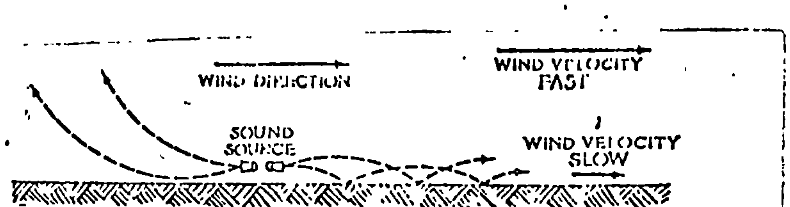


Fig. 10. EFFECT OF WIND DIRECTION ON PROPAGATION OF SOUND WAVES

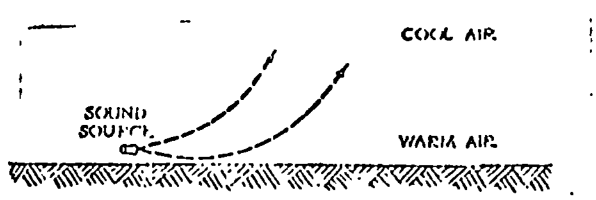


Fig. 11. EFFECT OF TEMPERATURE GRADIENT ON PROPAGATION OF SOUND WAVES-DECREASING TEMPERATURE WITH INCREASING ALTITUDE

If the air is in motion, or if the temperature changes, the sound speed will be altered. The speed of sound in the direction of the wind is equal to the speed of the wind plus the speed of sound in still air.

Suppose that the wind is blowing past a source of sound as shown in Fig. 10. Then, since the speed of the wind is generally slowest at the surface of the earth and increases at higher elevations above the surface, the normal to the wave front of the sound that travels with the wind is bent more and more toward the earth, whereas the normal to the wave front of the sound that travels against the wind is bent more and more away from the earth. Consequently, the upper portions of the sound waves that travel with the wind are deflected downward and they contribute to the flow of sound energy near the earth's surface, thus intensifying the sound near the earth and facilitating the propagation of sound to great distances in the direction of the wind. On the other hand, the upper portions of waves that travel against the wind are relatively retarded so that these waves are deflected upward from the level plane, thus making impossible the propagation of sound to great distances in the direction against the wind. The wind has a marked effect upon the distribution of sound; the pressure of the sound wave in the direction of the wind, at a given distance over a level plane, amounts to several times the pressure at the same distance but in the direction against the wind.

Temperature does have a significant effect on the speed, increasing it about 1.1 feet per second per degree Fahrenheit rise in temperature. The dependence of the speed of sound on temperature is one of the prime causes of the bending of sound rays in the atmosphere.

The speed of the upper portion of sound waves may be increased or decreased with respect to the lower portion as a result of temperature differences in the atmosphere. Suppose that the temperature of the air decreases with the altitude above the earth's surface, as it most commonly does. Then the upper portions of sound waves originating at a sound source will be retarded in relation to the lower portions, and consequently the wave front will be bent upward, as shown in Fig. 11.

Fig. 12. EFFECT OF TEMPERATURE GRADIENT ON PROPAGATION OF SOUND WAVES - INCREASING TEMPERATURE WITH INCREASING ALTITUDES

On the other hand, suppose that the air temperature increases with the altitude, as it frequently does over land surfaces just after sunset or whenever meteorological conditions give rise to an "inverted temperature gradient." Then the upper waves travel faster than the lower ones do, and consequently the wave front will be bent downward, as shown in Fig. 12. Under certain conditions of increasing temperature with altitude, an appreciable portion of the sound originating at a point source will be totally reflected by the upper and warmer layers of air. When these circumstances prevail there will be repeated reflections between the earth and the upper layers of air. Therefore, the pressure of the sound waves decreases only as the inverse square root of the distance instead of as the inverse of the distance, the usual decrease for a spherical wave in free space. These conditions often are approximated in the air over a frozen lake when it is possible on a quiet day to hear and understand ordinary conversation at a distance of a half mile or even more.

Closely associated with the absorption and scattering of sound in the atmosphere is the phenomenon of "fluctuations." The slow but sometimes large fluctuations in the loudness of the sound coming from a distant airplane is a familiar observation. A study of the micrometeorological properties of the atmosphere reveals great turbulence, especially near the surface of ground which has been heated by the sun. Temperature changes of 5°F or more, occurring several times a second, are not uncommon; the wind is ever-changing; convection currents keep the air in a state of agitation. The motion in the air of smoke particles or of small bits of paper reveals the turbulent nature of the atmosphere. Sounds of long wavelength are not greatly influenced by the micrometeorological properties of the atmosphere, but sounds of short wavelength are subject to violent fluctuations.

2.2.3 Effects of Clouds and Fogs on the Propagation of Sound - When a sound wave strikes a cloud or a fog bank, most of the sound energy usually is refracted (with a very small change of direction) into the cloud or fog, and only a small portion of the sound energy is reflected. If, however, the sound wave strikes the cloud or fog bank at nearly grazing incidence, the sound wave may be totally reflected, in which case the direction of propagation of the sound wave may be appreciably altered.

3.0 THE DECIBEL

Selecting a practical scale for noise measurement involves two problems. The first is caused by the tremendous range of sound power or pressures that is encountered, i.e., from 0.0002 microbar at the threshold of hearing under ideal conditions to 10,000 to 200,000 microbars for noises associated with jet or rocket propulsion systems. The second problem arises from the nonlinear manner in which the ear responds. The ear tends to respond logarithmically to the intensity of an acoustical stimulus.

Both of these problems can be solved by the use of the decibel (dB), a unit commonly used to express power or voltage levels. By definition, the decibel is a dimensionless unit used to express the logarithm of the ratio of a measured quantity to a reference quantity. In this way the dB is commonly used to describe levels of acoustic power, intensity, and pressure.

Most sound-measuring instruments are designed to respond to sound pressure changes and are calibrated to read in terms of the logaritm of the ratio of the root-mean-square (rms) sound pressure. The instruments provide a measurement of sound pressure level in dB; the level emphasizes the fact that this is a measurement in relation to a given reference pressure. In air a reference pressure of 0.0002 microbar has been selected as a standard reference point. Sound pressure level (SPL) is defined by:

$$SPL = 20 \log_{10} \frac{P}{P_o} \text{ dB}$$

where P = measured rms sound pressure

P_o = reference pressure

In Table 2 some typical sound pressures and sound pressure levels are shown.

Talk about sound press vs sound power

TABLE 2

Sound pressure (microbars)	Sound pressure level (dB re 0.0002 microbar)	Example
0.0002	0	Threshold of hearing
0.00063	10	
0.002	20	
0.0063	30	
0.02	40	
0.063	50	Residence
0.2	60	Conventional speech
0.63	70	
1.0	74	
2.0	80	
6.3	90	Subway
20	100	Looms in textile mill
63	110	Woodworking
200	120	Hydraulic Press
2000	140	Jet plane

Table 3 is similar to Table 2. It would be well to note that any doubling of sound pressure corresponds to an increase of 6 dB, in the sound pressure level. A change of sound pressure by a factor of 10 corresponds to a change in sound pressure of 20 dB. A discussion of the method of working with decibels follows the Table.

3.1 Addition of Decibels

Since decibels are logarithmic values it is not proper to add them by normal algebraic addition. For example, 63 dB plus 63 dB <u>does</u> <u>not</u> equal 126 dB but only 66 dB.

A very simple, but adequate schedule for adding decibels is as follows:

When two decibel values differ by:	Add the following amount to the higher value:
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 - 8 dB	1 dB
9 dB or more	0 dB

TABLE 3

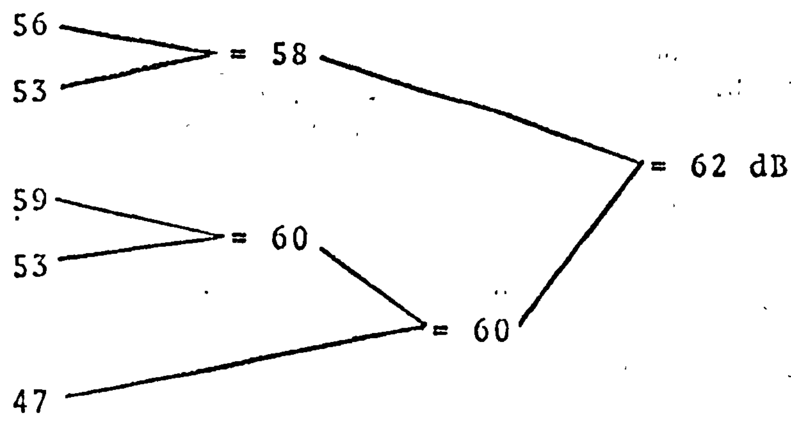
SOUND PRESSURE AND DECIBEL VALUES FOR SOME TYPICAL SOUNDS

Sound Pressure (microbars)	Overall Sound Pressure Level (dB re 0.0002 microbar)	Example
0.0002	0	Threshold of hearing
0.00063	10	
0.002	20	Studio for sound pictures
0.0063	30	Soft whisper (5 feet)
0.02	40	Quiet office Audiometric testing booth
0.063	50	Average residence Large office
0.2	60	Conversational speech (3 feet)
0.63	70	Freight train (100 feet)
1.0	74	Average automobile (30 feet)
2.0	80	Very noisy restaurant Average factory
6.3	90	Subway Printing press plant
20	100	Looms in textile mill Electric furnace area
63	110	Woodworking Casting Shakeout area
200	120	Hydraulic press 50 hp siren (100 feet)
2000	140	Jet plane
200,000	180	Rocket Launching pad

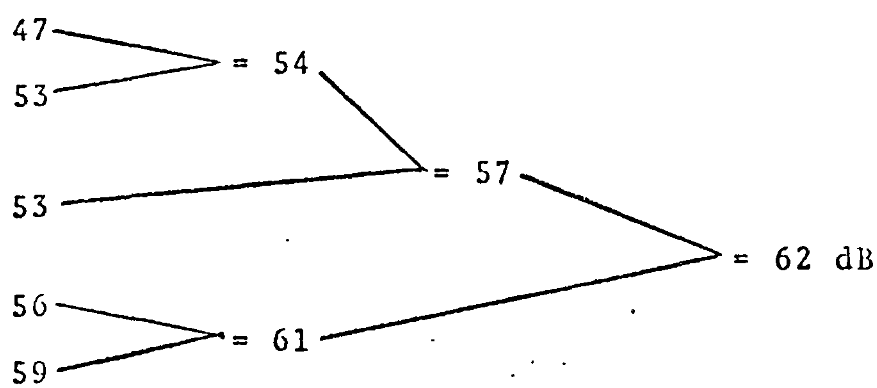
NOTE In the above table the doubling of any sound pressure corresponds to an increase of 6 dB in the sound pressure level. A change of sound pressure by a factor of 10 corresponds to a change in sound pressure level of 20 dB.

When several decibel values are to be added, perform the (Schedule shown on Page 22) operation on any two numbers at a time; the order does not matter. Continue the process until only a single value remains. A table repeating these rules is included in the section on noise sources.

As an illustration, add the following five noise levels:



Or, suppose the same numbers are arranged in a different order, as in



Sometimes, using different orders or adding may yield sums that might differ by 1 dB, but this is not too significant a difference in acoustics. In general, the above simplified summation procedure will yield accurate sums to the nearest 1 dB. This degree of accuracy is considered acceptable for the material given in these notes.

3.2 The Addition of Noise Levels

The addition of "random noises." This type of noise contains sounds of all frequencies and random phases and has a frequency distribution similar to the curve of Fig.13.

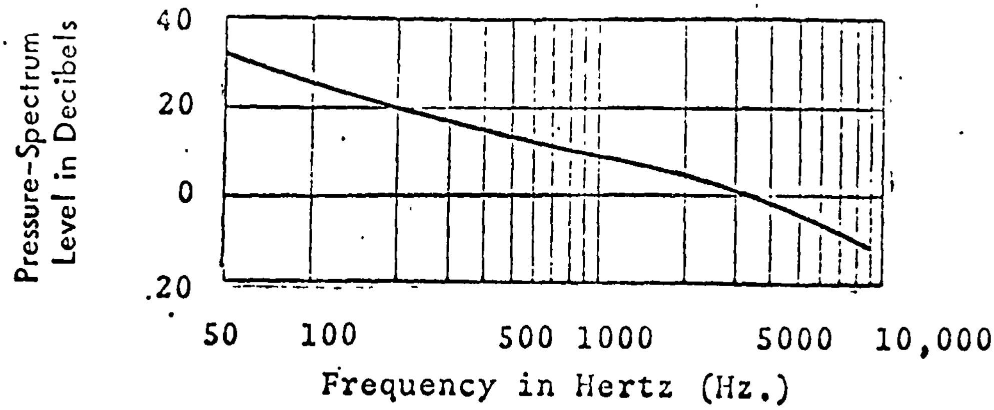


Fig. 13. AVERAGE ROOM NOISE SPECTRUM

It is similar in nature to the background noise in buildings or on busy streets. Suppose that L_1 is the average sound-pressure level of one such source of noise, that L_2 is the average level of a second source, and that L_2 is greater than L_1. Let their difference be denoted by D. Then the total noise level in decibels is equal to $L_2 + N$, where N is a number determined from the chart in Fig.13, which corresponds to the difference D. Thus, suppose that $L_1 = 40$ db and $L_2 = 50$ db. Here, D = 10 db. From Fig. 14, the corresponding value of N is about 0.4. Therefore, the total noise level is 50 + 0.4. Likewise, if $L_1 = 30$ db and $L_2 = 35$ db, N is 1.2, or the total noise level is 36.2 db. For the special case where two noise sources are equal in level, D equals zero, and the total noise level is 3 db higher than the level of either source. As a practical example, suppose that the average background sound level in a legitimate theater due to audience noise is 35 db.

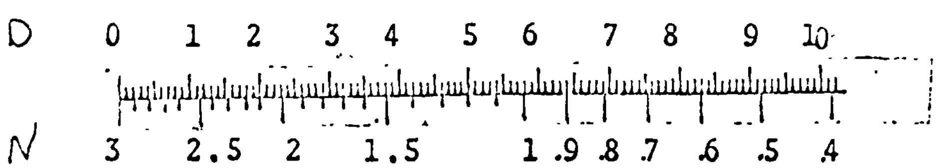


Fig. 14. CHART FOR COMPUTING THE SOUND LEVEL RESULTING FROM THE ADDITION OF TWO COMBINING NOISES. IF "D" IS THEIR DIFFERENCE IN DECIBELS, "N" IS ADDED TO THE HIGHER LEVEL TO OBTAIN THE TOTAL LEVEL.

Assume that the noise transmitted through the walls of the building from outside has a level of 25 db. Then the total level inside the theater resulting from both sources would be about 35.4 db, and the transmitted noise would probably not be detected by the average person. In general, the addition of noise which raises the total background level by less than 1 db will not be objectionable unless the weaker noise is quite different in character from the louder one.

The noise level is high in the equipment room of a ventilating system. This fact may not be important if the equipment is in an out-of-the-way location such as the basement. However, where the equipment noise is likely to be a source of annoyance to occupants adjacent to the equipment room, the motors and fans should be selected with regard to their quietness, acoustical treatment of the equipment room may be desirable, and the wall partitions should provide adequate attenuation of noise. In the past few years air-conditioning units for single rooms, small enough to fit into a window, have become popular. Such a unit may not be a source of annoyance in the room itself, but it may be a source of considerable disturbance to neighbors having windows near-by. Before purchasing such an air-conditioning unit, one should listen to it or check its specifications with regard to the noise it generates outside as well as inside the room it air-conditions.

4.0 NOISE AND COMMUNICATION

Noise is defined by the USASI as any undesired sound. This may be a pure tone, a combination of pure tones, or a broad band of sound that is undesired at a particular location at a particular time.

Noise is any undesired sound. At times one type of sound may be pleasing; at other times it may be annoying or harmful. A stereo set playing a record on the first floor of a house may have a pleasant psychological effect on some persons. For someone trying to sleep in an upstairs bedroom, it may be psychologically disturbing. Loudness of a sound is a psychological judgement, which the listener makes of a sound above his threshold for hearing.

Not all sounds are noise; many convey information, which is useful or essential to life. The sound of a machine, for example, conveys information to the operator. It lets him know whether it is running normally. But, to an adjacent operator tending another machine, the sound coming from his co-worker's machine would be considered noise.

Much of the sound we hear is noise to us, but it may convey useful information to someone else. A physicist would measure the properties and define the character of noise with the same equipment used to measure other sounds. A psychologist would consider noise as unwanted sound as contrasted with music and speech.

In the development of the mechanization of industry, machines of greater power and higher speed, often with correspondingly augmented noise output, replace smaller ones. Undoubtedly, the growth of mechanization has been accompanied by an increase in noise. Although commendable efforts are being made to reduce the noise of machines and appliances, there has been no marked reversal in the upward trend in city and industrial noise. On the other hand, the public is becoming increasingly conscious of the ill effects of noise.

The harmful effects of noise are well known. Even quite feeble noises interfere with the hearing of speech and music; moderately loud noises produce auditory fatigue; and very loud noises, if long endured, induce permanent losses of hearing. Although the influence of noise on the working efficiency and general health of human beings is generally recognized as harmful, those who have scientifically investigated these effects are not in complete agreement about their nature and extent.

There is evidence from one carefully conducted investigation that both the working efficiency and the total output of weavers increased when they wore ear plugs which reduced the noise level from 96 to 81 db. The detrimental effects of the noise were observed to be greatest at the beginning and near the end of work periods, possibly indicating that persons go through a process of adaptation to noise, endure it without noticeable effects for a time, but finally suffer from its incessant attack. The bulk of other evidence indicates that the reduction of noise and reverberation results in increases in output of labor and in human well-being that more than off-set the cost of the acoustical treatment. Although it is difficult to measure fatigue, most observers agree that excessive noise exacts a heavy toll in frayed nerves and physical exhaustion.

No one has determined the price we pay in loss of sleep resulting from avoidable noises. Several years ago, one of the authors kept a record of the number of times he was awakened each night. Approximately three fourths of all awakenings could be attributed to noise. Among the most frequent "offenses" were the honking of automobile horns, barking of dogs, the screaming of ambulance sirens, the late arrival of some members of the family, and the chirping of birds. The wearing of ear plugs, which attenuated these noises about 30 dB, reduced the total number of awakenings to less than one half.

4.1 Noise Type Definitions and Classifications

4.1.1 Discrete Tone - A discrete tone is a sound wave whose instantaneous sound pressure varies essentially as a simple sinusoidal function of the time.

4.1.2 Period of Observation - The period of observation is the time interval during which acoustical data are obtained. The period of observation is determined by the characteristics of the noise being measured and should also be at least 10 times as long as the response time of the instrumentation. The greater the variance in indicated sound level, the longer must be the observation time for a given expected accuracy of the measurement.

4.1.3 General - The spectrum of a noise is influenced by a number of factors, such as the characteristics of the source(s), environmental conditions, etc. The spectrum may contain components at one or more discrete frequencies whose amplitudes are substantially higher than those of components at adjacent frequencies.

Distinctions between the different types of noise are not sharply defined. However, the human ear may serve as a useful guide. To the typical observer, a change in noise level of less than one decibel is not likely to be detectable while a 6 decibel change will be considered significant. If the average noise level is relatively constant but the spectral distribution of the sound changes during the period of observation (as determined by listening), the noise should be classified as non-steady.

4.1.4 Steady Noise - A noise whose level remains essentially constant (i.e., fluctuations are negligibly small during the period of observation. There are two variations of steady noise; those with and those without audible discrete tones. Discrete tones may be audible in the presence of wide-band continuous noise. The human ear may serve to distinguish between these two types of steady noise.

4.1.4.1 Steady Noise Without Audible Discrete Tones This type of noise is frequently referred to as "broad-band" noise; prominent discrete components and narrow-bands of noise are absent. The plot of pressure spectrum level versus frequency is without pronounced discontinuities.

4.1.4.2 Steady Noise With Audible Discrete Tones This type of noise has components occurring at one or more discrete frequencies with significantly greater amplitudes than those of the adjacent spectrum. Several clusters of these types of components or "narrow bands" of noise may be observed. The plotted spectrum obtained with a narrow-band analyzer has very sharp peaks (predominent single-frequency components) or steep gradients (narrow-bands of noise). The distinguishing feature of a "narrow-band" of noise is that its energy is concentrated in a relatively narrow portion of the spectrum.

4.1.5 Non-Steady Noise - The level of a non-steady noise shifts significantly during the period of observation. This type of noise may or may not contain audible discrete tones. The classification of non-steady noises depends upon the period of observation which must be defined for each measurement. There are three major types of non-steady noise:

Fluctuating, Intermittent, and Impulsive. The distinction between these three types of noise is that the level of intermittent noise equals the ambient environmental level at least twice during the period of observation while that of fluctuating or impulsive noise does not.

4.1.5.1 Fluctuating Noise - A noise whose sound pressure level varies over a range greater than 6 decibels with the "slow" meter characteristic (see Instrumentation) and does not equal the ambient environmental level more than once during the period of oberservation. Alternatively, the noise may fluctuate between two or more steady levels when measured with the "fast" meter characteristic of a sound level meter. Fluctuations may occur because of beats between two or more audible discrete tones having nearly the same frequency.

4.1.5.2 Intermittent Noise - A noise whose sound pressure level equals the ambient environmental level two or more times during the period of observation. The period of time during which the level of the noise remains at an essentially constant value different from that of the ambient is of the order of one second or more.

4.1.5.3 Impulsive Noise (Bursts) - Impulsive noise is characterized by brief excursions of sound pressure (acoustic impulses) which significantly exceed the ambient environmental sound pressure.

Sub-Categories of Impulsive Noise - Impulsive noise is readily identified when only a single burst occurs during the period of observation or the time interval between acoustic impulses is long. The human ear is less valuable as a guide when a distinction is to be made between quasi-steady noise with a high burst repetition rate and steady noise. The distinction in this case should be made in terms of specified values of the parameters that characterize the impulsive noise. It is sometimes difficult to distinguish between isolated burst and quasi-steady noise.

To be classified as impulsive noise, an individual burst must have a duration of less than 0.25 second measured between the instants at which the instantaneous sound pressures have a value equal to one-half the peak value. If the noise is repetitive, the repetition rate of the bursts must be less than 5 per second and the arithmetic average of the peak pressure levels of 10 consecutive bursts in the train must be more than 15 decibels above the unweighted (rms) sound pressure level in the presence of the impulses.

4.1.5.3.1 - (a) Isolated Bursts - One or more bursts which occur during the period of observation. The envelope of the burst waveform may be that of a decaying transient or it may be of essentially constant amplitude, for example, a tone burst. The burst spacing (time interval between bursts) is such that each burst is individually distinguishable with a sound level meter.

4.1.5.3.2 - (b) Quasi-steady Noise - A train of two or more bursts may occur during the period of observation. Individual bursts in the train may have equal or unequal amplitudes and the burst spacing (time interval between bursts) may be uniform or non-uniform. As the burst repetition rate increases, the resolution of individual bursts by a sound level meter becomes difficult and the noise can be classified as quasi-steady.

Examples Examples of noises falling into the above categories are given in Table 4

TABLE 4

EXAMPLES OF SOURCES OF DIFFERENT TYPES OF NOISE

STEADY

Without Audible Discrete Tones	With Audible Discrete Tones
Distant city	Truck exhaust
Waterfall	Transformer
	Jet engine

NON-STEADY

Fluctuating	Intermittent	Impulsive
Heavy traffic (nearby)	Aircraft fly-over	Isolated Bursts
	Automobile passing by	Pile driver
Pounding surf	Train passing by	Dog barking
		Pistol shots
		Door slamming
		Electric circuit breaker
		Quasi-Steady Noise
		Riveting
		Pneumatic hammer
		Machine gun

4.2 Noise Criteria

The degree of disturbance or annoyance of an intruding unwanted noise depends essentially on three things: (1) the amount and nature of the intruding noise, (2) the amount of background noise already present before the intruding noise occurred and (3) the nature of the working or living activity of the people occupying the area in which the noise is heard. People trying to sleep in their quiet suburban homes would not tolerate very much intruding noise; while office workers in a busy mid-city office could have greater amounts of noise without even noticying it; and factory workers in a continuously noisy manufacturing space might not even hear a noisy nearby equipment installation.

INSERT

It is common practice in acoustical engineering to rate various environments by "noise criteria" and to describe these criteria by fairly specific noise level values. Detailed discussions of noise criteria can be found in other literature, and only a brief useful summary of that material is introduced here. In the interest of brevity, many important details and qualifications are omitted. Thus, in a complex problem, additional reading or acoustical assistance may be necessary.

~~4.2.1 Noise Criterion Curves~~ - From earlier studies of many types of noise environments that people have found either "acceptable" or "unacceptable" for various indoor working or living activities, a family of "Noise Criterion Curves" ("NC" curves) has been evolved. Table 5 represents these curves. Each curve represents a reasonably acceptable balance of low frequency to high frequency noises for particular situations. These curves are also keyed-in to the "speech communication" conditions permitted by the noise. Thus, the lower NC curves prescribe noise levels that are quiet enough for resting and sleeping or for excellent listening conditions, while the upper NC curves describe rather noisy work areas where even speech communication becomes difficult and restricted. The curves within this total range may be used to set desired noise level goals for almost all typical indoor functional areas where some acoustic need must be served. For convenience in using NC curves, octave band sound pressure levels are usually given in conjunction with them.

In Table 5, a number of typical hospital indoor living, working and listening spaces are grouped together into "categories" and each category is assigned a representative range of noise criterion values. Low Category Numbers indicate areas in which relatively low noise levels are desired; higher Category Numbers indicate areas in which relatively higher noise levels are permissible. Any occupied or habitable area not specifically named in Table 5 can be added under any appropriate Category Number as long as the acoustic requirements of the new area are reasonably similar to those of the areas already named under that category. A 5-10 dB range of NC values is given in Table 5 for each of the first five categories. In general, the lower limit of each range should be used for the more critical spaces or the more sensitive or critical occupants of an area, while the upper limit of each range may be used for the less critical spaces or occupants of an area. An exception to this generalization may occur when it is clearly known that the background noise of an area is so quiet and the walls between adjoining rooms have such low "transmission loss" that speech sounds or other clearly identifiable sounds may intrude from one office to another and be disturbing to occupants of either area. In this type of situation, "masking noise" may have to be introduced into the rooms in order to reduce some of the intelligibility of the intruding sounds, and the higher range of noise criterion values may actually be useful, as long as the mechanical equipment noise itself is relatively unobtrusive and not too identifiable. When properly controlled as to spectrum shape and sound level, ventilation system noise (the gentle "hissing" of diffusers, under-window induction units, dampers or air valves) sometimes provides some of this "masking noise". In more critical cases, where spectrum and level must be held under close control, electronic noise sources may be used.

A special note of concern is given for the Category 1 and 2 areas as they appear in Table 5 on the next page. For a very quiet community area or for a quiet building with no internal ventilation system noise, the NC-20 noise criterion should be applied for indoor conditions. For a noisy city environment outdoors or for a building with a ventilation system known to fall in the NC-30 noise range, an NC-30 noise criterion can be applied to rooms other than bedrooms or auditoriums. For bedrooms or auditoriums or for situations that do not clearly fall at the NC-20 lower limit or NC-30 upper limit, NC-25 indoor noise criterion levels should be applied.

For music or performing arts centers or concert halls, there is increasing evidence that a complete absence of noise is required in order to provide a full appreciation of the very low level sounds sometimes coming from the stage area. Thus, an NC-15 to NC-20 criterion should be applied as the goal for high quality concert halls. Acoustical assistance may be required to achieve these goals.

TABLE 5

CATEGORY CLASSIFICATION AND SUGGESTED NOISE CRITERION RANGE FOR INTRUDING MECHANICAL EQUIPMENT NOISE AS HEARD IN VARIOUS INDOOR FUNCTIONAL ACTIVITY AREAS

CATEGORY	AREA (AND ACOUSTIC REQUIREMENTS)	NOISE CRITERION
1	Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels, etc. (for sleeping, resting, relaxing).	NC-20 to NC-30
2	Auditoriums, theaters, large meeting rooms, large conference rooms, churches, chapels, etc. (for very good listening conditions).	NC-20 to NC-30
3	Private offices, small conference rooms, classrooms, libraries, etc. (for good listening conditions).	NC-30 to
4	Large offices, reception areas, retail shops and stores, cafeterias, restaurants, etc. (for fair listening conditions).	NC-35 to NC-40
5	Lobbies, laboratory work spaces drafting and engineering rooms, maintenance shops such as for electrical equipment, etc. (for moderately fair listening conditions).	NC-40 to NC-50
6	Kitchens, laundries, shops, garages, machinery spaces, power plant control rooms, etc. (for minimum acceptable speech communication, no risk of hearing damage).	NC-45 to NC-65

It is noted here that much of the known data on criteria do not extend down to the very low frequency band of 31 Hz. Some of the noise source data, however, include 31 Hz levels. For most ordinary noise problems, there will be no serious concern for the 31 Hz band so it can be ignored for most calculations. If it is known that a serious problem involves decision-making at 31 Hz, acoustical assistance should be obtained.

4.3 Speech Power

In this section we shall discuss the acoustical power output of speech. The average person is surprised at the exceedingly minute amount of energy contained in speech. Approximately 15,000,000 lecturers speaking at the same time generate acoustical energy at a rate of only 1 horsepower. When the speech power of a single speaker is diffused in a large auditorium, the sound pressure in the room is reduced to extraordinarily small values. Under such circumstances, it is easy to understand why it is difficult to hear well in a large room, and why very feeble sources of extraneous noise may produce serious interference with the speech. For example, the noise of a distant ventilating fan or motor, the shuffling of feet on the floor, the jarring of a near-by door, or the whispering or coughing of inconsiderate "spectators" may be sufficient to mask many of the speech sounds, and especially the feeble consonants, which reach an auditor in a large auditorium.

An extensive investigation of the conversational speech power output of individuals of two groups, 6 men and 5 women, was conducted by Dunn and White. This study indicates that the average male person produces a long-time-interval average sound-pressure level of about 64 db at a distance of 1 meter, directly in front of him, when he talks in a normal conversational voice; the average for women, as shown by this study, is about 61 db at a distance of 1 meter.

The above data are for conversational speech in a quiet location in the absence of reflecting surfaces. Noise, the size of the room in which a person is speaking, his distance from the auditor, the acoustical conditions of the room, and other factors affect the power output of his speech, and especially the sound-pressure distribution throughout the room. If a noisy condition prevails, he will raise his voice in order to "override" the noise. He will, in general, increase his power output as his distance from an auditor is increased.

4.3.1 Voice Sounds - Voice sounds are formed by passage of air through the vocal cords, lips, and teeth. As the air stream passes through the vocal cords, they are set in vibration. The cavities of the nose and throat impress resonant characteristics on these vibrations to produce speech sounds. All the vowel sounds and some of the consonant sounds are produced in this manner. Other sounds called unvoiced sounds, for example, f,s, th, sh, t, and k are produced by passage of air over the teeth and tongue without use of the vocal cords. Voiced consonants, such as b, d, g, j, v, and z, are combinations of the two processes.

The various vowel sounds are made by changing the shape of the resonant chamber so that different frequencies are enhanced. Each of the vowel sounds has certain characteristic frequency groups as shown in the frequency chart in Fig.15 and in Table 6.

The values given are average values and there is considerable variation for different individuals and for a single individual at different times. If one of these speech sounds is passed through a sound filter that absorbs frequencies in the neighborhood of one of the characteristic frequencies, the vowel sound is no longer recognizable.

TABLE 6
CHARACTERISTIC FREQUENCIES OF VOWEL SOUNDS

Vowel sound	Low frequency	High frequency
a (tape).....	550	2100
a (father)...	825	1200
e (eat)......	375	2400
e (ten)......	550	1900
i (tip)......	450	2200
0 (tone).....	500	850
u (pool).....	400	800

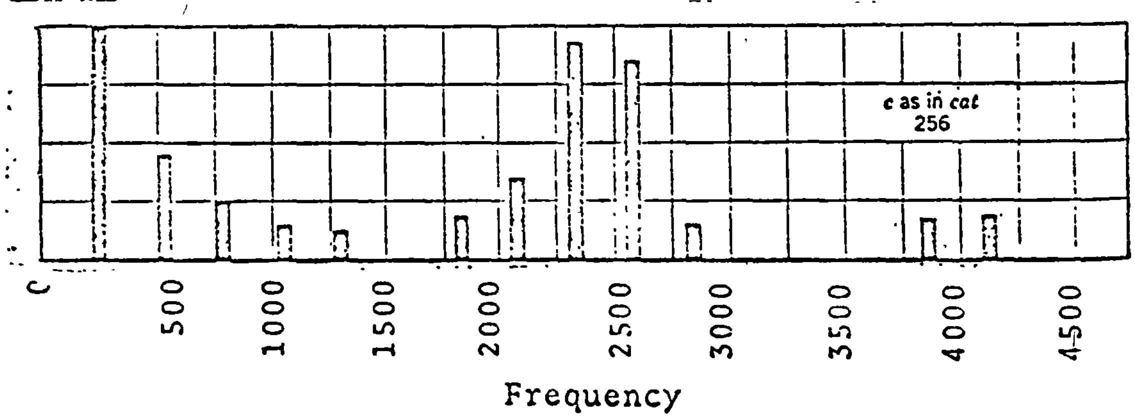


Fig. 15. FREQUENCY CHART FOR A VOWEL SOUND

Articulated speech consists of a flow of various combinations of consonants and vowels. The nature of the articulation of the separate syllables and words in speech, and the rapidity with which the separate syllables follow one another, have a great bearing upon how well the speech is heard. If the separate syllables are inaccurately formed, and if they follow each other in rapid succession, they may not be heard distinctly.

Intelligibility of speech is a phrase used by telephone engineers, signifying how well speech is recognized and understood.

The intelligibility of speech declines rapidly with the distance from a speaker in the open air, owing to the inverse relationship between sound pressure and distance. In a room the distribution of sound radiated by a source is greatly affected by the boundaries of the room; the distribution is altered; the sound levels are generally raised; and other phenomena such as room resonance, reverberation, and diffusion are introduced.

Sounds of equal sound pressure level may not be rated by listeners as being equally loud. Loudness is a subjective quantity that is measured by a human observer. To determine how loud a sound is, a standard sound is chosen and a significant number of people compare the unknown with the standard. The accepted standard is a pure 1,000 cycle (1K Hz) tone. The loudness level in phons of a 1,000 cycle tone by definition is the same as the sound pressure level in decibels. The loudness level of any sound in phons is numerically equal to the sound pressure level in dB of an equally loud 1K Hz standard sound. To human ears broadband sounds, like those of jet aircraft, seem much louder than pure tones or narrow band noise having the same sound pressure level.

4.3.2 Noise and Speech Interference - The most demonstrable effect of noise on man is that it interferes with his ability to use voice communication. A noise that is not intense enough to cause hearing damage may still disrupt speech communication as well as the hearing of othe desired sounds.

The arithmetic average of the readings in decibels for the three octave bands, centered on 500, 1,000 and 2,000 Hz, contained in a wideband noise has empirically been shown to provide an indication of the ability of that noise to affect the intelligibility of voice communication. The average of these three octave band dB values is called the speech-interference-level (SIL). In noises whose spectra yield an SIL greater than 75 dB, personnel would have to speak in a very loud voice and use a selected and possibly pre-arranged vocabulary to be understood over a distance of one foot. Telephone use under these noise conditions would be impossible. A SIL between 65 and 75 dB would barely permit reliable communication over two feet with a raised voice. This span of communications would be extended to four feet by using a loud voice and to eight feet by shouting. Telephone conversation under 65-75 dB SIL conditions would be difficult. In noise having an SIL between 55 and 65 dB, a normal voice level would be effective over a distance of three feet, a raised voice over a distance of six feet, and a very loud voice over a distance of twelve feet. Telephone use here would be practically unimpaired. A SIL of 55 dB or less would be permissible in large business or secretarial office areas. A SIL of 45 dB or less would be desirable for private offices or conference rooms. Fig.16 indicates distance between speaker and listener and voice level restrictions to insure intelligible speech for various SIL conditions.

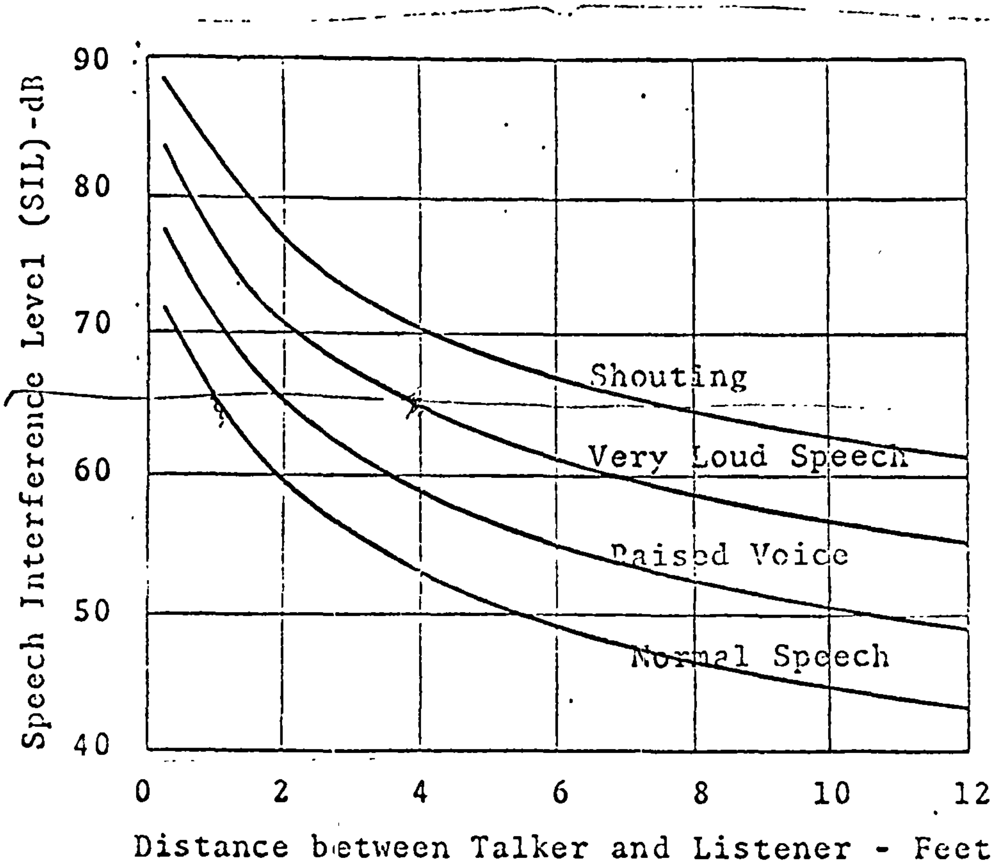


Fig. 16. SHOWS THE VOICE LEVEL AND DISTANCE CONDITIONS NEEDED TO INSURE SATISFACTORY SPEECH INTELLIGIBILITY

Table 7 gives the average "speech interference level" of a noise that will just barely permit reliable speech communication for a range of voice levels and distances. The data are based on tests performed out-of-doors where there are no reflecting surfaces to help reinforce the speech sounds, but the values can be used as approximations for indoor conditions as well. Also, to a first approximation (but not exactly), if a noise follows the shape of an NC curve, the "PSIL" value of the noise will nearly equal the NC curve number.

As a simple example of the use of Table 7, if the noise levels in a Mechanical Equipment Room average 62 dB in the 500, 1000 and 2000 Hz bands, barely reliable speech conversations could be carried on in that room by shouting at a 16-ft. distance, by using a loud voice level at a distance of 8 ft., by using a raised voice at a distance of 4 ft. or by using a normal voice level at a distance of 2 ft.

If two men are standing, facing each other in a noise field, the maximum speech-interference levels that just permit reliable communication at various voice levels and distances are as shown in Table 8 in making up this table, average male voices and good hearing are assumed, as well as unexpected word material. If the vocabulary is limited or if sentences only are spoken, the permissible speech-interference levels may be increased by about 5 db. If a woman is speaking, the permissible levels should be decreased by about 5 dB. Absence of reflecting surfaces is assumed.

TABLE 7

SPEECH INTERFERENCE LEVELS ("PSIL"):

AVERAGE NOISE LEVELS* (IN DB) THAT PERMIT BARELY ACCEPTABLE SPEECH INTELLIGIBILITY AT THE DISTANCES AND VOICE LEVELS SHOWN

	Voice Level			
Distance (ft)	Normal	Raised	Very Loud	Shouting
1/2	74	80	86	92
1	68	74	80	86
2	62	68	74	80
4	56	62	68	74
6	53	59	65	71
8	50	56	62	68
10	48	54	60	66
12	46	52	58	64
16	44	50	56	62

*PSIL (Speech Interference Level in "Preferred" Octave Bands) is arithmetic average of noise levels in the 500, 1000 and 2000 Hz octave frequency bands. PSIL values apply for average male voices (reduce values 5 dB for female voice), with speaker and listener facing each other, using unexpected word material. PSIL values may be increased 5 dB when familiar material is spoken. Distances assume no nearby reflecting surface to aid the speech sounds.

TABLE 8: Speech-interference Levels (in Decibels re 0.0002 Microbar) That Barely Permit Reliable Word Intelligibility at the Distances and Voice Levels Indicated. No Reflecting Surfaces to Aid the Direct Speech Are Assumed*

Distance, ft	Voice level (average male)			
	Normal	Raised	Very loud	Shouting
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61

*After L.L. Beranek

4.4 Effect of Noise on Hearing

Everyone has probably had the experience of being unable to hear some critical lines in a play because noises from the foyer or street often occur just as these lines are spoken. In spite of the apparent correlation, no one has demonstrated the existence of a "masking demon" that knows the play and takes delight in making noise at these most crucial moments. However, one may legitimately conclude that, aside from the annoyance that it causes, noise has the effect of reducing the acuity of hearing; that is, it elevates the threshold of audibility. This shift in threshold of audibility is called masking, and the shift, in decibels, defines the amount of masking. Unless the loudness of speech or music is sufficiently above the level of the surrounding noise, the speech or music cannot be fully recognized or appreciated because of the masking effect of the noise; it is impossible to ignore completely a loud noise and listen only to the wanted sound.

Masking data are generally represented in the form of a curve called a masking spectrum (sometimes called a masking audiogram) which gives the number of decibels at each frequency that the threshold level of a pure tone is shifted when heard by a normal observer in the presence of masking sounds. As an illustration, the masking spectrum due to "average room noise" is given in Fig.17 For instance, a tone of 1000 cycles would have to be raised 25 dB above the minimum audible threshold to be heard in the presence of this average room noise. The masking spectrum in this case, and in general, is not contant with frequency. It depends on the pressure level and the nature of the masking sounds. Here we shall discuss two types of masking sounds: first, a sustained pure tone; and, second, a continuous noise spectrum typical of those which occur in auditoriums.

4.4.1 <u>How We Hear</u> - Experiments indicate that low-pitched tones, especially if they are of considerable loudness, produce a marked masking effect upon high-pitched tones, whereas high-pitched tones produce only little masking upon low-pitched tones. The auditory masking of one tone upon another is greatest when the masking tone is almost identical with the masked tone. In general, all tones, especially if they are loud, offer considerable masking for all tones of higher frequency than the masking tone. Therefore, very intense low-frequency hums or noises are especially troublesome sources of interference for the hearing of speech or music since they mask nearly the entire audible range of frequencies.

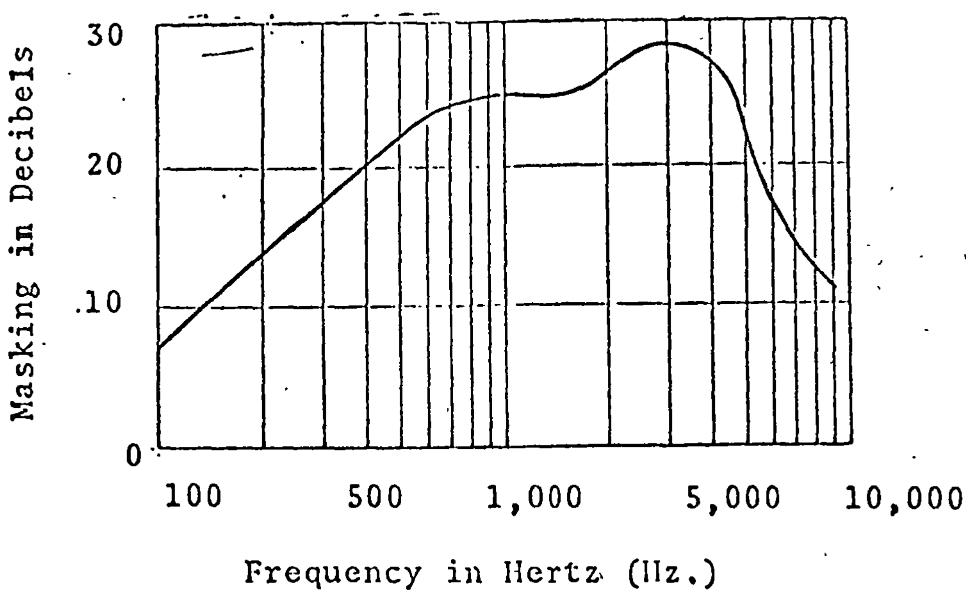


Fig. 17. MASKING SPECTRUM DUE TO AVERAGE ROOM NOISE HAVING A SOUND LEVEL OF 43 dB

4.4.2 Outdoor Noise - Sounds of outside origin are often the principal contributors to noise in offices, churches, and residences. The largest source of outdoor noise is generally automobile traffic. For this reason, it is desirable that all buildings in which quietness is an important factor, including churches, auditoriums, and hospitals, be not constructed near a busy, or potentially busy, street.

Street noise is an example of disordered sound. A spectrum analysis of this noise will show that practically all frequencies are present and that it is highly irregular in nature. This irregularity can be illustrated by means of sound spectrograms. These visual records, obtained with a sound spectrograph - an instrument developed by the Bell Telephone Laboratories - provide a frequency analysis of a sound source as a function of time.

The average level of street noise varies with the time of day. In many business districts, the average noise level is lowest between 3 A.M. and 4 A.M. and rises rapidly after 5 A.M. to a maximum at about 10 A.M. In other areas, the maximum occurs later in the day, often during evening "rush" hours. Fig.18 gives the average result of measurements made at the street curb in a large number of business and residential locations. The dashed lines give data for New York City, but they are reasonably representative of the noise conditions in congested areas of other large cities. They show the per cent of the locations surveyed which have noise levels less than the decibel reading indicated along the horizontal axis. Thus, in the New York business district, 30 per cent of the locations had noise levels of less than 70 db. The solid lines give average data for business and residential districts in other cities, which include a wide range of areas, from congested city districts to rural areas. As a result, the levels are lower than they are in New York City and the spread (range) of noise levels is greater.

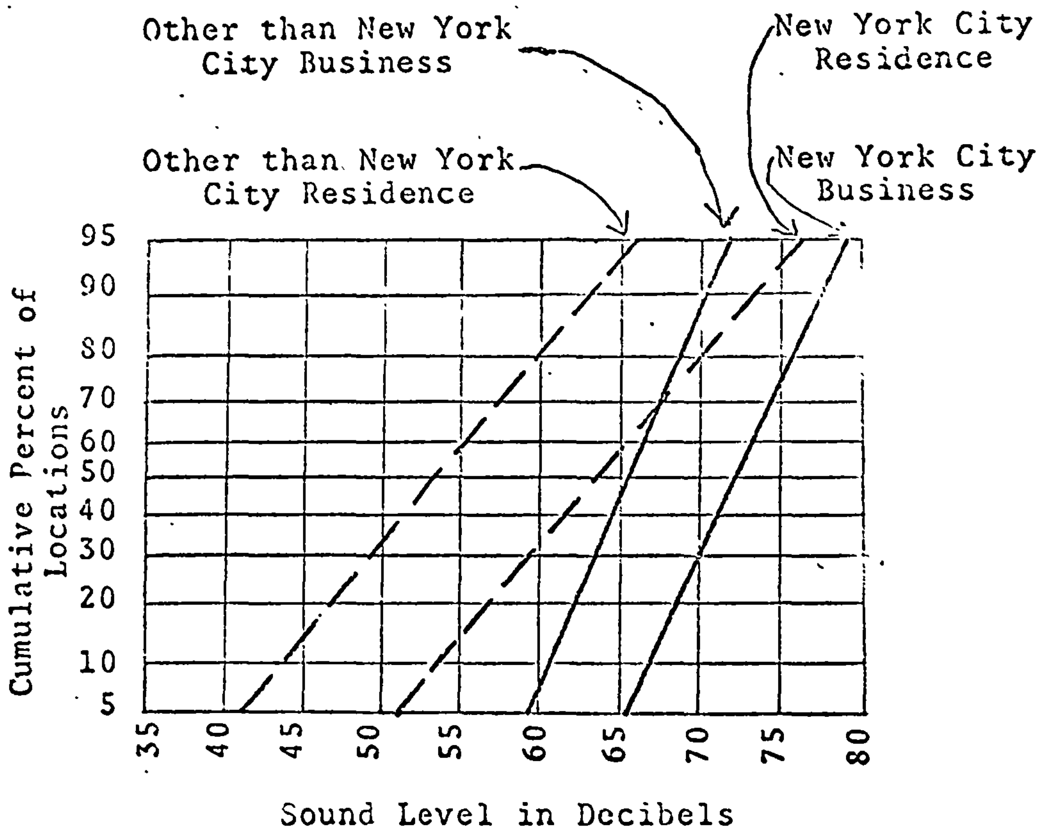


Fig. 18. DISTRIBUTION OF AVERAGE STREET NOISE LEVELS, SHOWING THE PERCENT OF LOCATIONS HAVING A NOISE LEVEL LESS THAN A VALUE SPECIFIED ALONG THE HORIZONTAL AXIS. PEAK LEVELS ARE 10 TO 15 dB ABOVE AVERAGE LEVELS.

4.5 Outdoor Background Noise

People tend to compare an intruding noise with the background noise that was present before the new noise came into existence. If the new noise has distinctive sounds that make it readily identifiable or if its noise levels are considerably higher than the background or "ambient" levels, it will be noticeable to the residents and it might be considered objectionable. On the other hand, if the new noise has a rather unidentifiable, unobtrusive sound and its noise levels blend into the ambient levels, it will hardly be noticed by the neighbors and it probably will not be considered objectionable.

Thus, in trying to estimate the effect of a new noise on a neighbor, it is necessary to know or to estimate the background noise levels in the absence of the new noise. Since the equipment is probably planned for continuous day and night operation, and since people are less tolerant of an intruding noise at night, the nighttime ambient noise levels are important to the evaluation of the problem.

Where possible (and especially if a sensitive neighborhood is located nearby), the average minimum nightime noise levels should be measured several times during several typically quiet nights. Readings should be taken in octave bands and readings should be taken when there is no nearby truck or auto traffic that would give falsely high values.

If background measurements, cannot be made, the ambient noise levels can be estimated approximately with the use of Tables 9 and 10. In Table 7 , the condition should be determined that most nearly describes the community or residential area or the nearby traffic activity (which frequently helps set the ambient levels in an otherwise quiet neighborhood) that would exist during the quietest time that the equipment would be in operation. For the condition that is selected, there is an appropriate "Noise Code No." at the right-hand side of Table 10 that is used to enter Table 9. For that particular Noise Code No., Table 9 then gives an estimate of the approximate average minimum background noise levels for that area and traffic condition. This is not an infallible estimate but it will serve in the absence of actual measurements.

It is cautioned that these estimates should be used only as rough approximations of background noise and that local conditions can give rise to a wide range of actual noise levels. It is, nevertheless, realistic to utilize a method such as this to help determine the amount of noise that a new noise can make without becoming noticeably louder than the general background.

TABLE 9

ESTIMATE OF OUTDOOR BACKGROUND NOISE BASED ON GENERAL TYPE OF COMMUNITY AREA AND NEARBY AUTOMOTIVE TRAFFIC ACTIVITY

(Determine the appropriate conditions that seem to best describe the area in question during the time interval that is most critical; i.e., day or night, probably night if for sleeping. Then refer to corresponding Noise Code No. in Table 5 for average minimum background noise levels to be used in noise analysis. Use lowest Code No. where several conditions are found to be reasonably appropriate.)

	CONDITION	NOISE CODE NO.
1.	Nighttime, rural; no nearby traffic of concern	1
2.	Daytime, rural; no nearby traffic of concern	2
3.	Nighttime, suburban; no nearby traffic of concern	2
4.	Daytime, suburban; no nearby traffic of concern	3
5.	Nighttime, urban; no nearby traffic of concern	3
6.	Daytime, urban; no nearby traffic of concern	4
7.	Nighttime, business or commercial area	4
8.	Daytime, business or commercial area	5
9.	Nighttime, industrial or manufacturing area	5
10.	Daytime, industrial or manufacturing area	6
11.	Within 300 ft of intermittent light traffic route	4
12.	Within 300 ft of continuous light traffic route	5
13.	Within 300 ft of continuous medium-density traffic	6
14.	Within 300 ft of continuous heavy-density traffic	7
15.	300 to 1000 ft from intermittent light traffic route	3
16.	300 to 1000 ft from continuous light traffic route	4
17.	300 to 1000 ft from continuous medium-density traffic	5
18.	300 to 1000 ft from continuous heavy-density traffic	6
19.	1000 to 2000 ft from intermittent light traffic	2
20.	1000 to 2000 ft from continuous light traffic	3
21.	1000 to 2000 ft from continuous medium-density traffic	4
[illegible]	1000 to 2000 ft from continuous heavy-density traffic	5
23.	2000 to 4000 ft from intermittent light traffic	1
24.	2000 to 4000 ft from continuous light traffic	2
25.	2000 to 4000 ft from continuous medium-density traffic	3
26.	2000 to 4000 ft from continuous heavy-density traffic	4

TABLE 10

OCTAVE BAND SOUND PRESSURE LEVELS OF

OUTDOOR BACKGROUND NOISE CODE NUMBERS OF TABLE 10

NOISE CODE NO. IN TABLE 9	OCTAVE BAND CENTER FREQUENCY IN HZ 63	125	250	500	1000	2000	4000	8000
1	40	37	32	27	22	18	14	12
2	45	42	37	32	27	23	19	17
3	50	47	42	37	32	28	24	22
4	55	52	47	42	37	33	29	27
5	60	57	52	47	42	38	34	32
6	65	62	57	52	47	43	39	37
7	70	67	62	57	52	48	44	42

4.6 Noise Resulting From Air Flow

When air flows through a ventilating system, obstructions of all types (bends, side branches, changes of duct size, grilles) produce eddy currents or other forms of turbulent flow. Noise containing sounds of all frequencies is generated as a result of this turbulence. However, noise arising from turbulence usually contains relatively more high-frequency noise than does motor-fan noise. Hence, streamlining often will contribute effectively to noise reduction. Some times the turbulence will set into vibration parts of the system, particularly the walls of unlined ducts, and give to the resulting noise a definite pitch.

Noise that results from the turbulent flow of air increases with increasing velocity of flow. From this standpoint, it is desirable to have the air velocity low; however, this involves relatively larger ducts and hence greater expense. If a certain level of noise is acceptable in a room, acoustical correctives will permit the ventilation system to have a higher velocity. The increase in noise with air flow velocity is illustrated by the curves of grille noise level shown in Fig.19. The measurements were taken at a distance of 6 feet from each of three typical grilles having a face area of 0.5 square foot. These data indicate that grilles that produce a large spread of air by deflectors which offer obstruction to the outward flow produce a somewhat higher noise level than do those having little air resistance. For a grille of a given type, increasing the face area increases the noise level if the air velocity is constant; the increase is approximately 3 dB for each doubling of the face area. For example, from Fig.19 the noise level for grille B, which has an area of 0.5 square foot, is 27 dB for a face velocity of 1250 feet per minute. The noise generated by a grille of this type having an area of 1 square foot would be 30 db for the same air velocity of 1250 feet per minute. If the total amount of air flowing past the grille remains the same, the noise level decreases rather rapidly as the size of the grille is increased.

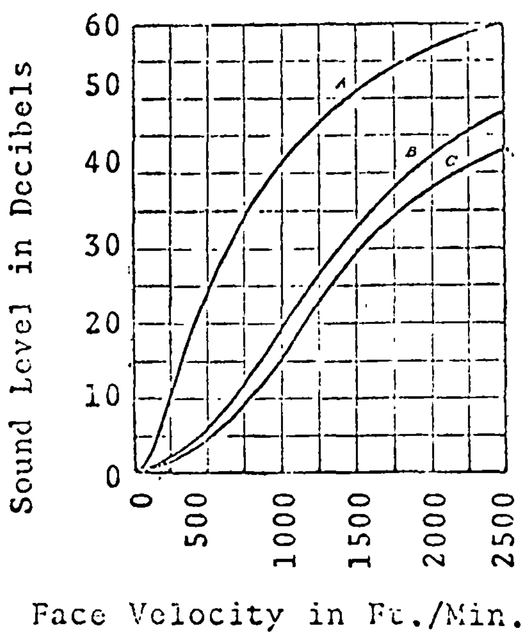


Fig. 19. NOISE LEVEL NEAR GRILLE VS. FACE VELOCITY OF AIR STREAM. CURVE A IS FOR A GRILLE PROVIDING LITTLE SPREAD. CURVE B IS FOR A GRILLE OF THE HONEYCOMB TYPE GIVING A SMALL SPREAD. CURVE C IS FOR A GRILLE PRODUCING A LARGE SPREAD.

4.6.1 <u>Minimize Noise at Its Source</u> - Two types of noise should be suppressed in a ventilating system - that resulting from solid-borne vibration and that which is air-borne. The principal sources of solid-borne vibrations are the motors and fans. In addition, turbulence in the air stream can cause the duct walls and other parts of the system to rattle. Motors and fans in which noise and vibration are deliberately and effectively suppressed are now manufactured. They are especially desirable, but if their cost is very much higher than others which are less quiet, it is sometimes cheaper to control the noise and vibration by other means. Proper mounting of the motors and fans, so that they will not communicate vibration to the ducts, walls, or floor, is important. There should be no direct contact between the building structure and the foundation of the motors and fans. Isolation of the machinery from the floor can be accomplished by methods described in the previous chapter. The blower and exhaust fans should be isolated from the ducts by a flexible sleeve, for example, one fabricated of canvas. It is also helpful to use rubber hose for the piping connections from pumps. The tendency of unlined duct walls to be set into vibration can be reduced by the application to its surface of a material which adds mechanical damping.

The noise level is high in the equipment room of a ventilating system. This fact may not be important if the equipment is in an out-of-the-way location such as the basement. However, where the equipment noise is likely to be a source of annoyance to occupants adjacent to the equipment room, the motors and fans should be selected with regard to their quietness, acoustical treatment of the equipment room may be desirable, and the wall partitions should provide adequate attenuation of noise. In the past few years air-conditioning units for single rooms, small enough to fit into a window, have become popular. Such a unit may not be a source of annoyance in the room itself, but it may be a source of considerable disturbance to neighbors having windows near-by. Before purchasing such an air-conditioning unit, one should listen to it or check its specifications with regard to the noise it generates outside as well as inside the room it air-conditions.

CONSTRUCTION COSTS OF HIGHWAY DESIGN

CONSTRUCTION HIGHWAY DESIGN	AVERAGE INDEX NO.	IN MILLIONS PER LANE/KILOMETRE*
GROUND LEVEL	1	.175
DEPRESSED OPEN CUTTING	1.5	.263
ELEVATED ON EMBANKMENT	2	.350
ELEVATED: RETAINED	3	.525
DEPRESSED: RETAINED	5.5	.962
ELEVATED: VIADUCT	7.5	1.312
TUNNEL: BOARD	13	2.275
TUNNEL: IMMERSED TUBE	25	4.375
TUNNEL: CUT AND COVER	14	2.624
TUNNEL: BORED UNDER RIVER	50	9.650

*COSTS BASED ON 1969 ESTIMATES (ENGLAND)

CONSTRUCTION COSTS OF BARRIERS

BARRIER TYPE	THICKNESS	COST/LIN. FT. FOR 10-FOOT BARRIER
WOODEN WALL	3/4 "	$12 *
EARTH BERM	60 " (TOP)	$25 *
CONCRETE WALL (PRE-CAST CELLULAR)	6 "	$42 - $55 *
BRICK	---	$25 **
ALUMINUM	3"	$40 *
GABION (STONE)	36"	$60 *

** BASED ON ONTARIO MINISTRY OF TRANSPORTATION

* ESTIMATE GRATER LONDON COUNTY COUNCIL

WINDOW TYPE: SOUND ATTENUATION

WINDOW TYPE	SOUND LEVEL dB(A)
SINGLE GLAZED, WINDOW OPEN	5-15
SINGLE GLAZED, FULLY CLOSED	20-25
DOUBLE WINDOW, STAGGERED OPENING	20-25
DOUBLE WINDOW, CLOSED	30-35
SINGLE WINDOW, SEALED	25-30
DOUBLE WINDOW, SEALED	35-45

VISUAL NO.
SUBJECT Swm B
"3M BRAND" MOUNTING FRAME
ST. PAUL, MINNESOTA 55101 MADE IN U.S.A. CATALOG NO. 15-1006-4
Visual Products Division 3M COMPANY

INTERIOR NOISE EXPOSURE STANDARDS: DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

Sleeping Quarters. For the present time, HUD field personnel should consider existing and projected noise exposure for sleeping quarters "acceptable" if interior noise levels resulting from exterior noise sources and interior building sources such as heating, plumbing, and air conditioning

--do not exceed 55dB(A) for more than an accumulation of 60 minutes in any 24-hour period, and

--do not exceed 45dB(A) for more than 30 minutes during night time sleeping hours from 11 p.m. to 7 a.m., and

--do not exceed 45dB(A) for more than an accumulation of eight hours in any 24-hour day

Other Interior Areas. HUD personnel should exercise discretion and judgement as to interior areas other than those used for sleeping. Consideration should be given to the characteristics of the noise, the duration, time of day, and planned use of the area.

SUBJECT_______________

"3M BRAND" MOUNTING FRAME

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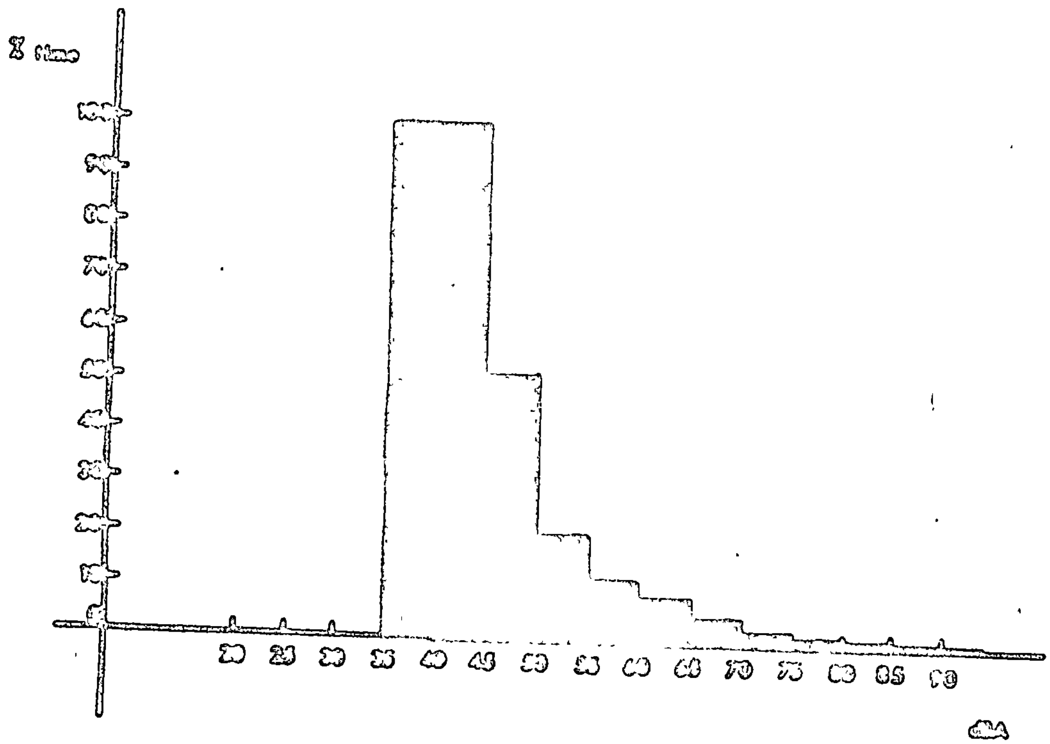
Visual Products Division 3M COMPANY



Cumulative distribution of Noise Levels at Measurement Location 1, 15-16 November 1972 for a 24 hour period.

NOISE RELATED ACTIVITIES

REQUIRING ENVIRONMENTAL IMPACT STATEMENTS

1. HIGHWAYS
2. AIRPORTS
3. POWER GENERATING FACILITIES
4. HOUSING DEVELOPMENTS

NOTES

ENVIRONMENTAL IMPACT STATEMENT

I. DESCRIPTION OF PROPOSED ACTION

II. PROBABLE IMPACT OF PROPOSED ACTION

III. PROBABLE UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECT

IV. ALTERNATIVES TO PROPOSED ACTION

V. RELATIONSHIP BETWEEN SHORT-TERM ENVIRONMENTAL USES & MAINTENANCE & ENHANCEMENT OF LONG-TERM PRODUCTIVITY

VI. ANY IRREVERSIBLE & IRRETRIEVABLE COMMITMENT OF RESOURCES

VII. DISCUSSION OF PROBLEMS & OBJECTIONS RAISED BY OTHER FEDERAL, STATE & LOCAL AGENCIES, PRIVATE ORGANIZATIONS & INDIVIDUALS

NOTES

SUBJECT SWMB

"3M BRAND" MOUNTING FRAME

ST. PAUL, MINNESOTA 55101 MADE IN U S A CATALOG NO. 15-1006-4

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"3M BRAND" MOUNTING FRAME
Visual Products Division 3M COMPANY
ST. PAUL, MINNESOTA 55101 MADE IN U S A CATALOG NO. 15-1006-4

SUBJECT SWmB

NOISE

FEDERAL HIGHWAY ADMINISTRATION: INTERIM/STANDARDS

DESIGN NOISE LEVEL/LAND USE RELATIONSHIPS

LAND USE CATEGORY	DESIGN NOISE LEVEL - L10	DESCRIPTION OF LAND USE CATEGORY
A	60 DBA (Exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 DBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playground, active sports areas, and parks.
C	75 DBA (Exterior)	Developed lands, properties or activities not included in Categories A and B above.
D	--	For requirements on undeveloped lands see paparagraphs 5.a(5) and (6) of PPM 90-2
E	55 DBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

SUBJECT ____________

"3M BRAND" MOUNTING FRAME

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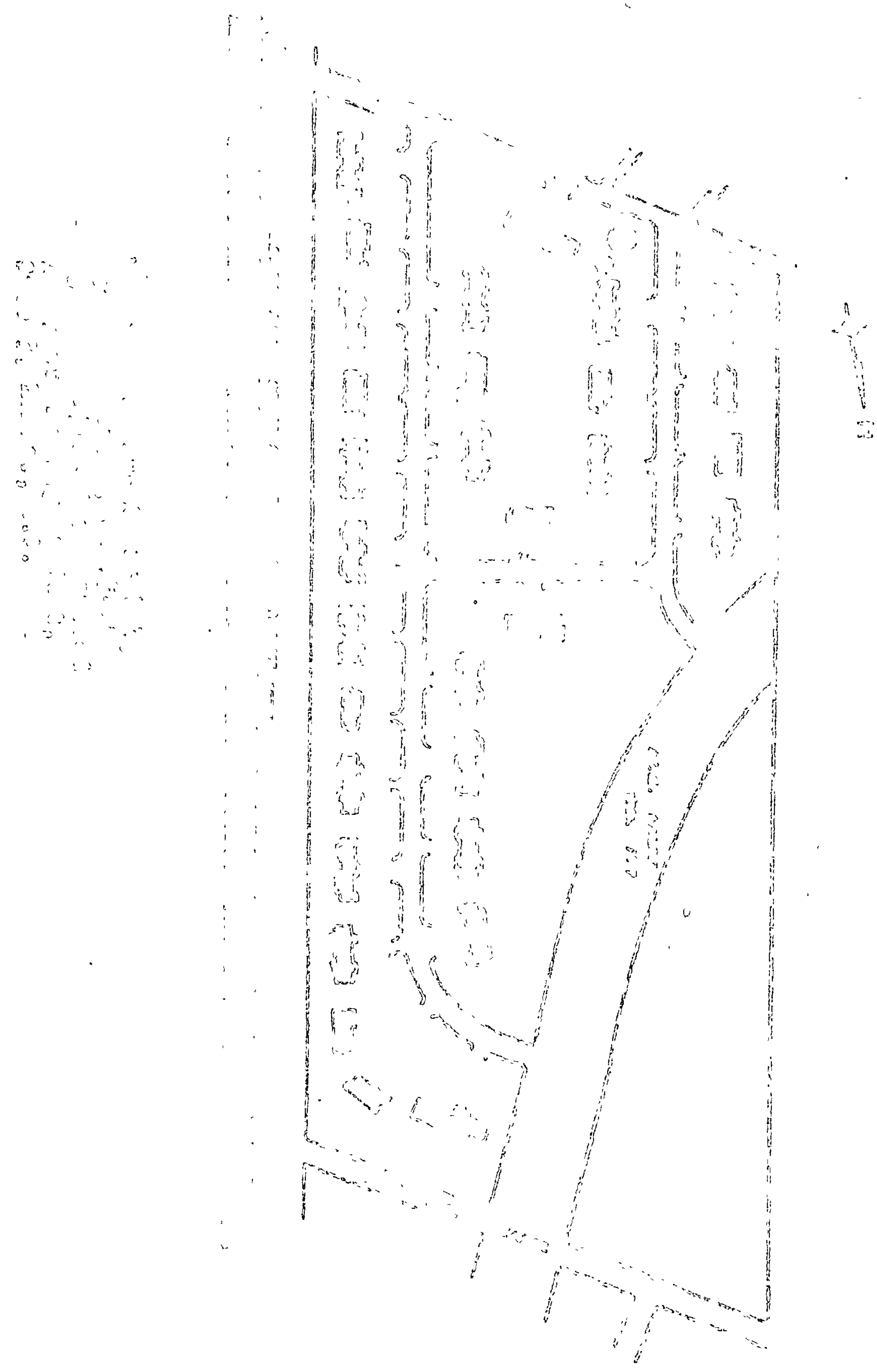
Visual Products Division 3M COMPANY



"3M BRAND" MOUNTING FRAME
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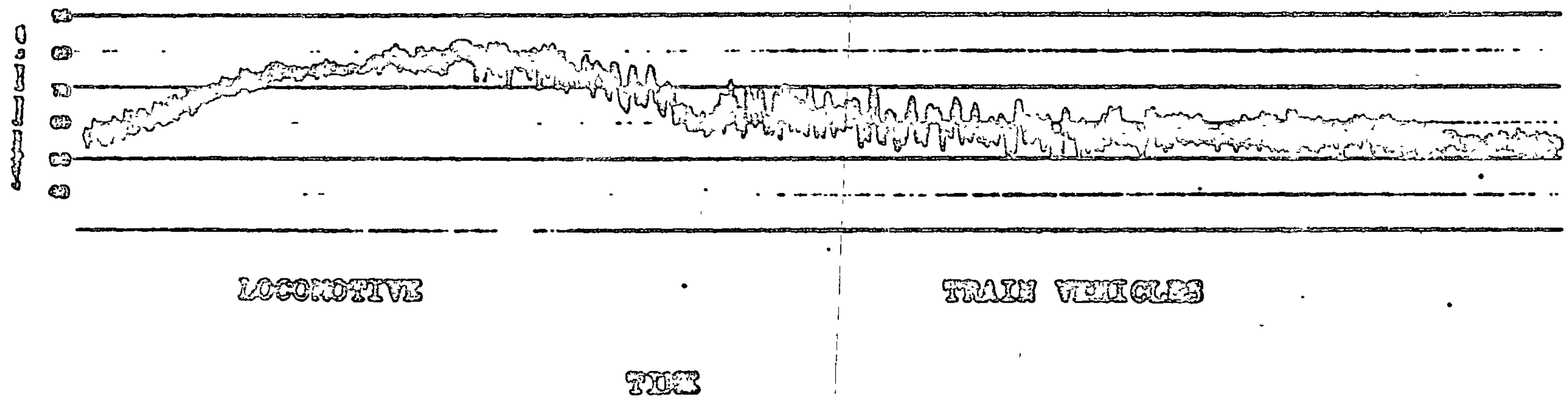
CATALOG NO. 15-1006-4 MADE IN U.S.A. ST. PAUL, MINNESOTA 55101
SUBJECT



Noise Level – Time Pattern during passage of a train

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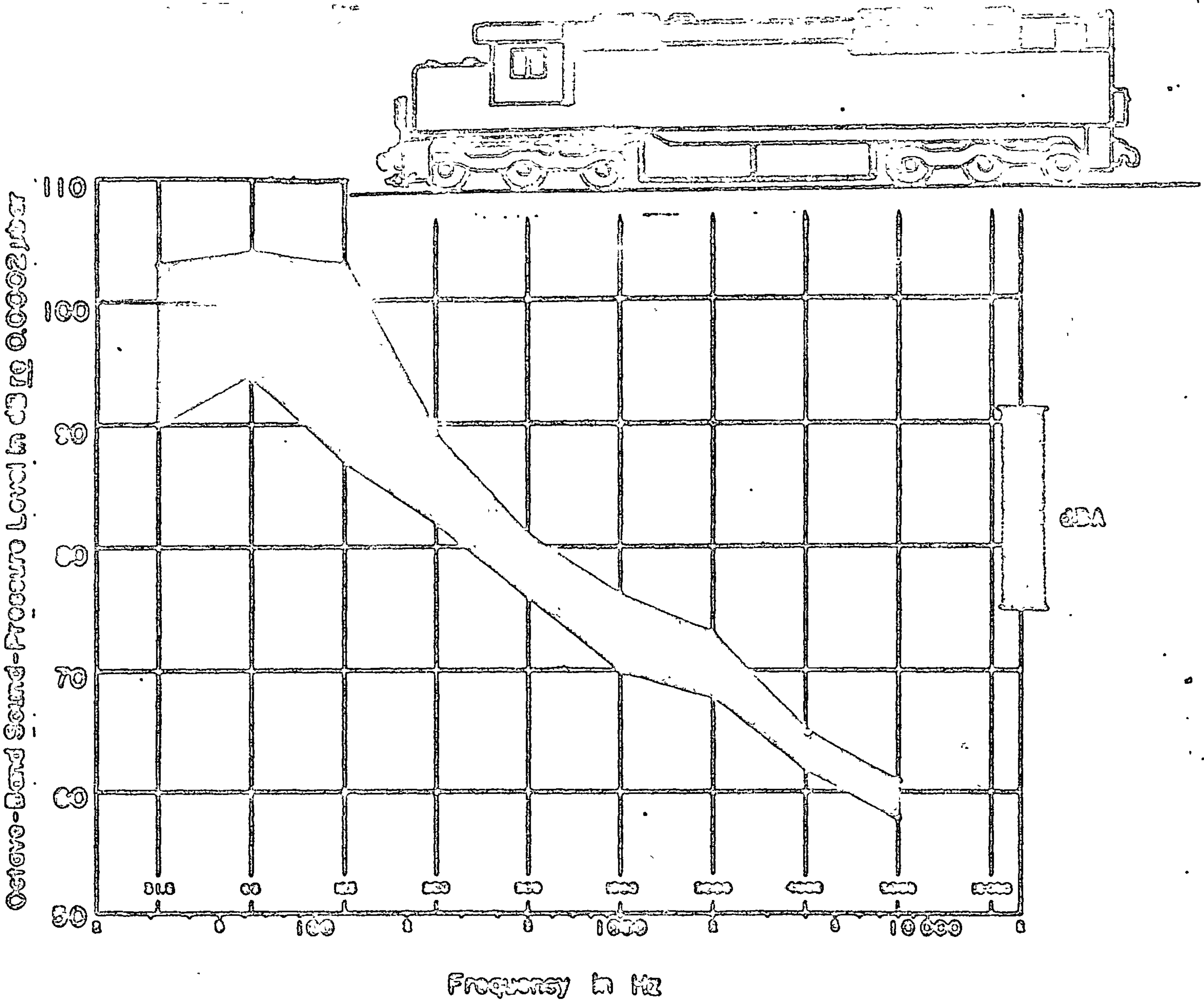

Range of octave band sound pressure levels at Measurement Location 1 of diesel locomotive passage. The upper bound of the range represents accelerating conditions; the lower bound represents decelerating conditions.

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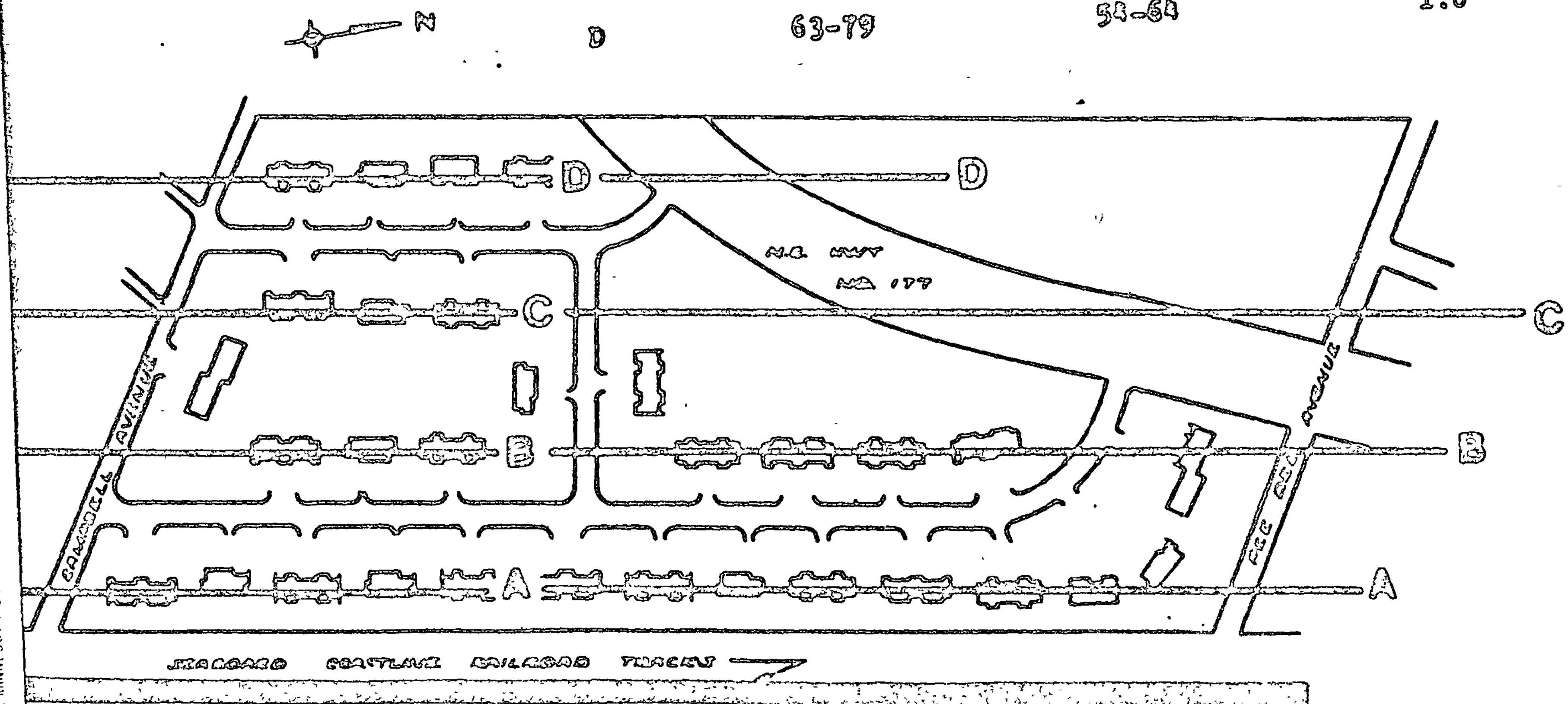
[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	100.0	100.0	100.0	[illegible]
[illegible]	93.9	66.6	92.9	[illegible]
50	35.0	33.7	30.8	[illegible]
55	19.0	20.2	20.4	[illegible]
60	7.1	14.6	6.6	[illegible]
65	4.0	8.6	[illegible]	[illegible]
70	2.3	3.5	[illegible]	[illegible]
75	1.6	2.9	[illegible]	[illegible]
80	1.2	1.4	0.5	[illegible]
85	0.6	[illegible]	0.2	[illegible]
90	0.1	0.1	0.0	[illegible]

[illegible]

CONTOUR	LOCOMOTIVE NOISE (dBA)	TRAIN VEHICLE NOISE (dBA)	PERCENT OF TIME NOISE LEVEL EXCEEDS 65 dBA
A	75-91	60-70	4.18
B	67-83	56-66	1.4
C	64-80	54-64	1.1
D	63-79	54-64	1.0



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SECTION IV

GENERAL PROCEDURES AND ENFORCEMENT BEHAVIOR

1.0 CODE OF RECOMMENDED PRACTICES FOR ENFORCER-VIOLATOR-CONTACT-PROCEDURES AND BEHAVIOR - GENERAL

1.1. Etiquette in Enforcement Work

1.1.1 Definition - Etiquette is defined as the "forms" required by good breeding or prescribed by authority to be observed in social or official life. One of the many synonyms of the word etiquette is "decorum" which is defined as "fitness" or "propriety and good taste in conduct or appearance."

1.1.2 Impressions - The great importance in rendering an enforcement service where personal contacts with the public are concerned. The eyes of the public are always on the enforcement inspector. His behavior is a contributing factor in the formation of a good impression of his department and its members. As soos as you act as a representative of the Department of Environmental Control, you lose your identity as a private citizen and become the representative of the Department. An errant doctor, lawyer, judge, legislator or tradesman will not bring public condemnation on his particular profession, but how often have you seen the entire Department condemned for the action of one inspector?

1.1.3 Etiquette - In enforcement work, etiquette applies to appearance, attitude and conduct. All three are important in establishing a good first impression. An inspector must give careful attention to his personal appearance. He must make sure his clothes fit properly and are neat, pressed and in good repair. Other "musts" to a smart appearance include:

1. Neatly trimmed and combed hair
2. Clean shaven face
3. Clean hands
4. Clean teeth and in good condition
5. Clean and trimmed fingernails
6. Body and breath free from odors
7. Good physical condition

1.1.4 Appearance - Certain practices distract from your appearance. Do not spit or chew tobacco or gum in public. Avoid backslapping, finger poking, shoulder leaning or constant handshaking. Do not lean or assume a loafing position. These actions only irritate the onlooking public. In this regard, it is assumed that the individual inspector will use good judgment. Specifically, an enforcement officer when on duty should:

1. Refrain from smoking when in conversation with a citizen regardless of the nature of the conversation.

2. Refrain from smoking when entering a private home in the performance of enforcement duties.

3. Refrain from smoking, regardless of the circumstances, when it will interfere with your enforcement duties or appearance.

On the other hand, smoking would be permissible under the following circumstances:

1. On a special assignment that is of such nature that you are not exposed to public view.

2. In an enforcement vehicle, provided that you do so in an inconspicuous manner.

3. Working inside a Department facility, where the atmosphere is private or semi-private and you are not in direct contact with the public.

4. Eating in a restaurant, the inspectors are called upon to render a wide variety of services. These services should be performed cheerfully. Problems that may seem insignificant to an inspector accustomed to dealing with sordid and distressing situations are most important to the citizen involved. It is imperative that such matters be approached with understanding, compassion and magnamity. The more friendly and courteous the agent is, the more people are likely to come to him for advice and help when they are in trouble.

1.1.5 Attitude - The overall attitude of an inspector in the performance of any public service can usually be detected by the citizen. Remember that your thoughts and emotions are revealed by facial expression, tone of voice, or a gesture. From these simple indications, a citizen can determine your attitude toward him and his particular problem. His opinion of you will probably be extended to include all Environmental Control personnel. No matter how cynical a n inspector becomes, he should not let feelings affect his behavior in public. The Department you represent does not give you any right to indulge in abusive oratory, personal vindictiveness, or to act in an officious and sarcastic manner. An attitude of blustering officiousness gains nothing. Cultivate the knack of meeting people easily. Remember tact and consideration will help in most tasks. Show respect to others in all contacts. You will invite respect in return. Make a sincere effort to understand the other person's point of view. To maintain a proper attitude, you must accept the fact that you are a public service employee. Strive to eliminate any indications of arrogance, conceit, indifference or impatience and develop a genuine and sincere interest in your work. Develop the ability of making a friendly approach without creating fear or suspicion. The first few seconds of your contact with a citizen are the most critical. First impressions are usually lasting ones. Show a friendly interest and do not bluff or cover a lack of knowledge. Attitudes are expressed in three ways:

1. Facial Expressions - To be friendly, a smile goes a long way in this regard. A scowl is a sign of a sullen disposition and could give a citizen a bad impression not only of the particular inspector but of the entire Department.

2. Bearing - Your bearing, whether it be in public, in a car or in private life, is always on display. When out of a car, an inspector should always stand erect. In private life, too, your bearing should reflect what you have been preaching to other citizens while you are working.

3. Voice - Voice and the spoken word can be best explained by the following chart:

THE SPOKEN WORD

Proper	Improper
Temperate language	Violent language
Clean language	Obscene language
Well-modulated tone	Loud, harsh, gruff speech
Truth	Lies and gossip
Charitable remarks	Sarcasm
Kind words	Vulgar remarks and stories

Never raise your voice. A big mouth does not indicate a big brain. Every time we speak, we reach the ears and mind of people. Ninety percent of all frictions of daily life stems from mere tone of voice. When we speak, our words convey our thoughts, but our tone conveys our mood. If he is loud, the inspector will be regarded by the citizen as a loudmouth and a braggart in whom he can have no confidence. If he uses vulgar remarks, is sarcastic and obscene, an inspector will not be thought of too highly. On the other hand, if he is courteous in his speech, the inspector will be looked upon as being a well-trained servant of the people. The citizen will have confidence in the inspector and will be happy to cooperate with him. Cooperation from the public greatly simplifies the work of any enforcement agency. The attitude behind a phrase can be as important as the phrase itself. "What do you want?" is a very blunt way of asking whether or not you may be of service. Be aware of the phrases you use in your approach, and be sure that they are of such a nature that they do not arouse antagonism. Refrain from the use of nicknames, such as "Bud," "Chum," "Fellow," etc. when addressing a citizen. Never address a female as "Lady." The titles "Sir," "Madame," or "Miss" should be used. Once the name is known, it should be used. When the person is addressed by name, the correct title should be used, such as: "Doctor," "Mr.," "Miss," or "Mrs." It is difficult to be firm without appearing tough. It is not easy to have an investigative attitude without appearing unduly nosy or to require citizens to do things against their will without appearing officious, but it can be done with the proper approach. The actual conduct of an inspector is i portant to correct enforcement etiquette. No one can set up rules of etiquette for every situation that an inspector will encounter during his daily duty. Listed are some of the more common guidelines of enforcement etiquette that will help you handle additional situations that could arise:

1. Treat all citizens with respect and consideration. Treat all of their complaints with respect, regardless of the importance you may place on them. A complaint is of great concern to the person making it.

2. Give the citizen your full attention. When you focus your attention elsewhere, the citizen with whom you are talking will get the impression that you care little about his problems. If something should divert your attention, so inform the person, and then get back to him and his problem as soon as possible.

3. Try not ti interrup a citizen needlessly during his explanation. If questions are essential to acquire a better perspective of his problem, wait until he finishes. Try not to ask him foolish questions, even though his questions might appear to you to be foolish.

4. When making an explanation of anything to a citizen, make certain that he understands you fully. Allow him to ask questions. If he should be asking directions make certain that he understands you fully before allowing him to proceed. If the directions are such that they are complicated, write them out. Never give a citizen the wrong information. If you do not know, politely inform him that you don't know and offer to find out for him or refer him to a source where he can obtain the information.

5. Enter a complainant's home as if you were a guest and not an unwelcome intruder. Proper decorum while in the house of a citizen indicates good grooming and training and will prompt the citizen to be more congenial. Conduct yourself as you would expect others to conduct themselves in your home. Treat persons in their homes as you would have your own family treated in your home. All forms of etiquette should be exercised while in the home. Remove your hat and wipe your feet before entering. Avoid placing keys, books, etc. on the furniture and do not smoke or lounge around as if you were in your own home. Acting in an official capacity as an Environmental Control inspector precludes the "make yourself at home" precept.

6. Never discriminate against any individual. Prejudice and discrimination have no place in any enforcement department in America. Do not become involved in any controversial subjects such as religion, politics or race.

7. Avoid being an inconsiderate driver when operating any motor vehicle and especially when operating Department vehicles. Do not interfere with traffic by driving too slowly and do not create a traffic hazard by driving too rapidly. Be thoughtful and considerate of the rights of other motorists while on patrol.

8. In dealing with ordinance violators, be courteous and civil. Never take the violation as something personal. Remember you are not the judge and the jury nor are you t render any penalties, lectures, etc. You must enforce the law and leave the punishment to the courts. Fair and impartial treatment of any lawbreaker is not an indication of weakness. By resorting to cruel or biased treatment, you do not alter the status of the criminal or wrongdoer but only lower yourself to their level of society. It must also be remembered that until a person acts overtly in violation of a law, no action can be taken against him. There is no law against making an enforcement officer angry. You just lower yourself by berating and demeaning a citizen in return for his remarks. The public is very interested in the Department of Environmental Control. Citizens have very high standards that they would like their enforcers to live up to. These standards include:

   (a) That the men have a professional interest in their job.

   (b) That they operate under excellent discipline.

(c) That they be well trained.

(d) That they cite violators quickly and without interference to ordinary citizens.

(e) That they be fair and impartial.

(f) That they be honest.

(g) That they be tireless.

On the other hand there are groups that are bent on reducing enforcement effectiveness by placing the inspector in the role of the villain in the eyes of the public. A sincere regard for the feelings and rights of others by ALL inspectors can reduce the chances of this happening. Proper utilization of the proper forms of enforcement etiquette is essential to good enforcement work.

Enforcement courtesy consists of quiet, unassuming behavior based on a sincere consideration for the feelings of others. Race, religion, color or creed do not influence the practice of courtesy. Courtesy presupposes an attitude of desiring to please, or desiring to serve. Both make necessary attributes of a good enforcement officer. As an Environmental Control inspector, you can be firm and conscientious in carrying out your enforcement duties and still be courteous. A courteous enforcement officer inspires confidence. Citizens look upon inspectors as representatives of the Department of Environmental Control. It is obvious, therefore, that the influence of inspectors on citizens is increased by reason of the authority they represent. Always remember that most citizens never come in contact with any other official of the city government except the enforcement officer, and as a representative you are judged as an official of city government whether on or off duty.

People under stress or under the influence of excitement are most susceptible to external stimuli than they would be under normal circumstances. They are likely to be more readily swayed by the actions of those with whom they come into contact. Enforcement officers must be careful that the influence of their authority does not become oppressive in their relationship with the public, particularly in situations of stress and excitement. The attitude of people toward the Department is molded by every experience in observing, talking to, and in being served and controlled by the Department representatives. Every inspector, therefore, unconsciously plays a major role in creating public reaction to the Department, be it good or bad. Every day the Department receives letters from grateful citizens complimenting members for some act of kindness or courtesy. Unfortunately most of these acts are known only to the recipient. But just let one act of discourtesy occur and the entire Department of Environmental Control gets the blame.

Inspector courtesy must be emphasized both in actions and in attitudes. The rules of etiquette that precribe the common acts of courtesy have been established by years of custom and usage, and their observance is a public acknowledgement of understanding and of a sincere acceptance of the rules of gentlemanly demeanor. Strict adherence to the standards of proper behavior curbs undesirable characteristics of personality.

An inspector's duty is to regulate the conduct of and minister to the needs of people of all walks of life. These should be performed cheerfully -- as a good neighbor. Problems that may seem insignificant to an enforcement officer accustomed to dealing with sordid and distressing situations are most important to the citizen involved. It is imperative that such matters be approached with understanding, compassion and magnanimity.

1.2 Rules of Courtesy to Remember

"Do unto others as you would have them do unto you" just about sums up the basic precept of courtesy. It would be impossible to list rules of courtesy that would cover every type of situation that confronts an inspector daily. The following are reiterations of the more common aspects of enforcement courtesy:

1. Treat all complaints with respect, regardless of importance since it is of prime concern to the citizen.

2. Understand thoroughly what is being told to you by a citizen, be it a complaint, a question or a request for service.

3. Give the citizen your full attention. When you focus your attention elsewhere, the citizen will get the impression that you are not paying attention to him. If something does direct your attention, so inform the citizen and get back to him as soon as possible.

4. Try not to interrupt the citizen needlessly during his explanation.

5. Don't be afraid or reluctant to take notes if necessary. No one likes to keep repeating himself and, by taking notes, it will not be necessary to ask questions.

6. As mentioned previously, the spoken word is an important factor exhibiting courtesy. The use of the expression "Sir" and "Madam" should be used extensively in addressing citizens. Avoid the over-friendly practice of using their first names. The expressions "Thank you" and "You are welcome" can never be overused.

7. Sarcasm, flippancy, flares of temper or expressions of envy or prejudice should be avoided at all times.

8. When making an explanation to a citizen, make certain that he understands you fully. If he is seeking directions, make sure he understands you fully before allowing him to proceed. If the directions are complicated, write out the information for him. In answer to questions for which you do not have the answer, don't give just any answer or brush off the citizen with "How should I know?" or "What are you asking me for? Do you think I know everything?" Either attempt to find out the answer or direct him to someplace where he will be informed.

9. Enter a complainant's home as if you were a guest, not as an unwelcomed intruder. Proper decorum while in the home of a citizen indicates good training and will prompt the citizen to be more congenial and display confidence in any future service.

10. Always operate your vehicle in the manner in which you expect everyone else to operate theirs.

11. Present a businesslike appearance when conversing with a citizen.

12. Do not get involved in controversial subjects, such as religion, race, or politics.

13. Never discriminate against any individual. Prejudice and discrimination have no place in any enforcement department in America.

14. In handling a traffic violator, the ultimate in courtesy is prescribed. Remember you are not there to penalize, irritate, lecture or scole the violator. He should be handled in a manner that will not duly embarrass him but will leave no doubt that he violated a traffic law.

15. Never allow your feelings to affect your actions and attitude toward the public. You must learn to take any constructive criticism in the sense that it is given. This criticism is often given with good intentions. It shows what the person thinks of you. An exceptional person will take such criticism and learn from it.

There are four basic causes which bring on discourtesy on the part of enforcement officers. All enforcement officers must take an inventory and guard against them:

1. Showing off - An enforcement officer in uniform is always seen by a great many more people than he sees. He must be careful not to show off. "Show-off" techniques do not result in the public's admiration and amazement at your brilliance, but in annoyance at your conduct.

2. Self-importance - A feeling of self-importance often tends to make you regard each violation of law as a personal offense against you. Your reaction will result in trying to "get even" rather than impartial enforcement of the law.

3. Discourteous behavior of others - You will often have the tendency of being discourteous because of another individual's obvious discourtesy. An offender will usually be on the defensive when he is approached by an enforcement officer and will often open with an attack of abusive language and discourteous behavior. For you to respond in like manner only worsens the situation. Bystanders will rarely see the discourteous behavior of the offender, but will never miss discourteous behavior by an enforcement officer. By maintaining self-control in all situations and dealing both firmly and courteously with an offender, an enforcement officer shows superiority to him, and his handling of the offender will be far more effective.

4. Ignorance - Discourtesy can sometimes be due to ignorance. Courtesy is something which is acquired through constant practice, imitation and thoughtfulness, based on a sincere consideration for the feelings of others. It becomes an intimate part of the personality and breeds good-will wherever the person possessing it goes.

1.3 Conclusion

The Department can be looked on as a super-sales organization with you as a super-salesman. For you, the Department, the community, and the city, respect for law and order, etc. are the principal commodities. Apply the more simple rules of salesmanship in your actions:

1. Use courteous words instead of sharp retorts. Avoid sarcasm. Be polite. Remember that politeness like civility requires one only to refrain from rudeness.

2. Reflect enthusiasm instead of dullness. If you don't appear enthusiastic, no one else will be either. You can't fool anybody on this part. Believe in yourself by showing confidence in your work.

3. Show response instead of indifference. Listen to the other fellow. Hear him out before taking any action.

4. Show warmth instead of coldness. Remember that coldness implies indifference.

5. Evidence attention instead of neglect. A person's problem paramount. Listen to him and him alone. Try to understand the problem at hand before making any decision. Discuss it with him.

6. Exhibit patience instead of irritation. Patience is a virtue you must learn. It does not imply weakness or resignation. It implies composure, perseverence and forebearance. It shows you have control of a situation, are steadfast in your purpose and are tolerant. It indicates that you have sufficient self-command to refrain from paying injury in kind or taking unrestrained and thoughtless retaliatory action.

7. Promote creative instead of humdrum ideas. Be creative in your thinking and in your approach. The day of blustering, muscle and indifference is gone. Always try to think ahead.

8. Maintain promptness instead of delay. Prompt action indicates a man that is energetic, aggressive, and confident in himself. Delay implies laziness or lack of confidence.

9. Show appreciation instead of apathy. A person who appreciates others is generally appreciated in return.

None of these traits are signs of weakness, but are indications of great strength of character which implies that a man possessing it is confident and has pride yet shuns the egotistical traits of the braggart. An enforcement officer, to operate efficiently and in a professional manner, must develop pride in himself and in his organization. He must be proud to be an enforcement officer and must conduct himself with the dignity of his office. Dignity displays courtesy. And remember: "COURTESY IS CONTAGIOUS."

1.4 Stopping and Approaching the Noise Violator

When a noise violator has been overtaken, the pursuit phase has ended and the stopping and approaching phase begins. Because of the inherent dangers of maneuvering in traffic, the inspector must follow certain preplanned procedures to insure his own safety and the safety of the violator.

The violator must be made aware that you want him to pull over and stop. You can get his attention by use of spotlight or the horn or by pulling abreast of his auto and giving him verbal instruction. Once you have the violator's attention and have made him aware that you want him to pull over, give definite and clear instruction for him to follow. Don't be vague, for when the violator submits to your control and is under your direction, you, the inspector, have a responsibility for his safety.

Choose a location large enough to park your vehicle and the violator's safely and direct the violator to it. Alert surrounding traffic as to your intended maneuvers to avoid possible accidents. Be especially alert at this time for a nervous reaction by the violator, such as an involuntary swerving of his vehicle to one side, or pressing too heavily on the accelerator causing his vehicle to surge ahead.

When a violator does not stop after you have signaled him to do so, move your vehicle alongside of his on the driver's side. Leave about three feet between vehicles; position your vehicle's front door so that it is even with the rear door. Study the driver from this position for positive later identification, and also scrutinize any passengers who may be in the vehicle with him. Be alert for any suspicious actions at this time.

If the violator you have stopped is a suspected intoxicated driver, do not allow him to drive the auto, or even move it. Once you suspect intoxication, all changes of the vehicle's position are to be made by you, or your partner, if you have one.

After choosing a nearby, LEGAL parking place, both the enforcement vehicle and the violator's vehicle should be pulled to the shoulder, or curbside of the street or road. The enforcement vehicle should be eight to fifteen feet to the rear of the violator's vehicle. The left edge of the enforcement vehicle should be two feet to the left of the violator's vehicle to offer protection to the officer from on-coming traffic. The dome and flasher lights should remain in operation during the entire time a violator is stopped unless the stop is made on a limited access roadway and the violator's and inspector's vehicles are both safely off the road. Under these circumstances, and only these, the dome and flashers will be turned off.

Before leaving the vehicle, check the violator's state license number, write the state license number down and leave it in your car.

Approach the violator on the left side of his auto. Stand slightly behind the front door as you ask the violator for his license. Your position puts him at a psychological and physical disadvantage because he is forced to turn slightly to rear and is prevented from hitting you with his door by suddenly opening it.

Ask the violator for his driver's license, and check his description thereon against his actual appearance. If there is any discrepancy, ask him to step out of his car and stand up. If there is a passenger in the car of the same sex, have him step out and stand up also. The license may actually belong to the passenger who gave it to the driver as you approach the auto in hopes of avoiding a citation for driving without a license or having a revoked or suspended license. When the description of the license fits both the passenger and the driver, ask the passenger for his license.

When you are operating as a two-man unit, one officer can remain with the car as the other approaches the violator's vehicle. While there is safety in numbers, there is no justification for you, the approaching inspector, to abandon due caution while making your approach.. The inspector who remains with the car must not be inattentive, either. He must remain alert for any sudden or suspicious movements on the part of the passenger or driver, and immediately inform his partner. He should also be alert for any traffic conditions that would endanger his partner or the violator, and take traffic control action, if necessary.

The alternative procedure would be for both inspectors to approach the violator's vehicle from opposite sides, and, if circumstances warranted, the second inspector would remain and give whatever assistance is necessary until the required action is completed and the contact is terminated.

The first concern of the officer stopping and approaching a violator is his own safety and the safety of the violator. The officer must be alert to any sudden change of circumstances that reveal to him that this is much more than a noise violation, and take whatever steps the particular situation may require or demand.

When you, the officer, determine that this is nothing more than a noise violator, a new phase is entered into and that phase is "officer-violator" relationship. This is the only contact that most citizens ever have with an Environmental Control inspector, and from your conduct during such contact, they will form their opinion of the entire Department. If you conduct yourself properly, courteously and efficiently, you will be practicing good public relations in addition to performing a law enforcement duty.

Some very simple instructions for making the issuance of citation as painless as possible are as follows:

1. Assume the initiative at the outset of your contact with the violator.

2. Do not ask questions, such as "Do you know why I stopped you?" or "Do you know what you did?" These questions invite a denial.

3. Briefly tell the violator what his violation was. Don't preach.

4. Ask the violator for his license. Don't let the violator hand you his wallet. Inform him politely but firmly to remove his license from the wallet or other container, place him under arrest and have him transported to the nearest station.

Some violators may become antagonistic while being issued a citation and may become abusive to you in particular and the police department in general. Do not make a personal issue out of your contact with the violator, no matter hos abusive he becomes. If you remain in control of your temper and maintain a courteous manner, you have bested the violator and he knows it. This in itself should be a source of much greater satisfaction than any retort you might make. Don't become arrogant or cocky, however. It is only human nature that the violator will attempt to rationalize or justify his actions that he is receiving the citation for. You can avoid the necessity for commenting on his explanations by returning to your squad to complete the citation.

1.5 Calibration Procedure

1.5.1 Calibration Procedure for the Impulse Precision Sound Level Meter Type 2204

1. Attach the 1" condenser microphone, type 4145, to the flexible gooseneck type UA0196 with attached five pin microphone preamplifier section.

2.a. Plug the above assembly into the socket at the top of the precision sound level meter.

2.b. If the microphone extension cable is used plug the assembly described in 1. into the socket end of the extension cable. Take the seven pin plug of the extension cable and plug it into the socket at the top of the precision sound level meter.

3. Turn the diamond shaped knob from the top off to the battery position. (Note the little flashing light labeled "Power".)

4. The meter scale should be labeled "Precision Sound Level Meter", which is found at the lower left corner of the white meter face plate. If the label says "Vibration Meter", pull the meter face plate to the right of the meter housing, turn it over and reinsert.

5. The meter needle should indicate in the white section of the lower most scale labeled "Battery". If the meter needle is not in this white section, the batteries should be replaced.

6. Near the top of the sound level meter are the two "range" knobs. The window between the two red lines on the clear now should be aligned with the back dot at the right of the two knobs. Turn the lower black knob until the number 120 appears below the window of the clear plastic knob.

7. Turn the meter switch, which is the larger black knob below the black diamond shaped knob, to the position marked "C".

8. Hold the pistonphone, type 4220, near your ear and turn it on. You will hear a tone. Now move the switch to check. You should now hear a tone with a higher pitch. If this is not the case, the batteries of the pistonphone should be replaced.

9. Place the precision sound level meter and the gooseneck assembly in an upright position and attach the pistonphone, type 4220, squarely and firmly to the microphone cartridge.

10. Turn on the pistonphone.

11. Turn the diamond shaped knob to the position marked "Fast". At this point approximately 2 minutes should have elapsed. A minimum of 2 minutes, are required for instrument warm up.

12. The meter needle should deflect and be directly over the "4" on upper-most scale marked from -10 to 10 and labeled "dB".

13. If the meter needle is not directly over the "4", insert the small screwdriver, which is taped to the instrument, into the small black hole labeled "Gain Adj". Turn the small screw in the small black hole until the meter needle is directly over the 4.

14. The meter is now calibrated.

15. Turn off the pistonphone.

Check for internal noise.

1. While the pistonphone is still attached to the microphone cartridge and turned off, turn the meter switch to the position marked "Ext. Filter".

2. Turn the large black knob on the Octave Filter Set, type 1613 to the position marked "1000".

3. Note that the meter needle is completely over to the left.

4. Turn the black Range knob clockwise as far as it will go, or until you get a reading on the meter. If you get a reading, the instrument is not functioning properly and noise measurements should not be taken.

   A needle deflection due to bumping or movement of the pistonphone should not be considered a valid reading.

5. Now, turn the clear plastic Range knob counter-clockwise until the meter needle gives a reading.

6. Add the number from the uppermost scale of the meter to the number appearing below the window of the clear plastic knob.

7. Record this number; if this number is over 10 "dB" do not proceed to make noise measurements.

8. Turn the clear plastic Range knob completely clockwise.

9. Turn the black Range knob until the number 120 appears under the window in the clear plastic knob.

10. Carefully remove the pistonphone.

11. You are now ready to make noise measurements.

1.5.2 Calibration Procedure for the Precision Sound Level Meter Type 2206

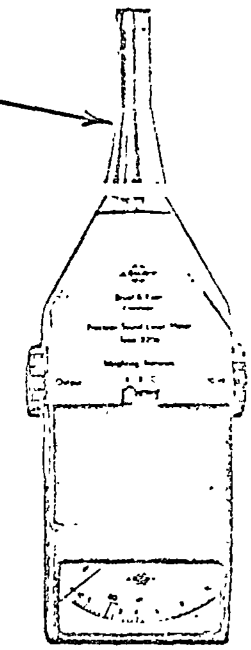
1. Remove the Precision Sound Level Meter from its protective case.

2.a. If no microphone extension cable is used procede with step 3.

2.b. When a microphone extension cable is used, unscrew the preamplifier section from the front of the Sound Level Meter.

The preamplifier section consists of the total stainless steel portion, with the exception of a 1/4" stainless steel collar which stays attached to the light green portion of the meter.

Preamplifier Section



Attach the preamplifier section to the microphone extension cable.

Attach the extension cable to the Precision Sound Lever Meter.

3. Turn the large knob on the left side of the meter to the position marked "Batt" battery check.

The meter needle should deflect in to the section of the scale marked "Batt" with a red boundary. If the needle is not within this boundary, the battery is weak and should be changed. (To change battery, remove stainless steel cover on left side of the meter and replace the "C" cell battery)

4. Attach the Sound Level Calibrator Type 4230 to the microphone cartridge.

5. Rotate the large knob on the right hand side of the Sound Level Meter until the number 90 appears in the window above the 0dB mark on the meter face.

6 Turn on the calibrator.

7. Turn the knob on the left side of the meter to the position marked "Fast".

8. The meter needle should deflect to the 4dB position.

9. If the meter needle is not over the 4dB Position, insert a small screwdriver into the little black hole marked "Sensitivity Adjustment" on the back side of the meter.

10. Adjust until meter needle is over the four mark.

11. The meter is now calibrated.

12. Turn the knob on the right side of the meter until the number 120 appears in the window on the meter face.

13. Remove the Sound Level Calibrator Type 4230.

14. You are now ready to make Noise Measurements.

2 CODE OF RECOMMENDED PRACTICES PROVIDING TEST PROCEDURE SPECIFIED IN SECTION 17-4.24 OF THE ENVIRONMENTAL CONTROL ORDINANCE

2.1 New Motor Vehicle Noise Measurement

2.1.1 Introduction - The following test procedure shall be used to determine that the maximum noise emitted by new motor vehicles offered for sale shall meet the noise limits stated in the Environmental Control Ordinance: Chapter 17-4.7b. This procedure includes noise testing of: (1) Motorcycles, (2) Any motor vehicle with a gross vehicle weight of 8,000 pounds or more, (3) Passenger cars, motor-driven cycle and any other motor vehicle. This test procedure is concerned primarily with the maximum noise produced during acceleration and deceleration of a passing vehicle. Vehicles that have noise generating auxillary equipment that may be operated with the vehicle stationary shall also be tested in accordance with the procedures in Chapter 17-4.8. The following test procedure is based on Standards and Recommended Practice established by the Society of Automotive Engineers, Inc. These include: SAE Standard J331 Sound Levels for Motorcycles and Motor-Driven Cycles, SAE Recommended Practice J366 Exterior Sound Level for Heavy Trucks and Buses, and SAE Standard J986 Sound Level for Passenger Cars and Trucks.

2.1.2 Test Area Selection - The surface over which the test vehicle is to be operated shall be sufficiently smooth so that abnomal tire noise is not produced. Normal concrete or asphalt road surfaces are adequate. The location shall be flat open area free of any large reflective surfaces, such as signboards, buildings, trees, shrubs, hillsides and parked vehicles, within a distance of 100 feet of the microphone and within 100 feet of the centerline of the path of the vehicle from the point where the throttle is open to the point where throttle is closed. (Figure 1) The surface within the measurement area shall be pavement and free of powdery snow, grass, loose soil or ashes. Sound measurement shall not be conducted when wind velocity exceeds 12 mph.

2.1.3 Equipment Setup - Calibration and operation of the noise measuring instrumentation shall be performed by persons trained and qualified in the techniques of noise measurement and the operation of noise measuring instrumentation. Instrumentation used in making vehicle noise measurements shall be selected by technically trained personnel and shall meet SAE Recommended Practice J184 Qualifying A Sound Data Acquisition System. Connect a 60-foot extension cable between the microphone and the sound level meter. Attach microphone to a tripod and turn the instrument on. Raise the tripod so that the microphone is four feet (+ one half foot) above the ground. Locate the tripod so that the microphone is 50 feet ($\pm$ one foot) from the center of the lane over which the test vehicles are to be operated.

The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path. (Figure 1). The microphone shall be oriented relative to the source of the sound in accordance with the instrument manufacturer's instructions to provide a uniform frequency response. Bystanders occupying positions in the vicinity of the test vehicle or the microphone will influence the test results. No bystander shall be closer than 50 feet from the microphone and the vehicle being tested. Set up the sound level meter and recorder at least 50 feet from the noise measuring microphone. Connect the output of the sound level meter to the recorder. Set the sound level meter to A-Weighting and "Fast" meter. External (end-to-end) calibration checks shall be made before and after each period of use and at intervals not exceeding one hour when the instrument is in use longer than this time.

2.1.4 Transmission Gear Selection - Passenger cars, light trucks, and buses that are equipped with automatic transmissions or three or four speed manual transmissions shall make test runs as outlined in low gear. Vehicles equipped with four speed manual transmissions shall make additional runs in second gear. Vehicles with five speed manual transmissions shall be operated in second gear. Vehicles equipped with an "overdrive" shall not make test runs with the overdrive engaged. Vehicles which reach maximum rated engine speed at less than 30 miles per hour or before reaching a point 25 feet beyond the microphone line shall be tested in the next higher gear. Wheel slip that affects the maximum noise level shall be avoided.

2.1.5 Vehicle Test Procedure - Sufficient preliminary runs shall be made to familiarize the driver with the vehicle operation and to ensure that the engine has reached normal operating temperature. Vehicles being tested shall make at least four runs in each direction with a one-minute wait between each run. Trucks, truck tractors and buses having a manufacturer's gross vehicle weight rating of 8,000 pounds or more shall be operated under the condition of load, acceleration, deceleration and gear selection that is found to produce the maximum noise emission at speeds up to 35 mph. Passenger cars, light trucks, truck tractors and buses having a manufacturer's gross vehicle weight of less than 8,000 pounds shall proceed down the test lane at a constant approach speed of 30 mph. When the front of the vehicle reaches line A or AA (Figure 1), a wide open throttle will be applied. A wide open throttle shall be maintained, provided maximum rated engine speed is not exceeded, until the rear of the vehicle has passed line B or BB (Figure 1). When engine overspeed occurs or when vehicle reaches line B or BB, release throttle.

Motorcycles shall follow the procedures outlined in the paragraph above except that they shall proceed down the test lane at a steady speed corresponding to either an engine speed of 60 percent of the speed at which the engine developes maximum horsepower, or at 30 mph, whichever is lower. In most cases operation in second gear will meet this requirement.

2.1.6 Deceleration Test - Deceleration tests need be conducted only when there is an indication that the deceleration noise might exceed the acceleration noise. When conducting a deceleration test, the vehicle shall proceed along the test path in the gear which was used for acceleration test and at a constant approach speed equal to the maximum rated engine speed. When the front of the vehicle reaches a point 25 feet beyond a line through the microphone, the throttle shall be closed as rapidly as possible.

2.1.7 Reporting Test Results - The sound level readings for determining compliance of new motor vehicles with Chapter 17-4.7b shall be obtained by making at least four measurements for each side of the vehicle. The reading recorded shall be the highest dB(A) sound level obtained as the vehicle passes by, disregarding unrelated peaks due to extraneous ambient noises. The A-Weighted sound level (with fast meter response) for each side shall be the average of the two highest readings on that side which are within 2 dB of each other. The noise level reported for the vehicle shall be the sound level of the loudest side of the vehicle. Obvious vehicle malfunction shall nullify the test. Measurements shall be made only when the A-Weighted ambient sound level, included wind effects, due to all sources other than the vehicle being measured is at least 10 dB(A) lower than the sound level of the vehicle.

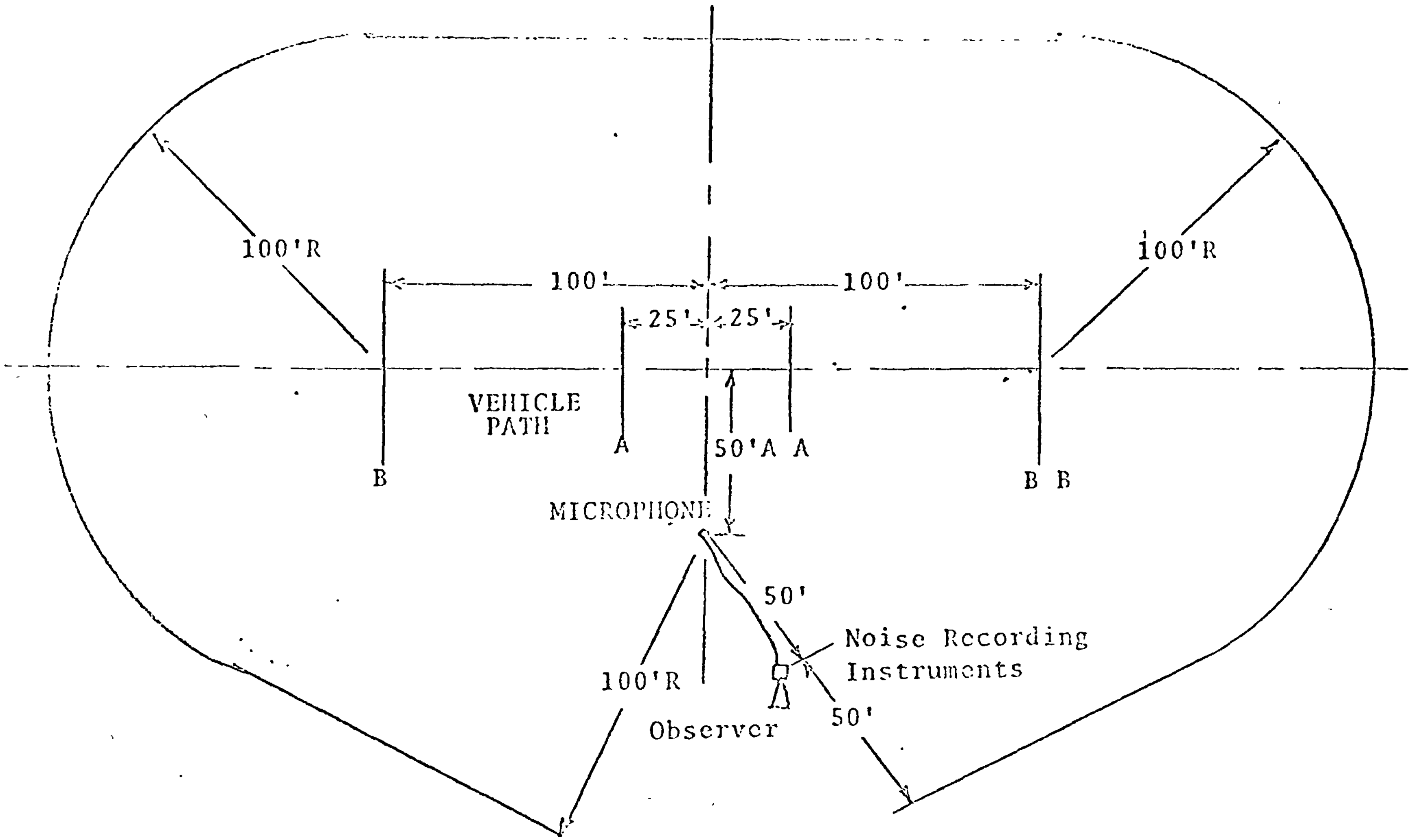

100'R
100'R
100'
100'
25'
25'
VEHICLE
PATH
A
50'A
A
B
B B
MICROPHONE
50'
Noise Recording
Instruments
100'R
Observer
50'

Figure 1

3 CODE OF RECOMMENDED PRACTICES PROVIDING TEST PROCEDURE SPECIFIED IN SECTION 17-4.25 OF THE ENVIRONMENTAL CONTROL ORDINANCE

3.1 Motor Vehicle Operation Noise Measurement

3.1.1 Introduction - The following test procedure shall be used for determining noise limit compliance as stated in Chapter 17-4.7c. This test procedure describes the techniques for determing the noise level of vehicles in use. This procedure is based on Standards and Recommended Practice estab lished by the Society of Automotive Engineers, Inc.

3.1.2 Test Site - Only highways that are paved with concrete or asphalt shall be selected for noise measuring sites. The surface shall be free of standing water. The preferred location shall be an open area free of large reflective surfaces such as signboards, buildings, bridges, solid fences, hillsides, or parked vehicles. This open area shall include a 100-foot radius of the microphone and a point where the microphone line intersects the center of the vehicle path at 90°. (Figure 1). The surface of the ground between the microphone and the path of the vehicle shall be free of standing water, although shrubbery, or grass are permitted.

3.1.3 Alternate Test Site - The meter reader and all other persons shall be 50 feet to the rear or side of the microphone. No other person or vehicle shall be permitted in the vicinity of the microphone. The preferred location described above meets the requirements of SAE Standard J986, J331 and Recommended Practice J366. However, there are very few possible sites in Chicago that can meet the open area requirement of the SAE Standards. Studies and experiments confirm that large reflecting surfaces within 100 feet of the vehicle or noise measuring microphone do indeed affect the noise test results. If the roadway is raised relative to the surrounding area; the measured noise levels are always low provided there are no large reflecting surfaces nearby. If the roadway is depressed or if there are large reflecting surfaces nearby, the measured noise levels are consistently high, relative to results obtained at large flat open areas. Site locations containing large reflecting surfaces shall receive a noise level tolerance according to the following table:

Site Selection Tolerance Correction Factor

Minimum distance between reflecting surface and vehicle or microphone at time of maximum noise reading	dB(A) correction factor to be added to maximum permitting noise limit
100 Feet	1/2 dB(A)
50	1
25	2

12	3
6	4
3	5
1	6

The above correction factors apply to either the vehicle or noise measuring microphone and they are additive if there are reflecting surfaces on both sides of the roadway. The above correction factors are for vertical reflecting surfaces with dimensions of at least 20 feet x 20 feet (i.e., a 2 story house). For solid vertical surfaces less than 10 feet high or a sloped surface of less than 45°, reduce the correction factors to half the value shown in the table. The height or the reflecting surface is relative to the roadway elevation. No measurements shall be made within 100 feet of an underpass or overpass.

3.1.4 Noise Measuring Instrumentation - Persons selected to conduct noise measurement testing or to measure the noise level of vehicles operated on a public right-of-way shall have been trained and qualified in the techniques of sound measurement and the operation of sound measuring instruments. Instrumentation used in making vehicle noise measurements shall be selected by technically trained personnel and shall meet SAE Recommended Practice J184 Qualifying a Sound Data Acquisition System. Connect a 60 foot extension cable between the microphone and sound level meter, attached the microphone to a tripod and turn the instrument on. Place the microphone and tripod 44 feet from the outer paved edge of the traffic line.

This measurement is based on a 12-foot lane so that the meter should be located 50 feet from the center of the lane traveled. If the lane is of a different width, adjust the measurement accordingly so as to comply with the 50-foot requirement. The microphone shall be positioned four feet (± one half foot) above the surface of the ground. It shall be oriented relative to the source of the sound in accordance with the instrument manufacturer's instructions to provide a uniform frequency response. Set up the sound level meter (and a graphic level and/or magnetic tape recorder if a permanent record is desired) about 50 feet to the side or behind the microphone. Connect the output of the sound level meter to the recorder. Set the sound level meter to A-Weighting and "Fast" response. An external calibration check shall be made before and after each period of use and at intervals not exceeding one hour when the instrument is in use longer than this time. The reading recorded shall be the highest noise level obtained as the vehicle passes by, disregarding unrelated peaks due to extraneous ambient noises. Measurements shall be made only when the ambient noise level due to all sources other than the vehicle being measured, including wind effects, is at least 10 dB(A) lower than the level of noise being measured.

3.1.5 Reporting Test Results - Prepare a calibration log and checkoff list. This form should be filled out as completely as possible each time an instrument calibration is made. The completed form should be filed for use as evidence.

3.1.6 Noise Level Tolerance - Allowances are necessary due to unavoidable variations in measuring sites, test equipment temperature, and wind gradients. Vehicles specified in Chapter 17-4.7c shall not be considered in violation unless they exceed the statutory limit by more than 1 dB(A). This 1 dB(A) tolerance is in addition to Site Selection Tolerance.

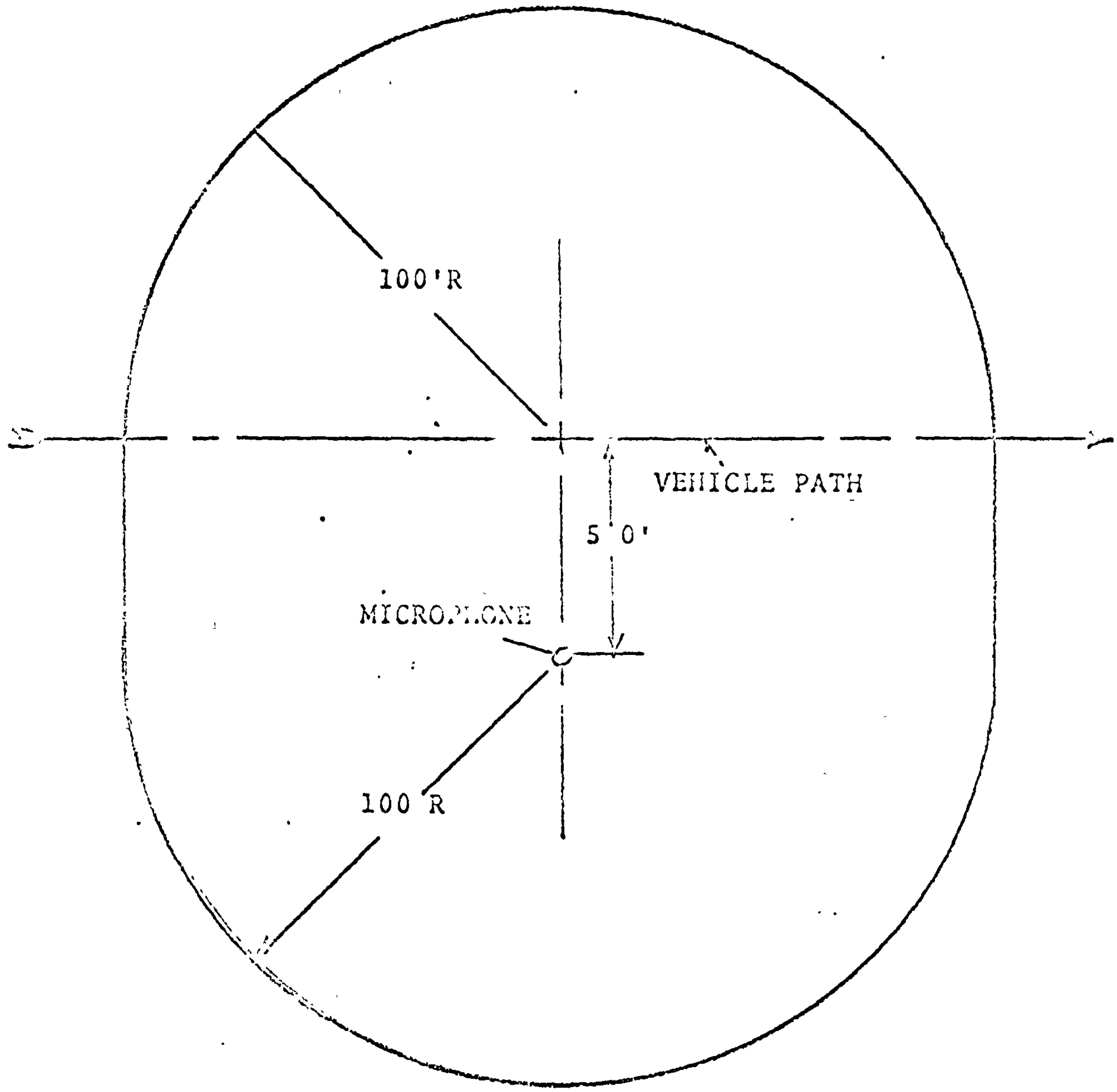


FIGURE 1

4 CODE OF RECOMMENDED PRACTICES PROVIDING TEST PROCEDURE SPECIFIED IN SECTION 17 4.26 OF THE ENVIRONMENTAL CONTROL ORDINANCE

4.1 Engine-Powered Equipment Noise Measurement

4.1.1 Introduction - The following test procedure shall be used to determine that the maximum noise emitted by engine-powered equipment offered for sale shall meet the noise limits stated in the Environmental Control Ordinance: Chapter 17-4.8. This procedure includes the noise testing of construction equipment, industrial machinery, agricultural equipment, engine-powered equipment and pneumatic powered equipment. The noise test procedure is based on the SAE Standard J952b entitled Sound Levels for Engine Powered Equipment.

4.1.2 Test Site - The test area shall consist of a flat open space free of any large reflecting surfaces such as a signboard, billing, parked vehicles or hillside located within 100 feet of either the microphone or the equipment being measured (see Figure 1). The location or path of equipment travel shall be concrete, asphalt, or similar hard material except for moving tests of steel wheel or track-type mobile equipment which shall be hard-packed dirt. The surface shall be free of standing water or snow.

4.1.3 Noise Recording Instrument - Persons selected to conduct the noise measurement testing described below shall have been trained and qualified in the techniques of sound measurement and the operation of sound measuring instruments. Instrumentation used in making noise measurements shall be selected by technically trained personnel and shall meet SAE Recommended Practice J184 Qualifying a Sound Data Acquisition System. Connect a 60ft. extension cable between the microphone and the sould level meter. Attach microphone to a tripod and turn the instrument on. Raise the tripod so that the microphone is four feet (± one half foot) above the ground. For mobile equipment locate the tripod so that the microphone is 50 feet (± one foot) distance normal from a major side surface along a path of straight line travel. For stationary tests locate the tripod so that the microphone is at a distance of fifty feet (± one foot) from the four major surfaces of the equipment. Generally four major surfaces refer to front, rear, and sides of an imaginary box that would just fit over the machine but does not include attachment items such as buckets and booms (see Figure 2). The microphone shall be oriented relative to the source of the sound in accordance with the instrument manufacturer's instructions to provide a uniform frequency response. When using a windscreen it should be calibrated for the type of noise source being measured and data corrected if necessary. It is recommended that measurements be made only when wind velocity is below 12 mph.

Set up the sound level meter and/or recorder at least 50 feet from the noise measuring microphone. Connect the output of the sound level meter to the recorder, if used. Set the sound level meter to A-Weighting and "Fast" meter. Measurements shall be made only when the ambient noise level due to all sources other than the vehicle being measured, including wind effects, is at least 10 dB(A) lower than the level of noise being measured. External (end-to-end) calibration checks shall be made before and after each period of use and at intervals not exceeding one hour when the instrument is in use longer than this time.

4.1.4 Equipment Operations - STATIONARY TEST - Operate the stationary equipment at the combination of load and speed which are typical of its normal use and produce the maximum sound level without violating the manufacturer's operation specifications. For stationary test of mobile equipment the engine shall be operated at maximum normal attainable speed with no load. Pneumatic equipment shall be operated as specified in CAGIPNEUROP Test Code for the Measurement of Sound from Pneumatic Equipment prepared by the Compressed Air and Gas Institute. STEADY-STATE MOVING TESTS - Mobile equipment shall be operated in an intermediate forward gear over a path of travel typical for its operation with the engine at its rated speed and load. The load can be obtained with any combination of rolling resistance, blading, drag load, or vehicle brakes. Intermediate is intended to mean third gear for machines with five or six gears, etc. Hydrostatic or electric drive equipment will be operated at one-half their maximum ground speed and rated engine load. If the condition of rated engine speed at load cannot be obtained due to stall (for instance as on some loaders), wheel slip, or other reasons, the equipment shall be operated in the same intermediate gear at maximum attainable engine speed and no load. ACCELERATION TESTS - Only rubber-tired mobile equipment is normally roaded between job sites and does not require special over-width or over-weight permits for road travel should be run through the acceleration test. The path of equipment travel for this test shall be concrete, asphalt, or similar hard material. The mobile equipment should approach line E headed toward line M in Figure 1 at a steady speed of 30 mph or three-quarters of a maximum speed, whichever is lower. Where alternate forward drive positions are available that position that results in the highest mean acceleration of the vehicle between Line E and Line W should be selected. When the front of the vehicle reaches Line E the throttle is fully opened as rapidly as practicable and held there until the rear of the vehicle reaches Line W and then the throttle is closed as rapidly as possible.

Equipment that has major noise generating machinery, such as elevating scraper, combine or field cutter, shall have this machinery in operation during the STATIONARY AND STEADY-STATE MOVING TESTS.

4.1.5 Noise Test Procedure - For stationary tests record the highest sound level obtained at a distance of 50 feet from the four major surfaces of the equipment. Because of the interference between direct sound waves and those reflected from the ground, large errors may occur when strong discrete frequency components are present. Tests shall be made by moving the microphone vertically approximately ± 2 feet at each location where strong discrete frequency components are suspected. The maximum value of the sound level observed during this test will be the value reported. This discrete frequency component test is the only condition where a by-stander is permitted near the noise measuring microphone. His position should be to the side of the microphone relative to a line between the microphone and the equipment under test. For mobile equipment, take measurements at 50 feet distance normal from a major side surface along a path of straight line travel. Without changing microphone location, repeat the above procedure in opposite direction of travel. The applicable reading will be the highest sound level obtained from the equipment as it moves along the line of path travel (see Figure 1). Observations for each test condition shall be repeated until the number of readings equals or exceeds the range in decibels of the A-Weighted sound levels obtained. At least four measurements shall be made. Readings more than 6 dB(A) below the maximum reading for each test condition shall not be considered valid. The averages of all valid readings shall be reported as the sound level of the particular equipment being tested for that particular test condition. These results will be considered in compliance with noise limits in Chapter 17-4.8 provided the equipment or machinery does not produce impact or percussive-type noise. If the noise is predominantly impact, impulsive, or percussive, the equipment or machinery is not considered in compliance unless the measured noise levels are at least 5 dB(A) below the noise level limits in Chapter 17-4.8. Note: To be classified as impact, impulsive or percussive noise, an individual noise burst must have a duration of less than 0.25 second measured between the instants at which the instantaneous sound pressures have a value equal to one-half of the peak value. If the noise is repetitive, the repetition rate of the burst must be less than 5 per second and the arithmetic average of the peak pressure levels of 10 consecutive bursts in the trains must be more than 15 dB above the unweighted (rms) sound pressure level in the presence of the impulses.

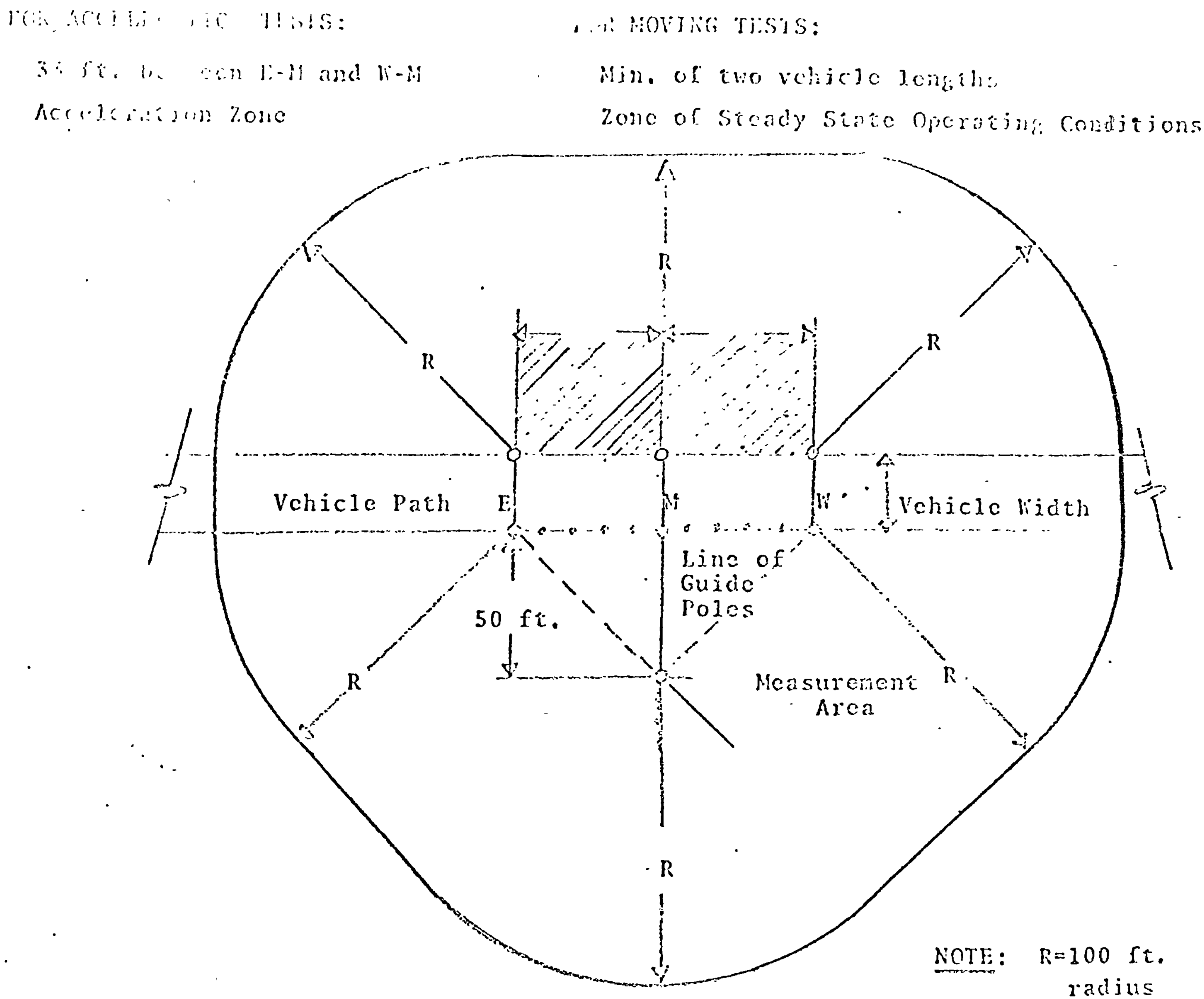


Fig. 1 Minimum Unidirectional Test Site

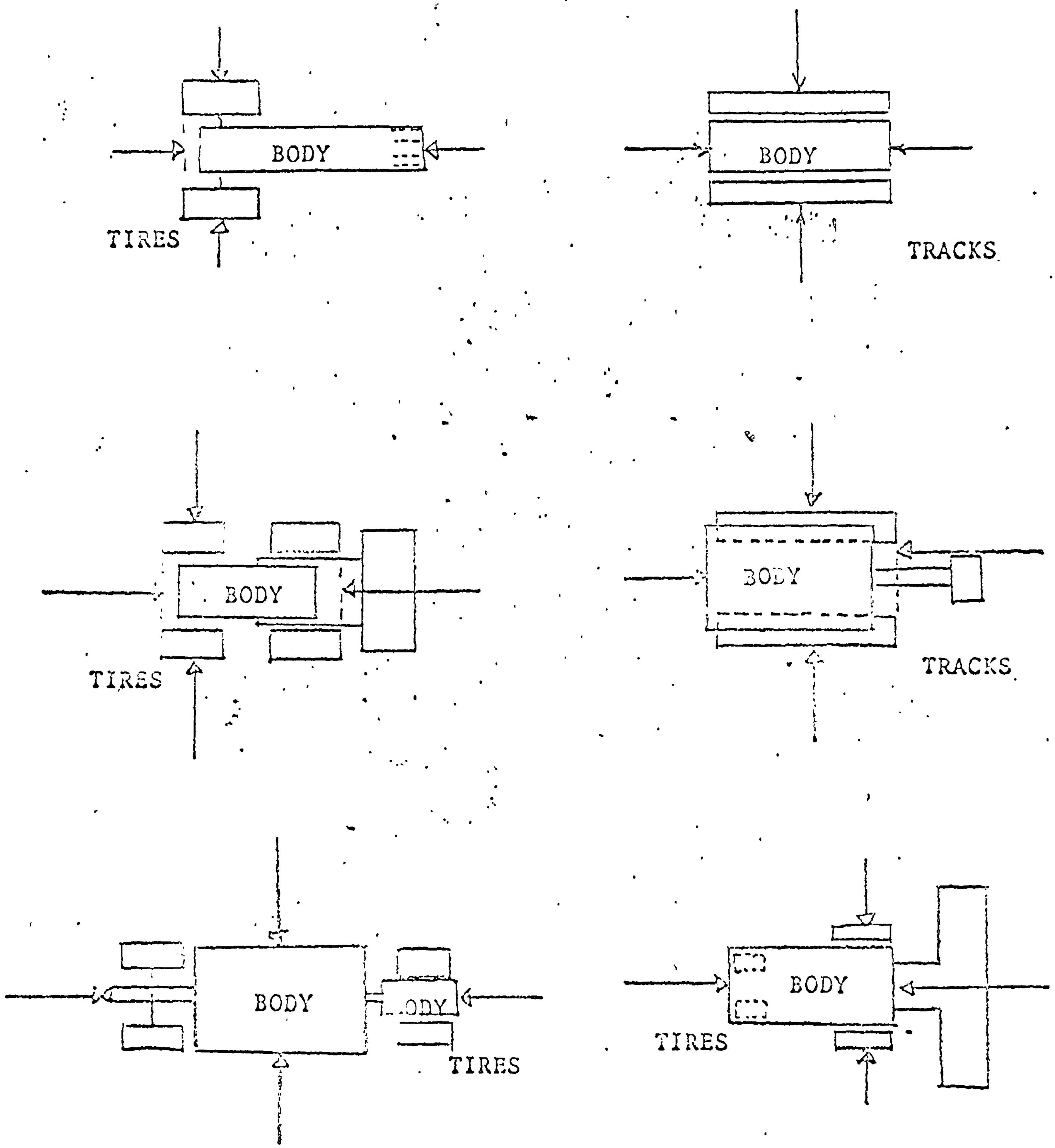


Fig. 2 Major Surface Outline

5 CODE OF RECOMMENDED PRACTICES PROVIDING TEST PROCEDURE SPECIFIED IN SECTION 17-4.27 OF THE ENVIRONMENTAL CONTROL ORDINANCE

5.1 Zoning District Boundary and Property Line Noise Measurement

5.1.1 Introduction = The following test procedure shall be used to determine the noise levels along district boundaries, along property lines or other locations discussed in Chapter 17-4.12, 4.13, 4.14 and 4.20. The procedure permits the use of a hand-held sound level meter to perform noise surveys with limited accuracy and describes more detailed measurement techniques for determining noise levels in octave or narrower frequency bands with high accuracy. Persons selected to conduct the noise measurements described below shall have been trained and qualified in the techniques of sound measurement and the operation of sound measuring instruments. The selection of sound measuring instruments and the measurement technique are discussed in detail in the Chicago Department of Environmental Control Code of Recommended Practices: Methods of Measuring Noise Levels.

5.1.2 Noise Measuring Instrumentation - Survey Method: The instrumentation for conducting a noise survey shall conform with ANSI Standard S1.4-1961 Specification for General Purpose Sound Level Meters or IEC Standard 123-1961 Recommendations for Sound Level Meters. The meter shall be set for "Fast" response and the A-Weighred network. Precision Method: Instrumentation for making accurate noise level measurements required laboratory quality instrumentation meeting the following standards: ANSI Standard S1.4-1961 Specification for General Purpose Sound Level Meters. ANSI Standard S1.12-1967 Specifications for Laboratory Standard Microphone. ANSI Standard S1.11-1966 Specifications for Octave, One-Half Octave and One-Third Octave Band Filter Sets. IEC Standard 179-1965 Precision Sound Level Meters. IEC Standard 225-1966 Octave, One-Half Octave and One-Third Octave Band Filters. Intended for the Analysis of Sounds and Vibrations. SAE Recommended Practice J184 Qualifying a Sound Data Acquisition System. The precision method may be used to measure A-Weighted noise level, octave, one-third octave band frequency analysis, or narrower freqyency band analysis when deemed necessary. The "Fast" meter response or equivalent shall be used on the sound level meter or other read-out device. It is essential that technically qualified personnel select and calibrate the instrumentation and that all tests be conducted only by persons trained in the current techniques or noise measurement.

5.1.3 Noise Measurement Procedure - Noise measurements shall normally be made with microphone positioned four feet ± one half foot above the ground. Other microphone heights may be used if they prove to be more practicable as, for example, in making measurements near an open window; the microphone shall be centered on the open window and outside at a horizontal distance of one to two feet from the plane of the window. All microphone positions shall be described in the recording of the data. The microphone shall be oriented relative to the source of noise (if any) in accordance with the instrument manufacturer's instructions to provide a uniform frequency response. Site locations containing large reflecting surfaces shall receive a noise level tolerance according to the following table:

Site Selection Tolerance Correction Factor

Minimum distance between reflecting surface and vehicle or microphone at time of maximum noise reading	dB(A) correction factor to be added to maximum permitting noise limit
100 Feet	1/2 dB(A)
50	1
25	2
12	3
6	4
3	5
1	6

The above correction factors apply to either a single reflecting surface and becomes additive if there are reflecting surfaces on both sides of the measurement microphone. The above correction factors are for vertical reflecting surfaces with dimensions of at least 20 feet x 20 feet (i.e., a 2 story house). For solid vertical surfaces less than 10 feet high or a sloped surface of less than 45°, reduce the correction factors to half the value shown in the table. Measurements shall be made only when wind velocity is below 12 mph. If a wind screen is used it should be calibrated for the type of noise being measured and the data corrected, if necessary.

Because bystanders may have an appreciable influence on the microphone response, the instrument manufacturer's specifications for location of the observer relative to the microphone (meter) shall be followed. Instrument manufacturer's recommended calibration practice of the instruments shall be made at the appropriate times. Field calibration should be made immediately before and after each complete test. Detailed discussion of the measurement of steady and non-steady noise is contained in Section 7 of Methods for Measuring Noise Levels. Techniques for correcting the mesured data for ambient noise are described in Section 8 and the information required for the reporting of noise measurements is contained in Section 9.

5.1.4 Noise Level Tolerance - Tolerance or limits of accuracy have not been established for the Precision Method of Noise Measurement. Noise level measurement errors can be reduced to one dB by following the procedures as outlined in Methods for Measuring Noise. Techniques are described in this Code of Recommended Practices for determining the frequency and level of audible discrete frequency components that may be 10 dB to 20 dB below the measured A-Weighted noise level. Noise that contains predominant discrete frequency components is not considered in compliance unless the measured levels of the discrete frequency components are at least 5 dB below the statutory limit. Noise that is predominantly impact, impulsive or percussive is not considered in compliance unless the measured levels are at least 5 dB below the statutory limit. Note: To be classified as impact, impulsive or percussive noise, an individual burst must have a duration of less than 0.25 second measured between the instants at which the instantaneous sound pressures have a value equal to one-half the peak value. If the noise is repetitive, the repetition rate of the bursts must be less than 5 per second and the arithmetic average of the peak pressure levels of 10 consecutive bursts in the train must be more than 15 dB above the unweighted (rms) sound pressure level in the presence of the impulses. The measurement of impact noise (often not suitable for measurement by a conventional sound level meter) is described in Methods for Measuring Noise.

6 CODE OF RECOMMENDED PRACTICES PROVIDING TEST PROCEDURE SPECIFIED IN SECTION 17-4.28 OF THE ENVIRONMENTAL CONTROL ORDINANCE

6.1 Recreational Vehicle Noise Measurement

6.1.1 Introduction - The following test procedure shall be used to determine that the maximum noise emitted by new motor-driven recreational or off-highway vehicle offered for sale shall meet the noise limits stated in the Environmental Control Ordinance: Chapter 17-4.22a. This is for vehicles not subject to registration. This procedure includes noise testing of: snow-mobiles, go-carts, mini-bikes, dune buggies and all terrain vehicles. This test procedure is concerned with the maximum noise produced during acceleration and deceleration of a passing vehicle measured at a distance of 50 feet. The following test procedure is based on Standards and Recommended Practice established by the Society of Automotive Engineers, Inc. These include: SAE Standard J331 Sound Levels for Motorcycles and Motor-Driven Cycles, and SAE Standard J986 Sound Level for Passenger Cars and Light Trucks.

6.1.2 Test Site - A suitable test site is a level open space free of large reflecting surfaces such as parked vehicles, sign boards, buildings, or hillsides located within 100 feet of either the vehicle path or the microphone. (see Figure 1). The microphone shall be located 50 feet from the centerline of the vehicle path and four feet above the gound plane. The normal to the vehicle path from the microphone shall establish the microphone point on the vehicle path. A starting point before the microphone point shall be established on the vehicle path. An end point shall be established on the vehicle path 50 feet beyond the microphone point. The measurement area shall be the triangular area formed by the maximum engine rpm point (see vehicle operation procedure below), the end point, and the microphone location. During measurement, the surface of the ground within the meaurement area, including the vehicle path, shall be covered with vegetation not exceeding 3 inches in height. The reference point on the vehicle, to indicate when the vehicle is at any of the points on the vehicle path, shall be the front of the vehicle.

6.1.3. Vehicle Operation Procedure - Full throttle acceleration test as specified below is the basis for establishing maximum noise capability of the vehicle. A starting point and maximum engine speed point must be determined for use during measurements. The starting point for the vehicle is established by carrying out a reverse direction procedure as follows: From a standing start at the microphone point rapidly establish wide-open throttle and allow the vehicle to accelerate until maximum engine speed is reached.

MINIMUM UNIDIRECTIONAL TEST SITE

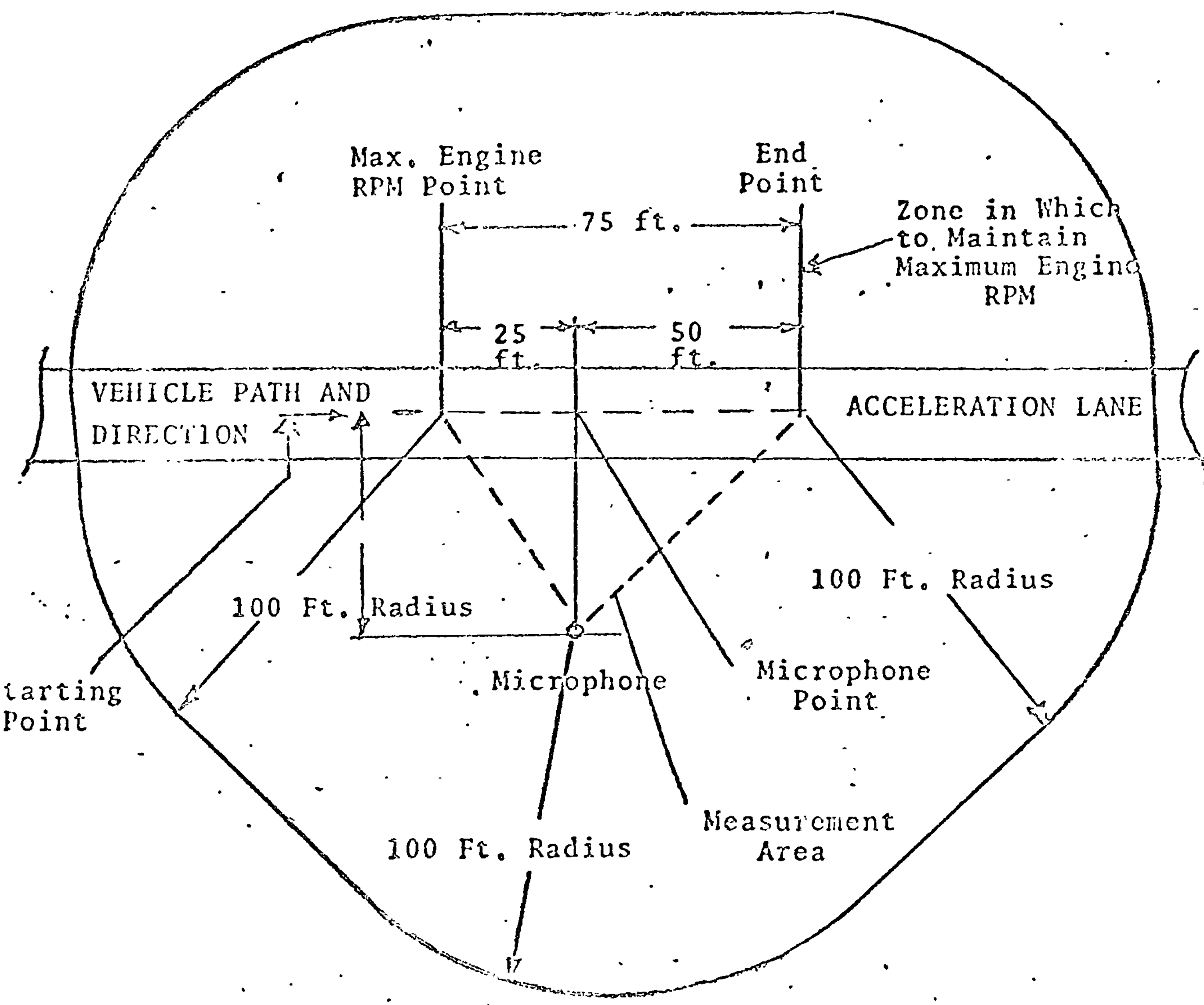


FIGURE 1

IT PAYS TO TALK SOFTLY

For years public officials in Rome have pleaded--unsuccessfully--with fellow citizens to reduce noise.

Last month the Rome daily newspaper "Il Tempo" fired a warning salvo that may finally get some attention: Noise, the newspaper reported, appears to reduce virility. The effect, says the paper "also includes impotency." It is still too early to tell whether this affront to sexuality has curbed the Roman decibel.

I. Importance of hearing

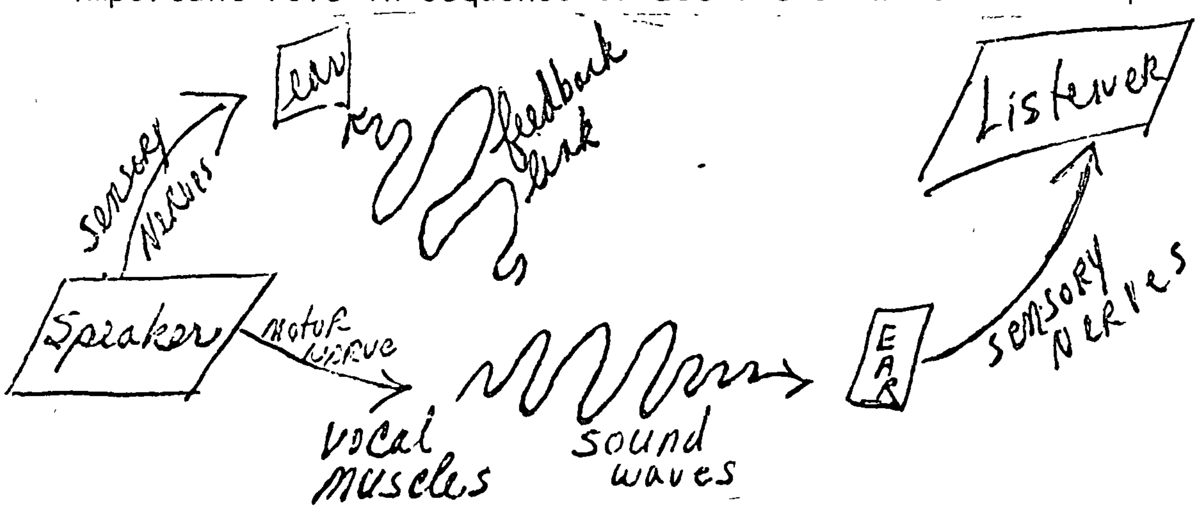
A. It is not until we lose some of our sensory capabilities that we realize how remarkable they are-and how little of the "real" world.exists for us without them.

B. Hearing

1. Lower animals-can mean the diff betw life and death.
   - locating prey
   - protection
   - warning

2. Man - also some primitive functions
   but pleasure also

Important role in sequence of activities we call the speech chain



II. Anatomy and Physiology

A. General function-physical function of the hearing sense organs is to receive acoustic vibrations and to convert them into signals suitable for transmission along the auditory nerve toward the brain. Complex processing of these signals in the brain creates the perceptual world of sound.

B. Let's walk through the ear

Outer - Middle - Inner

1. Outer ear

Auricle-ear canal-eardrum

Auricle - in animals used to channel and localize sound.

Similar function in man but to very limited extent

EAR CANAL - air filled passage-about one inch long - closed at one end by eardrum- open at other to outside.

Sound waves travel to eardrum.

Acts as acoustic resonator-Amplifies sound waves at freq. near its resonating freq. (3-4000 Hz)- may be 2 to 4 times grater pressure at eardrum than at entrance.

serves to protect eardrum from physical damage and changes in temp. and humidity.

EARDRUM (TYMPANIC MEMBRANE)

Separates outer and middle ear.

2. Middle Ear

-Chamber is cavity in bones of skull

Ossicular Chain

3 small bones - connected

Malleus (hammer) - attached to eardrum-covers over 1/2 of drum area - receives motions of ear drum transfers to Incus (anvil) - which is connected to the Stapes (stirrup) footplate of stapes covers OVAL WINDOW- entrance to inner ear.

2. FUNCTIONS

Increases the amount of acoustic energy entering fluid filled inner ear.

-to protect the inner ear from extremely loud sounds- by using some antagonistic muscle actions - but unfortunately this does not occur instantaneously - and sudden loud sounds (gunshot) can cause permanent damage.

Eustachian Tube

3. Inner Ear

a small intricate system of cavities in the bones of the skull

One cavity - coiled like a snail's shell - THE COCHLEA - accomodates the important transformation from mechanical vibrations to nerve impulses.

Cochlea divided - 2 distinct regions - by a membraneous structure called the COCHLEAR PARTITION -the interior of this partition forms a 3rd region.

OVALWINDOW - or entrance to inner ear - on this side of C.P. lies the SCALA VESTIBULI - on the other side is the SCALA TYMPANI.

Both are filled with PERILYMPH a fluid almost twice as viscous as water.

An opening in the apical end of partition allows perilymph to pass freely betwean two scalae - opening called HELICOTREMA.

At the basal end of the cochleathe Scala tympani ends at the sound window- a membrane covered opening that leads back into middle ear. (accom. flow of fluid-pressure) release allows room for vibration.

COCHLEAR DUCT (center of partition) sound vibrations - which cause pressure variations in fluid- causes whole partition to vibrate)-

filled with ENDOLYMPH - highly viscous-jelly like-

Reisners Membrane - forms boundary between S.V. and duct

BASILAR MEMBRANE - separates duct from S.T.

bony shelf extends out of core central of cochlea - one end of basilar mem. is connected - other end conn. to Spiral ligament which coils along outside wall of cochlea.

B. M. very narrow at basal end near oval window and quite stiff and light.

most lax and massive at helicotrema.

Mechanical properties relate to pattern of excitation

For high freq.-vibration in partition is highest near oval window: visa- versa

We still have not converted the mechanical motion of the basilar membrane into electro-chemical nerve symbols that can be transmitted to brain.

The "converting" organ - The Organ of Corti - is made up of many minute hair cells

One end of each cell rests on the basilar membrane-and the other end is inbedded in the Tectorial Membr.

4 Rows of hair cells

1 row- inner

3 rows- outer

about 3500 inner cells

20,000 outer cells

These cells- in response to vibrations of the basilar membrane-and hair cells are transmitted to the related nerve cells (hair cells receive → nerve cell)- and transfered into electro-chemical energy-

Transmitted along auditory nerve to brain where perceived as sound-

III Audiometry

Hearing is usually measured using a pure tone audiometer
(Demostrate Audiometer and audiogram air and bone conduction)

Results are recorded on an audiogram

Measure:

A. Frequency

125 Hz to 8000 Hz

(range of useful hearing for human ear is 20 to 20,000 Hz at peak)

B. Intensity

decibel -

Audiometric 0 - arbitrary sound pressure level - theshold of hearing for "average-normal ear as conducted during a health survey of a US. Public health service in 1936-37

ASA adopted 1951

(Mention ISO (1964))

European studies - lower levels

Sound pressure levels in db re 0.0002 dyne/cm^2 for audiometric 0 (ASA and ISO)

Frequency	ASA	ISO	diff. shown on audiogram
125	54.5 db	45.5	
250	39.5	24.5	add # to
500	25.0	11.0	threshold
1000	16.5	6.5	for ISO (from
1500	(16.5)	6.5	ASA)
2000	17	8.5	
3000	16	7.5	
4000	15	9	
6000	17.5	8	
8000	21	9.5	

Audiometer should always be checked to see whether calib. is to ISO or ASA

Frecuency = psycholigical correlate of pitch

Intensity = loudness

eg.

0dB = sound barely perceptible (threshold of hearing)

20 dB- average whisper - 4 ft from speaker

40 dB- level of night noises in city

70 dB- normal conversation at a distance of 3 ft.)

90 dB- preumatic drill 10 ft. away

115 dB- hammering on a steel plate 2 ft. away

120 dB- threshold of feeling

140 dB- pain

Another reference point - hearing loss

20-40 dB mild

40-60 dB moderate

60-75 severe

75-100 profound

Important speech frequencies for speech are 500, 1000, 2000 a mild loss through these frequencies may be disabling

Hearing Testing in and industrial program

1. Reference Audiogram

A. Room = properly sound treated-

That is - so that a normal - hearing listener can respond to all test tones from 250 Hz - 6000 Hz at a hearing level of OdB-

Can be accomplis hed if

If the band levels in room do not exceed:

40 dB - for	150-300 300-600 600-1200
48 dB for	1200-2400
57 for	2400-4800
and 67 for	4800-9600

B Audiog. should include thresholds by air conduction for 250, 500, 1000, 2000, 3000, 4000 and 6000 Hz

3000cps(not always used in regular thereshold testing) is included because some states in U.S. include it in computing percentages of hearing loss - and also a loss at 3000 cps is know to affect discrimination of speech materials under conditions of difficult listening.

6000 is the highest frequency tested as results at 8000 are comparatively unreliable.

C Audiometer

Usually a standard pure tone audiom.,- results often obtained by industrial nurse

(Zenith - Maico - Beltone) popular brands

May be obtained by use of automatic audiometry

Subject pushes a botton and results are automatically recorded

(RUDMOSE)

- as described in

James F. Jerger , ed.

(1963) Modern Developments in Audiology-Academic Press New York, N.Y.

For all new and current employers - esp. if working under hazardous noise conditions.

2. Monitoring

First within 90 days

- If no change at any freq. of more than 10 dB - then yearly monitoring

Since 4000 cps is most sensitive to sound-monitoring may be done of that freq. only.

NOISE INDUCED HEARING LOSS

All in our modern society exposed to noise- possible that our daily exposure to ordinary environmental noise contributes to the of our hearing mechanism.

Presbycusis - sensori - neural hearing impairment often attributed to advancing age - was called Sociocusis (re: sociological) - as there is evidence to suggest that primitive tribesmen in Africa - do not show any appreciable decrease in hearing acuity with advancing age.

1. Acoustic Trauma

   - sudden loss of hearing -

   due to blast, explosion - etc

   May cause ruptured ear drum as well as permanent damage to the hair cells in the Organ of Corti

2. Noise Induced Hearing Loss

   - your main concern

   A. Amount of hearing impairment incurred from noise exposure is proportional to the intensity of the stimulus and the length of the exposure

      - Also- consider individual susceptibility - no reliable tests for susceptibility - but anyone showing dip at 4000 cps should take precaution in noisy situations.

   B. Loss associated with noise exposure is sensori-neural (as apposed to conductive)-and cochlear in origin.

Usually begins with a dip or notch in Audiogram at 4000

Gradually shows a deepening and widening notch.

   (use audiogram for demonstration)

   C. Temporary threshold shift vs. Permanent Thrshold Shift

      TTS- after short exposure to noise - notch in audiogram may disappear after period of rest - some hair cells become fatigued but are not damaged permanently

      TTS may be induced with as little as 15 min of exposure to intense noise.

      After continued exposure-

      4000 caps - notch begins to widen - hearing loss eventually does not recover after rest - becomes Permanent Threshold Shift.

Typical progression in hearing loss as a function of years of exposure to industrial noise of high intensity

AUDIOGRAM

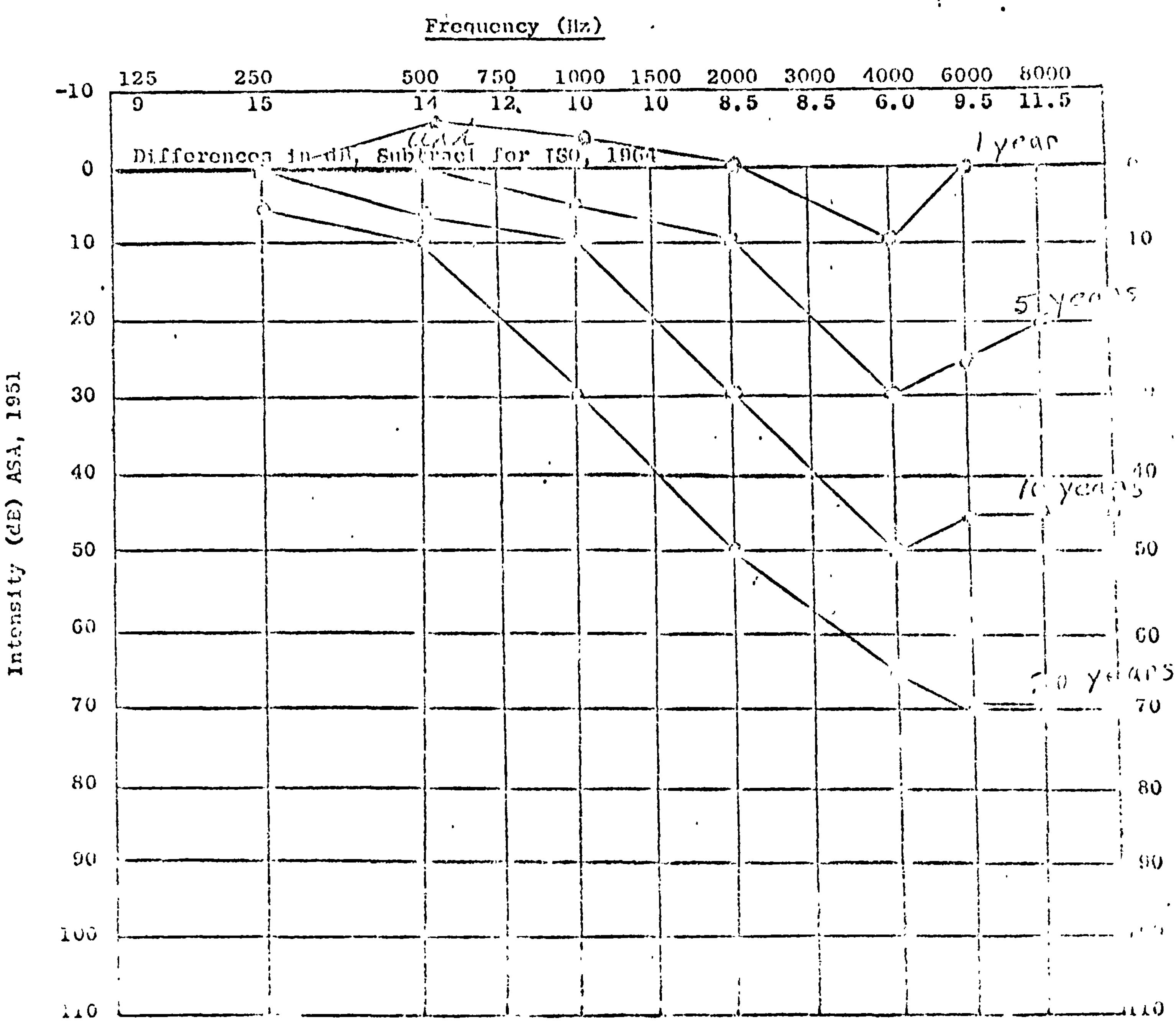
☐ 1964 ISO Reference Thresholds

☐ 1951 ASA " "

NAME: ____________ DATE: ________

AGE: ______ SEX: ______

OCCUPATION ____________ YRS. ON JOB: _____



Air Conduction (O = Right Ear (X = Left Ear

Bone Conduction (> = Right Ear (< = Left Ear

Noise induced hearing loss can occur without the affected individual being aware that his hearing is being damaged.

Noise-sound is not uncomfortable (painful) until if reaches 120 - 140 db - but sounds much lower can produce damage

Also - early damage usually does not include speech frequencies - 5-1-2000 cps
only when notch widens (i.e. to include 2000) is there any noticeable affect on speech - by then it may be too late to reverse damage.

3. Other effects of noise

   Interference with communication (Important if safety is concerned).

   Psychological effects

   Interference with production rates, etc.

EAR PROTECTORS

Most effective - to control noise at the source

If this is impossible - use ear protectors

Two types

1. Inserts

   A. disposable - such as wax- impregnated cotton

   B. or of rubber or neoprine

      - these are usually made in 5 or 6 sizes as the must fit the ear canal snugly to be effective - may require a diff size for each ear.

      Inserts should be fitted by a trained person - to insure proper size selection.

Can be uncomfortable difficult for supervisor to check at a glance

2. Muffs

do not require special fitting

May be more comfortable for long wear.

Somewhat more efficient than inserts.

disadvantages - may not get a tight seal when worn with glasses - are very hot if working in a warm area.

- Some muffs come with liquid filled seals that increase attenuation
- May be fitted with helmets that protect the whole head.
- May be used as cutions for earphones and serve a dual purpose.

C. In conditions of extreme noise

maximum attenuation is provided by the use of inserts and muffs.

(see chart)

Difficulties in getting employers to cooperate - almost has to be a mandatory program

WARNING - Dry cotton is almost useless as an ear protector.

Attenuating Characteristics of Ear Protectors *EAR PROTECTORS*

AUDIOGRAM

☐ 1964 ISO Reference Thresholds

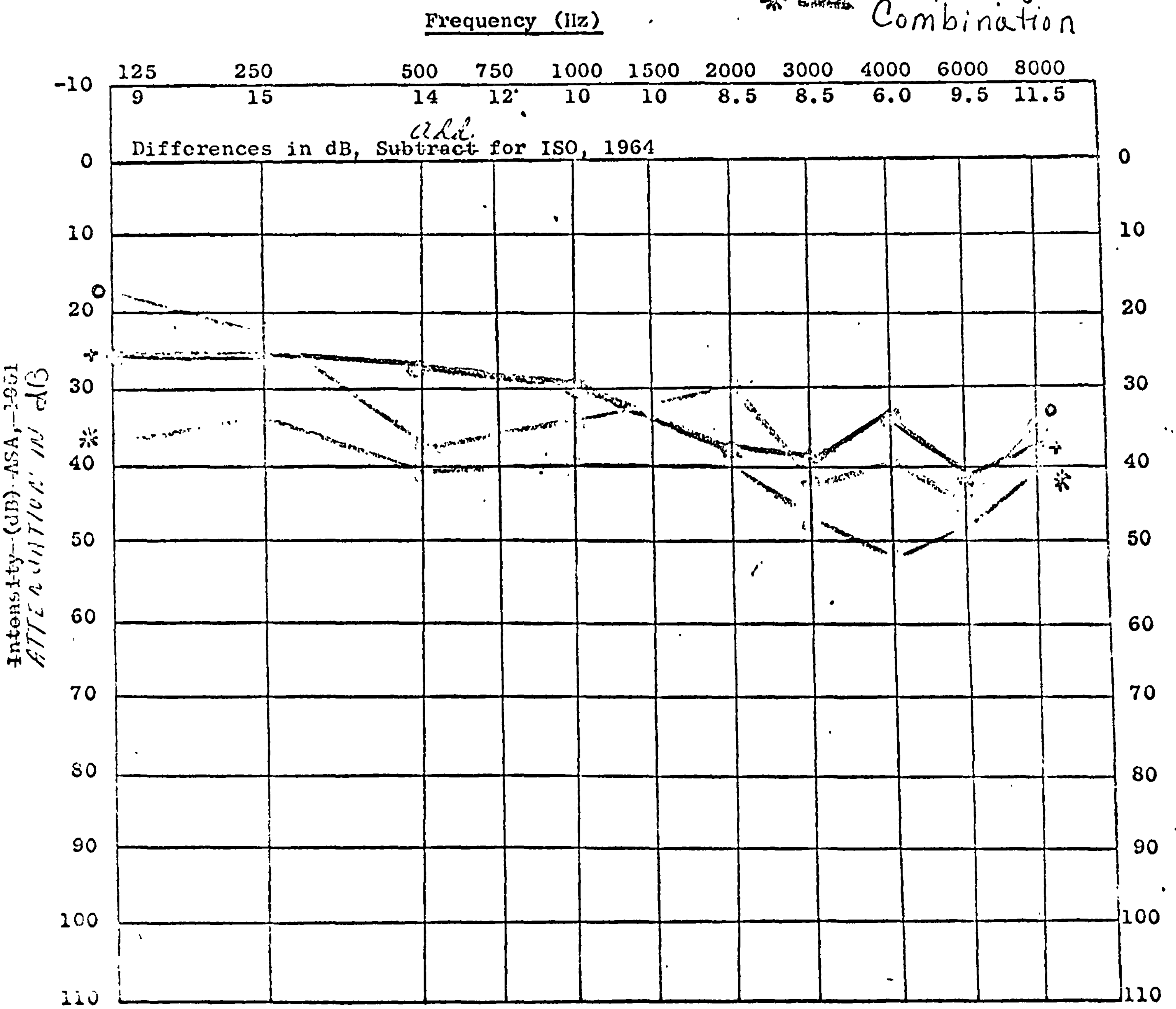
☐ 1951 ASA " "

NAME: ____________________ DATE: __________

AGE: ______ SEX: ______

OCCUPATION ____________________ YRS. ON JOB: ____

O —— Ear Muffs
+ —— EAR plugs (Inserts)
* —— Combination



Air Conduction (O = Right Ear (X = Left Ear

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SECRETARIA DE SALUBRIDAD Y ASISTENCIA
SUBSECRETARIA DE MEJORAMIENTO DEL AMBIENTE
DIRECCION GENERAL DE INVESTIGACION

CUADERNO DE TRABAJO DEL PRIMER ANTE-PROYECTO DE REGLAMENTO PARA PREVENIR LA CONTAMINACION AMBIENTAL POR RUIDOS

- 1 9 7 2 -

CAPITULO

I

DISPOSICIONES GENERALES

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ARTICULO 1.-

La contaminación ambiental provocada por la emisión de ruidos de fuentes artificiales será objeto de prevención y control por parte del Estado, constituyendo un servicio de orden público y de interés social.

ARTICULO 2.-

Este Reglamento es de observancia general en toda la República y su aplicación para exigir el cumplimiento de las obligaciones que impone, a quienes provocan la emisión de ruidos, corresponde a:

I.- El Consejo de Salubridad General.

II.- La Secretaría de Salubridad y Asistencia.

III.- Los Ejecutivos de los Estados y el C. Jefe del Departamento Central.

IV.- Las demás autoridades a que se refiere el último párrafo del Artículo 5o. de la Ley para Prevenir y Controlar la Contaminación Ambiental, en el ámbito de sus respectivas competencias.

ARTICULO 3.-

En lo no previsto por este Reglamento, la Secretaría de Salubridad y Asistencia dictará las disposiciones técnicas y las normas de observancia general obligatoria a que se deberán sujetarse las personas físicas o morales, de carácter público o privado, que posean, instalen u operen fuentes emisoras de ruidos.

Las demás autoridades encargadas de la aplicación de este Reglamento, dictarán los instructivos, circulares y ordenamientos especiales necesarios, y en general, realizarán los actos de autoridad y de servicio convenientes para proveer a su exacto cumplimiento.

ARTICULO 4.-

La Secretaría de Salubridad y Asistencia en coordinación con las demás autoridades correspondientes podrárestringir, y aún prohibir, el uso, aprovechamiento u-operación de fuentes productoras de ruidos, o la con - ducta que los provoque.

ARTICULO 5.-

La Secretaría de Salubridad y Asistencia en coordina - ción con las demás autoridades competentes será la en-cargada de:

I.- La planeación de investigaciones y el estudio sistemático de la contaminación ambiental por ruidos para la observación de sus efectos mo-lestos o peligrosos en las personas.

II.- El estudio y diseño de programas y normas que deban ponerse en práctica para prevenir y con trolar las causas de contaminación ambiental-por ruidos.

III.- El control de este tipo de contaminación exis tente, en zonas urbanas y suburbanas.

IV.- La aplicación de las medidas conducentes para prevenir la contaminación ambiental por rui - do, ya sea industrial, comercial, derivado - del tránsito, doméstico, o de cualquier otra-naturaleza.

V.- La supervisión y vigilancia necesarias para - prevenir y controlar la emisión de ruidos.

VI.- La aprobación y supervisión de los proyectos-para la construcción, reconstrucción, amplia-ción o modificación de fuentes emisoras de - ruidos y de los lugares donde éstas operen.

VII.- La aprobación y supervisión de los planos y - proyectos para construir y operar obras que - controlen o abatan el ruido.

VIII.- En general, la aprobación y supervisión de - las obras públicas o privadas que al ponerse-en servicio u operación contaminen o puedan - contaminar el ambiente por la emisión de rui-dos.

ARTICULO 6.-

La Secretaría de Salubridad y Asistencia en coordinación con las demás Dependencias del Ejecutivo Federal, dentro de sus ámbitos de competencia, realizará estudios e investigaciones conducentes para determinar:

I.- La intensidad, frecuencia, cadencia, duración y características del ruido en las industrias, zonas comerciales y habitacionales.

II.- La presencia de ruidos específicos en zonas determinadas, señalando cuando proceda áreas de protección o de veda.

III.- Las características de las emisiones de ruido de algunos dispositivos de alarma o de situación.

ARTICULO 7.-

La Secretaría de Salubridad y Asistencia podrá realizar con su personal de planta, con personal contratado expresamente, o mediante contrato con empresas o instituciones, las actividades que le correspondan de acuerdo con la Ley y el presente Reglamento, así como la planeación, estudio, diseño, construcción y operación, para la determinación de los efectos y repercusiones a la salud, inmediatas o mediatas, de la contaminación ambiental por ruidos o para lograr su prevención y control.

CAPITULO

II

DE LA PREVENCION Y CONTROL DE LA CONTAMINACION DEL AMBIENTE POR EL RUIDO.

ARTICULO 8.-

Los propietarios o los responsables del uso o funcionamiento de fuentes emisoras de ruido, deberán proporcionar a las autoridades competentes la información y facilidades que se les requieran.

ARTICULO 9.-

El conocimiento objetivo de la contaminación del ambiente producida por ruidos, para resolver si se superan los valores límites de tolerancia establecidos, se realizará mediante mediciones de su intensidad, frecuencia y demás características, en los lugares, en las condiciones y según los procedimientos que señale la Secretaría de Salubridad y Asistencia.

ARTICULO 10.-

Los valores límites de tolerancia de intensidad, frecuencia y otras características del ruido que se señalan en este Reglamento, podrán modificarse de oficio, en cualquier tiempo:

I.- Atentos los adelantos tecnológicos;

II.- Porque las condiciones demográficas o ecológicas lo hagan recomendable; y

III.- A propuesta fundada de cualquier institución pública o privada.

ARTICULO 11.-

Las modificaciones de los valores límites de tolerancia de intensidad, frecuencia y otras características del ruido se harán mediante Acuerdos Generales que formarán Apéndices de este Reglamento y a los que se dará la debida publicidad, en el Diario Oficial de la Federación para señalar su vigencia.

ARTICULO 12.-

Para los propósitos de este Reglamento, se entiende por ruido: toda percepción acústica que origina un estado de tensión en el individuo; que puede resultar desagradable; capaz de provocar una molestia o bien de producir un daño.

ARTICULO 13.-

En este Reglamento para medir la intensidad y frecuencia del ruido se adopta el decibel y la escala de frecuencias ajustada conocida como A, que se abreviarán dBA.

ARTICULO 14.-

Son objeto del presente Reglamento los ruidos en cuanto puedan alterar el estado normal del ambiente e interferir la tranquilidad, causar molestias, o perjudicar la salud humana por:

I.- Molestias e Interferencias con:
   a) la comunicación
   b) el aprendizaje o el trabajo
   c) el descanso, el reposo, el sueño o la recuperación de la salud.
   d) la diversión o esparcimiento.

II.- Trastornos o alteraciones:
   a) mentales o nerviosas
   b) cardíacas y circulatorias
   c) musculares
   d) articulares
   e) de la conducta

III.- Hipoacusias y sorderas ocupacionales.

ARTICULO 15.-

Queda prohibido realizar actividades o incurrir en omisiones que provoquen la emisión de ruido, salvo que se recaben las autorizaciones, se instalen los dispositivos aprobados para su control o se cumplan las prevenciones que en este Reglamento se establecen.

ARTICULO 16.-

Se consideran como fuentes artificiales de ruidos las- siguientes:

I.- Fijas propiamente dichas.- Que comprenden la maquinaria y equipo fabril, y las demás instalaciones y procesos industriales, de talleres y comercios que producen ruidos.

II.- Estacionarias circunstanciales.- Que incluyen todos los ruidos que se producen mediante el- uso o manejo de instrumentos musicales o de - otra naturaleza, herramientas, aparatos o -- equipo, en un lugar determinado, pero no en - forma permanente.

III.- Móviles.- Que abarcan los aviones, helicópteros, embarcaciones, ferrocarriles, tranvías,- camiones, automóviles, motocicletas y demás - medios de transporte, tractores, y equipo similar y todo instrumento, aparato o equipo que se desplace y produzca ruido.

IV.- Domésticas.- Que abarcan toda clase de bie -- nes; eléctricos, mecánicos o de cualquier otra naturaleza, que al operar o usarse en el ho - gar producen ruidos, así como las actividades que los provoquen.

Para los efectos del presente Reglamento se equiparan a los ruídos artificiales, los producidos directamente por la voz humana de cantantes y pregoneros, - así como los producidos por los animales cuando se encuentren en las zonas urbanas.

ARTICULO 17.-

Se prohibe, sin contar con la autorización respectiva, la operación de fuentes emisoras de ruidos contínuos - superiores a 115 dBA ó de ruidos de impulsos superio - res a 140 dBA.

ARTICULO 18.-

Todo dispositivo, aparato electromecánico o maquinaria de uso doméstico, comercial o industrial que en su funcionamiento emita ruidos iguales o superiores a 95 dBA, será objeto de una marca cuyas características indicará la autoridad competente.

ARTICULO 19.-

Para que pueda instalarse y funcionar una industria, taller o establecimiento, que por su maquinaria, aparatos, equipo, herramienta, o por sus procesos de trabajo resulte una fuente emisora de ruidos, deberá gestionarse el permiso correspondiente.

Al efecto, el interesado deberá someter a las autoridades competentes solicitud con:

1.- Datos generales de identificación.

2.- Croquis de ubicación y colindancias.

3.- Planos y memorias técnicas descriptivas de procesos, inventario y localización de maquinaria, herramienta; flujo de los procesos, describiendo particularmente las actividades que causan ruidos.

4.- Descripción de las medidas técnicas o de otra naturaleza que se proponen para controlar la emisión o transmisión de ruidos.

5.- Relación de personal expuesto y medidas de protección que se tomarán.

6.- Los demás datos que, en su caso, se le soliciten.

Dentro de los sesenta días hábiles siguientes al de la recepción de la solicitud, la autoridad resolverá lo que proceda.

ARTICULO 20.-

Solamente podrán expedirse permisos para ubicarse y funcionar a industrias ruidosas, en los sitios que designen coordinadamente las autoridades competentes en materia de urbanismo o sus equivalentes de la población de que se trate, y las de salubridad.

ARTICULO 21.-

Las empresas, industrias o talleres ruidosos ya establecidos, deberán adoptar las soluciones arquitectónicas o de ingeniería que resulten necesarias o convenientes para controlar el ruido, tales como:

I.- Cimentación y aislamiento de las fuentes emisoras de ruido.

II.- Construir barreras aislantes del ruido en el medio transmisor.

III.- Contar con una zona de protección tan amplia como sea necesaria, a juicio de la autoridad, a partir del recinto en que se encuentre instalada la fuente emisora.

IV.- Modificar las características de la fuente o fuentes emisoras de ruidos.

ARTICULO 22.-

Las naves, locales o áreas de trabajo, dentro de los recintos de industrias y talleres se ubicarán o construirán de manera que los ruidos que se produzcan no trasciendan a los predios colindantes o a la vía pública.

ARTICULO 23.-

Cuando las actividades de empresa, industria o talleres que producen ruidos trasciendan a la vía pública o a predios colindantes, no obstante haber cumplido con disposiciones señaladas con anterioridad, éstas actividades serán objeto de relocalización dentro de la empresa o a otro sitio en las condiciones que apruebe la autoridad competente.

ARTICULO 24.-

En los ambientes laborales ruidosos el tiempo máximo permisible de exposición para los trabajadores que carezcan de equipo protector de ruido, en una jornada de trabajo será:

Tiempo máximo de exposición	Ruido Ambiental dBA
8 horas	menos de 90
7 horas 30 minutos	90
6 horas 30 minutos	91
5 horas 30 minutos	92
4 horas 45 minutos	93
4 horas 15 minutos	94
3 horas 40 minutos	95
3 horas 20 minutos	96
2 horas 45 minutos	97
2 horas 15 minutos	98
2 horas	99
1 hora 50 minutos	100
1 hora 30 minutos	101
1 hora 20 minutos	102
1 hora	103
55 minutos	104
50 minutos	105
45 minutos	106
40 minutos	107
35 minutos	108
30 minutos	109
25 minutos	110
23 minutos	111
20 minutos	112
17 minutos	113
15 minutos	114

ARTICULO 25.-

Es responsabilidad del patrón en las industrias, la aplicación de medidas técnicas, administrativas y normativas, para controlar el ruido.

ARTICULO 26.-

Las medidas administrativas incluirán la obligación de realizar exámenes audiométricos aprobados por la Secretaría de Salubridad y Asistencia, del personal expuesto al ruido, previos a la contratación y cada seis meses durante el tiempo de vigencia del contrato de trabajo.

ARTICULO 27.-

El trabajador expuesto a ruidos deberá contar con equipo protector de uso personal, aprobado por la Secretaría de Salubridad y Asistencia, siendo responsabilidad del patrón su dotación, guarda, mantenimiento y reposición.

ARTICULO 28.-

Para los efectos del presente Reglamento se entiende por hipoacusia o sordera ocupacional cualquier pérdida parcial o total, transitoria o permanente, de la capacidad de percepción auditiva originada por el trabajo o a consecuencia del mismo.

ARTICULO 29.-

Los ruidos industriales que se originen por la operación de maquinaria y equipo, o por el movimiento de material, u otras causas relacionadas con la ocupación, que causen hipoacusias, dan derecho al trabajador, a la indemnización laboral que corresponda, según la incapacidad que provoquen en los términos de la Ley Federal del Trabajo, sin perjuicio de que se ejercite, cuando proceda, la acción penal correspondiente, por lesiones imprudenciales.

ARTICULO 30.-

Las empresas, industrias o talleres ruidosos:

I.- Podrán gestionar de las autoridades competentes, la asesoría para la investigación de laboratorio y de campo que resulte necesaria.

II.- Solicitarán la asesoría conducente o la elaboración de las normas de normalización aplicables a la maquinaria, equipo, herramienta y procedimientos, referidos a la industria de que se trate, para lograr los fines de este Reglamento.

III.- Promoverán campañas educativas permanentes, contra el ruido.

IV.- Realizarán trimestralmente cuando menos, la supervisión interna.

V.- Otorgarán a los trabajadores los estímulos que correspondan y en su caso, promoverán la aplicación de las sanciones que procedan.

ARTICULO 31.-

Las industrias, talleres o establecimientos comerciales que necesiten hacer cambios o modificación a sus procesos, equipos o maquinaria de trabajo, deberán gestionar, previamente, el permiso correspondiente ante las autoridades competentes, presentando la documentación e información que se les requiera.

ARTICULO 32.-

Se establecen como niveles máximos recomendables de seguridad a la exposición de ruido, los señalados en la tabla siguiente:

	dBA	CORRECCION POR: Ruido de impacto ó de tono puro.
Planta, nave o área industrial ocupada por personal que requiere comunicación verbal.	80	- 10
Talleres	75	- 5
Oficinas generales	60	- 5
Oficinas privadas	50	- 5
Salas de conferencias	40	- 5
Area urbana habitacional	55	- 5
Area suburbana	50	- 5
Area rural	45	- 5
Interior de las casas	40	- 5
Hospitales, sanatorios y demás lugares para enfermos o convalecientes.	35	- 5
Guarderías, asilos, escuelas, bibliotecas, museos, templos y otros lugares de estudio o meditación.	35	- 5

C O R R E C C I O N E S Por horario	dBA
de 22 p.m. a 6 a.m.	- 5
Ruídos de 15 min/hora	+ 5
Ruídos de 5 min/hora	+10
Ruidos de 1 min/hora	+15
Ruidos de 1 min/día.	+20

ARTICULO 33.-

Toda industria, taller o establecimiento comercial en donde se produzcan ruidos con intensidades iguales o superiores a las que señala la tabla del artículo anterior y estén situados en zonas habitacionales, no podrán operar o realizar las actividades que originan el ruido, a pesar de que hayan cumplido los ordenamientos señalados por la Secretaría de Salubridad y Asistencia, entre las 22 hs. y las 6 hs. del día siguiente en días hábiles y a ninguna hora en días de descanso obligatorio.

ARTICULO 34.-

Los propietarios, encargados o responsables de sitios donde haya personas temporal o permanentemente expuestas a ruido de una intensidad igual o superior a 95 dBA, deberán señalar en lugar visible los tiempos máximos recomendables para una permanencia contínua según la tabla siguiente:

Nivel de Ruido dBA	Tiempo máximo recomendable de permanencia.
95	4 horas
97	3 horas
100	2 horas
102	1 hora 30 min.
105	1 hora
110	30 min.
115	15 min.

ARTICULO 35.-

La autoridad urbanística o su equivalente de la población de que se trate señalará las zonas comerciales que resulten convenientes a los fines del presente Reglamento y se limitarán, o regularán, en su caso, los permisos de ubicación y funcionamiento que para cada zona o tipo de zona, puedan concederse, imponiendo los requisitos que para evitar o controlar el ruido, deban cumplirse.

ARTICULO 36.-

En la vía pública, en establecimientos, industrias, talleres y comercios se prohibe el uso de silbatos, campanas, magnavoces o amplificadores de sonido, timbres y dispositivos que produzcan ruido.

Solo se autoriza su uso en establecimientos, industrias, talleres y comercios en ocasión de alarma, siniestro o simulacro.

ARTICULO 37.-

Las personas físicas o morales, cualesquiera que sea su condición, que ocasionen ruido por la construcción, reconstrucción, ampliación, modificación o demolición de edificios, o por la realización de obras en la vía pública requerirán de un permiso previo que otorgará la autoridad competente.

ARTICULO 38.-

Los permisos que se otorguen, en los términos del artículo anterior, estarán condicionados a que:

I.- Se ejecuten con estricto apego a los horarios que en cada caso se autoricen.

II.- Se realicen de acuerdo con el calendario de obras que se somete con la solicitud o con las modificaciones que imponga la autoridad que corresponda.

ARTICULO 39.-

Para que se instalen y funcionen carpas, ferias y juegos mecánicos que se anuncian y operan emitiendo ruidos, se requiere permiso de la autoridad competente.

Estos permisos se otorgarán, previo estudio y dictamen pero en general no se autorizará su funcionamiento, ni su ubicación en las cercanías de hospitales, sanatorios, maternidades, guarderías, escuelas, bibliotecas y otras instituciones similares que se consideran áreas de veda.

ARTICULO 40.-

Se considera zona de veda al área comprendida dentro de los 50 mts. radiales a partir de los linderos de la construcción o del sitio que se pretende proteger.

ARTICULO 41.-

Para realizar desfiles, manifestaciones, concentraciones de personas y para el uso de aparatos amplificadores de sonido y otros dispositivos y actividades que produzcan ruido en la vía pública, se requerirá permiso que sin costo alguno otorgará la autoridad competente, que señalará las condiciones y limitaciones a que deberán sujetarse esas actividades.

ARTICULO 42.-

Para autorizar la ubicación, construcción y funcionamiento de aeródromos y aeropuertos, públicos y privados, y sus servicios auxiliares, se cumplirán las disposiciones de la Ley de la materia y sus reglamentos, así como las prevenciones del presente Reglamento.

ARTICULO 43.-

Las autoridades competentes tendrán en cuenta las opiniones de la Secretaría de Salubridad y Asistencia a fín de determinar en relación a los aeródromos y aeropuertos:

I.- Su distancia a las áreas urbanas de la población.

- Las soluciones a la ingeniería que resulten convenientes, en cuanto a las distancias y orientación de las pistas de despegue y aterrizaje, así como de su intersección con las pistas de carreteo y las áreas de estacionamiento de los aviones.

III.- Las características arquitectónicas de los servicios auxiliares.

ARTICULO 44.-

Queda prohibido volar aeronaves de pistón o de hélice en zonas habitacionales a menos de 300 mts. de altura sobre el nivel del suelo, excepto en operaciones de estudio, investigación, búsqueda o rescate.

Las aeronaves a reacción no deberán sobrevolar zonas habitacionales a una altura inferior a 500 mts. sobre el nivel del suelo.

ARTICULO 45.-

En una área de 6 kms. de largo y 0.5 km. de ancho a partir de los extremos de las pistas de aterrizaje y despegue de aeronaves a reacción, no se permitirá el establecimiento de habitaciones, escuelas, sanatorios y otras instituciones similares.

ARTICULO 46.-

Los propietarios de construcciones habitacionales existentes en el área que señala el artículo anterior, podrán realizar, previa autorización de la Secretaría de Salubridad y Asistencia, modificaciones a sus construcciones para abatir el nivel ruido. Los gastos que esto ocasione se cubrirán en un 50% por parte de Aeropuertos y Servicios Auxiliares, S.A., con cargo a quienes utilicen el aeropuerto de que se trate. El otro 50% con cargo al propietario y en su caso con la aportación proporcional de los arrendatarios.

ARTICULO 47.-

Los propietarios de los predios ubicados en el área a - que se refiere el artículo anterior, tendrán derecho a- solicitar y obtener una reducción no inferior al 25% en el pago del impuesto correspondiente.

ARTICULO 48.-

Las empresas concesionarias de vías generales de comu - nicación aplicarán, dentro de las poblaciones, las medi das técnicas de ingeniería y de arquitectura que resul- ten convenientes para controlar el ruido y su transmi - sión a los predios colindantes a la zona del derecho de- vía.

Para los efectos del párrafo anterior, el gobierno fe - deral otorgará facilidades técnicas y financieras.

ARTICULO 49.-

Los Ferrocarriles Nacionales de México y las demás con- cesionarias de este tipo de servicios son responsables de la lubricación y servicios de mantenimiento de los - rieles, ruedas durmientes, balasto y en general, del - sistema de rodamiento y de enganche, así como que las - maniobras de carga y descarga sean convenientes para -- prevenir la emisión de ruidos.

ARTICULO 50.-

Las vías y las estaciones de ferrocarril, dentro de las poblaciones, se ubicarán de conformidad con lo que al respecto señale la autoridad urbanística o su equiva lente en la población de que se trate.

E[illegible] a co struc[illegible] ene[illegible] sal s de espera y dem s - servicios auxiliares se aplicarán las normas técnicas de arquitectura y de ingeniería que resulten convenien- tes para abatir y controlar el ruido.

ARTICULO 51.-

Se prohibe a los operadores de ferrocarriles el uso de silbatos, campanas, sirenas y demás aditamentos similares dentro de las zonas urbanas entre las 22 y las 6 horas.

ARTICULO 52.-

Corresponde a las autoridades de tránsito de la Ciudad señalar las vías de tránsito rápido, de los vehículos automotores de superficie, dentro de las zonas urbanas.

Para prevenir el ruido por la circulación de vehículos automotores las autoridades de tránsito competentes fijarán las rutas, horarios y límites de velocidad a los servicios públicos de auto-transporte.

ARTICULO 53.-

El límite máximo de ruido tolerable, producido por vehículos de motor será:

VEHICULOS	dBA
Motocicletas o motonetas hasta 200 c.c. de cilindrada (2 tiempos)	82
Cualquier otro tipo de motocicleta	85
Automotor hasta 1500 c.c. de cilindrada	85
Cualquier otro tipo de vehículo automotor	90

ARTICULO 54.-

Se considera de interés público la construcción de estaciones terminales de auto-transporte, que se ubicarán estratégicamente en la periferia de las zonas urbanas.

Asimismo, se considera de interés público la construcción de libramientos para evitar, en lo posible, que las vías generales de comunicación atraviesen las ciudades.

ARTICULO 55.-

Queda prohibida la circulación en áreas habitacionales de vehículos que produzcan ruidos por manejo inadecuado, a causa del desajuste de su carrocería o fallas - mecánicas, el arrastre de piezas metálicas, o por la-- carga que transporta u otras circunstancias.

ARTICULO 56.-

En toda operación de carga o descarga de recipientes - que se golpeen contra el pavimento, la plataforma u -- otras partes de los vehículos de carga, se deberá utilizar recipientes de plástico, o en su defecto, recubrir las zonas de golpeo con un material no metálico - del grosor que determine la autoridad competente.

ARTICULO 57.-

Los responsables de los hospitales, sanatorios y de - aquellos sitios donde haya enfermos sujetos a tratamiento o recuperación, podrán obtener de las autoridades de tránsito que correspondan, cuando lo justifiquen, el -- señalamiento de zona de veda temporal o permanente a la emisión de ruídos.

ARTICULO 58.-

Se prohibe la emisión de ruidos por el uso de cualquier dispositivo como claxon, campana, bocina, timbre, silbato o sirena instalados en vehículos automotores, de - las 22 hs. a las 6 hs.

ARTICULO 59.-

Ninguna persona hará funcionar dispositivos sonoros, - como claxon, campana, bocina, timbre o sirena instalados en vehículos automotores cuando se encuentre circulando en zona de veda o bien a velocidad inferior de 2[illegible] km. por hora o estén parados ó estacionados. En caso de inminente peligro de colisión, atropellamiento o -- alarma, solo podrá accionarse el dispositivo en una ocasión durante un segundo, pudiéndose volver a usar en -- igual forma cuando se presenten otras circunstancias -- de peligro o alarma diferentes. Quedan exceptuados de-esta disposición los vehículos de bomberos, policía y ambulancias en servicio.

ARTICULO 60.-

Los vehículos automotores que salgan al mercado a partir del año de 1975, deberán contar con dispositivos sonoros de alarma de aproximación o posición, cuyas características serán fijadas por las autoridades competentes.

ARTICULO 61.-

Los fabricantes, importadores, ensambladores y distribuidores de vehículos automotores tales como camiones, automóviles, motocicletas, aeronaves, tractores, embarcaciones y otros similares, serán responsables de que estas unidades tengan silenciador, cámara de expansión u otro dispositivo adecuado con eficiencia de operación aprobada por las autoridades competentes, para reducir el ruido del escape de los gases que se producen por el funcionamiento del motor.

ARTICULO 62.-

Cuando el silenciador, cámara de expansión o dispositivo a que se refiere el artículo anterior, sufra algún desperfecto que lo inutilice, su cambio o reposición se hará por otro similar, que cumpla con las características aprobadas para los dispositivos originales. Las reparaciones de estos dispositivos también estarán sujetas a la aprobación de las autoridades competentes.

ARTICULO 63.-

Para aprobar nuevas construcciones cualquiera que sea el uso a que se destinen y para reconstruir, ampliar o modificar edificios, las autoridades competentes exigirán que los planos y proyectos que se presenten consideren aspectos básicos para la prevención y control del ruido.

ARTICULO 64.-

Para prevenir el ruido en conjuntos habitacionales, - condominios, casas de departamentos, viviendas y demás- edificios en los que existan bienes de uso común, se - establecerá por las autoridades competentes en coordina ción con el dueño, los condueños o administrador en su- caso, las normas de uso y aprovechamiento de esta clase de bienes.

ARTICULO 65.-

Los ruidos producidos en casas habitación por la vida - doméstica no son objeto de sanción. Excepcionalmente,- la realización de eventos ruidosos en forma reiterada - con molestia a los vecinos, podrán ser causa de aperci- bimiento y aún de sanción, cuando sean comprobados los- hechos motivo de queja por la autoridad competente.

ARTICULO 66.-

No serán motivo de inspección las casas habitación, - salvo el caso del artículo anterior o cuando por otros- medios, que no sean la delación o la visita expresa y - directamente ordenada, exista la certeza de que el lo - cal de que se trata se usa para fines distintos de la - vida doméstica.

ARTICULO 67.-

Toda persona que anuncie o pregone su mercancía o sus - servicios en la vía pública, solamente podrá valerse de las fuentes emisoras de ruido autorizadas o de su voz,- como reclamo de su actividad en las áreas urbanas y en- el calendario y los horarios que le señale la autoridad competente.

ARTICULO 68.-

Se prohibe causar ruido por la explosión de cohetes, - tronadores, petardos, así como el uso de armas de fuego y artificios detonadores en la vía pública.

ARTICULO 69.-

Los carillones, campanas y demás dispositivos que emitan ruido a la vía pública, solo podrán operarse entre las 6 y las 20 hrs.

ARTICULO 70.-

La tenencia de animales en predios dentro de áreas urbanas será motivo de autorización especial cuando causen molestias por ruidos que trasciendan al vecindario o a la vía pública.

CAPITULO III

MEDIDAS DE ORIENTACION Y EDUCACION

ARTICULO 71.-

Las Dependencias del Ejecutivo Federal, dentro de sus correspondientes ámbitos de competencia, elaborarán y pondrán en práctica los planes, campañas y cualesquiera otras actividades tendientes a la educación, orientación y difusión de lo que el problema de la contaminación ambiental por el ruido significa, sus consecuencias y en general los medios para prevenirla, controlarla y abatirla.

ARTICULO 72.-

La Secretaría de Educación Pública en sus programas de educación, del ciclo preescolar de educación media o vocacional, incluirá el estudio del ruido y sus problemas, con el propósito de ilustrar a los escolares sobre el peligro que representa para la salud y el bienestar humano, la presencia de ruidos en el ambiente.

La propia Dependencia, en sus programas educativos, incluirá la enseñanza obligatoria en primaria y media, de los aspectos elemtales del origen y prevención del ruido, acerca de los cuales se harán referencia en los libros de texto gratuitos.

ARTICULO 73.-

La Secretaría de Educación Pública solicitará a las Universidades y demás instituciones de enseñanza superior del país, que auspicien la investigación científica de la contaminación ambiental por el ruido y la forma de combatirla, y que incluyan dentro de sus programas de estudio, las prácticas y seminarios correspondientes, así como la difusión en tesis, gacetas y revistas, de las recomendaciones técnicas y científicas que contribuyan a la prevención, disminución y control del ruido.

ARTICULO 74.-

El Gobierno Federal y las autoridades auxiliares deberán realizar campañas de orientación a través de periódicos, revistas, radio, televisión, cinematografía y demás medios de difusión sobre los problemas de la contaminación ambiental por el ruido y las medidas para prevenirla, así como para evitar la degradación del ambiente.

ARTICULO 75.-

La Secretaría del Trabajo y Previsión Social, dentro - de su ámbito de competencia y en especial en lo que se refiere a la higiene del trabajo, promoverá campañas - de difusión sobre la contaminación ambiental por rui - do y sus peligros.

CAPITULO IV

DE LA VIGILANCIA E INSPECCION

ARTICULO 76.-

La vigilancia del cumplimiento de las disposiciones del presente Reglamento, estará a cargo de la Secretaría de Salubridad y Asistencia directamente, o a través de los Servicios Coordinados de Salud Pública en Estados y Territorios. El Departamento del Distrito Federal y los Gobiernos de las demás Entidades Federativas, la Secretaría del Trabajo y Previsión Social, la de Comunicaciones y Transportes y las demás que correspondan vigilarán su cumplimiento dentro de sus respectivos ámbitos de competencia.

ARTICULO 77.-

Para comprobar el cumplimiento de las disposiciones contenidas en este Reglamento, así como de aquellas que del mismo se deriven, la Secretaría de Salubridad y Asistencia, realizará visitas con fines técnicos de investigación; de asesoría y de inspección. La vigilancia y la inspección relativas a fuentes móviles, se realizarán por personal de la Secretaría de Comunicaciones y Transportes o de las Autoridades Locales en materia de Tránsito, según corresponda.

ARTICULO 78.-

Los inspectores que se designen, deberán tener los dispositivos y conocimientos necesarios para la valoración de la emisión de ruídos, de los medios de control, y en su caso nociones sobre los procedimientos para suprimirlo, controlarlo o abatirlo.

ARTICULO 79.-

Las inspecciones podrán ser ordinarias y extraordinarias. Las primeras serán aquellas que se realicen periódicamente y las segundas, las que la autoridad estime necesarias y convenientes en cualquier momento.

ARTICULO 80.-

Las inspecciones ordinarias se efectuarán en días y horas hábiles y las extraordinarias en cualquier tiempo.

ARTICULO 81.-

Las visitas, sean técnicas, de asesoría o de inspección, deberán sujetarse a las órdenes escritas de la Autoridad Ordenadora, que en cada caso girará oficio en el que se precise el objeto de la visita.

De no encontrarse en el establecimiento el propietario o encargado, el personal comisionado dejará citatorio para que lo esperen a la hora que fije, dentro de las horas hábiles, a partir del día siguiente.

De no atenderse el citatorio, la visita o la inspección se practicará con la persona que se encuentre.

ARTICULO 82.-

Al efectuar visitas el personal comisionado se identificará debidamente, exhibirá el oficio de comisión y después de practicada la diligencia procederá a levantar el acta correspondiente, entregando un ejemplar del oficio de comisión y uno del acta, a la persona en cuya presencia se haya practicado la diligencia.

En el acta que se levante se hará constar la entrega de esos documentos y se requerirá la firma por su recibo.

ARTICULO 83.-

Al iniciar la diligencia se requerirá del propietario o encargado, la designación de dos testigos que deberán permanecer durante el desarrollo, de la visita. En caso de negativa, o ausencia de aquéllos el personal comisionado podrá designarlos.

ARTICULO 84.-

Los propietarios o encargados del establecimiento objeto de la visita, están obligados a permitir el acceso y dar todo género de facilidades e informes para el desarrollo de la diligencia, debiendo hacerse cuando proceda, la advertencia de las penas en que pueden incurrir quienes estorben o impidan la diligencia.

ARTÍCULO 85.-

Al concluir el acta, el personal comisionado requeri - rá del propietario o encargado del establecimiento y de los testigos a la firma del documento; y en caso de ne- gativa, lo que no afecta su validez, se hará constar -- esa circunstancia.

ARTÍCULO 86.-

El personal que haya practicado la diligencia deberá - entregar el acta levantada, en el curso de las siguien - tes veinticuatro horas hábiles, a la autoridad que orde nó la diligencia.

ARTÍCULO 87.-

Durante la práctica de la diligencia se señalarán las - deficiencias que se observen o las causas por las que - se estime que no se están aplicando las medidas técni - cas adecuadas, para prevenir o controlar la emisión de- ruidos, lo cual se hará constar en el acta correspondien te.

Al finalizar la inspección, se dará oportunidad al pro- pietario o encargado de manifestar lo que a su derecho convenga, haciéndose constar en el acta.

CAPITULO V

SANCIONES Y PROCEDIMIENTOS PARA SU APLICACION

ARTICULO 88.-

Son responsables de las infracciones al presente Reglamento todos los que tomen parte en la concepción, preparación o ejecución de los actos u omisiones que constituyen la violación; los que instiguen directamente a alguno a cometerlas y los que presten auxilio o cooperación por acuerdo previo o posterior de cualquier especie.

Las autoridades competentes fijarán las sanciones respectivas dentro de los límites señalados por la Ley, según la participación de cada infractor.

[illegible]TCUL. 89.-

[illegible] castigarán con multa de 100 a 1,000 pesos, las infracciones a lo dispuesto en los artículos 24, 26, 27, [illegible] 34, 36, 41, 51, 52, 53, 55, 56, 58, 59, 62, 63, 64, [illegible], 67 y 68.

Artículo 90.-

Se castigarán con multa de 100 a 5,000 pesos, las infracciones de los artículos 8, 15, 17, 19, 21, 31, 37, 3[illegible], 39, 49 y 66.

ARTICULO 91.-

Se castigarán con multa de 100 a 10,000 pesos o clausura parcial o total, temporal ó permanente ó ambas sanciones a juicio de la autoridad, las infracciones a lo dispuesto por los artículos 33,44, 45, 60 y 61.

ARTICULO 92.-

La autoridad competente podrá decretar la clausura parcial o total, permanente ó transitoria, de las industrias, comercios y talleres, en los que se superen los valores de seguridad establecidos y exista renuencia manifiesta para desarrollar acciones de protección de la audición de personas expuestas.

También podrá ordenar la suspensión parcial o total, - temporal o definitiva, de obras o trabajos, públicos o- privados, por las mismas causas.

Asimismo, podrá poner sellos para impedir el uso u operación de maquinaria, equipo o aparatos que signifiquen fuentes emisoras peligrosas de ruidos.

ARTICULO 93.-

La clausura total o parcial, permanente o transitoria,- solamente podrá dictarse en los casos de rebeldía a cumplir los ordenamientos de la Autoridad Competente, dictados con apoyo en el presente Reglamento, o en las disposiciones que de ellos se deriven.

ARTICULO 94.-

Tratándose de infractores que comprueben su calidad de- jornaleros u obreros, la multa que se les imponga nunca podrá ser mayor que el importe de sus jornales o salarios en una semana.

ARTICULO 95.-

La acción para imponer o hacer efectivas las sanciones a que se refiere el presente Reglamento, prescribirán en- el término de 3 años, contados a partir del día siguiente de aquél en que se tenga conocimiento del hecho, acción u omisión de que deba sancionarse.

ARTICULO 96.-

Toda acción u omisión, contraria a los preceptos del - presente Reglamento, o de las disposiciones que con fundamento en ellos se dicten por las autoridades competentes, será objeto de atención administrativa para fines- de educación, independientemente de la aplicación de - las sanciones que correspondan.

ARTICULO 97.-

A petición del infractor, se podrá conmutar la multa - por la obligación que se asuma, de invertir su monto bajo la dirección control y vigilancia de la autoridad - competente, en la adquisición de equipo o en la ejecución de obras, para abatir, controlar, o suprimir las - causas eficientes del ruido. Esta facultad es discrecional de la autoridad.

CAPITULO VI

DEL PROCEDIMIENTO PARA LA APLICACION DE SANCIONES

ARTICULO 98.-

Las autoridades que tengan a su cargo la aplicación de este Reglamento, deberán de acuerdo con el resultado de las inspecciones, dictar los ordenamientos procedentes y notificarlos al interesado, dándole plazos adecuados y razonables para su cumplimiento, o imponiendo, previa calificación, lasanción que proceda.

ARTICULO 99.-

En caso de que se dicten ordenamientos y se otorguen plazos para su cumplimiento y además se impongan sanciones, o sólamente lo último, se le otorgarán treinta días hábiles para que formule su defensa por escrito, [illegible] a [illegible] aebas o alegue lo que a su derecho convenga.

[illegible] términos para cumplir ordenamientos y para formular [illegible] por escrito, son independientes y corren a partir del día siguiente del de su notificación.

ARTICULO 100.-

Transcurrido el plazo otorgado al infractor para formular su defensa, deberá dictarse resolución fundada y motivada señalando la o las normas infringidas dentro de los treinta días hábiles siguientes, la cual será notificada al interesado en forma personal o por correo certificado con acuse de recibo.

Esta resolución sólamente podrá modificarse administrativamente, por el procedimiento de reconsideración.

ARTICULO 101.-

Para la individualización de las sanciones, cuando este Reglamento señale un máximo y un mínimo, se tendrá en cuenta:

I.- El carácter intencional o imprudente de la acción u omisión que las motiva:

II.- El daño causado o el peligro que provoque.

III.- Las condiciones culturales y económicas del infractor, y;

IV.- La reincidencia o habitualidad.

Son excluyentes de responsabilidad, el caso fortuito y la fuerza mayor.

ARTICULO 102.-

En los casos de ocupación, de clausura temporal o definitiva, o parcial o total, y para imponer sellos, el personal comisionado para ejecutar estas sanciones procederá a levantar acta detallada de la diligencia, siguiendo para ello los lineamientos generales establecidos para las inspecciones.

CAPITULO VII
RECURSO ADMINISTRATIVO DE INCONFORMIDAD

ARTICULO 103.-

A partir de la fecha de notificación de una sanción comenzará a correr para el infractor, el término de quince días hábiles para interponer, por escrito, el recurso de inconformidad.

ARTICULO 104.-

El recurso de inconformidad se interpondrá directamente ante el titular de la Dependencia que hubiera impuesto la sanción, o por correo certificado con acuse de recibo. En este caso, se tendrá, como fecha de presentación, la del día en que haya sido depositado el escrito correspondiente en la oficina de correos.

En el escrito en que se interponga el recurso, se ofrecerán y rendirán pruebas, en los casos que proceda.

ARTICULO 105.-

Recibido el escrito en que se interponga el recurso de inconformidad, el Titular de la Dependencia dictará resolución fundada y motivada en un término de treinta días hábiles. Esta resolución se notificará al interesado personalmente o por correo certificado con acuse de recibo.

El titular que conozca del Recurso, oyendo a la autoridad señalada como responsable, podrá confirmar, modificar o anular la sanción en ejercicio de la facultad que tiene de enmendar determinaciones de autoridades subalternas.

ARTICULO 106.-

La interposición del recurso suspenderá la ejecución de las sanciones pecuniarias, si el infractor garantiza el interés fiscal, en los términos que establece el Código Fiscal de la Federación.

CAPITULO VIII
DE LA ACCION POPULAR

ARTICULO 107.-

La acción popular, para denunciar la existencia de alguna de las fuentes de contaminación a que se refiere este Reglamento, se ejercitará por cualquier persona ante la Autoridad Competente, bastando para darle curso, el señalamiento de los datos que permitan localizarla, así como el nombre y domicilio del denunciante.

ARTICULO 108.-

Al recibir la denuncia, la autoridad que corresponda, identificará debidamente al denunciante y siempre escuchará a la persona a quien pueda afectar el resultado de la misma.

ARTICULO 109.-

La autoridad competente, deberá efectuar las visitas, inspecciones y diligencias necesarias para la comprobación de la existencia del ruido denunciado y su valoración.

Después de realizados estos trabajos comprobatorios, si fuere procedente, se sugerirán o dictarán los ordenamientos conducentes.

ARTICULO 110.-

Localizada que sea la causa ó fuente productora del ruido denunciada y después de que se dicten y apliquen las medidas correspondientes, se hará saber al denunciante, en vía de reconocimiento a su cooperación cívica.