PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF NOISE ON MAN

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INTRODUCTION

Technological advancements in our daily living situations have given rise to at least one undesirable byproduct—excessive noise. Job situations have become noisier as the result of more mechanized equipment being used in plants and offices. Indeed, not too long ago, a noise survey of 200 workplaces in 40 different industrial plants found 50 per cent of the machines in use to produce noise levels believed intense enough to pose some hazard to the hearing of the exposed worker (1). Other probable adverse effects (e.g., interference in speech communication) were not considered in the context of this survey. In six industries alone (saw and planing, wood products, furniture and fixtures, fabricated metals, textiles, transportation) it has been estimated that the number of workers exposed to potentially damaging noise is 6,000,000 (2). Some experts even feel that the number of workers subjected to potentially harmful noise levels probably exceeds the number exposed to any other significant hazard in the occupational environment (3, p. iii).

Besides job situations, communities have become noisier. This is due to the spill-over of increased factory noise, the flyovers of jet and heavy propeller aircraft, and the increased volume of traffic along the nation's rapidly expanding highway system. The problem of excessive community noise is documented in terms of reports of localities taking action to curtail airport and aircraft activities (4, 5, 6) as well as to halt other real and potential sources of community noise (7).

Lastly, home situations have become noisier. This condition has been caused by the upsurge in the use of power appliances such as garbage disposals, dishwashers, and power lawnmowers. Although not in the same category as the aforementioned items, the booming hi-fi

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set and excited children at play have also contributed to the over-all noise problem in homes.

It is the aim of this presentation to describe and discuss the physiological and psychological effects stemming from this noise exposure.

Noise and Hearing Loss

By definition, noise is unwanted sound. It can cause hearing loss and other undesired physiological changes, interference in speech communication, and, of course, annoyance. As already noted, noise-induced hearing loss constitutes a major health problem in industry and for this reason will be given extensive treatment in this paper.

Exposing the ear to an intense noise will most probably cause hearing loss. This loss may be temporary, permanent, or a combination of the two. Temporary hearing loss, sometimes called temporary threshold shift or auditory fatigue, represents loss in hearing acuity which can occur after a few minutes exposure to an intense noise and is recoverable following a period of time away from the noise. Fig. 1

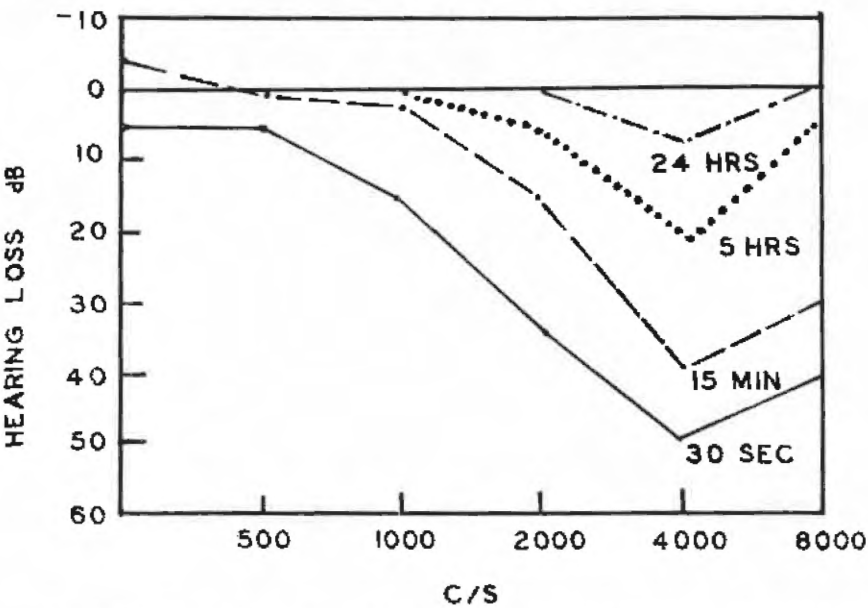


Fig. 1.—Changes in Hearing Threshold Levels, Relative to Pre-exposure Values, for Different Test Frequencies Measured at Various Times After a 20-Minute Exposure to 115 dB (Sound Pressure Level re 0.0002 Dyne/cm²) Broad-band Noise. (Unpublished Data).

shows hearing threshold levels, i.e., minimum audible sound levels, for different pure tone test frequencies measured at various times following a 20 minute exposure to an intense broad-band noise. The horizontal line drawn through the "O" hearing level value on the vertical axis represents a listener's pre-exposure threshold levels for hearing the different test frequencies. Differences between these hearing levels and those plotted on the remaining curves indicate the extent of the listener's loss at specified times following the noise exposure. Note how the differences between the pre- and post-exposure hearing levels diminish with increasing time away from the noise, therein depicting the recovery of the ear from this noise exposure.

With daily continuous exposures for months or years to intense noise, there may be only partial recovery of the observed loss, the non-recoverable or residual loss being indicative of a permanent noise-induced hearing impairment. Fig. 2 describes apparent permanent hear-

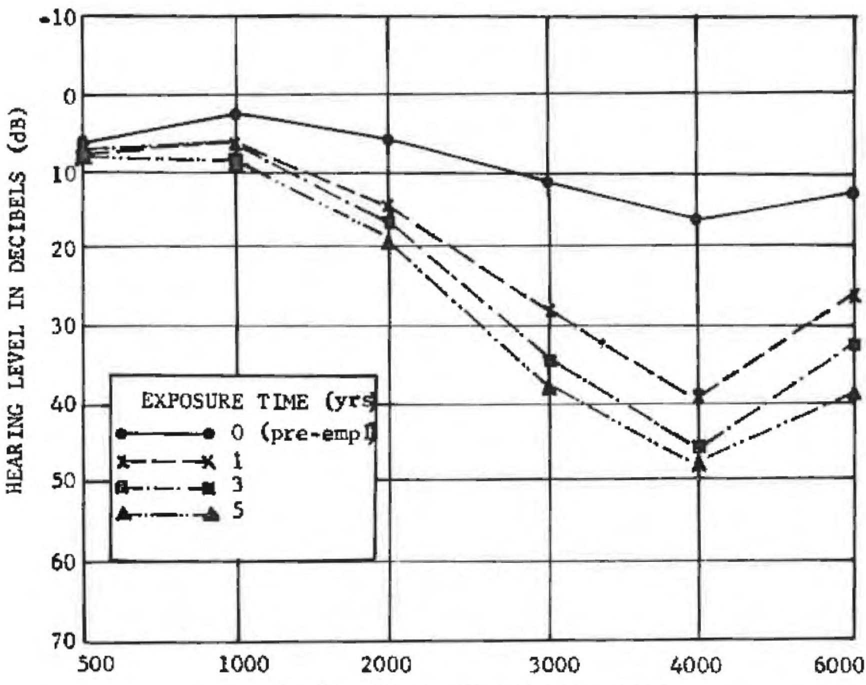


FIG. 2.—MEDIAN HEARING LEVELS FOR WEAVERS OBTAINED JUST PRIOR TO EMPLOYMENT (0 YEARS) AND AFTER VARIOUS YEARS OF EXPOSURE TO WEAVING AREA NOISE. DATA TAKEN FROM YAFFE AND JONES (3, 8).

ing losses for weavers as a function of their years of exposure to weaving room noise (3, 8). It is indicated that significant hearing losses occur first in the frequency range 3000 to 6000 cycles per second (cps) on the audiogram, with 4000 cps showing the most sizeable impairment. Losses in this frequency range are not believed critical to speech reception so that the individual may be completely unaware of the first signs of a noise-induced hearing loss. With longer exposure time significant hearing loss will also occur at frequencies below 3000 cps which can affect speech perception. Workmen's compensation laws for industrial hearing loss in several states presently regard only the hearing losses in the speech frequency range 500 to 2000 cps as being compensable (9, 10).

Complicating the evaluation of hearing loss due to noise is the fact that hearing acuity normally decreases with increasing age (11, 12). Further, the losses associated with age are quite similar to those caused by undue noise in that the hearing for high frequency sounds is most affected in both instances (compare Figs. 2 and 3). Consequently, how much of a given worker's hearing loss is caused by occupational noise exposure?—and how much is due to his age? Hearing data for different age and sex groups having had negligible noise exposure, such as shown in Fig. 3, are subtracted from the total hearing loss values obtained for noise exposed persons in order to leave a "purer estimate" of the amount of noise-induced loss. The hearing loss data plotted in Fig. 2 for the weavers has not been corrected for the age effects on hearing.

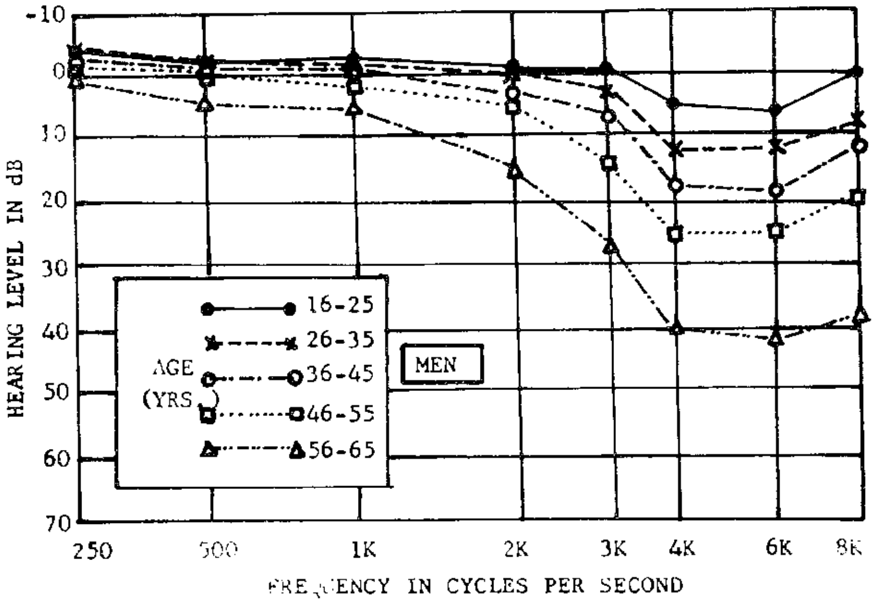
The factors believed to be critical in assessing the severity of noise exposure on hearing are the following:

1. The over-all sound level of the noise.
2. The spectrum of the noise.
3. The total duration of noise exposure.
4. The frequency and time distribution of noise exposure.
5. The susceptibility of the exposed individual's ears to noise-induced hearing loss.

Over-all Sound Level of the Noise

Airborne sound refers to alternate increases and decreases in atmospheric pressure. The amplitude of such changes relative to the resting or normal atmospheric pressure provides an indication of the strength of the sound. These pressure amplitudes are averaged[1] and

[1] A root-mean-square (RMS) average is used in these instances in which the positive and negative



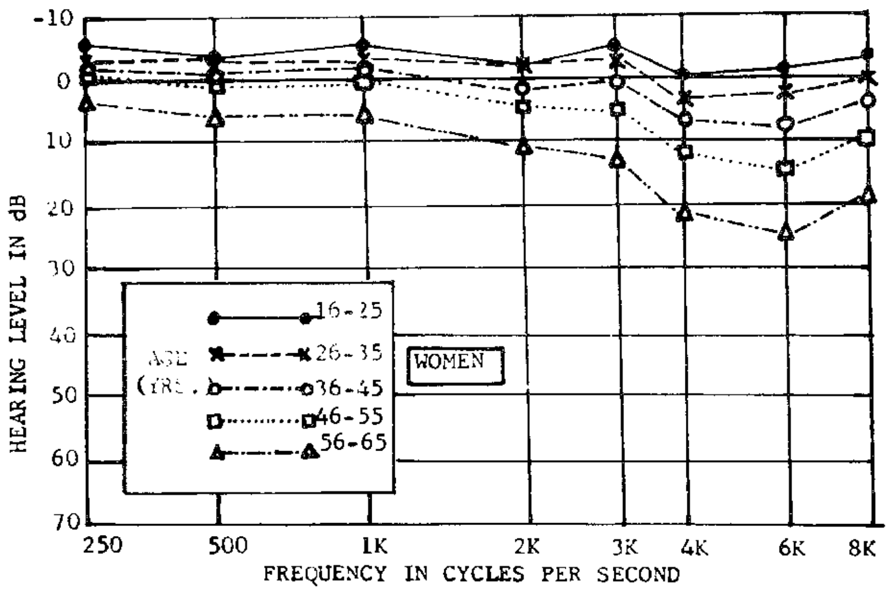


FIG. 3.—MEAN HEARING LEVELS FOR PERSONS HAVING MINIMAL NOISE EXPOSURE AS A FUNCTION OF AGE AND SEX. DATA ARE REPLOTTED FROM RILEY ET AL. (12).

quantified on a decibel scale in accordance with the formula:

$$N_{dB} = 20 \log_{10} \frac{P}{P_0}$$

where N_{dB} = number of decibels, P = the average of the pressure changes underlying the sound being measured, P_0 = a reference pressure, usually 0.0002 dyne/cm^2, which is the weakest audible pressure change that a healthy young ear can detect under ideal listening conditions.

Two important points to remember about sound pressure measurements on a decibel scale are as follows:

1. The decibel scale is a logarithmic scale such that while a change from 0 dB to 10 dB represents a 10-fold increase in sound energy, a 0 dB to 20 dB change represents a 100-fold increase in sound energy, a 0 dB to 30 dB change represents a 1000-fold increase in energy, and a 0 to 40 dB change corresponds to a 10,000-fold energy increase (see Table I).

2. Two decibel values cannot be added together directly. The combined decibel level when adding one 80 dB sound to a second 80 dB sound is not 160 dB. Actually, it is 83 dB.

Sound pressure levels in dB (re .0002 dyne/cm^2) are indicated for some typical noise sources in Table I. Also shown are the RMS pressure values equivalent to the specified decibel notations, and the relative changes in energy.

With reference to over-all sound levels of noise and hearing loss, it is believed that any amount of exposure to unprotected ears to noise in excess of 135 dB is hazardous and should be avoided (13). At the other extreme, exposure to noise whose over-all pressure level falls below 78 dB[2] will not generally produce significant temporary hearing loss in unprotected ears and therein is not assumed to cause any permanent hearing loss. Most industrial noise conditions fall between these two limits and require other information such as the noise spectrum and the length of exposure before a judgment can be made as to the potential harmfulness of the noise to hearing.

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pressure amplitudes (measured relative to the resting pressure level) are first squared and then added together. This sum is then divided by the number of pressure changes involved and a square root extracted from the result. In actuality, instruments designed to measure sound pressure (i.e., sound pressure level meters) carry out this computation. Sound levels measured by these instruments give readings in decibels based on comparing the RMS pressure change for the sound under study with the stated reference RMS pressure value of .0002 dyne/cm^2.

[2] Temporary threshold losses have also been found to occur for over-all noise levels below this value. Such changes, however, are not believed to be a fatiguing of the ear but rather a process of adaptation. See Selters (14) for a discussion of this point.

TABLE I

RELATIONSHIPS BETWEEN SOUND PRESSURE IN DYNE/CM^2, SOUND PRESSURE LEVEL IN DECIBELS (dB), AND ENERGY CHANGE

SOUND PRESSURE (DYNE/CM^2)	SOUND PRESSURE LEVEL IN dB		SOUND PRESSURE LEVEL IN dB	RELATIVE CHANGE IN ENERGY
200	120	PNEUMATIC CHIP HAMMER @ 5 FT.	120	10^{12}
100				
50	110	AUTOMATIC PUNCH PRESS @ 3 FT.	110	10^{11}
		CUT-OFF SAW @ 3 FT.		
20	100		100	10^{10}
10		SUBWAY TRAIN @ 20 FT.		
5	90		90	10^9
		SMALL TRUCKS ACCELERATING @30 FT.		
2	80		80	10^8
1		OFFICE WITH TABULATING MACHINES		
0.5	70		70	10^7
		CONVERSATIONAL SPEECH @ 3 FT.		
0.2	60		60	1,000,000
0.1				
0.05	50	PRIVATE BUSINESS OFFICE	50	100,000
0.02	40		40	10,000
0.01				
0.005	30		30	1,000
		BROADCAST STUDIO (MUSIC)		
0.002	20		20	100
0.001				
0.0005	10		10	10
0.0002	0	THRESHOLD OF HEARING	0	1

Noise Spectrum

Common types of noise as well as music and speech sounds are each composed of many different frequencies within the audible frequency range. The spectrum of a sound or noise refers to the manner in which the energy contained in the noise or sound is distributed across the component frequencies. In obtaining spectral measurements of noise for most purposes, the frequencies comprising the noise are filtered into eight frequency bands, each one octave in width, and sound pressures are determined for each band. The octave band frequency limits usually used are 37.5-75, 75-150, 150-300, 300-600, 600-1200, 1200-2400, 2400-4800 and 4800-9600 cps. Two noises having the same over-all level may differ in terms of the distribution of such energy when analyzed into octave bands. For example, Fig. 4 shows a forging ham-

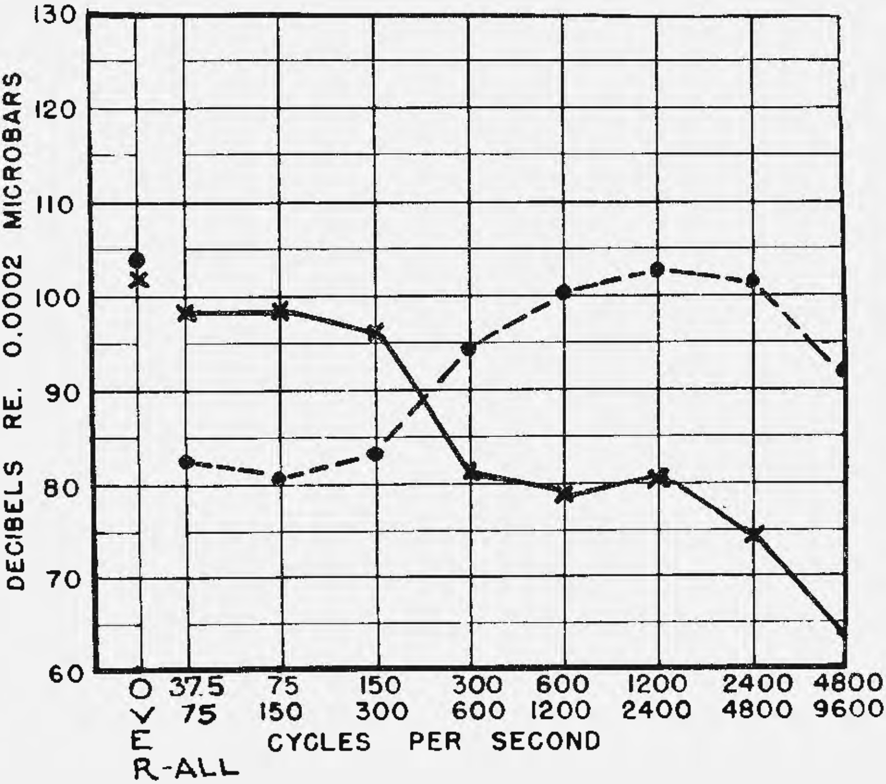

FIG. 4.—OCTAVE-BAND ANALYSES OF ANNEALING FURNACE (FILLED CIRCLES) AND PUNCHPRESS (X-POINTS) NOISE. DATA TAKEN FROM NOISE MANUAL—AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, DETROIT, MICHIGAN, APRIL, 1958, p. 1-5.

mer and annealing furnace to produce noise having the same over-all sound level—about 102 dB. The annealing furnace, however, has most of its energy in the octave bands above 1200 cps while the forging hammer has most of its energy in those bands below 1200 cps.

With reference to noise spectra and hearing loss, it is believed that noises containing large concentrations of energy in the higher octave bands (above 1200 cps) are more damaging to hearing than those noises which have energy concentrations in the lower octave bands (15, 16). Fortunately, noise control procedures are quite effective in reducing the more damaging high frequency sounds (17, 18). They are least effective in suppressing the less harmful low frequencies.

Total Duration of Exposure

As the total exposure time to a noise increases so too does the likelihood that the noise will cause a permanent hearing impairment. Recently, however, it was shown that the amount of permanent hearing loss at 4000 cps stemming from daily exposures of five to eight hours to noise reached a maximum at about 12 years of exposure (19). Further losses at this frequency with continuing exposure appeared to be due to the aging process (presbycusis). This finding is believed particularly significant since 4000 cps on the audiogram usually shows the greatest loss from industrial noise exposure. An incidental finding here was that the maximum permanent hearing loss at 4000 cps after 10 years' exposure was correlated to the temporary hearing loss noted at the same frequency for a new employee group after their first day's exposure to the same noise conditions. This would suggest that temporary hearing loss might be correlated with permanent hearing loss and therein serve as an indicator of the susceptibility of a given ear to noise-induced hearing loss. The relationship between permanent and temporary hearing loss is still not firmly established, however, and to some experts appears untenable (20).

Frequency and Time Distribution of Noise Exposure

In many instances industrial noise exposure for a given worker is not continuous or of a constant nature. More typically, the worker is intermittently exposed to noise conditions which are fluctuating in level as well as spectra. Under these conditions, it is difficult to quantify accurately the amount of noise impinging upon the worker so that some judgment can be made about the harmfulness of the exposure. Much like a radiation badge, noise dosimeters are now being developed which can be worn by an individual for purposes of totalizing the amount of sound energy to which he is exposed. Through read-out devices and some routine computation, the dosimeter provides decibel readings for sound energy averaged over any desired time period. These more definitive estimates of intermittent noise exposure, when correlated with hearing loss, will provide a basis for establishing more realistic noise limits for such exposure situations. At the present time there is little agreement as to the establishment of noise exposure limits for intermittent exposure conditions (21). Most experts do agree, however, that less hearing loss will occur from an intermittent noise exposure than from a continuous one of the same total energy (22). This would suggest that rotating a worker in and out of a continuous type noise situation will provide some protection to his hearing.

Susceptibility of the Individual

The magnitude of both temporary as well as permanent hearing loss for the same amount of noise exposure may vary greatly from one person to another. For this reason, some effort has been directed toward developing a technique which will identify the noise-susceptible or weak ears. Several investigators have considered the nse of temporary threshold losses following a standardized noise exposure test as a susceptibility indicator (23, 24). Those persons showing the greatest temporary losses from the exposure would be considered as most susceptible to permanent hearing losses and consequently would be placed in non-noisy work areas or otherwise protected. This procedure is not fully accepted at this time because of insufficient data concerning the relationship between temporary and permanent hearing loss. Measures of temporary hearing loss are being used, however, to check whether workers in noisy areas are using the ear protection issued to them. Individual workers may be selected for spot audiometric tests. If excessive threshold losses are noted relative to some previously obtained hearing values, it is considered as evidence that ear protection is not being used.

At present, attempts are being made to establish valid and acceptable noise tolerance criteria for preventing hearing damage. The need for such criteria in industry cannot be over-emphasized. They could serve as guidelines for (1) determining the noise reduction needed to create an acoustically safe work environment, (2) the establishment of hearing conservation programs which would include monitoring audiometry so as to identify early those ears which are unusually susceptible to noise-induced loss, and (3) fair rulings in court cases involving compensation claims for noise-induced hearing loss.

Many proposals for damage risk criteria to noise exposure have been made which are intended to minimize the risk of noise-induced hearing loss in a vast majority of the exposed worker population for their working lifetime (13, 24, 25, 26, 27, 28). Several of those criteria governing 5 – 8 hour continuous exposure to noise on a daily basis are shown in Fig. 5.

Each of the plotted curves represents maximum octave band limits for noise exposure and, if exceeded, would prompt recommendations for

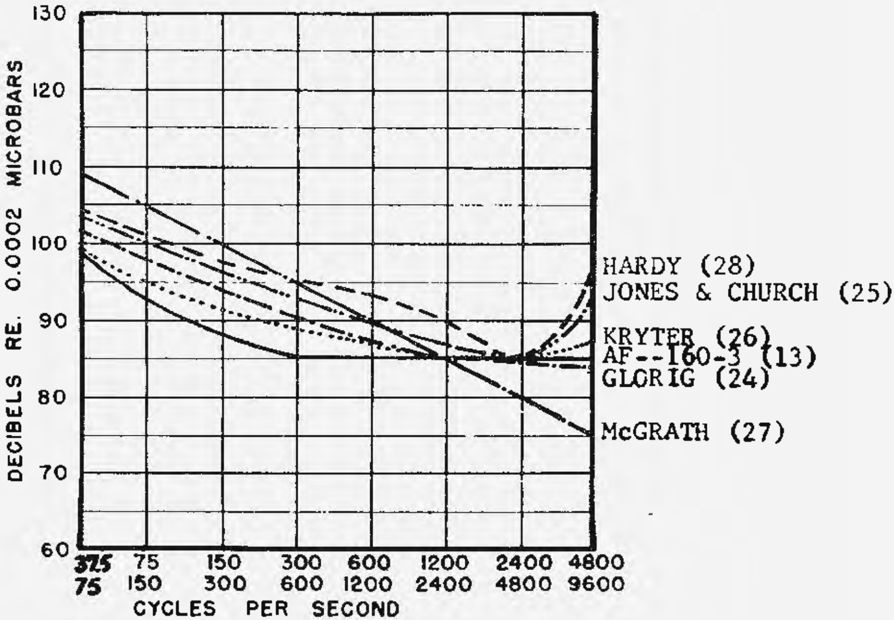

FIG. 5.—PROPOSED LIMITING OCTAVE-BAND PRESSURE LEVELS (IN dB) FOR PREVENTING HEARING LOSSES FROM CONTINUOUS 5-8 HOUR DAILY EXPOSURES TO NOISE FOR A WORKING LIFETIME.

ear protection or other means of noise control. While not too different, a given noise condition could be considered safe in applying one criterion and unsafe in applying another. Which of these various criteria has most merit in reducing the risk of noise-induced hearing loss, while not, of course, requiring needless amounts of noise control, remains to be completely determined. Answers to this question are sought in studies correlating hearing loss with long term exposure to noise conditions defined as safe or unsafe by the various criteria. The U.S. Public Health Service (3) conducted such a study in prison industries where groups of inmates experiencing known occupational noise conditions were given pre-employment and follow-up hearing tests at regular intervals to determine apparent hearing changes with duration of exposure. Actually, the prison situation was ideal for controlling not only the industrial noise exposure but also the noise occurring when the men were not working. On the other hand, exposures to the industrial noise could not be studied on the same men for more than 5 years because of the turnover of inmates in the prisons.

Table II summarizes the prison study data, showing the typical shifts in hearing threshold levels (relative to the pre-exposure values) for test frequencies 500 to 6000 cps following 2 to 5 years of exposure to the noise found in the specified work situations. Coupled to the hearing data obtained for each industrial noise situation is a notation (right hand margin) of whether that noise condition exceeded any of the criteria shown in Fig. 5. In all instances, a criterion was considered to be exceeded if any one octave band level of the specific noise under observation was greater than the octave limits imposed by the criterion. It is indicated that when no criteria are exceeded, the threshold losses at any frequency rarely are more than 10 dB. On the other hand, noise conditions which exceed all of the criteria are associated with quite sizeable shifts, especially for frequencies 3000, 4000 and 6000 cps. As already noted, severe losses at these frequencies mark the early stages of noise-induced hearing loss. With longer exposure to the same condition, significant losses in hearing would also be expected to occur at lower frequencies where hearing for speech could be impaired. Note that comparatively large threshold losses at high frequencies occur for several noise conditions where all criteria were exceeded with the exception of one (Hardy). This suggests that the limits imposed by this criterion may not always provide sufficient protection against noise-induced hearing loss.

Based on a recent poll of experts in the noise and hearing field (21), it is generally contended that a noise whose sound pressure levels fall below 85 dB in the octave bands 300-600, 600-1200, 1200-2400, 2400-4800, 4800-9600 cps, poses no significant risk of hearing damage for fairly continuous daily noise exposures for a working lifetime. For these same exposure durations, the experts believe that the permissible sound pressure levels for the lower octaves 37.5-75, 75-150, 150-300 cps can be somewhat higher than 85 dB. They disagree markedly, however, on criteria for intermittent noise exposure and also on limits for noise conditions in which a strong tone may be present in the noise field (e.g., compressor whine, transformer hum). More data relating noise exposure to hearing loss, given more accurate characterization of the intermittency and nature of the noise condition, will be needed before the acceptable criteria for the latter types of situations can be prescribed. The lack of information regarding the effects of impact noise on hearing also make no judgment possible at this time regarding limits for these types of exposure.

TABLE II
RELATIONSHIP OF PROPOSED NOISE TOLERANCE CRITERIA TO MEDIAN HEARING LEVEL SHIFTS AFTER YEARS OF EXPOSURE TO NOISE FOUND IN PRISON INDUSTRIES

		Median Hearing Level Shifts in Decibels*						
Department	Exposure in Years	500	1000	2000	3000	4000	6000	Criterion Exceeded
Cotton Mill (Spin)	4	0.5	0.5	1.0	3.0	2.5	1.0	All except Hardy
Cotton Mill (Twist)	2	1.0	3.5	3.0	12.5	18.0	12.5	All except Hardy
Cotton Mill (Weave)	5	1.5	5.0	6.5	26.0	28.5	20.5	All
Woolen Mill (Spin, Finish)	2	—1.5	—2.5	0.5	8.5	1.0	5.0	None
Woolen Mill (Weaving)	2	1.5	2.0	9.5	14.5	21.5	11.0	All except Hardy
Shoe Factory (Fitting)	4	0.5	4.0	3.0	4.0	6.5	7.0	None
Shoe Factory (Lasting cutting)	3	2.5	1.5	2.0	1.0	1.0	2.5	None
Shoe Factory (Making, Tracing)	4	2.5	2.5	3.0	6.0	5.0	3.5	Glorig
Brush Factory	5	3.0	3.0	5.0	4.5	0.5	20.0	None
Furniture Mills	3	5.5	2.0	2.5	28.0	26.5	25.0	All except Hardy
Furniture (Cabinets)	2	1.0	—1.5	0.0	3.5	10.5	—0.5	None
Printing Factory	3	—0.5	2.0	4.0	2.5	—1.0	2.0	None
Clothing (Tailoring)	3	1.5	2.0	0.5	1.0	—1.0	—1.0	None

NOTE: This table was previously published in an article by Cohen (21, p. 235).
* Threshold shift with negative sign indicates hearing is better after exposure than before.

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. It should be mentioned, however, 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. While perhaps desirable in emergencies, these changes are not wanted 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 by noise, man must exert greater effort than necessary under more quiet conditions. Measures 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 (29, 30).

Sounds of tremendously high intensity level (over 140 dB) are capable of causing dizziness or loss of equilibrium since the balancing organs (semi-circular canals) are being stimulated. Such high intensity exposures may also cause alterations with other types of sensory behavior, e.g., the eyeballs may flutter in the noise field, 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.

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 which is not intense enough to cause hearing damage may still disrupt speech communication as well as the hearing of other desired sounds. Obviously, such disruption will affect performance on those jobs which depend upon reliable voice communication. The inability to hear commands or danger signals due to excessive noise may also increase the probability of accidents.

Averaging the readings in decibels for the three octave bands 600-1200, 1200-2400, and 2400-4800 contained in a wide-band 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 prearranged vocabulary to be understood over a distance of one foot. Telephone use under these noise conditions would be impossible. Noise conditions having an SIL between 65 and 75 dB would permit barely reliable communication over two feet with a raised voice. This span of communication 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 could communicate effectively over a distance of three feet, a raised voice over a distance of six feet, a very loud voice over a distance of twelve feet. Telephone use here would be practically unimpaired. An SIL of 55 dB or less would be permissible in large business or secretarial office areas. An SIL of 45 dB or less would be desirable for private offices or conference rooms. Table III indicates maximum permissible values for different rooms or areas where speech communication is going to be a major function.

Impairments in Performance (Efficiency)

Contrary to popular thinking, there is little evidence to support the notion that noise degrades performance. Laboratory studies of this

TABLE III
Speech-Interference-Level (SIL) Criteria for Different Room Areas

Type of Room Area	Maximum Permissible SIL (Measured While Room is Not in Use)
Small private office	40
Conference room for 20	30
Conference room for 50	25
Movie theatre	30
Theatres for drama (500 seats, no amplification)	25
Sports coliseum (amplification)	50
Concert halls (no amplification)	20
Secretarial offices (typing)	55
Assembly Halls (no amplification)	25
School rooms	25

NOTE: This table is taken from Peterson, A.P.G. and Gross, E.E. Handbook of Noise Measurement, General Radio Company, West Concord, Massachusetts, 1963, p. 4.

problem (summarized in 31, 32) have shown that tasks involving simple, repetitive operations are not affected by noise. While 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 (32, 33, 34) 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 which 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. Recently completed research on vigilance at this Facility (35) has found such performance to be quite high and unaffected by variations in background noise when a large number of signals are presented for detection on a 10-dial display. These results might suggest that an increased signal rate improves vigilance performance to the extent of overcoming the adverse effects which certain conditions might otherwise have on this type of task.

Deserving of more interest in laboratory studies of noise and performance is the typical marked inter-subject variability revealed in the data. This variability may be due to individual differences in attitudes toward noise, in physiological reactivity to noise, in ability to adjust to noise, or in motivation to overcome the stressful effects of the noise. In exploring some of these factors, the noise-vigilance study described above related performance of the subjects in noise with (a) their noise tolerance as determined by objectionability ratings to a set of laboratory generated noises, and (b) specific personality measures (extroversion-introversion, manifest anxiety, neuroticism) as obtained from a standardized personality questionnaire (Minnesota Multiphasic Personality Inventory). The poorest vigilance performers in noise were found to be less tolerant of noise and showed greater tendencies toward extroversion and neuroticism than the best performers in this test situation. Another study conducted at this Facility (35) found that subjects showing the greatest physiological changes to noise (measured by galvanic skin response) tended to give better performance in noise on a set of learning or practice trials requiring essentially repetitious behavior. This heightened physiological response, however, tended to impair performance when the task was switched. These results would suggest that accurate predictions of the effects of noise on work efficiency would depend upon a fuller appreciation of the physiological and psychological factors operating in the situation. Giving further support to this contention are the results of field studies concerned with efficiency effects associated with changes in noise conditions. Some investigations have noted that increased output has resulted from noise reduction in work areas (summarized in 31, 32, 36). This improved performance level was maintained, however, with the restoration of the original 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 occupation noise conditions upon performance (37). For the same reasons, it is difficult to establish cause and effect relationships between industrial noise conditions and accident rate, absenteeism, and employee turnover.

Noise and Annoyance

Perhaps the most widespread reaction to noise is that it is annoying. What constitutes an annoying sound, however, is not an easy question to answer since noise-annoyance judgments depend upon many factors besides the acoustical stimulus. For example, a sound may be judged annoying because it has unpleasant association to an individual. In a poll dealing with the annoyance of aircraft noise in a community near an airport, 80 per cent of those residents complaining of the aircraft noise also reported some fear in connection with airplanes, either fear of the planes crashing into their homes, or else unwillingness to fly themselves (38). A sound may also be considered as annoying on the basis of whether it is believed necessary. In a survey of British homes, 10 per cent of the residents were troubled by the noise of delivery trucks in a neighborhood as compared with 40 per cent who complained over the less intense noises produced by the neighbor's pets (39). A sound may be judged annoying if it is inappropriate to the activity at hand. Complaints to noise in communities impacted by noise are more numerous in the evening, presumably because sleep and relaxation are being interfered with. Conversely, an individual will tolerate certain sounds if there is an advantage associated with them. The comforts derived from air-conditioning apparently outweigh the noise produced by such units. The economic values to the community of nearby factories or airports may partially offset the noise-nuisance produced by such noise sources. Along with the above factors, there are many differences in individuals with regard to their ability to tolerate noise. Some individuals complain about all kinds of noise, indeed any kind of annoyance. One study has reported, for example, that many people who were greatly affected by aircraft noise were preoccupied with other physical problems in their communities including other kinds of noises, litter, air pollution (summarized in 32). There is some support for the notion that people who have adjustment problems also seem to be more affected by noise than others (40).

Turning to 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 of frequency is judged more annoying than one which is continuous and unchanging.
4. Localization—a sound which repeatedly tends to change in location or point of origin is less preferred than one which remains stationary.

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 (41).

A new measure called perceived noisiness in decibels (PNdB) (42) 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. JFK Airport (formerly Idlewild) for example, has a noise ceiling of 112 PNdB 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, conversion to loudness measures in sones or phons as developed by Stevens' (43) or by Zwicker's (44) 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 (45). Inherent to the A-scale readings as well as the conversion procedures noted are weighting schemes which reflect, in various ways, established relationships 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 Ref. 44, 46).

At present much research is being done in an attempt to determine which of the various methods just described can best serve to index noise-annoyance for the possible range and variety of community noises encountered. In a recent study at this Facility (46), the annoyance levels of recorded samples of roadway noise, aircraft flyover noise and train noise, as computed by the various proposed procedures, were each correlated with listener's annoyance ratings of the noises. In this investigation, samples of roadway, aircraft and train noise were presented in pairs; 100 listeners having to judge which of the two noises in each pair was more objectionable. Such judgments yielded scaled objectionability ratings[3] for the noise samples which were then correlated with A-scale sound level readings of the noises in dB, and with conversions of their spectral measurements into loudness magnitudes in phon units, as computed by Stevens' and by Zwicker's techniques, and into perceived noise level (PNdB) as determined by Kryter's procedure. Fig. 6 plots the scaled ratings of noise annoyance against the measures derived from the various proposed procedures. A plot of noise ratings vs. the unweighted sound pressure levels (C-

[3] Paired comparison judgments of the noise samples supplied scale values which not only gave the relative rank of each noise in terms of its objectionability, but also indicated the size of the intervals between successive ranks. This latter scale property is meaningful. For example, the size of the interval between the noises ranked first and second in objectionability is liable to be much greater than the intervals between the noises ranked second, third and fourth. This would suggest that the first ranked noise is clearly more objectionable than the next three ranked samples which, in turn, are quite close to one another in objectionability. The scale just described however, has no absolute zero and its graded units are arbitrary. See Guilford (47) for a discussion of paired comparison procedures and scaling.

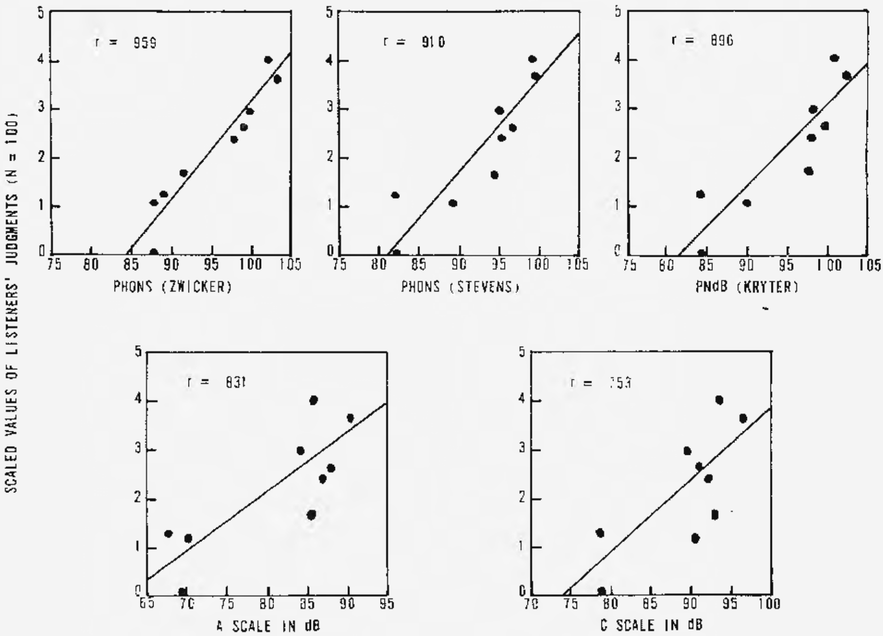

FIG. 6.—SCALED OBJECTIONABILITY RATINGS FOR SAMPLES OF AIRCRAFT FLYOVER, TRAIN, AND ROADWAY NOISES PLOTTED AGAINST MEASURES OF LOUDNESS (ACCORDING TO ZWICKER (44) AND STEVENS (43)), PERCEIVED NOISE LEVEL (ACCORDING TO KRYTER (42)), AND A- AND C-SCALE (OVER-ALL) READINGS FOR THE VARIOUS NOISES.

scale) of the noises is also shown. The relationship of Zwicker's measures of loudness to the scaled objectionability ratings deviated least from a straight line fitted to the data by the least squares method and, accordingly, had the highest observed correlation coefficient (r = .96). This indicated that of the different noise annoyance indices under evaluation, Zwicker's loudness values most closely correspond with subjective judgments of noise annoyance. Relationships between the scaled noise ratings and Stevens' loudness and Kryter's perceived noisiness values also showed fairly good agreement, yielding correlation coefficients of .91, and .89 respectively. The A-scale readings showed lesser correspondence with the objectionability ratings of the noise samples used in the study (r = .83). As expected, plotted values relating over-all noise levels (C-scale) to the objectionability ratings for the noises showed the most deviation from the least squares fitted line, therein indicating the poorest degree of correspondence and the lowest observed correlation (r = .75).

It must be emphasized again that the procedures under evaluation here can give only limited prediction of community noise nuisance because they only consider 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 (48, 49). One of these models is described in the Appendix. The accuracy of the predictions 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 over-all level, the spectrum of the noise, total exposure duration, time and frequency distribution of short term exposure periods, the susceptibility of an individual's ears to noise-induced hearing loss. Specifications for valid damage risk criteria 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 where effective speech communication is needed. 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.

APPENDIX

The following procedure, developed by Stevens, Rosenblith and Bolt (48), is intended to predict the probable nature of neighborhood reactions to noise taking into account the physical acoustics of the noise as well as other factors of a psychological and sociological nature. The procedural steps are as follows:

1. Develop initial rank for noise spectrum.

a. Obtain octave band analysis for noise condition under evaluation, preferably using numerous measurements at the property lines of the closest residences and deriving an average spectrum for the subject noise.

b. Superimpose this spectrum on the family of curves shown in Fig. 7 which define the level of rank of the curve of the noise spectrum.

The level rank for a given spectrum is that letter (from A (low) to M (high)) corresponding to the highest zone into which any part of the spectrum protrudes.

2. Adjust noise level rank for other influencing factors.

a. Determine for the noise characteristics and neighborhood in question, correction numbers to take account of different conditions as shown in Table IV.

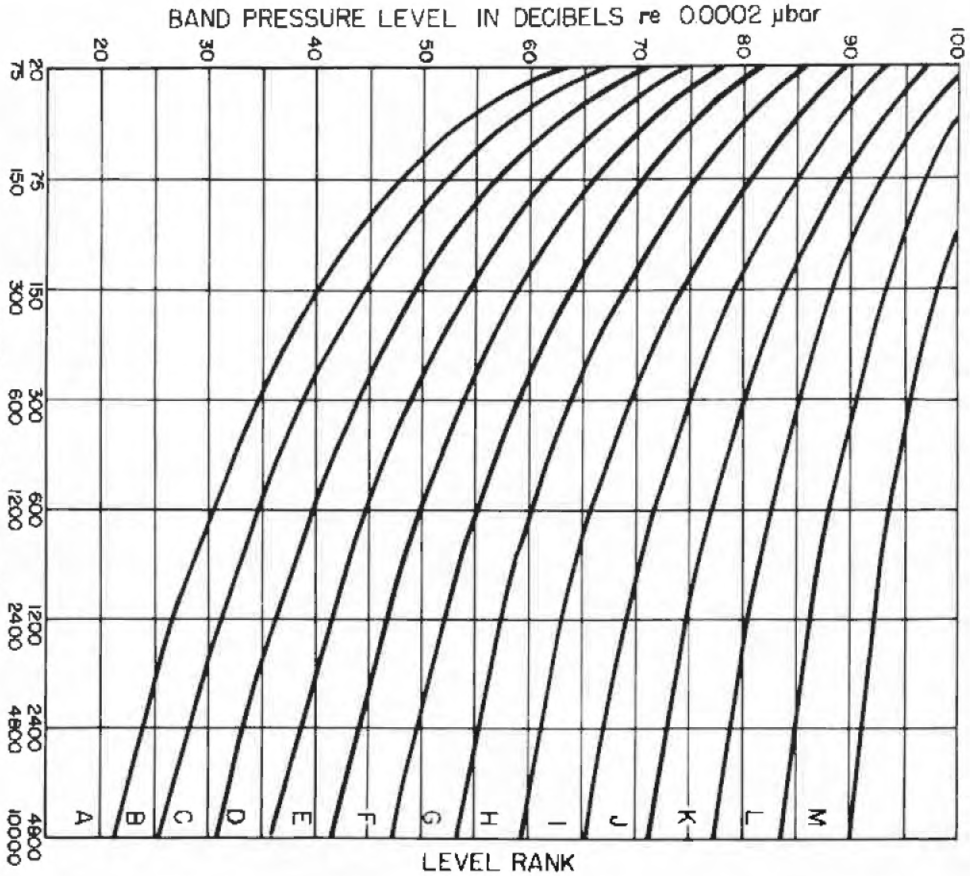

FIG. 7.—SET OF CURVES FOR ASSIGNING A LEVEL RANK TO A COMMUNITY NOISE. THE OCTAVE-BAND LEVELS OF THE NOISE UNDER EVALUATION ARE PLOTTED ON THIS CHART. THE HIGHEST OF THE ALPHABETICALLY LABELED ZONES INTO WHICH ANY OF THE BAND LEVELS PENETRATES IS THE LEVEL OF THE NOISE. CHART TAKEN FROM STEVENS, K. N., ROSENBLITH, W. A., AND BOLT, R. H. (48, p. 66).

b. Depending on such conditions, add or subtract the appropriate correction values, and obtain their algebraic sum to derive a net correction factor.

c. Obtain a corrected noise level rank by adding or subtracting the number of level ranks indicated by correction factor obtained in Step 2b from the original noise level rank defined in Step 1b. Thus, if the original noise level rank was E, and the correction factor was -2, the two ranks would be subtracted from E leaving a level of C. This rank (C) would be the corrected level rank.

3. Determine predicted neighborhood response.

a. Identify the point corresponding to the corrected noise level rank on the horizontal axis of Fig. 8. Follow a vertical line from this point to the shaded

TABLE IV
LIST OF CORRELATION NUMBERS TO BE APPLIED TO LEVEL RANK TO GIVE NOISE RATING

Influencing Factor	Possible Conditions	Correction Number
Noise Spectrum Character	Pure-tone components	+1
	Wide-band noise	0
Peak Factor	Impulsive	+1
	Not Impulsive	0
Repetitive Character (about one-half minute noise duration assumed)	Continuous exposures to one per minute	0
	10-60 exposures per hour	—1
	1-10 exposures per hour	—2
	4-20 exposures per day	—3
	1-4 exposures per day	—4
	1 exposure per day	—5
Background Noise	Very quiet suburban	+1
	Suburban	0
	Residential Urban	—1
	Urban near some industry	—2
	Area of heavy industry	—3
Time of Day	Nighttime	0
	Daytime only	—1
Adjustment to Exposure	No previous conditioning	0
	Considerable previous conditioning	—1
	Extreme conditioning	—2

NOTE: Table taken from Stevens, K. N., Rosenblith, W. A. and Bolt, R. H. (48, pp. 67-68).

area indicated. The vertical range of this shaded area for that rank, when referred to the vertical axis on the left, will indicate the probable expected neighborhood response to the noise under study.

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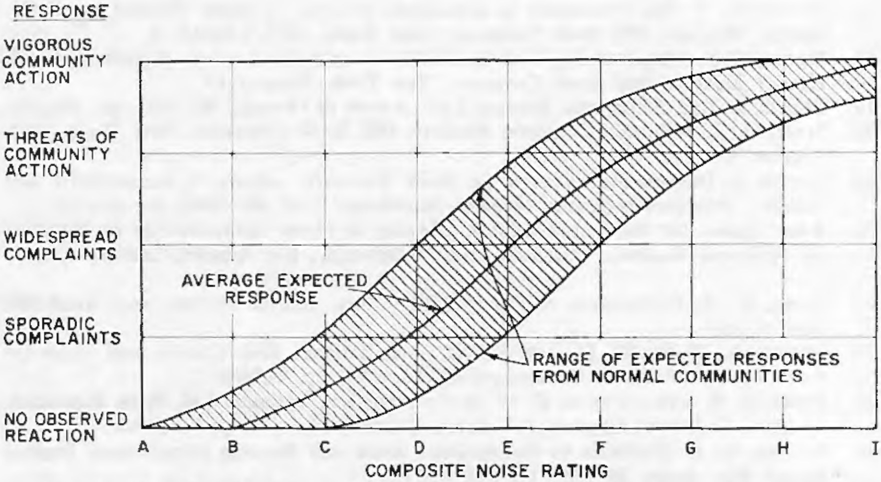

FIG. 8.—RELATION BETWEEN CORRECTED NOISE LEVEL RANK AND EXPECTED RESPONSE FROM THE RESIDENTS EXPOSED TO THE NOISE. GRAPH TAKEN FROM STEVENS, K. N., ROSENBLITH, W. A., AND BOLT, R. H. (48, p. 64).

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