NOISE
An Occupational Hazard and Public Nuisance

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Noise has always played an important part in the life of man, but in the present age of the internal combustion engine, the jet plane, and more and more complicated machinery of all kinds it has become not an occasional adjunct but a permanent part of man's life.

Noise is particularly important in occupational health, and it was because of the World Health Organization's close concern with occupational health that Dr Alan Bell was appointed to study it as an occupational hazard. This volume in the Public Health Papers series contains the results of Dr Bell's study, which is intended to be an introduction to a complex subject that will help towards an understanding of its fundamental concepts and enable readers not only to grasp the issues involved but also to play a part in improving the working—and indeed the community—environment. For the increase in noise that is so much a feature of the contemporary scene is much more than an occupational hazard; it is, as Dr Bell says, a public nuisance and a danger to mental and physical health.

Although much has been written on noise, there is room for a short and relatively simple account of the effects of noise on the human body and mind and on the methods that have been, and remain to be, tried to control it. It is hoped that this volume will help fill the gap, and arouse interest in the problem of noise. Stress is laid on the failure in many countries to pay sufficient attention to it, even though enough is already known to prevent most cases of occupational impairment of hearing. It is recommended that, if they have not done so, government departments concerned with noise should assess the situation within their own countries and take whatever steps are needed to protect workers from the hazards noise entails for them. In any such assessment the related problem of community noise should in no circumstances be overlooked.
CHAPTER 1

GENERAL CONSIDERATIONS

In many countries comparatively little attention is paid to noise, despite its importance in the industrial scene. It is not a new hazard, and many occupationally exposed workers develop hearing losses which may be severe, though fortunately not invariably so. In the present study the word “deafness” refers to any loss of hearing and does not of necessity refer to a total loss. There is much to suggest that this hazard is increasingly prejudicing social life and in some instances earning capacity.

While the results of an inadequate guarding of machines and of exposure to toxic materials are comparatively well understood—because their sequelae are often dramatic—this is rarely the case with noise. The onset of noise-induced hearing loss is usually insidious and often quite unappreciated by the individual affected. Again, it is sometimes difficult to distinguish clearly between hearing impairment due to advancing age and impairment of occupational origin. Difficulties also arise when employers fear that investigation of the problem may provoke litigation or legislation. On other occasions difficulties sometimes result from the attitudes of labour organizations.

DEFINITIONS

The word “sound” denotes a mechanical disturbance in gases, fluids or solids and is based on molecular vibration. With airborne sound, the vibratory movement of molecules of the atmospheric gases sets up small variations in atmospheric pressure, known as “sound pressure”. The latter can be expressed in microbars or as dynes per square centimetre (Burns, 1965).

Noise has been described as a sound without agreeable musical quality, or as an unwanted or undesired sound. The decibel (dB) is a term used to describe the intensity of sound. It is a unit of gradation; to say that a sound is 60 dB means that it is 60 dB more intense than a
sound standardized as the reference level. In making physical measurements, we use as a base a sound pressure of 0.0002 microbar, "the weakest sound pressure detectable by the keen young human ear under very quiet conditions" (Sataloff, 1957).

The frequency of sound is the number of times a complete cycle, which consists first of an elevation and then of a depression below atmospheric pressure, occurs in one second. It is measured in cycles per second (c/s) or in hertz (Hz), these units being equivalent to each other.

The unit interval on a loudness scale is called a "sone"; a pure tone of 60 sones is three times as loud as one of 20 sones. There is no similar arithmetical relationship for decibels (Stevens, 1959). The loudness level of a sound is expressed in phons, and there is a relationship between decibels, phons and sones (Aldersey-Williams, 1960).

ULTRASONICS

"Ultrasonics" refers to sound in the frequency range above some 15 kHz i.e., beyond the upper limit of normal hearing. Certain noises, of course, have both an audible and an ultrasonic component. At present, ultrasound is rarely, if ever, an occupational hazard. However, Angeluscheff & Coleman (1953) comment that "sounds considered innocuous may, by their supersonic components, exert a deleterious effect on the cochlea and hearing mechanism". They state that ultrasound can cause distinct alterations in bony and collagenous tissues, and they discuss a possible relationship to otosclerosis.

Ultrasound may affect other tissues, such as the whole plasma protein. It has been shown that radiation of the occiput of the skulls of rabbits produces an increase of certain urinary metabolic products (Jankowiak, 1964). It is possible experimentally to kill insects and mice in ultrasonic fields; in the latter, death being due to overheating from absorption of sound energy by the fur. One reason why man is not similarly affected is the different absorption coefficient of human skin. Ultrasonics have many applications in medicine, science and industry, and the future will probably see an increase in the numbers of occupationally exposed persons. There are important differences between the therapeutic and industrial uses of ultrasonics; one should keep an open mind about possible occupational hazards.

VIBRATION

This is not discussed here, despite the fact that it may be necessary to investigate its origin when attempting to reduce the volume of noise.
Any noise-investigation unit should preferably be able to carry out basic vibration measurements.

The relations of vibration and ultrasonics to audible noise are indicated in Fig. 1.

**FIG. 1. THE AUDITORY FIELD**

Adapted, by permission, from Glorig (1956).

**THE GROWTH OF THE PROBLEM**

Auditory damage from excessive noise was known hundreds of years ago. Ramazzini in *De Morbis Artificum* (1713) describes how those engaged in the hammering of copper "have their ears so injured by that perpetual din . . . that workers of this class become hard of hearing and, if they grow old at this work, completely deaf". Nevertheless, before the Industrial Revolution, comparatively few people were exposed to excessive noise. The position changed rapidly with the advent of power-driven machinery. Today, industrial machinery and most forms of transport all contribute to the total exposure, and noise has become omnipresent. Those exposed by virtue of their work, apart from employees in heavy industry, include farmers, some office staff, numerous categories of building and transport workers, many men and women
engaged in secondary industries, certain research and university personal, and members of the armed forces. However, not all sound is harmful or useless. Masking sound may be used to relieve tension during dental surgical procedures (Gardner & Licklider, 1959), and noise is a possible method of pest control.

The average sound-pressure levels of familiar noises, expressed in decibels, are set out in Table 1. Such figures have little exact meaning without reference to the conditions in which measurements are made.

<table>
<thead>
<tr>
<th>Non-industrial</th>
<th>Industrial</th>
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<tr>
<td>Whisper—20 dB</td>
<td>Lathes—85-95 dB</td>
</tr>
<tr>
<td>Tick of watch at 1 metre—30 dB</td>
<td>Punch presses—95-105 dB</td>
</tr>
<tr>
<td>Conversation—60 dB</td>
<td>Circular saw (wood)—100-110 dB</td>
</tr>
<tr>
<td>Street noises—40-70 dB</td>
<td>Sand blasting—118 dB</td>
</tr>
<tr>
<td>Sports car—80-95 dB</td>
<td>Riveting and chipping on steel plates—130 dB</td>
</tr>
</tbody>
</table>

**TABLE 1. NOISE LEVELS (DECIBELS)**

**THE COST OF NOISE**

"The potential cost of noise-induced hearing loss to industry is greater than for any other occupational disease" (Glorig, 1961b).

In considering cost one must think in terms of hearing impairment, worker’s compensation, reduced output, increased accident rates, communication difficulties, etc. Sataloff (1964) has emphasized the importance of a hearing loss on an individual’s personality. Programmes must be based on the preservation of hearing, not of money.

It has been estimated that, before the Second World War, office noise was costing business in the USA 2 million dollars a day through inefficient operation (Hooper, 1958). More recently, this figure is stated to have been doubled. In some cases, as with ex-servicemen, reasonably accurate estimates of the cost of hearing loss can be made. Unfortunately, this is rarely possible for civilian populations. It has been estimated that there are, in the USA, 1,700,000 males in the 50-59 age-group with hearing levels of 15 dB or more at 1000 Hz, of whom perhaps 10% are eligible to file claims for workmen’s compensation. In fact, many of those suffering minor degrees of industrial noise-induced hearing loss do not claim compensation, possibly in part for fear of jeopardizing their future employment prospects.
AWARENESS OF THE PROBLEM

There has in the past been a comparative lack of interest in this health hazard. Indeed, it has been said that noise is a dominant factor in engineering policy only in the design of concert halls, or in other special cases (Robinson, 1962). Until comparatively recently, suitable and accurate methods of measuring noise and evaluating hearing loss were not available, and we still know too little of the relation between exposure and hearing impairment. Another factor is the relatively small number of suitably qualified medical, engineering and scientific staff. Before the over-all problem can be solved, there must be an awareness of its existence. Industrial indifference, if present, can be reduced if doctors inquire into the occupations of patients with deafness, if factory inspectors encourage managements to seek advice about noisy processes, and if governments develop comprehensive occupational-health services equipped for noise evaluation (Hickish, Jones & Murphy, 1962). In many cases insurance companies can play an important part, since any reduction of working hazards resulting from thorough noise evaluation will, at least ideally, reduce accident and insurance costs.

Industrialists must learn to place noise control in the same category as, for example, the control of toxic fumes and machine-guarding, if only because this is good business in terms of health, accident prevention and industrial relations. Workers are entitled to be protected against loss of hearing as much as they are against injury and other occupational diseases. It is important to educate industrial managements and staffs, as well as the general public, to regard noise as a possible cause of hearing impairment as well as a distressing nuisance. That public opinion is awakening in some countries is attested by conferences at various levels, of which those originating within industry are particularly valuable. An increasing number of papers on the problem are read at national safety conferences.

RESEARCH

No national noise-control programme should be regarded as complete unless it includes research. More and more departments are being established in universities and other centres to study the many aspects of normal hearing and of hearing affected by noise. Possibly the world's largest medical research laboratory devoted to these problems was recently opened in the USA (Lawrence, 1962), and in the United Kingdom in 1963 the Institute of Sound and Vibration Research was established at the University of Southampton. There are also research stations in some of the smaller nations—e.g., the Department of Applied Acoustics set up within the Building Research Station in Israel a few years ago.
(L. Schaudinischky—personal communication, 1964). The number of publications on noise is also growing, as may be shown by the number of articles on noise abstracted by the Industrial Hygiene Foundation of America (1955) given in Table 2. There are technical journals devoted
to this subject. Unfortunately, despite these journals and the abstracting service of the International Occupational Safety and Health Information Centre of the International Labour Office (ILO), it remains difficult for workers in this field to familiarize themselves with the results of research published in other languages, and unnecessary obstacles and duplication of effort arise. There is also a need for the data to be made available in non-technical language to managers and safety officers.

An increasing number of universities and other institutions now offer courses on noise, but the consensus at a recent conference was that acoustics was inadequately taught (Lindsay, 1965). The technical education of the factory inspector is particularly important. The report of the ILO-WHO Symposium on the Medical Inspection of Labour, held at Geneva in 1963, stated that “the medical inspector should have a sufficient knowledge of the hazards which can be associated with environmental conditions, including noise”, and accorded the latter an importance as great as that of the more familiar hazards of poor lighting and dust. It is encouraging that these international organizations recommend developing countries to give due consideration to this problem at an early stage of their industrial evolution.

In the USA, the American Academy of Ophthalmology and Otolaryngology appointed a subcommittee on noise in industry in 1947. A few years earlier, the American Standards Association had established an exploratory subcommittee on acoustics, vibration and mechanical shock, which was assigned the task of “exploring the possibility of

<table>
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<th>Number of titles listed by the Industrial Hygiene Foundation of America (1955) of articles published:</th>
<th>Before 1900</th>
<th>1901-1920</th>
<th>1921-1940</th>
<th>1941-1955</th>
</tr>
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<td>0</td>
<td>0</td>
<td>71</td>
<td>352</td>
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<tr>
<td>Effects of noise</td>
<td>1</td>
<td>4</td>
<td>83</td>
<td>339</td>
</tr>
<tr>
<td>Measurement of hearing loss</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>671</td>
</tr>
<tr>
<td>Reduction and control of noise</td>
<td>0</td>
<td>0</td>
<td>37</td>
<td>441</td>
</tr>
<tr>
<td>General</td>
<td>3</td>
<td>3</td>
<td>72</td>
<td>226</td>
</tr>
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establishing bio- and psycho-acoustical criteria for noise control, particularly in the sphere of industrial noise exposure" (American Standards Association, 1954). The American armed services also instituted a national research committee on hearing and bio-acoustics. There have likewise been industrial efforts in the same direction. In California an All-Industry Noise Committee was set up to develop "a constructive hearing conservation programme to reduce hearing losses caused by industrial exposure", aided by medical, legal and technical subcommittees (Bonney, 1962). In Europe, research at various centres into the noise problems of the mining and steel industries has been supported by the European Coal and Steel Community.

THE CONTROL OF NOISE

Noise-control personnel and committees have also been established within particular industries. In some large factories the problem receives the attention of a special committee, rather than that of the general accident-prevention authority. Noise-abatement societies have been formed in many countries and have made full use of educational media. Awards may be made to local authorities for the effectiveness of their control measures. In Britain, the Committee on the Problem of Noise (1963) issued an exhaustive and authoritative report.

Many countries have standards organizations producing a wide variety of codes and specifications. Thus, the 1965 catalogue of the American Standards Association lists more than two dozen entries under the heading "Acoustics, Vibration, Mechanical Shock and Sound Recording". These deal with such matters as terminology, the criteria for background noise in audiometry rooms, specifications for sound-level meters and audiometers, and specifications for the electroacoustic characteristics of hearing aids. National specifications may vary and differ not only on specific topics but also in their range of studies. An increasing number of manufacturers are designing their products to meet these specifications (Annex 1).

Working parties of the International Organisation for Standardisation are considering a wide variety of topics, including normal hearing thresholds, architectural acoustics and sound transmission in buildings, the method of assessment of loudness by objective analysis, traffic and industrial noise, and the measurement of machinery noise. The International Electrotechnical Commission has also produced publications of interest. Finally, more and more countries are promoting legislation to control noise, to establish damage-risk criteria, and to compensate those who develop hearing loss.
CHAPTER 2

ANATOMY, PHYSIOLOGY AND PATHOLOGY

The ear is made up of three parts: the outer, middle and inner ear (Fig. 2).

The outer ear extends to the ear-drum, which is at the bottom of an oval cylindrical canal some 4 cm long, formed of cartilage, membrane and bone and lined by skin containing wax-secreting glands. This canal directs sound to the drum. It has a slight S-shaped curve which sometimes causes difficulty with the insertion of earplugs; its diameter varies at different points, and it is narrower at the inner end. In talking, chewing or yawning, the shape of the outer third of the canal changes, so tending to displace even well fitting plugs. The elliptical ear-drum is thin and transparent, and rendered taut by its attachment to the malleus bone.

The middle ear contains a chain of three small movable bones called the auditory ossicles—malleus, incus and stapes—and two minute muscles: stapedius and tensor tympani. The stapes is like a stirrup whose flat base fits into and is attached to the membrane of the oval window, so that it moves as a hinge-like structure. The Eustachian tube connects the middle-ear cavity with the pharynx, so as to equalize air pressure on both sides of the drum in normal health; this is necessary if the latter is to vibrate when sound impinges on its surface. The extent to which the drum moves also depends on other factors: the tone of the nasopharyngeal muscles, the presence or absence of middle-ear congestion, and the degree of protection afforded by earplugs, etc.

The inner ear, a complex system of cavities contained within dense bone, includes three semicircular canals at right-angles to each other and the cochlea. The canals, as part of the body’s balancing mechanism, need not concern us further here.

The cochlea (Fig. 3) is the site of damage when hearing impairment results from exposure to excessive noise. In shape it resembles a snail’s shell, with 2½ turns around a central hollow pillar, the modiolus, which carries the nerve fibres leaving the sensory cells. The cochlea contains
two membranous canals. The first begins at the oval window, travels the length of the spiral tube and, turning on itself at the apex, travels down to the round window. The second, a closed system containing the delicate organ of Corti, lies within the space formed by the doubling of the first canal. Both canals contain fluid, called perilymph and endolymph respectively.

**FIG. 3. THE COCHLEA**


The cochlear coil is divided into two sections by an incomplete bony shelf and the basilar membrane. The organ of Corti, consisting of over 20,000 sensory cells, rests on this membrane; numerous fine hairs project from the free edges of the cells towards the tectorial membrane, and the fibres originating in these hair cells come together to form the auditory nerve. When sound reaches the external ear it is channelled to the drum, which vibrates and moves the auditory ossicles. As the stapes is attached to the oval window, the fluid in the membranous canals is set into wave-like motion which, in turn, stimulates the organ of Corti.
Current views of cochlear function are largely based on von Békésy’s studies of the movements of the basilar membrane and of the electrical potentials in the hair cells (Békésy & Rosenblith, 1951; Békésy, 1956). Displacement of the free ends of these cells produces an electrical impulse that travels along the auditory nerve to the brain and is there interpreted as sound. Sounds with a frequency between 1000 and 5000 Hz are probably transmitted more efficiently than others. Depending on the format of the incoming waves, certain hair cells are activated more than others, resulting in selective stimulation of the nerve endings; the cells at the base and apex of the cochlea respond to the highest and lowest frequencies respectively. When stimulated, these cells give rise to an alternating potential, and this output is decreased by injurious factors. Such changes are presumed to be detectable audiometrically and are indicative of inner-ear deafness (Lawrence, 1960a).

The ears of healthy young adults are sensitive to frequencies ranging from approximately 20 to 20,000 Hz (Fig. 1). The auditory sensitivity curve is saucer-shaped; certain frequencies are heard at lower intensities than others, and the ear’s greatest sensitivity is in the range 1000-4000 Hz. The normal average hearing ability as measured with an audiometer, 0 dB, is not necessarily the best hearing that a normal person is capable of; many can hear —10 dB, if this is recordable on the audiometer. Normal hearing therefore extends on both sides of the so-called “reference zero”. Sound may be uncomfortable at 100–120 dB and painful at 130–140 dB; a ticklish feeling may be felt at intermediate levels.

ACOUSTIC DAMAGE FROM SOUND

The mechanism by which the cochlea suffers damage is not completely clear, despite the recent application of techniques such as X-ray diffraction and electron microscopy (Iurato, 1962).

Prolonged exposure to excessive noise produces varying degrees of inner-ear damage, which is initially reversible. This transient auditory fatigue, known as temporary threshold shift, is discussed in a later section. With further exposure, the changes become irreversible. The exact nature of the cellular changes responsible is unknown; it may be a disturbance of metabolism in the end-cells of the organ of Corti. The histopathological lesions have been studied in experimental animals and closely resemble those noted in microphotographs of the human organ of Corti after exposure to excessive sound. One of the earliest detectable changes is swelling and altered staining qualities of the hair cells. The swelling is eventually accompanied by the destruction of occasional outer cells in the basal turn of the cochlea in the area of localization
corresponding to 4000 Hz, and the damage may progress from this mild form to involve the entire cochlea and completely disrupt the organ of Corti, leaving only the bare basilar membrane (Rosenwinkel, Stewart & Doerfler, 1959a). It can be shown polarographically that the permeability of the basilar membrane may increase after intense sound stimulation (Ward & Fernandez, 1961). There are, however, no detectable changes in the nerve bundles accompanying noise-induced hearing loss. The cochlear segment corresponding to 4000 Hz, which is most vulnerable, lies at about 10 mm from the oval window; it is also susceptible to skull injuries and poisons. Lawrence (1964) has discussed current concepts on the mechanism of occupational hearing loss.

ACOUSTIC REFLEX

Acoustic reflex partially protects the ear exposed to high sound levels. The stapedius and tensor tympani muscles contract, limiting movement of the ossicles and so attenuating the general disturbance. The protection afforded by this reflex averages 10 dB for frequencies at or above 1000 Hz, and may be as much as 50 dB for sensitive individuals (Simmons, 1959).

The reflex can be triggered by sound received either monaurally or binaurally (Møller, 1962). It is ineffective in certain situations, such as exposure to violent impulse sounds from gunfire or metal stamping, because a delay of a few milliseconds must elapse between sound reaching the ear and activation of the reflex. The small muscles gradually relax with sustained exposure but contraction may revive with a change of frequency. The protective action of the reflex has been demonstrated by experimentally exposing men to the sound of machine-gun fire with and without previous exposure to a 1000 Hz tone. The temporary threshold shift was significantly smaller in the former case (Fletcher & Riopelle, 1960). The characteristics of the optimum reflex-arousal stimulus are such that, for gun crews, it should precede firing by at least 150 ms (Ward, 1962a). Encouraging experimental results have been obtained regarding the possibility of eliciting this reflex to protect against industrial impulse noise (Chisman & Simon, 1961).

NORMAL HEARING

Normal hearing may be defined as the average hearing of a group of persons essentially representative of the population—"average" because normal hearing is not a specific figure but a range extending 15 dB
on either side of the mean value. Originally, it was designated for the following frequencies: 64, 125, 250, 500, 1000, 2000, 4000, 8000 and 12 000 Hz but the first two and the last of these are now regarded, by some authorities, as unreliable and unnecessary (Glorig, 1961b). With young people, the standard deviation of these variations is about 7 dB at 125 Hz, 6 dB at 2000 Hz and up to 9 dB at 8000 Hz (Dadson & King, 1952). An audiometer is used to determine the extent of an individual's hearing and measures the acuity in dB compared to a standard reference level. The point in the intensity scale at which each tone is just heard is the auditory threshold for that person, i.e. a person with a threshold of 50 dB at a particular frequency requires 50 dB more sound at that frequency to hear the test tone than a person with average normal hearing. Auditory thresholds are different for different stimuli, and the stimulus used must be specified. Variations are found between different groups of any population, one important reason being the occupations of those tested (Yaffe, Jones & Weiss, 1958).
CHAPTER 3

EFFECTS OF NOISE ON HEARING, COMMUNICATION AND BEHAVIOUR

In general, deafness may be of the following types:

(a) conductive hearing loss, in which there is interference with conduction of sound to the inner ear; there are many causes, such as wax in the canal;

(b) inner-ear deafness, of which excessive noise is one of the main causes, sometimes called nerve, perceptive or neurosensory deafness; the disability may be temporary or permanent;

(c) mixed losses, a combination of (a) and (b);

(d) functional losses, due to psychological factors or to malingering.

It is not always easy to differentiate between pathological and psychological hearing losses.

The list of causes of impaired hearing is long. It includes hereditary factors, trauma, blast, excessive nose-blowing, diseases such as otosclerosis, the action of poisons and chemical agents, brain tumours, infections of the ear and upper respiratory tract, and the effects of ageing. Thus, deafness is very far from being always occupational in origin (Glorig, 1958). In forming a diagnosis, it may be necessary for the doctor to ascertain the precise complaint, inquire into medical, family and detailed occupational history, and sometimes carry out full physical examination and biochemical tests in addition to audiometry. Repeated examination may be needed before the etiology is defined, and the diagnosis of occupational deafness is not always simple.

OCCUPATIONAL DEAFNESS DUE TO FACTORS OTHER THAN NOISE

Factors other than noise are statistically of relatively minor importance in producing occupational deafness. Blows on the head, or explosive blasts near the ear, may rupture the drum, damage the organ of Corti, or dislocate the ossicular chain. The drum may be damaged by the noise.
of fireworks or of the battlefield. Deafness in artillery men has been reviewed by Murray & Reid (1946). Other things being equal, the degree of deafness is approximately proportional to the peak blast pressure of the gun. The shock-wave subjects the ear to an oscillatory rather than a single transient pressure load, and the acoustic damage is mainly for the frequencies above 2000 Hz (Muirhead, 1960).

Explosive noise may concuss the inner ear, producing cochlear damage and permanent nerve deafness, sometimes immediate; the loss may be as high as 70 dB at some frequencies (Merewether, 1954). The term "acoustic trauma" is often used to indicate the immediate injury resulting from one or a few exposures to the intense sounds of blasts and explosions.

Aviators, tunnel workers and divers may be affected by sudden changes in the barometric pressure. In divers, cochlear and vestibular damage is commoner in those who have experienced decompression symptoms (Rozsahegyi & Gömöri, 1961).

Burns of the middle or inner ear may also cause deafness, and occasionally occupational deafness is toxic in origin (Calvet & Coll, 1964).

THE AUDITORY EFFECTS OF NOISE

Short exposure to high-intensity noise

Rupture of the human eardrum has been observed to occur under conditions of short exposure to high-intensity noise. There is intense pain sometimes followed, after healing, by prolonged loss for high tones above 9000 Hz (Davis, Parrack & Eldredge, 1949). If infection does not occur, a torn drum usually heals readily, unless the tear is very extensive. Very rarely, excessive noise may cause meningitis; sounds in the region of 160 dB may drive the stapes through the oval window, allowing the inner-ear fluid to become infected.

Prolonged exposure

It is beyond dispute that hearing loss may result from prolonged exposure, although it rarely amounts to total deafness. Not everyone subjected to noise suffers impairment. Its characteristics—loudness, pitch or periodicity—may not be such as to cause damage, or the exposure may not be long enough. Occupational deafness is usually bilateral, but one ear may be more affected when the sound intensity is unequal on the two sides, either because of position relative to the source or because of wax in one ear. In telephonists the loss is often only in the ear to which the receiver is habitually held (Katsuki, 1957).
It is difficult to gain a correct assessment of the extent and nature of the problem from compensation figures, partly because of inexactitudes in classification. There is reason to believe that the difficulties of obtaining accurate national statistics are frequently such that the problem is grossly understated; comparisons between countries are therefore frequently invalid.

Clinical features

The victim may be completely unaware of the early stages of impairment, which may be detected only at a chance medical examination; or it may be first noticed during an illness such as a cold. As much as 40% bilateral impairment may be present without the individual's knowledge. Sometimes there is awareness of loss in one ear, though audiometry shows that both are affected. The clarity of heard speech is affected first, but the resulting errors of interpretation may be ascribed to other causes. There may be difficulty in hearing high-pitched female voices, or in following group conversations. Words containing many consonants, the frequencies of which run as high as 10,000 Hz, may be hard to catch.

A phenomenon known as loudness recruitment may be present in cases of hearing loss involving the cochlea, but not in conductive hearing loss or deafness of central-nervous origin beyond the cochlea (Hirsh, 1962). The subjective sensation of loudness is out of proportion to the increase in the physical intensity of the signal. A patient whose ear recruits usually presents other symptoms.

Some persons are unable to sleep because of ringing in the ears (tinnitus) and related subjective phenomena may occur; these often become less noticeable. As the loss increases the victim hears his own voice less clearly and often speaks with a characteristic loud, unmodulated voice. Pain and vertigo are uncommon and the clinical appearance of the drum is usually normal.

Temporary threshold shift

Strictly, temporary threshold shift (TTS) refers to any loss from which the ear recovers, however long this takes. It can result from either monaural or binaural exposure to noise (Ward, 1965). An understanding of this condition, sometimes known as auditory fatigue, is essential when considering damage-risk criteria and workmen's compensation. Temporary deafness is a common experience after a noisy aeroplane flight. In recent years there has been much study of TTS in
man and animals—its pathology, recovery period and relation to permanent hearing loss—but the picture is far from complete.

The International Organisation for Standardisation (1963a) defines TTS as "an elevation of the hearing threshold level following exposure to noise which shows a progressive return towards the pre-exposure threshold level and ultimate recovery in less than 10 days". Temporary hearing loss usually means a loss resulting from a day's exposure to noise from which the ear has recovered by the following morning (Glorig, 1958). Most recovery occurs within an hour or two of the end of the exposure; therefore, audiograms made on a person exposed to loud noise will probably differ at different times of day.

In animals, brief exposures of approximately 130 dB can be shown to cause reversible swelling of the hair cells in the organ of Corti, and similar changes may accompany human threshold shift, though opinion is not unanimous. The changes may be metabolic rather than structural. Studies of the electrical potentials arising from the organ of Corti indicate that TTS need not invariably reflect the state of this structure (Lawrence, 1960b). TTS in man is usually greatest for a frequency approximately half an octave above the exposure tone, but no physical, anatomical or physiological correlates have been established to account for this upward shift (Davis, 1957b).

The extent of TTS depends on the type of noise responsible. The majority of TTS occurs during the first hour of exposure to noise (Shilling, 1942). For any person the extent of TTS is a more or less consistently repeatable phenomenon. Significant shift is not produced by a continuous steady noise with a sound pressure level of less than 78 dB (Glorig, Ward & Nixon, 1961). Many consider that such low intensities have no influence on the production of, or recovery from, TTS caused by higher levels of exposure (Ward, 1960). Other authorities, however, have shown that pre-exposure to low levels—such as 15 minutes "white" noise at 78 dB—which are insufficient in themselves to produce any temporary shift can modify the development of TTS in reaction to more intense sounds (Trittipoe, 1959). Bell & Fairbanks (1963) have investigated the extent of TTS produced by low-level tones. Within limits, the amount of shift produced by a noise of given intensity is greater for high-frequency than for low-frequency octaves (Kylin, 1959).

It is possible (Fig. 4) to calculate approximately the TTS from varying time exposures to certain broadband noises (Glorig, 1961b; Selters, 1963; Ward, Glorig & Sklar, 1958).

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1 The document referred to is in draft form only and does not constitute an officially recognized standard of the ISO. This fact should be borne in mind in all references to the document made in this paper.
Intermittent noise is important in this context because it is often encountered under industrial conditions. A noise of 4000 Hz that is not heard in alternate minutes causes only half the TTS that the same noise would have produced if continuous (Ward, Glorig & Sklar, 1958). Studies by Rol (1956) suggest that proportionality between TTS and the "on" fraction is valid only down to pulses of half a second or so;

**FIG. 4. GROWTH OF TEMPORARY THRESHOLD SHIFT**

Adapted, by permission, from Glorig (1960b).

pulses shorter than this produce more TTS. It appears that the degree of shift caused by exposure to impulse noise, up to 9 seconds' duration, is relatively independent of the inter-pulse interval, i.e., from this point of view the total number of impulses may be more important than the actual exposure time, although it is not known whether this is also true for permanent hearing loss (Ward, 1962b; Selters, 1963). Differences in hearing losses from intermittent and continuous noise have been studied
in men exposed to the noise of gunfire on army ranges or to the noise of tanks. For the first 80 months the losses due to both types of noise were similar; thereafter they were higher in men exposed to steady-state noise. Men working around jet aircraft do not develop hearing loss as rapidly as might be expected, and the intermittence of exposure appears to be the partial protective factor (Ward, 1957). There may be lessons here regarding the value of enforced rest periods and job rotation in limiting auditory damage in factories.

Ward, Glorig & Selters (1960) and Selters (1963) have discussed TTS resulting from changing noise levels.

Collins & Capps (1965) have shown, in a small number of subjects, that the amount of auditory fatigue can vary with the type of mental activity performed. It is likely that this aspect will be investigated in greater depth in the future.

RECOVERY FROM TEMPORARY THRESHOLD SHIFT

The speed of recovery from temporary threshold shift depends on the extent of the initial loss; in general, the greater this is, the faster the recovery (Trittipoe, 1958). So long as the TTS two minutes after cessation of the fatiguing stimulus is less than 50 dB, the rate of recovery on a logarithmic time-scale is proportional to the initial shift, and recovery will be complete about 16 hours after a 2-hour exposure. When the TTS at the end of 2 minutes exceeds about 50 dB, recovery is much slower, and some people may develop a permanent elevation in their hearing threshold (Ward, Glorig & Sklar, 1958). Complete recovery from a 60 dB loss may take several days and tends to be slowest for frequencies in the region of 4000 Hz, regardless of the original fatiguing frequency (Davis et al., 1946). Referring to weavers, Atherley (1964) doubts whether a week-end is an adequate interval for recovery from TTS.

TTS and intensity difference thresholds have been considered as indices of fatigue resulting from repeated exposure to high-intensity sound. It may be that the change in the recovery function results from a factor common to both ears (Riach, Elliott & Frazier, 1964).

Permanent hearing loss

Loss in acuity occurs first in the 3000-6000 Hz band, usually at 4000 Hz. As hearing becomes progressively worse, loss at these frequencies increases and lower frequencies are involved. An early loss index has been proposed. This early-detection method, which can be used for the
prevention of hearing losses, is based on a mathematical quantitation of hearing acuity data at 4000 Hz (Herman, 1964). Fig. 5 shows the audiometric findings for varying degrees of noise-induced hearing loss; as this extends into the speech range both reception and discrimination fall off. The shape of the audiogram is not uniquely characteristic, but the early high-tone dip around 4000 Hz is characteristic of occupational deafness; from the shape of the equal-loudness contours, it appears that, for the same region, the ear requires less energy to experience a certain sensation of loudness than at any other frequency (Littler, 1958). Variations in the pattern of deterioration may occur (Burns, 1965). In general, impairment of hearing tends to be maximal at the end of 10 years' exposure, and then to remain constant for 30 years (Glorig & Davis, 1961). However, it is not necessarily safe to conclude that anyone who has worked
in a noisy environment for 10 years or more need expect no further loss (Lawrence, 1963). Gallo & Glorig (1964) recently reported that from a study of almost 2200 audiograms of people working in high-level industrial noise, most hearing-level changes at 3000, 4000 and 6000 Hz occurred in the initial 15 years, whereas, at 500, 1000 and 2000 Hz changes were approximately linear with exposure time. A Swedish study suggests that, in the case of apprentices, the loss at 4000 Hz develops at the rate of 6 dB per year (Oppliger, Grandjean & Schulthess, 1960). It has been said that the rate at which noise-induced hearing loss is experienced is proportional to the amount of hearing remaining to be lost (Herman, 1965).

The full relationship between temporary threshold shift and permanent loss is not quite clear. The greater the permanent loss at any frequency, the smaller will be the TTS at this frequency (Glorig, 1961b). The results of a ten-year follow-up study to determine the relationship between temporary and permanent hearing loss, from average daily noise levels of 90 dB overall, have recently been reported by Sataloff, Vassallo & Menduke (1965). A noise that does not cause temporary loss rarely, if ever, causes permanent impairment in the same individual. Noise-induced temporary shift and permanent impairment run parallel, though on a differing time-scale (Glorig, Ward & Nixon, 1962). If prolonged exposure to any noise causes permanent loss, it is unlikely that this will exceed the TTS produced by the same noise over a short term; in other words, the shift in dB resulting from an 8-hour exposure closely parallels the permanent loss at the end of 10 years’ exposure (Glorig, 1958; Glorig, Ward & Nixon, 1962). For the average individual habitually exposed to loud noise, it may be predicted that the ultimate hearing level at 4000 Hz will be equal to the temporary level found two minutes after 5 hours’ continuous exposure to the noise in question (International Organisation for Standardisation, 1963a).

NOISE SUSCEPTIBILITY

Not everyone develops the same hearing loss when exposed to the same noise. Some susceptible persons develop impairment comparatively quickly. It is true that, with prolongation of the exposure, such differences disappear, and industrial noise rarely, if ever, causes total deafness even with susceptible ears. Such persons are often aware that noise disturbs them more than others; many suffer from undue head noise after a day's work and some from nausea and vertigo. Individual susceptibility can exist either for pure tones or for more complex sounds,
such as engine-room noises (Waal, 1961). Many authors consider that the condition follows a normal statistical distribution, with the change from noise-susceptible to non-susceptible individuals a gradual one, and that the number of the highly susceptible is small. Some ratings, however, are as high as 20% (Glorig, 1957; Leeuwen, 1958).

The cause of susceptibility is not apparent. It may be an innate fragility of the organ of Corti or some abnormality of the fluid of the inner ear (Lawrence, 1960a). Nor is it known whether the condition is permanent and stable throughout life, or the temporary outcome of a disordered metabolic state (Carhart, 1957). Many surveys have shown that the hearing acuity of young adult women, especially for high frequencies, is greater than that of males, and the difference increases with age. However, differential exposure rather than innate differences of susceptibility may be the reason for this (Ward, Glorig & Sklar, 1959b). The issue is not clear-cut.

Attempts have been made to detect the susceptible person, assuming that the likelihood of permanent damage is proportional to the amount of TTS from exposure to varying types of sound at different frequencies and intensities. There are tests; but none is generally accepted for field use, although predictive tests have been used in pre-employment examinations in a few centres (Lawrence & Blanchard, 1954; Christiansen, 1956; Kilm, 1947). It is important to consider whether damage-risk criteria should be set low enough to protect this sensitive minority. The group is also important with regard to compensation.

INTERFERENCE WITH SPEECH COMMUNICATION

This is possibly the best understood of the non-auditory effects of noise. It is also the most important since, in industry, the ability to communicate by speech is vital. In general, noises that are hazardous will also interfere with speech, though the converse is not necessarily true. Normal speech varies greatly in amplitude, but a level of 65 dB at 1 m is fairly representative, with an over-all range of 20 dB (Carpenter, 1962).

The frequencies 200 to 6000 Hz are particularly important in speech perception, with the vowel frequencies—broadly speaking—below 1500 Hz and the consonant frequencies above. The latter convey most of the information content of speech; they are weaker in intensity than vowels and so more readily masked (Sataloff, 1957).

The interference caused by noise is basically a masking process. Background noise increases our hearing threshold. This masking of communication occurs at relatively low levels. The extent to which the
hearing threshold is increased is called the speech-interference level and is expressed in decibels. The average of the sound-pressure levels, in dB, in the octave bands 600-1200, 1200-2400 and 2400-4800 indicates the degree of interference with the ability of two people to speak to each other. Discontinuous or impulsive noises often produce less interference than expected because speech that is partly masked may be complemented by interpolation or gesture to make good the gaps in what is actually heard. This factor may contribute as much as a third to total intelligibility (Carpenter, 1962). However, where noise habitually gives rise to difficulties in communication it may be in the interests of safety for certain personnel to learn to lip-read or for a visual warning system to be introduced.

The effects of noise on communication were studied during the Second World War; in the early days it was found that less than 30% of test words could be heard over the intercommunication systems of certain aircraft. Maximum speech-interference levels have been laid down for various types of office and auditorium, and for predicting the usability of telephone equipment under noisy conditions.

For purposes of speech communication, noise is rated according to the highest value of the sound-pressure levels in the three octave bands whose mid-frequencies are 500, 1000 and 2000 Hz. The value obtained in this way is called the noise-rating number. Table 3 gives the maximum distances at which everyday speech of (a) conversational level and (b) raised voice level is considered intelligible for different noise-rating numbers.

**TABLE 3. NOISE-RATING NUMBERS FOR INTELLIGIBILITY OF SPEECH COMMUNICATION**

<table>
<thead>
<tr>
<th>Noise-rating number (dB)</th>
<th>Maximum distance (m) at which everyday speech is considered to be intelligible</th>
<th>Maximum distance (m) at which speech at raised voice level is considered to be intelligible</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>45</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>50</td>
<td>2.2</td>
<td>4.5</td>
</tr>
<tr>
<td>55</td>
<td>1.3</td>
<td>2.5</td>
</tr>
<tr>
<td>60</td>
<td>0.7</td>
<td>1.4</td>
</tr>
<tr>
<td>65</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>70</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>75</td>
<td>0.13</td>
<td>0.25</td>
</tr>
<tr>
<td>80</td>
<td>0.07</td>
<td>0.15</td>
</tr>
<tr>
<td>85</td>
<td>--</td>
<td>0.08</td>
</tr>
</tbody>
</table>

This table is reproduced from the Draft Secretariat proposal for noise rating numbers with respect to conservation of hearing, speech communication and annoyance (ISO/TC 43 (Secretariat 194) 314). It is emphasized that this document is in draft form only and does not constitute an officially recognized standard of the International Organisation for Standardisation.
numbers. For voice levels about 6 dB higher, a greater distance (about double) can separate speaker and listener. The expected quality of telephone communication is indicated in Table 4 (International Organisation for Standardisation, 1963a).

**TABLE 4. QUALITY OF TELEPHONE COMMUNICATION**

<table>
<thead>
<tr>
<th>Noise-rating number (dB)</th>
<th>Quality of telephone communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 or less</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>60</td>
<td>Slightly difficult</td>
</tr>
<tr>
<td>70</td>
<td>Difficult</td>
</tr>
<tr>
<td>75 or more</td>
<td>Unsatisfactory</td>
</tr>
</tbody>
</table>

This table is reproduced from the Draft Secretariat proposal for noise rating numbers with respect to conservation of hearing, speech communication and annoyance (ISO/TC 93 (Secretariat 194) 314). It is emphasized that this document is in draft form only and does not constitute an officially recognized standard of the International Organisation for Standardisation.

In practice, it may suffice for measurement purposes if conversation in a normal voice is carried on while the distance between speaker and listener is increased. If speech is intelligible at the specified distance, no further measurement is required. Approximate metering methods also exist, utilizing weighting curve A of the sound-level meter. Because testing for speech intelligibility is a time-consuming procedure, French & Steinberg (1949) developed the concept of the articulation index—a measure of the percentage of the total information actually conveyed. This uses physical and acoustic measurements made on a communication system to indicate the intelligibility scores to be expected under actual test conditions and is useful in predicting the effects of particular noises on communication (Kryter, 1962; Webster & Klumpp, 1963).

**THE EFFECTS OF NOISE ON BEHAVIOUR**

Until comparatively recently this aspect received more attention than actual hearing loss, and there is an extensive literature on the problem (Kryter, 1950). It is often asserted that noise reduces output and efficiency and affects morale. Because some of these factors are intangible, and because of human adaptability, difficulties are experienced in assessing them quantitatively. Some of the early investigations were not carried out under controlled conditions, and the conclusions are not necessarily valid. In any given situation it is not always simple to dis-
To discriminate between the relative importance of noise and other considerations such as personal relations, emotional factors, and the physical environment. It is probable, however, that the behavioural effects of noise are not a major health problem, although individual well-being may be prejudiced under certain circumstances (Glorig, 1958). It is possible to become "acclimatized" to some noises, although only to the extent that one may become less aware of their subjective effects. However, the reverse may also occur and the noise become more noticeable.

**Annoyance**

Noise has been defined as any sound that is regarded or treated as a nuisance. The degree of annoyance is not necessarily directly related to the intensity of the sound; it may be influenced by subjective factors, such as familiarity and personal attitudes, and by physical factors such as the microclimate. Annoyance is largely an individual response, and varies with persons and situations. The noise of racing cars may be pleasant to their drivers but maddening to those living near the track. Extremely weak sounds can also be distracting, and so annoy. Attitude of mind and environment are of major importance.

In general, from laboratory studies, the louder the noise and the higher the pitch of its components, the greater is the nuisance likely to be; other factors are the characteristics of the sound and modulation of loudness and pitch. A slow rate of repetition for a pattern of tones is considered to be slightly more annoying than a rapid rate (Sataloff, 1957; Hinchcliffe, 1958). It is of interest that groups of people with different backgrounds of work experience have differing annoyance thresholds (Kryter, 1957). Oliver (1961) describes the findings of a poll in some US cities served by commercial airlines. The factors influencing community responses included lack of sleep, interference with television reception, fear of crashes, the educational levels of the affected persons, and the effectiveness of the public relations departments of the airline companies.

**Efficiency, performance and distraction**

Our knowledge of the effect of noise on efficiency is derived partly from industrial experience and partly from laboratory studies. It is difficult to demonstrate any prolonged effect on performance or working efficiency but, inasmuch as sound can cause annoyance, accidents or difficulty in communication, and may be a factor in absenteeism, some effect may be presumed. Generally speaking, human adaptability
nullifies any permanent effect on output and performance. There may be an adverse initial effect both on mental and muscular performance—often of no great magnitude—but this rapidly wears off. In difficult work, the subjects tend to concentrate on the task and ignore the noise; noise does not necessarily affect the performance of simple or routine tasks because they tend to become automatic.

Kryter (1950) states that there is no convincing evidence from industrial surveys that noise exerts any deleterious effect on non-auditory tasks, and that some laboratory experiments purporting to demonstrate such effects must be accepted with reservation.

Two early and widely quoted field investigations were made on Lancashire weavers (Weston & Adams, 1932, 1935). They found a 12% average increase of personal efficiency when earplugs were worn, the gain in material production being around 1%. A similar investigation in Indian jute mills led to the conclusion that individual protection can benefit production in specific cases (Ganguli & Rao, 1950). It has been shown that film breakages in photographic works are notably fewer when the noise level is reduced (Broadbent & Little, 1960).

Because of psychological considerations, often resulting from taking part in investigations, employee work performance may improve under noisy conditions. Meaningful noise, especially if elusive, may be more distracting than meaningless noise (Carpenter, 1958). Tests on naval ratings exposed to short bursts of loud sound during a visual matching task showed that most suffered an immediate performance deterioration, even when they were aware of the possibility of interruption, but recovered completely in the next half-minute (Woodhead, 1958). A continuous noise may mask the distracting influence of intermittent sounds, or excite an intense concentration reaction, at least temporarily. When US Army recruits were exposed to simulated battle sounds, the accuracy of their performance in range finding and tracking was not adversely affected. More recently, however, it has been reported that astronauts subjected to a reproduction of the 145 dB sound of a jet engine at full thrust experienced difficulty in carrying out simple arithmetical operations, and tended to put down any answer in order to end the experiment.

Only comparatively recently has it been realized that short performance tests are of dubious value, and that the task must continue until the novelty effect has worn off (Carpenter, 1962). Techniques are now being developed that take into account the psychological factors of distraction and habituation (Teichner, Aries & Reilly, 1963). Even though performance impairment may not be extensive in numerical terms, there is a consistent, increasing and statistically reliable "fatigue" effect, which arises from the fact that noise is a sensory input, devoid of information, that nevertheless demands attention to check this very absence
of information. Even brief diversion may lead to error in a serial reaction task, or—in a vigilance test—to a missed signal or delayed response.

**Fatigue**

It is not easy to prove that employees become more tired working in a noisy environment than in a quiet one. Fatigue may result from having to talk loudly or from the extra effort caused by misunderstandings—a matter difficult to assess objectively (Pugh, 1954).

It has been claimed that many noisy occupations cause "nervous irritability and strain", but the reaction varies greatly in different individuals (Vernon, 1940).

In general, morale is related more to the degree of ego involvement in one's work than to noise levels or other disturbing conditions (Felton & Spencer, 1961).

**OTHER EFFECTS OF NOISE**

In certain circumstances, noise may cause a decreased electrical resistance in the skin, reduction of gastric activity, or electromyographic evidence of increased muscle tension (Davis, 1932; Oginski, Radecki & Bugajski, 1964; Göpfert, 1960). The laboratory exposure of animals to short loud sounds can cause diverse effects, such as a temporary rise in breathing and heart rates, a rise of blood pressure, or a lessened flow of gastric juice; but these responses quickly subside when the noise ceases. It does not follow that similar reactions occur in workers subjected to such noise (Finkle & Poppen, 1948).

During the Second World War detailed studies were made at Harvard on the effects of simulated aircraft noise (115 dB) on metabolism, body steadiness, distance judgement, and on many other activities: there was no evidence of any disturbance.

Work on noise-induced stress reactions in animals suggests that the endocrine system appears to act as a multiloop feedback system to compensate for the effects of sound on the central nervous system (Anthony, Ackerman & Lloyd, 1959). With mice subjected to single or intermittent noise of 110 dB, transient adrenocortical activation is demonstrable by cytological changes in the gland and by a fall in circulating eosinophils (Anthony & Ackerman, 1955). It has been suggested that noise may cause dysfunction of the diencephalon-pituitary system (Sakamoto, 1964).

Excessive noise may cause dizziness; in guinea-pigs exposed to very loud noise the saccule of the vestibular labyrinth may be damaged, and
this may be the basis of auditory vertigo (McCabe & Lawrence, 1958). Bernabi (1953) records that drillers of borax wells suffer vertigo, when the noise exceeds 130 dB. Some persons exposed to the sound of a jet engine at full thrust experience nystagmus and uncontrollable oscillation of the eyeballs.

It has been shown electroencephalographically that limited discrimination between auditory stimuli is possible during sleep; changes occur related to the depth of sleep and the ambient noise levels (Loomis, Harvey & Hobart, 1937; Liberson, 1945).

The neurological examination of Italian weavers has shown their reflexes to be hyperactive; in some, electroencephalography revealed a diffuse desynchronization resembling that seen in psychoneurosis or personality disturbance (Granati, Angeleri & Lenzi, 1959).

That there may also be autonomic effects is suggested by the fact that some workers exposed to severe noise suffer from impaired circulation in the extremities, as evidenced by digital plethysmography and rheographic studies (Carpenter, 1962; Caporale & De Palma, 1963. German studies suggest that during hard work the blood vessels dilate so extensively and persistently that the effect of noise cannot be detected (Jansen, 1964). Nesswetha (1964) has carried out clinical experimental studies on the adaptations of the vegetative nervous system and considers that noise-acclimated subjects possess compensatory mechanisms that enable them to work in a noisy environment, whereas in the case of non-habituated subjects these systems must be gradually formed. In a study carried out in the USSR, many workers exposed to continuous noise, 85-120 dB, complained of precordial distress, and electrocardiographic changes were found in some of those stressed at the highest level (Satalov, Sajtanov & Glotova, 1962). More recent experimental work in the USSR has shown that long-term exposure to intensive high-frequency noise produces numerous temporary shifts in the activities of the central nervous and cardiovascular systems such as weakening of cardiac-muscle contractions (Strakhov, 1964). Increased labyrinthine reflexes have been reported in telephonists (Alivisatos, Eliakis & Pontikakis, 1960).

Excessive noise can influence occupational accident rates by affecting the movements on which accuracy depends and the perception of auditory signals (Merewether, 1954). Balance and clarity of vision may also be affected, the visual fields being diminished for both colour and form (Benko, 1962). Alterations in other visual functions such as accommodation and ocular movement have been noted (Kryter, 1950).

It may, however, be pertinent to recall a well known authority's comment that "... the non-auditory effects of noise encountered under industrial conditions do not produce a health problem. Many employees work under noisy conditions for many years and show no general health
changes that can be said to be related causally to noise exposure” (Glorig, 1961a). Nevertheless, Lee (1964) has emphasized industry’s concern with the effect of noise on loss of attention, work efficiency and their possible relationship to productivity.
CHAPTER 4
HEARING IMPAIRMENT
IN THE GENERAL POPULATION:
OCCUPATIONAL DEAFNESS

Not all hearing loss is of occupational origin. Acuity of hearing depends on many other factors: age, previous medical history, military service, exposure to the noise of everyday life. Increasing industrialization is making it more difficult to find populations that have not been greatly subject to man-made noise; a study of such groups would afford opportunities to separate the effects of age and of normal environmental noise on hearing acuity. The keenest sense of hearing in the world is said to reside in certain African tribes who are influenced only by natural sounds.

PREVALENCE OF DEAFNESS IN THE GENERAL POPULATION

Generalizations about the over-all incidence of deafness are numerous, accurate assessments few. A conservative estimate indicates that between 8 and 10 million persons in the USA need hearing aids (Braun, 1958). The actual hearing-aid rate in the urban United States is claimed to be 6.8 persons per 1000 population; under 45 years of age the rate is 1.3 per 1000, while at 75 or over, it rises to 72.6 (United States Department of Health, Education and Welfare, 1961). Glorig (1959) states that approximately 1 million males between the ages of 10 and 59 years in the population of the USA have a hearing level of 30 dB or more at 1000 Hz—an extrapolation from a sample survey of over 30,000 persons (Table 5).

A few surveys have been carried out in the USA to obtain more detailed results. A national survey of a sample of 250,000 persons performed by the Public Health Service in 1935-36 yielded the findings set out in Table 6 (Beasley, 1940). Among employed males, hearing impairment was most prevalent in the skilled and semi-skilled industrial groups, and lowest in professional and business groups. There was an excess prevalence among the unemployed of each occupational class,
possibly because this reflects selection by employers at the time of large-scale dismissals. It was clear that the influence of deafness on employment depended directly on the importance of oral communication.

At the US World's Fair of 1939, listeners tested their hearing for musical tones through a single telephone receiver (Table 7). Despite some criticism of the techniques used, it can be seen that both sexes show increasing impairment with advancing age, and there was evidence that

<table>
<thead>
<tr>
<th>Age-group</th>
<th>Size of sample</th>
<th>Males with hearing level of 15 dB or more at 1000 Hz</th>
<th>Males with hearing level of 30 dB or more at 1000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Proportion found in survey %</td>
<td>Number in US population (extrapolated)</td>
</tr>
<tr>
<td>10-19</td>
<td>6 204</td>
<td>3*</td>
<td>400 000*</td>
</tr>
<tr>
<td>20-29</td>
<td>8 542</td>
<td>3</td>
<td>300 000</td>
</tr>
<tr>
<td>30-39</td>
<td>7 000</td>
<td>6</td>
<td>700 000</td>
</tr>
<tr>
<td>40-49</td>
<td>6 836</td>
<td>12</td>
<td>1 300 000</td>
</tr>
<tr>
<td>50-59</td>
<td>2 867</td>
<td>21</td>
<td>1 700 000</td>
</tr>
<tr>
<td>10-59</td>
<td>31 449</td>
<td>About 4 400 000</td>
<td>About 1 030 000</td>
</tr>
</tbody>
</table>

* Percentages and extrapolated figures are rounded.
* Out of 54 000 000 (US 1955 census).

Reproduced, by permission, from Glorig (1959).

better hearing went with higher economic status (Steinberg, Montgomery & Gardiner, 1940). In 1948, several thousand persons in San Diego were tested binaurally for ability to hear pure tones. Those who had worked in noisy conditions made up almost one half of the persons with demonstrable impairment, but only a third of those without such handicap. Women proved to be more sensitive than men to the higher frequencies (Webster, Himes & Lichtenstein, 1950).

A Wisconsin survey in 1954 demonstrated differences between the auditory thresholds of office, farm and factory workers. The last group, except at ages 20-29, showed significantly more loss than the office employees, and this was also true of farm workers in the older age-groups (Glorig et al., 1957; Glorig & Nixon, 1960).

The results of many thousands of audiometric examinations of factory workers from 16 to 65 years of age indicated that 56% were suffering from varying degrees of hearing loss. This contrasted sharply with the
findings of routine pre-employment testing, where only 38% had any
degree of impairment (Paviere, 1957).

It is likely that the early detection of aural disease by school medical
services, apart from recent advances in surgical techniques, must even-
tually reduce the prevalence of hearing impairment in the general
population.

**TABLE 6. PREVALENCE OF SEVERELY IMPAIRED HEARING OF
VARIOUS STAGES IN A HEALTH SURVEY POPULATION (1935-1936)**

<table>
<thead>
<tr>
<th>Social history of hearing difficulty (Household census)</th>
<th>Reciprocal proportion of cases in the following age-groups:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All ages</td>
</tr>
<tr>
<td>All stages of deafness</td>
<td></td>
</tr>
<tr>
<td>Partial deafness</td>
<td>78</td>
</tr>
<tr>
<td>Stage 1</td>
<td>152</td>
</tr>
<tr>
<td>Partial deafness</td>
<td>292</td>
</tr>
<tr>
<td>Stage 2</td>
<td>503</td>
</tr>
<tr>
<td>Partial deafness</td>
<td></td>
</tr>
<tr>
<td>Stage 3</td>
<td>2326</td>
</tr>
<tr>
<td>Totally deaf for speech</td>
<td></td>
</tr>
</tbody>
</table>

**Male**

| All stages of deafness                                  | 85       | 2326   | 442  | 341  | 200  | 108  | 65   | 38   | 18   | 7         |
| Partial deafness                                        | 181      | 8333   | 962  | 658  | 385  | 211  | 136  | 81   | 40   | 18        |
| Stage 2                                                 | 294      | —      | 2273 | 1818 | 794  | 391  | 209  | 127  | 61   | 24        |
| Partial deafness                                        | 508      | —      | 3704 | 3125 | 1754 | 800  | 418  | 216  | 101  | 34        |
| Stage 3                                                 | 2000     | 20000  | 7143 | 6667 | 5882 | 3030 | 1923 | 926  | 402 | 167       |
| Totally deaf for speech                                |          |         |      |      |      |      |      |      |      |            |

**Female**

Reproduced, by permission, from Beasley (1940).

**PRESBYCUSIS**

Hearing acuity generally decreases with age, a process known as
presbycusis, although quite normal hearing may persist to advanced
years. This change is not necessarily physiological since everyone is
exposed to the noise of everyday life, the results of which are sometimes
referred to as sociocousis or micronoise trauma.
TABLE 7. MEAN HEARING LOSS, WORLD'S FAIR
HEARING TESTS (1939)

<table>
<thead>
<tr>
<th>Age-group</th>
<th>Sex</th>
<th>Mean hearing loss (dB)</th>
<th>Number of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Frequency</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>440 Hz</td>
<td>3520 Hz</td>
</tr>
<tr>
<td>10-19</td>
<td>M</td>
<td>1.0</td>
<td>-1.2</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>0.5</td>
<td>-4.4</td>
</tr>
<tr>
<td>20-29</td>
<td>M</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>0</td>
<td>-2.0</td>
</tr>
<tr>
<td>30-39</td>
<td>M</td>
<td>1.4</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>2.6</td>
<td>2.4</td>
</tr>
<tr>
<td>40-49</td>
<td>M</td>
<td>3.7</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>6.0</td>
<td>7.8</td>
</tr>
<tr>
<td>50-59</td>
<td>M</td>
<td>6.8</td>
<td>25.6</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>10.3</td>
<td>13.8</td>
</tr>
</tbody>
</table>

Adapted, by permission, from Steinberg, Montgomery & Gardiner (1940).

The precise pathological changes in this condition are obscure, and quite different lesions may be responsible for the losses at present grouped together clinically as presbycusis (Pestalozza & Shore, 1955). It is known that ageing is accompanied by degeneration in the basal turn of the cochlea, and that this process spreads up the cochlea and affects the contained structures, including the afferent and efferent nerves (Schuknecht, 1955). It is unlikely that the effect can be attributed to changes in the ossicular chain of the middle ear, such as occur in otosclerosis (Nixon, Glorig & High, 1962). One view, however, is that the gradual auditory decrement of ageing is not due to sensory neural degeneration at all, but to changes primarily involving the tissues of the middle-ear mechanism.

Presbycusis is important because, when carrying out surveys, it is often necessary to decide whether hearing loss is due to age or to occupation, or to both. This is frequently difficult. It is difficult, too, to find a suitable population or ethnic group in whom this aspect of deafness may be studied in isolation. In general, at equal ages, men have poorer hearing and more variable hearing than women, except below 1000 Hz in older persons. The major break in the audibility curves for men occurs around the age of 32, from which time presbycusis advances in discrete steps of approximately 15 years. For women, the critical point is at about 37 years, after which the process proceeds at a more uniform rate (Corso, 1963).
Glorig, Summerfield & Nixon (1959), studying men and women not occupationally exposed to noise, and comparing them with other groups, found that even without any high-level exposure or ear disease, loss of hearing occurs first and predominantly in the region of 4000 Hz, and that even occasional exposure to high-level noise, as from basic military service, suffices to produce measurable impairment (Fig. 6).

**FIG. 6. MEDIAN HEARING LEVELS AT 4000 Hz FOR FOUR DIFFERENT POPULATIONS WITH DIFFERENT NOISE EXPOSURES**

Presbycusis curves for men and women are shown in Fig. 7 and 8 (American Standards Association, 1954), but, because some of the persons tested must have been occupationally exposed to noise, these data should be regarded as approximate. In a rural Scottish population, Hinchcliffe (1959) found that for clinically normal female ears the rate of deterioration increases with frequencies above 500 Hz and that, at 12,000 Hz, ageing from 20 to 70 years was associated with a hearing loss of over 70 dB. The median hearing thresholds for men are significantly different from those of a comparable series of female ears. Corso (1959) confirms that women have more sensitive hearing than men and that there is less variation between individual women. He also notes that there are, in general, only minor differences (less than 5 dB) between the average thresholds of right and left ears. There is no doubt that significant sex differences exist for both auditory sensitivity and threshold variability. Later reports on this subject include those of Glorig & Nixon (1961) and Riley et al. (1961).
FIG. 7. PRESBYCOUSIS CURVES FOR MEN: AVERAGE HEARING LOSS TO BE EXPECTED WITH AGE

The relation between presbycusis and noise-induced hearing loss in the same individual may be clarified in either of two ways. If the average loss expected at a given age be subtracted from the over-all loss at that age, the net impairment can be averaged with the corrected losses of other subjects who have been exposed to the same noise. Alternatively, the gross losses of the whole group may first be averaged and the presbycusis loss for the mean age of the group deducted to yield the mean net hearing loss. The two procedures should give the same results unless the age distribution of the group is too broad or too skewed (American Standards Association, 1954). Losses from noise...
and presbycusis are, in general, believed to be additive (Glorig & Davis, 1961). Cumulative deterioration, causing social handicap must be avoided.

FIG. 8. PRESBYCUSIS CURVES FOR WOMEN:
AVERAGE HEARING LOSS TO BE EXPECTED WITH AGE

This graph is reproduced from the report on The relations of hearing loss to noise exposure, Z24-X-2, copyrighted by ASA, copies of which may be purchased from the American Standards Association, 10 East 40th Street, New York, N.Y. 10016.

PREVALENCE OF OCCUPATIONAL DEAFNESS

Occupational deafness may form only a small proportion of the total industrial morbidity of an employed population; nevertheless, it is often preventible—in some instances, prevention is easy; in others, part of a long-term and possibly expensive project. Numerous industrial surveys (Table 8) have shown the ubiquitous nature of this hazard. It is important, when comparing the results of such surveys, to make sure that the comparisons are statistically valid and that due allowance is made for presbycusis.

Over 560 occupations were classified as noisy by the Detroit Health Department approximately 25 years ago (McCord, Neal & Witheridge, 1938). In many cases, the introduction of mechanization has produced a noise problem where none previously existed. An incomplete list of occupations known to be associated with hearing loss includes aircraft crewing and maintenance, boilermaking, forging, weaving, punch-press operating, tunnelling, foundry work, blasting, the use of circular saws,
<table>
<thead>
<tr>
<th>Reference and country</th>
<th>Nature of work investigated</th>
<th>Findings</th>
</tr>
</thead>
</table>
| Grings, Summerfield & Glorig (1957) USA  | Employees of aircraft company, 9145 audiograms taken of 3212 factory workers and 2604 flight line personnel | Adjusted approximate median hearing loss at 4000 Hz for 1190 male workers with riveting experience only; age correction applied:

<table>
<thead>
<tr>
<th>Years of exposure</th>
<th>Hearing loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12 dB</td>
</tr>
<tr>
<td>3</td>
<td>16 dB</td>
</tr>
<tr>
<td>6</td>
<td>25 dB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Katsuki (1957) Japan</th>
<th>Iron rolling mills, Automobile factory, Alumina factory, Spinning and weaving factory, Steam power plant, Electric power plant, Steel factory</th>
<th>Number of men examined</th>
<th>Percentages of men with the following hearing losses in speech-frequency range: 16-30 dB, 31-43 dB, above 43 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>371</td>
<td>38</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>437</td>
<td>29.5</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>6.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>374</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>117</td>
<td>14.5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>243</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>316</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>D'Onofrio, Ameli &amp; Pesce (1958) Italy</td>
<td>Large metal-working establishment</td>
<td>Maximum noise levels: in boiler-shop, 115 dB; in engine-testing shop, 105 dB; in small-parts shop, 78 dB. 343 workers. In boiler-making shop a progressive hearing loss was recorded at all ages for frequencies down to 4000 Hz; in engine-testing shop greatest loss for all ages was at 4000 Hz; in small-parts shop only slight loss even after 20 years' work.</td>
<td></td>
</tr>
<tr>
<td>Reference and country</td>
<td>Nature of work investigated</td>
<td>Findings</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------</td>
<td>----------</td>
<td></td>
</tr>
</tbody>
</table>
| Keatinge & Laner (1958)  
United Kingdom       | Riveting                   | Maximum noise-level reading in 3 shops ranged from 115 dB to 128 dB.  
|                      |                            |          |
|                      |                            | Period of exposure (years)  
|                      |                            | Number of workers, all under 60 years of age  
|                      |                            | Mean hearing loss (%)  |
|                      |                            | 0  | 20 | 15.7 |
|                      |                            | 1  | 7  | 22.3 |
|                      |                            | 2  | 7  | 27.2 |
|                      |                            | 3  | 8  | 34.8 |
|                      |                            | 4  | 14 | 36.8 |
|                      |                            | 5  | 11 | 38.6 |
|                      |                            | 6-7| 16 | 32.6 |
| Lierle & Reger (1958)  
USA       | Tractor drivers              | Pure-tone threshold sensitivity measurements made on 80 full-time tractor operators. "Tractor noise is sufficiently high to produce high-frequency loss with noise-susceptible ears if exposed over a period of many years." |
| Calearco, Fior & Pestalozza (1959)  
Italy       | Steel industry               | Of 734 steelworkers from 15 different trades all had varying degrees of hearing loss, mainly due to sounds of high frequency. |
| Bonati (1960)  
Italy       | 103 shipyard workers (riveters, caulkers, and fitters and test- ers of diesel engines and turbines) | Every riveter and caulkers affected. |
<table>
<thead>
<tr>
<th>Reference and country</th>
<th>Nature of work investigated</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coles &amp; Knight (1960) United Kingdom</td>
<td>Workers in diesel-engine test-house</td>
<td>Maximum noise level 116 dB. Of six men who worked continuously in the intense noise of the two-stroke test-house (average period 3½ years) all had losses of 45-60 dB in one or both ears at 3.4 and 6 kHz and none could be accounted for by an ageing factor.</td>
</tr>
</tbody>
</table>
| Ermisch, Haydn & Wittgens (1961) Federal Republic of Germany | 2415 railway workers exposed to noise in excess of 90 phons | "Largest hearing loss in boilermakers. Even when exposure time is short (1-5 years) the average hearing loss is still well above that of workers who are not exposed to noise."
| Opplerger, Grandjean & Schulthess (1960) Switzerland | 33 metalsmith apprentices | At 4000 Hz the hearing loss grows at the rate of 6 dB per year. |
| T. Toyama, J. Kubola & K. Tsuchiya (1961) (unpublished document) Japan | Mass screening examination of 87 890 workers exposed to noise | 16.8% found to be suffering from a hearing defect. "... at least 10% was considered to be directly due to their working environment."
| Frolik (1961) Czechoslovakia | 100 aeroplane pilots | "15% of them did not hear the tuning fork C5... occupational damage in pilots reaches such a percentage that it is necessary to improve preventive measures in order to protect their hearing."
<p>| Široký &amp; Navrátil (1961) Czechoslovakia | People working in pump test room—noise level 80-85 dB | In approximately 40% of the subjects examined occupational hearing loss was found. |</p>
<table>
<thead>
<tr>
<th>Reference and country</th>
<th>Nature of work investigated</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waal (1961) Netherlands</td>
<td>Engine-room personnel</td>
<td>“… out of 234 threshold curves of 117 persons from engine room, 197 curves of 107 persons revealed a threshold shift of 15 dB or more in the frequency range of 1000-8000 Hz… in 69% the centre of the threshold shift lies between 3600 Hz and 5600 Hz.”</td>
</tr>
<tr>
<td>Brohm &amp; Zlámal (1962) Czechoslovakia</td>
<td>Noise in cabins of heavy trucks 90-110 dB</td>
<td>Examinations made on 51 truck drivers and in each case a loss of hearing was determined.</td>
</tr>
<tr>
<td>Davies (1962) United Kingdom</td>
<td>55 companies representing an extremely broad cross-section of industry</td>
<td>“About a quarter of the firms, each employing more than 30 persons, feel that they may have a case, or more, of occupational deafness” (replies to a questionnaire).</td>
</tr>
<tr>
<td>Laverge et al. (1962) France</td>
<td>Textile workers</td>
<td>5 cases at different stages of hearing loss for traumatic exposures varying from 15 to 40 years.</td>
</tr>
<tr>
<td>Mancini &amp; Stancari (1962) Italy</td>
<td>50 fettlers</td>
<td>Men worked in 9 foundries with noise levels of 92-110 dB. In men who had been working for more than 5-6 years in noisy conditions almost all frequencies were involved; those who had worked less than 2-3 months in noisy conditions showed a loss varying from 30 to 50 dB at 4000 Hz.</td>
</tr>
<tr>
<td>Monoca (1962) Italy</td>
<td>Biscuit works, macaroni factories, edible-oil refineries, bottling of beverages</td>
<td>In biscuit factory, 80 dB maximum; in other factories, 90-95 dB maximum. Audiograms showed mean hearing loss of 6 dB in biscuit factories; in other factories 12-15 dB.</td>
</tr>
<tr>
<td>Reference and country</td>
<td>Nature of work investigated</td>
<td>Findings</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Piesse, Rose &amp; Murray (1962)</td>
<td>5127 skilled and unskilled workers of all ages</td>
<td>Results of initial hearing tests on 5127 skilled and unskilled workers of all ages, performed during reference audiometry, showed 33% of the total number of ears had hearing losses in excess of 45 dB. The hearing losses of 786 tradesmen were as follows (approximate percentage of ears with losses of 45 dB or more at 4000 Hz): boilermakers 65%, drop forge operators 62%, plumbers 42%, sheet-metal workers 38%, joiners 25%, fitters 22%, electrical mechanics 19%, and painters 18%.</td>
</tr>
<tr>
<td>Amelotti &amp; Bandini (1963)</td>
<td>Shipyard workers</td>
<td>6930 audiometric examinations in 38 different occupations. Hyperacusia is characterized by swifter development, and by definite after-effects, even after a few years' exposure to harmful sound levels.</td>
</tr>
<tr>
<td>Chadwick (1963)</td>
<td>12 men exposed to noise from industrial gas-turbine (jet) engine noise</td>
<td>Noise levels reached as high as 113 dB flat. &quot;...the low-tone loss in just over two years was in the region of 10 dB and from 2000 Hz to 4000 Hz was in the order of 20 dB...the average loss for the speech frequencies was...eight times more than that to be expected in a more conventional industry with a known noise hazard.&quot;</td>
</tr>
<tr>
<td>Reference and country</td>
<td>Nature of work investigated</td>
<td>Findings</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Filin (1963) USSR</td>
<td>Drivers of self-propelled jumbos in underground ore mining</td>
<td>Noise levels of 127 dB at frequencies between 1000 Hz and 8000 Hz. Hearing loss in 91 of 135 miners examined; after 10 years’ work, loss at 4000 Hz was 53 dB; after only 1-2 years’ work, 28 dB loss at 4000 Hz.</td>
</tr>
<tr>
<td>Weston (1963) Australia</td>
<td>Agricultural tractor drivers</td>
<td>53 drivers of tractors of different horse-power; audiograms showed greater impairment in inland drivers where the tractors are of higher power and exposure is for longer periods than on coastal-plain farms. Noise levels ranged from 92 dB to 106 dB, occasionally as high as 114 dB.</td>
</tr>
<tr>
<td>Houlléguette (1964) France</td>
<td>Forging and stamping plant workers</td>
<td>95 of 225 workers had occupational hearing loss.</td>
</tr>
<tr>
<td>Maggio &amp; Zazo (1964) Italy</td>
<td>118 668 workers in variety of factories including small ones</td>
<td>9.2% had occupational noise-caused pathology.</td>
</tr>
<tr>
<td>Harris (1965) USA</td>
<td>Several hundred diesel-engine-room personnel</td>
<td>About 15% of ears had permanent threshold shifts of more than 20 dB at any frequency.</td>
</tr>
</tbody>
</table>
shipbuilding, timber-milling and papermaking. Others, less known to
be potential hazards, are bell-ringing, combine-harvester driving, the
use of earth-moving equipment, well-drilling, shooting practice, and the
use of some types of automated equipment for a variety of clerical
operations.

The paucity of data in some countries makes it difficult to assess the
total extent of occupational deafness. Thus, in Canada, the actual
incidence cannot be gauged from compensation claims because com-
pensation is rarely granted in certain provinces unless the deafness
interferes with earning capacity. Similar difficulties are met with in
some other countries. The figures for New York State (Table 9) also
probably understate the position; the increase for 1961 no doubt reflects
the growing application of recent legislation.

<table>
<thead>
<tr>
<th>Year of closing</th>
<th>All cases</th>
<th>Occupational-disease cases</th>
<th>Occupational-loss-of-hearing cases (mainly due to continuous exposure to loud noises)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1952</td>
<td>126,649</td>
<td>4,167</td>
<td>7</td>
</tr>
<tr>
<td>1957</td>
<td>115,298</td>
<td>3,434</td>
<td>61</td>
</tr>
<tr>
<td>1961</td>
<td>95,558</td>
<td>2,667</td>
<td>186</td>
</tr>
</tbody>
</table>

In Czechoslovakia, where occupational deafness is covered by the
Workmen’s Compensation Act, reported noise-induced hearing loss as a
percentage of all occupational disease averaged 3.99% between 1956 and
1962, with a maximum of 5.61% in 1956, and such hearing impairment
ranked fifth or sixth in the tables of occupational disease (J. Roubal—
personal communication, 1963). In Denmark, 5%-8% of patients at the
State hearing centres (6000-7000 a year) have a hearing loss of industrial
origin (A. Grut—personal communication, 1963). A recent careful
American study (Table 10) lists the impairment in men occupationally
engaged in a wide variety of workshops in Federal penitentiaries (Yaffe

The extent of the problem is also illustrated in surveys of noise levels
in factories. In Sweden, 5500 working areas out of 6500 studied in 1700
factories had noise levels exceeding 80 dB. The Bell Telephone Com-
pany noted that, in 1700 factory locations where telephones were installed,
the average sound level was 77 dB and the level exceeded 85 dB in 25%
of the factories. There are similar findings in Brazil and Japan (Z. Bueno—personal communication, 1963; Miura et al., 1964).

### TABLE 10. HEARING LEVEL SHIFTS AFTER 24 MONTHS' EXPOSURE TO NOISE

<table>
<thead>
<tr>
<th>Factory and departments</th>
<th>Shift in hearing level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printing—all departments</td>
<td>2.5</td>
</tr>
<tr>
<td>Shoe—lastling and cutting</td>
<td>7.5</td>
</tr>
<tr>
<td>Shoe fitting</td>
<td>8.0</td>
</tr>
<tr>
<td>Shoemaking</td>
<td>9.5</td>
</tr>
<tr>
<td>Brush—all departments</td>
<td>12.0</td>
</tr>
<tr>
<td>Cotton mill—spinning</td>
<td>12.5</td>
</tr>
<tr>
<td>Furniture—miscellaneous</td>
<td>12.5</td>
</tr>
<tr>
<td>Woollen mill—card and spin</td>
<td>15.0</td>
</tr>
<tr>
<td>Cotton mill—twist</td>
<td>43.0</td>
</tr>
<tr>
<td>Woollen mill—weave</td>
<td>47.0</td>
</tr>
<tr>
<td>Cotton mill—weave</td>
<td>71.0</td>
</tr>
<tr>
<td>Furniture mill</td>
<td>79.1</td>
</tr>
</tbody>
</table>

Adapted, by permission, from Yaffe & Jones (1961).

### NOISE EXPOSURE

It is sometimes not easy to be certain that exposure to a particular noise has produced, or will produce, hearing loss; but this should not necessarily deter the making of recommendations on the various aspects of a hearing-conservation programme.

There are four important factors to be considered: the over-all noise level, its composition, its duration and distribution during the working day, and its total duration throughout the expected working life. All may be interrelated; in general, whether a noise is potentially harmful depends on all the factors considered together. Other factors are: the progress of temporary threshold shift; the sensitivity of the individual; the presence or absence of aural pathology; age; and the efficiency of any protection used. It is often very difficult to evaluate the relative importance of these factors.

Some of the difficulties of assessment of noise exposure may be partially overcome by the use of instruments such as noise dosimeters (Rosenwinkel & Stewart, 1959). The evaluation of exposure in different plants by this method leads to the conclusion that there is a linear relation between hearing loss in the test population and the calculated cumulative noise dose. This is true for all frequencies of 2000 Hz and
over and is particularly valid at 4000 Hz. It is impossible, however, to use this as a basis for predicting individual impairment since the observed losses vary widely about the mean. Dosimeters have been briefly described because the reader should be aware of such instruments; however, they are not, as yet, widely used in industry.

Research may prove that other factors, such as peak sound levels, are at least as important as those listed above. It has been suggested that permanent hearing loss may be more closely related to factors influencing the recovery pattern than to those responsible for the initial shift, i.e., that the physiological state of the ear before and during recovery is important (Lawrence, 1961).

The relationship between noise and hearing loss has been discussed in the 1954 report of the American Standards Association; the findings, based on carefully selected audiograms, are shown in several trend curves. These represent a first step in predicting trends in net hearing losses resulting from continuous exposure to steady noise. This report draws attention to some of the many problems then unsolved.

Over-all noise level and its composition

Although opinion is not unanimous (von Gierke, 1954), it has been stated that the maximum intensity (up to 10 seconds' duration) to which an unprotected person should be subjected is 135 dB (Eldred, Gannon & von Gierke, 1955). Again opinion is not unanimous, but Glorig & Nixon (1960) state that levels as low as 80 dB may produce some loss; however, this does not mean that all noise in excess of this figure is potentially harmful. There is no direct relationship between hearing loss and the energy content of the noise (Glorig, 1961b).

Other things being equal, and within certain limits, high-frequency sounds produce greater damage than those of low frequencies (Grove, 1949; Sataloff, 1953). This is why the spectrum of a noise needs usually to be determined before the latter's potential deafening effect can be evaluated. The 1954 report of the American Standards Association states that in a small group of people exposed predominantly to low-frequency noise, little or no loss was experienced at 1000, 2000 and 4000 Hz, even after twelve years.

The above-mentioned points are discussed, in greater detail, in a later chapter.

Periodicity and duration

Intermittence of exposure is of prime importance and probably accounts for the differences observed between jet-aircraft mechanics and
employees working in factories making containers. The former suffered less impairment, though working in a much higher noise level, because of the time distribution of their exposure. The spectra of the respective noises were similar. In the same way, riveters are only intermittently exposed to noise and this, comparatively speaking, lessens its effect on their hearing.

In studies made on groups of employees exposed to various intermittent noises, drop-forging impact noise was found to cause the most rapid shifts in thresholds with exposure time; measurable shifts for frequencies as low as 1000 Hz were detectable after two years' exposure (American Standards Association, 1954).

Finally, the longer the exposure to noise, the greater the potential hazard; and the frequent changing of jobs undoubtedly provides some protection against hearing loss. From the economic point of view, however, such changes may be undesirable.
CHAPTER 5

HEARING-CONSERVATION PROGRAMMES

Ideally, the object of a hearing-conservation programme is to ensure that an employee’s hearing is not affected during his working life to an extent greater than that normally occurring with age, and to preserve it at a level sufficient for normal speech perception. It is recognized that it may not always be possible to prevent impairment in the noise-susceptible person or in all of the occupationally exposed population. The American Academy of Ophthalmology and Otolaryngology (1957, 1964) have issued an important guide on the conservation of hearing, the contents of which have been approved and accepted by many organizations of international repute. The US Bureau of Labor Standards has made recommendations concerning comprehensive noise-control programmes (United States, Department of Labor, 1964). Witwer & Cole (1961) have discussed the military aspects of such programmes.

No conservation programme is likely to succeed unless its aims are fully discussed with both employers and employees, and supported by management at every level. Though this may be regarded as basically a medical problem, the doctor needs help from others: from managements in instituting the programme; from managers and unions in inducing workers to participate; from scientists in measuring and analysing sounds; and from engineers in ensuring that, wherever possible, noise is reduced at source. The physician is best qualified to judge whether their combined efforts have been effective, and any programme that does not include a medically trained person is likely to prove inadequate, though the leadership and composition of the team must be dictated by circumstances. It is also part of the physician’s task to teach workers and their employers to regard a hearing-conservation programme in the same light as accident-prevention measures.

Manifestly, a programme must be instituted forthwith if workers find it difficult to communicate by speech, if they experience head noises or ringing in the ears after work, or if they notice a loss of hearing persisting several hours after exposure. Pain and annoyance are not necessarily,
in themselves, reliable indicators of potential hearing loss, and their presence or absence should not influence any decision on a programme.

For reasons discussed later in detail, it is difficult to state categorically what constitutes a safe exposure to noise. The sound levels at which conservation programmes become advisable are not of general applicability because they vary with types of noise and schedules of exposure. But a hearing-conservation policy valid for years of exposure to broadband noise with relatively flat spectra—though not for impact noises or narrow-band noises, when a more severe standard may be necessary—was stated tentatively by the American Academy of Ophthalmology and Otolaryngology (1957, 1964): “If the sound energy of the noise is distributed more or less evenly throughout the eight octave bands, and a person is to be exposed to this regularly for many hours each day, week by week for years, and if the noise level in either the 300-600 Hz band or the 600-1200 Hz band is 85 dB, then the initiation of noise-control measures, hearing testing and the provision of defenders are advisable. The more the octave-band level exceeds 85 dB, the more urgent the need for conservation efforts.”

Other criteria have been suggested, e.g., when it is difficult to hear a loud voice at a distance of one foot (0.3 m) or when noise levels exceed 90 dB as measured on the B-weighting network of a noise meter (Shone, 1958). Glorig (1963) considers the use of the A-weighting network more suitable because it filters the low-frequency sounds that are not significantly related to hearing losses. N. E. Murray (personal communication, 1963) proposes 90 dB A-weighting as a limit for conservation of hearing for habitual exposure. It is possible that most authorities would now recommend the A network, rather than the B. As proper measuring instruments are not always available, the loud-voice test is one any factory inspector with normal hearing can use as a yard-stick applicable to many jobs such as sand-blasting, steam-cleaning, or grinding.

**TABLE 11. MEASURES REQUIRED FOR HEARING LOSSES OF VARYING MAGNITUDE**

<table>
<thead>
<tr>
<th>Hearing loss at 4000 Hz</th>
<th>Conservation programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 dB</td>
<td>Not required</td>
</tr>
<tr>
<td>15-25 dB</td>
<td>Protection or reduced exposure advisable</td>
</tr>
<tr>
<td>35-40 dB</td>
<td>Protection or reduced exposure essential</td>
</tr>
<tr>
<td>45 dB and higher</td>
<td>Full procedures of a hearing-conservation programme must be applied</td>
</tr>
</tbody>
</table>

Adapted, by permission, from Pless, Rose & Murray (1962).
In Australia, the programme recommended by the Commonwealth Acoustic Laboratory stresses the detection of early permanent hearing loss with the object of maintaining it below 15 dB, averaged over the speech frequencies. A person with 15 dB average loss is just beginning to notice difficulties in the social perception of speech, and this loss is the minimum that legislation usually considers to be a handicap. A conservation programme based on detecting hearing loss at 4000 Hz, and preventing this from exceeding 45 dB will usually ensure that the average over-all loss is less than 15 dB (Murray, 1962). In Table 11 the measures required for hearing losses of differing magnitude are listed (Piesse, Rose & Murray, 1962). Excess noise levels due to impact noises have been investigated by Murray, Piesse & Rose (1959).
CHAPTER 6
MEASUREMENT AND ENGINEERING
CONTROL OF NOISE

MEASUREMENT

To determine whether a noise is a potential hazard to hearing it is usually necessary to measure its over-all level and to perform a sound analysis. An evaluation of other factors may also be required. The investigator must possess instruments appropriate to this task and be capable of calibrating and using them correctly. Measuring instruments can develop faults, and these must be promptly recognized, particularly in the light of possible litigation. It is impossible to stress too much the need to train suitable staff in the intricacies of instrumentation, and such staff should not be expected to give evidence in the law courts until they have gained sufficient technical expertise.

It is unfortunate if sound-measuring equipment is used without a full understanding of its capacities and limitations, and if the results are imperfectly understood and poorly correlated. There are many possible sources of error such as interference from electrical equipment, and humidity. It may be necessary to apply corrections to meter readings to allow for these and other errors such as those due to microphone-cable loss, or the manufacturing tolerances of the measuring instruments. Readings may also be affected by vibration, circuit noise and air currents (American Industrial Hygiene Association, 1958). Background noise is particularly important and must be allowed for in assigning a factor to a particular local sound level. If the observer stands too near his sound-level meter, its readings may be significantly disturbed. Due consideration must be given to other matters such as the geometry of the room and the nature of its contents.

The cost of instrumentation varies with the country and the type of meter. In the United Kingdom, the measurement and analysis of a noise into octave bands cost about £600. Methods of evaluation do not remain static but must change as new problems arise, such as the sonic boom of aircraft. It is to be hoped that it may eventually be possible to develop
a small and inexpensive portable instrument that will give the over-all sound-pressure level, octave bands, phons, speech-interference levels, etc.

It is always advisable to buy equipment meeting the specifications of authoritative national or international standards organizations. Some of the relevant American and British acoustic standards are listed in Annex 1. It is also important for efficient calibration and maintenance services to be readily available. Routine calibration should be frequently performed by the actual user, and less frequently a more intensive calibration by the makers or by an independent laboratory. Since unfavourable conditions of temperature or transport may affect the instrument’s performance, field calibration may also be needed, especially when the instrument is used for several hours at a stretch. In certain circumstances both electrical and acoustic calibration may be advisable; the latter is usually considered more accurate, and differences of more than a few decibels need to be investigated.

The instruments used to measure and evaluate noise, apart from the necessary microphones, include the sound survey meter, sound-level meter, impact- or peak-noise meter, cathode-ray oscilloscope, octave-band analyser, tape-recorder, high-speed sound-level recorder, and the noise cumulator. Bruusgaard et al. recommend the following basic items: pocket sound-level meter, sound-level meter, octave-band analyser, and audiometer.

The sound survey meter is a small inexpensive instrument used to measure noise levels in terms of a standard reference level. It is often used in preliminary field surveys, e.g., in screening sites where there is a possibility of hearing damage. Measurements are quickly taken.

The sound-level meter indicates sound-pressure levels in the audible range. Though used in the same way as the survey meter, it has the advantage that it can be used in conjunction with an analyser, and in general is more sensitive and accurate. The microphone voltage, caused by the alternating pressure of the sound waves, is amplified and expressed in decibels based on a reference sound-pressure level.

Both these instruments measure over-all noise level; but since neither can simulate the response of the human ear over the entire frequency and intensity range, they usually contain three electrical weightings or filter networks enabling them, in some instances, to approximate this response at different sound levels; these weightings are usually referred to as A, B and C. In general, for levels below 55 dB the A weighting is used; above 85 dB the C weighting. This scale gives a more or less uniform response over the whole frequency range; modern views tend to place

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greater emphasis on the use of the A weighting. It is possible to calculate an approximate analysis in three very broad frequency bands by using the networks. With most meters, the sound-pressure level of a noise is measured on a scale giving a flat or uniform frequency response. The range of the instruments is usually from 24 dB to 140 dB, or higher.

With impact noises, it is essential to know the peak sound-pressure level. In many meters the needle cannot move fast enough to follow these abrupt changes, and to overcome this difficulty a peak-noise meter, often called an impact-noise analyser, is used. Such instruments may record up to 30 dB higher than an ordinary meter. It may be difficult to decide whether a particular noise should be classified as continuous or as intermittent impact. Impulses repeated oftener than 18 times a second behave as steady-state noises and have been evaluated as such (Williams & Majer, 1963).

The cathode-ray oscilloscope permits observation of the waveform of a noise and is especially useful in the study of impact noises.

The octave-band analyser is important because, broadly speaking, deafness is better correlated with octave-band levels, rather than with over-all noise intensity. Such analyses are often necessary when evaluating loudness and annoyance, when advising on methods of engineering control, and in determining speech-interference levels. An analyser consists of band-pass filters dividing the audible range into several components. These frequency groupings may, of course, be very numerous; the modern tendency is to use bands with mid-frequencies of 125, 250 and 500 Hz, and so on. Some analysers measure sections of octave bands, often thirds. Except possibly in the case of impact noises, the logarithmic sum of the individual band levels obtained on analysis approximately equals the over-all level as given by a sound-level meter. In general, octave-band analysis is performed in the laboratory from a calibrated tape-recording of the noise. The technical specifications of quality tape-recorders are known. The field use of a high-quality instrument provides a permanent record that can be brought back for detailed study. Other instrumentation enables such analyses to be done at the job site.

High-speed sound-level recorders (graphic recorders) are used in conjunction with a meter to record sound-pressure levels on a paper strip. Such an instrument is often used to record noise levels over a long period, e.g., when assessing traffic noise.

Finally, as in some instances it is not always possible or practicable for the investigator to remain a full work shift with the employee, in order to obtain a reasonably precise estimation of the latter's exposure, the use of a noise cumulator may be helpful. Such an instrument, an exposimeter, can record the total amount of time a worker is exposed at
or above a selected level (Church & Hendricks, 1964). In special instances, employees can carry a small radio transmitter, the information being recorded at a distance. It must be stressed that frequently it may not be necessary for an experienced investigator to spend several hours measuring employee exposure to assess a given problem.

Various authorities and standards organizations have made recommendations on the methods of measuring sound, either in general or for specific problems and situations. If the actual sound level fluctuates markedly and irregularly, different observers may obtain different results for the average level even when using the same meter; observer differences are small for steady noises (Klumpp & Leonard, 1963). It is often useful to make a preliminary visit to a factory to gain some general acquaintance with local conditions. Frequently readings must be made in several places; they must be representative of the exposure of those employees whose hearing loss is in question, since it is past, not present, noise that is probably responsible for the impairment. Measurements should be taken as near to the ear of the employee as is practicable, and it is often important to determine the contribution of background noise. In some cases it may be valuable, with the cooperation of unions and management, to supplement the objective findings with an assessment of the psychological setting.

The techniques of carrying out noise surveys have been documented (American Industrial Hygiene Association, 1958).

THE CONTROL OF INDUSTRIAL NOISE

Whenever an industrial environment is causing, or is likely to cause, ill health, consideration must be given to controlling the hazard in such a way that the worker is inherently safe, no matter what his own actions or attitude may be. Techniques now available permit of economical and effective noise reduction where this was once considered too difficult or expensive; and because control measures impossible today may become feasible tomorrow, the problems must be kept under review. It is important to ensure that noise abatement procedures are consistent with good safety practices.

It is only recently that some machine manufacturers have begun to appreciate the noise problem and to design their products accordingly. Even so, their efforts may be thwarted by technical difficulties or the prohibitive costs of incorporating sound-reducing devices. Designs should be kept under constant review (Cohen, 1963). Measurement techniques for assessing machinery noise have been described (International Organisation for Standardisation, 1963b). In Saskatchewan,
under the 1958 Agricultural Machinery Act, tests are made on new equipment, and details of noise levels are included in reports on farm machinery as a guide to farmers (N. Williams—personal communication, 1963).

In industries without suitable engineering control measures and where large numbers of persons are exposed to a severe noise hazard, governments should encourage research and provide, directly or indirectly, the necessary financial assistance.

Noise control in factories is often expensive and may have to yield priority to protection against hazards immediately dangerous to life; even so, there must not be unnecessary procrastination. Even when money and technical skill are available, efforts may be wasted on control measures that are totally unsuitable. Managements should therefore seek help from private or government consultants and, since hazards are often greatest in smaller factories that cannot afford private advice, the services of a government department of Health or Labour should be freely available. It should not be forgotten that technical solutions for specific problems are often to be found in authoritative textbooks and journals.

Despite technological advances, there are many situations for which satisfactory engineering control measures have not yet been devised. In other cases, the problem must be tackled step by step. First, a sound survey is made to delineate the problem. Then, when engineering modifications have been made, further measurements are obtained. It may be necessary to repeat this cycle until the over-all noise and frequency composition have been reduced to an acceptable level—an empirical approach that is often costly. Control measures fall into several broad categories: administrative, engineering, legislative, and the use of personal protective devices. The last two categories are discussed in a later section.

Administrative measures

Managements may be able to reduce exposure by task rotation or reducing hours of work. A noisy machine may sometimes be placed in a little-used section of a factory, or operated on shifts when there are fewer workers; care must be taken not to annoy near-by residents, either during the day or at night.

Engineering measures

It is wiser, and cheaper, to consider the total factory environment including the site and design of the premises at the planning stage, before
purchasing and installing machinery. Planning should allow for the acquisition of quiet machinery and the modification of existing machines, and there should be some attempt to predict the noise levels that will be created on installation. Unfortunately, in certain circumstances there may be a difference between the manufacturer's rating and the noise produced when the machine is actually in service. Economy and noise reduction often go hand in hand. Thus, the too free use of compressed air may add expense to noise. Machinery often becomes increasingly noisy with wear, especially with inadequate maintenance. The source of a noise must be determined accurately, and it may be helpful in planning control measures to make a flow diagram, tracing the noise path from its source until it reaches the free air (Saunders, 1957).

**Substitution of a quieter process.** Noise reduction may be effected by changing a machine, process or material. Thus, welding can replace riveting, metal can be cleaned chemically instead of by high-speed polishing. The over-all noise level from chipping inside a tank may reach 126 dB but flame gouging will reduce this by 20 dB or more. There are other examples such as the use of mechanical instead of air ejectors on presses, the replacement of metal by rubber or plastic parts, and the employment of slow-acting pressure instead of high-velocity impact of metal on metal (Gutkeunsk, 1954).

**Reduction of noise at source.** This may be achieved in many ways: lubricating regularly, replacing worn parts, inserting sound-peak limiters in telephone circuits, limiting the revolution speed of fans, and using vibration dampers. With processes generating impact noise, the minimum effective power and number of impacts should be used.

**Reduction of sound transmission.** If the transmission is airborne, reduction may be achieved by enclosure, by absorption in suitable materials, and by the use of mufflers. If the transmission is through the structure of the machine or building, reduction may be effected by the use of isolators.

**Enclosure of noisy machines.** The effectiveness of enclosure depends on several factors such as the insulation value of the barrier, the nature of the sound-absorbing material lining the enclosure, its openings and mountings, and the level and spectrum of the noise.

It may be possible to enclose a machine completely and operate it by remote control.

The sound-transmission losses of various building materials and structures, such as doors, glass and different types of wall, are known.
Many tables relate such losses to frequencies (United States, National Bureau of Standards, 1955, 1956). Enclosures have been used effectively to reduce noise from belt drives, from combustion engines and from vibrating screens, etc. The nature of some technical processes is such that only partial enclosure is possible; even so, much can be achieved.

**Absorption.** The coefficients of absorption of various materials, of different thicknesses, and different interior finishes are known (Beranek, 1954). This coefficient is the ratio of sound-energy absorbed to the energy incident upon the material. Published tables give, for the different frequencies, coefficients expressed as decimal equivalents of fraction of sound absorbed. Therefore, if the spectrum of the noise is known, it is possible to choose the correct material and calculate probable benefits from its use (Knudsen & Harris, 1950). Graphs and formulae suitable for use when studying architectural plans are available (Marin, 1963). The noise reduction coefficient of a material is an index of its over-all effectiveness—the arithmetical average of the coefficients at 250, 500, 1000 and 2000 Hz, expressed to the nearest multiple of 0.05.

Treating a room with sound-absorbing materials reduces the reverberation time, i.e., the persistence of sound after direct reception from the source has ceased.

In most industrial situations where hazardous noise levels exist, reduction to a safe level cannot be effected by such treatment of the walls and ceiling (Glorig, 1961a). The reduction obtained by the use of absorbent materials is usually much less than can be obtained by engineering modifications to machines and processes, and may be less effective in terms of money spent. It is also ineffective in protecting an operator stationed close to a machine. This method is most successful when the desired noise reduction is not great, when the room is reverberant and when the operator is not close to the origin of the noise.

The enhancement of room absorption of sound is, of course, widely applicable to lecture halls and other auditoria, as well as to factories. A coating of sound-absorbent material may be sprayed on to objects of irregular shape.

In general, hard, smooth, impervious surfaces reflect sound; soft, porous materials absorb it.

Sound insulation is not identical with absorption; it refers to the interposition of a barrier between the source of the noise and the point to be protected. The effectiveness of insulation may be increased by the associated use of a material with a high coefficient of absorption; this is particularly so when reflected sound is of importance. The most important factors are that the partitions should be heavy and that they should provide an airtight seal across the noise pathway (Purkis, 1962;
United Kingdom, 1960). The use of absorbing materials along transmission paths can be effective, as in the lining of ventilation ducts (Sabine, 1940).

Sound may also be absorbed by resonators (Harris, 1957), and by mufflers. Of the latter, there are two types—namely, dissipators, which use porous sound-absorbing materials, and non-dissipators, which attenuate noise by reflecting the energy back to the source.
CHAPTER 7

PERSONAL PROTECTION DEVICES

Sir Thomas Legge, the first English medical inspector of factories, wrote of protection from occupational hazards: “If you can bring an influence to bear external to the workman (i.e., one over which he can exercise no control) you will be successful; and if you cannot or do not, you will never be wholly successful.” (Legge, 1934). This is as true for noise as for protection from toxic dusts or gases. In addition to the elimination of hazards at their source, safety can be ensured only by the full co-operation of the employee, and this may be difficult to obtain if he is not moved, or is little moved, by health considerations (Mass, 1961). Management has the responsibility of educating and training the workers. Care must be taken to ensure that one side does not unjustifiably place blame for failures or difficulties on the shoulders of the other; there is need for full co-operation between management and employees.

Much has been written on the difficulties of persuading workers to wear ear-protectors, even in industries known for their high incidence of occupational deafness. At the International Congress on Occupational Health, held in 1957 in Helsinki, Swedish speakers reported that in some 10% of the places where protectors were issued, few of the workers used them. Personal protection is, to some extent, a long-range educational project, since the worker often willingly accepts noise as part of his job; hence the importance of engineering control of noise at source whenever possible.

In some factories, for one reason or another, personal protective devices are the only practical and economical method of reducing the risk, and in such instances no programme can be considered successful until the workers themselves insist on wearing their protectors. The object of an ear-protector is to limit the amount of sound reaching the drum, so lessening the possibility of annoyance or hearing loss. This cannot always be achieved, particularly for the susceptible minority. There are four main types of device; plugs, semi-insert plugs, muffs, and helmets. Sometimes more than one type is worn simultaneously, as
when mechanics working near aircraft sometimes use both plugs and muff to gain the fullest protection. But it is unlikely that the total attenuation will ever exceed 50 dB or thereabouts since, at this point, bone conduction becomes significant.

Earplugs are cheap, and are made in various sizes and shapes from plastics, rubber, etc. A good fit between the plug and the external auditory meatus is sometimes more important than the nature of the material used; the fit may be improved by the use of a lubricant. Some manufacturers have displayed considerable ingenuity of design (De Mar, 1962; Zwislocki, 1952).

Temporary plugs made from cotton wool offer little effective protection; those made from materials such as fibreglass may be quite effective, though not necessarily for long periods of time.

Individually moulded plugs, though more expensive, are generally effective and comfortable to wear. Because of medical considerations, they may be the only suitable type.

Semi-insert earplugs, moulded to the shape of the individual's meatus, do not penetrate the canal. Because they are comfortable to wear, they may be accepted in situations where it is difficult to persuade employees to use other types. Piese (1962) does not recommend their use in high noise levels; attenuation is poor owing to their loose fit.

The ear-muff consists of a pair of cups, designed to cover the external ear, connected and held in place by a head-band. They often afford better protection than plugs because of their closer fit and higher insulation value and inertia. Some muffins have telephone receivers built in for communication in very noisy areas. In seeking to obtain greater attenuation, manufacturers are constantly trying new designs and seal materials; the fluid-seal type is very satisfactory, but wearing spectacles may reduce its effectiveness.

In Sweden, directives specify the attenuation characteristics of plugs and muffins.

Helmets may be made from either a firm material or soft cloth. The latter give adequate attenuation at moderate noise levels. For maximum effectiveness, the face should be covered (Williamson, 1955). They are frequently used to support muffins, being designed to cover most of the bony portion of the head, thereby reducing bone-conducted sound.

With any type of ear-protector, important factors to be considered, apart from sound attenuation at the desired frequencies, include comfort during wear, ease of speech communication, ease of fitting and maintenance, availability of components, and absence of skin irritation (Piese, 1962). Where there is resistance to their continued use, it may be advisable for workers to try several suitable types under supervision and to select the most comfortable, which they are then more likely to
use. When purchasing protectors it is necessary to know the over-all attenuation required to reduce the noise reaching the drum to a safe level, and this may require a preliminary sound survey and a decision on acceptable levels. It may also be important to know the frequencies concerned, the wearer's hearing acuity and his conversational needs while using the device. The efficiency of a protector may be roughly assessed in the field by comparing the amount of temporary threshold shift on different working days when it has, and has not, been worn. Alternatively, the degree of attenuation may be accurately determined, preferably in an anechoic room, by measuring binaural free field thresholds for several specified frequencies with and without the protector. The average of the measured attenuation over the four octaves 250 to 4000 Hz is called the noise-protection figure, and safe working conditions are ensured if this is greater than the excess noise level (Piesse, Rose & Murray, 1962). Suitable devices need not necessarily be expensive (Zenz & Berg, 1965). Under working conditions the wearer receives some 5 dB less attenuation than under laboratory conditions. Some approximate over-all attenuation values are given below.

**Earplugs**: cotton-wool, 8 dB; waxed cotton-wool or glass-fibre wool, 20 dB; individually moulded acrylic, 18 dB; individually moulded silicone rubber, 15-30 dB; mass-produced rubber plugs, 18-25 dB; semi-insert silicone rubber, 14 dB.

**Ear-muffs**: heavy, 40 dB; medium, 35 dB; light, 25 dB.

The Division of Industrial Safety in California has listed the average attenuation for acceptable ear-protectors (United States, State of California, 1964), and attenuation values at the different frequencies for many of the above-mentioned items may be found in the literature. Such knowledge may be required to select the most suitable type for the noise in question.

Most of the devices available provide between 10 and 20 dB protection below 1000 Hz, and 30-45 dB above this. Attenuation of frequencies above 2000 Hz is easy if there is a tight seal, but the effectiveness diminishes with frequency (Glorig, 1956). Since the wearer must often adjust the position of the protector, and since head movements, speaking and eating tend to loosen the seal, it is important to check the protector's effectiveness from time to time by audiometry—particularly with susceptible persons and at high noise levels.

The efficiency of a protector is lessened by leaks through or around the device, by its vibration, and when bone-conduction short-circuits
the barrier. The better the seal between insert and auditory canal, the better the protection, but the possibility of discomfort also increases. There must be a balance between efficiency and comfort, taking into account the period during which the device must be constantly worn (Thiessen, 1962). This is but one reason why medical personnel should be associated with the fitting of earplugs and with indoctrinating workers and managements. Even with a good fit there may be some initial discomfort; indeed, if there is no sensation of pressure, protection is likely to be inadequate (Wheeler & Glorig, 1955). If a man genuinely cannot wear properly fitted protectors, it may be advisable to allow him to start with a comfortable but less efficient pair and change later to more suitable ones. To issue plugs indiscriminately without any attempt to ensure that they fit correctly is to court failure, since auditory canals vary from person to person and from one ear to the other. There may be anatomical reasons for fitting difficulties and discomfort. Users should be able to choose from several types and sizes and then preferably be medically examined with the devices in situ. There is often a knack in inserting earplugs correctly. If a worker will not or cannot use ear-defenders every effort should be made to find out why.

There is rarely any difficulty in persuading workers to wear protectors if they are exposed to very high noise levels, for their use then prevents pain, if not necessarily auditory damage (Williamson, 1955). With decreasing noise levels, persuasion becomes more difficult. Earplugs and other safety devices are too often introduced into factories without previous explanation. An educational programme is an essential preliminary, aimed at both management and workers and perhaps particularly at works foremen. While care should be taken not to create alarm, staff must be made aware of the risks in their total medical and industrial perspective, presented in simple terms with emphasis on the fact that noise-induced hearing impairment may develop without the individual's knowledge. Personal and serial audiograms demonstrating the extent of such loss may be effective propaganda. Disciplinary action may eventually be required, if only to protect managements against compensation claims. In some countries legislation requires not only that employers should provide ear-protectors, but that employees should use them (Italy, 1956).

The use of ear-protectors is contraindicated for an infected discharging middle ear or an inflamed external canal. Defenders must be kept clean. Many workers refuse to wear plugs on the grounds that they will be unable to hear and that the danger of accidents will be increased. It is important to explain that, with some insert types of defender and at high noise levels, these fears are groundless (Kryter, 1950; Zwislocki, 1952). The signal/noise ratio in particularly noisy environments may be
increased by incorporating earphones into the protectors (Thiessen, 1962). Michael (1965) has discussed the usefulness and limitations of ear-protectors.
Audiometry is an essential part of any hearing-conservation programme. It facilitates work placement, the detection of changes in auditory acuity (it enables hearing losses at 4000 Hz to be detected long before the victim notices any difficulty in conversation), the identification of noise-susceptible persons, and the evaluation of the effectiveness of ear-protectors and noise-control measures (Davis, Hoople & Parrack, 1958). Kryter (1963a) has reported on the use of pure-tone audiometry to assess impairment in speech comprehension resulting from noise-induced hearing loss.

An audiometer is used to measure hearing acuity. Electrical instruments first became available in 1930, and their earliest use in determining the extent of industrial deafness was probably in connexion with a survey made by the New York State Labour Department in that year.

Kranz (1963) has reviewed the principles and history of the audiometer.

Measurements may be made with speech or tone signals. Industrial audiometry is limited almost entirely to air-conduction threshold tests using pure tones generated by earphones placed over the ears. Simpler tests, such as the whispered or spoken voice or watch-tick tests, are of little practical use in industry. Tuning-fork tests are sometimes used diagnostically.

Managements sometimes claim that audiometric schemes are too expensive; but the cost of a single successful compensation case may considerably exceed that of the necessary testing equipment (Lovejoy, 1958).

Where the number of employees does not warrant the expense of a factory's installing its own audiometric room, arrangements for examinations may be made with a local medical practitioner or hospital on a fee-for-service basis, or in conjunction with national health services.

Employers may also fear that the introduction of audiometry could lead to an increase in claims: this is possible, although it does not seem
to happen very often in practice. Audimetry takes a little time to perform, sometimes an additional reason for its unpopularity with managements. A quick screening test, for certain frequencies only, has much to commend it, and the use of a mobile test chamber may also be time-saving (Pennington, 1958).

The two main types of electroacoustic generator are the pure-tone and the speech audiometers. Some instruments can be used for diagnostic purposes, others for screening only. Some instruments are manually operated, others automatic. Many pure-tone audiometers generate test tones in octave steps, from 125 to 8000 Hz, the signal intensity ranging from -10 dB to 100 dB. In some countries construction and performance requirements are specified by standards organizations. Audiometers must be calibrated regularly—at least weekly if in regular use. The operator can do this himself if he knows the status of his own hearing as determined on an accurate diagnostic audiometer. Some countries have their own national laboratories for more accurate and precise calibration; scientific measurements have shown many instruments to be inaccurate (Knox & Lenihan, 1958). Riley et al. (1965) have suggested that audiometers should be calibrated in physical units rather than in units referred to the arbitrary audiometric zero.

Those performing audiometric testing must be properly trained. If technicians are required to test large numbers of persons at speed, fatigue may vitiate the results. Because an audiogram is a potential medico-legal document, and because the task is repetitive, the right persons for the work must be selected, trained and supervised (Bonney, 1962). Many audiograms are unsuitable for research purposes, because initial planning is inadequate or the information is incompletely recorded. Carefully designed hearing-conservation data cards exist and should be used whenever possible. A continuous audiogram, on which the results of successive tests are recorded, has certain uses (Piesse, Rose & Murray, 1962).

Many writers have outlined audiometric techniques (Sataloff, 1957). There are many modifications of basic method. One method, utilizing a single descent, is simple for auxiliary medical personnel to learn and to use with consistent results. The hearing-loss dial is turned up steadily from zero and the subject instructed to indicate when he first hears the tone. At this point the dial is at about 10 dB above the actual threshold. The tone is then interrupted and presented in short bursts, decreasing in

1 Prepared by the Research Center of the Subcommittee on Noise in Industry of the Committee on Conservation of Hearing, American Academy of Ophthalmology and Otolaryngology, 111 N. Bonnie Brae Street, Los Angeles 26, Calif., USA.
2 There are two possible methods. In conventional clinical audiometry the test tones are presented, to each ear separately, through earphones. There are controls for frequency and intensity. Bekesy's method (1947) makes possible the production of a graphic record from which hearing-level values may be read.
intensity by 5-dB steps, until the lowest point is reached at which the
subject gives two out of three responses. This reading indicates the
hearing loss. Where there is little loss, only a single rapid measurement
for each ear is required (Murray, Piesse & Rose, 1959).

The Research Center of the Subcommittee on Noise has produced a
narration for an approved technique for air-conduction audiometry.
Local legislation may specify the test frequencies to be used.

RELIABILITY OF AUDIOMETRIC MEASUREMENTS

It is important to determine the reliability of test results, especially
when differences between consecutive audiograms are used as a basis for
work placement. Knight (1964) has commented that some of the audi-
ometric testing carried out by the medical profession and otologists is of
poor standard. The variable factors that may act as sources of error
can be physical, physiological or psychological. The first includes the
nature of the test stimulus, the ambient noise conditions, and the charac-
teristics of the equipment. Physiological considerations are age, sex,
general health, auditory fatigue, and the structure of the auditory meatus.
Some of the psychological variables refer to the motivation, intelligence
and personality of the subject, and his mode of response. Finally, there
are variations related to methodology in testing (High, Glorig & Nixon,
1961).

It is impossible to discuss these factors in detail, but a few points may
be made. Many individuals tested show definite improvement after
removal of wax from the ear (Kawchak, 1961). Spectacles may interfere
with the proper fit of test muff's. The threshold of audibility improves
with practice, at least for some frequencies (Zwislocki et al., 1958).
There are different techniques of rating an audiogram. As discussed
earlier, because of the phenomenon of auditory fatigue, the audiogram
of a person working in a noisy environment may vary at different times
of the day. Therefore, whenever possible, and especially for pre-place-
ment testing, at least sixteen hours should have elapsed since the subject's
last exposure to noise, and the longer the better. This is why some
consider that Monday-morning screening is the ideal. Because of
difficulties associated with the time factor, compromise procedures have
been suggested (Whitaker, 1957).

The results of audiometry are influenced by high background noise,
and it is not satisfactory to apply a correction factor. Background noise
is taken into account in the American Standards Specification S3.1—1960
(see Annex I) for audiometer rooms. Unfortunately, it is not always
possible to carry out tests in specially constructed or sound-treated enclosures, although prefabricated test booths are sometimes used. Matters such as the dimensions, temperature and ventilation of the room used must all be allowed for. The use of audiometric earphones within ear-muffs may enable tests to be carried out satisfactorily where ambient noise is too disturbing.

Because of the variables listed, repeat audiograms may differ by 10 dB or more at certain frequencies, and the comparison of results from different factories is not a straightforward matter (Grings, Summerfield & Glorig, 1957). Even in conditions precluding all sources of variation (other than the inherent uncertainty of any audiometric measurement), Atherley & Dingwall-Fordyce (1963) have stated that, for young men, an apparent drop in auditory threshold for one ear can be considered significant only if it amounts to at least 17.5 dB at the higher frequencies. It follows that no one should be transferred to alternative work on the basis of audiometric findings unless re-check audiograms have been made on perhaps three different days with consistent results. The greater the degree of hearing loss, the easier it is to obtain accurate and consistent results. Robinson (1959) has stated that the thresholds in conventional audiometry of the highest accuracy are accurate to 2 dB if the average of two or three threshold measurements is used. Using a Rudmose audiometer, Knight (1964) found that in 5% of the total observations the measured level may differ from the true level by 8 dB or more at the lower frequencies. Audiometric changes must therefore be carefully scrutinized.

PRE-PLACEMENT AND FOLLOW-UP TESTS

Pre-placement audiometry may permit an apportionment of responsibility for hearing loss between employers, and this will tend to reduce the financial burden of many claims. The main purpose is to obtain an audiogram serving as a reference level to check any subsequent changes in hearing. It should be applied to all required to work in very noisy surroundings, and used, not to debar persons from work, but rather to protect them by suitable allocation (Davis, Hoople & Parrack, 1958). Revision of reference audiograms should preferably be carried out only by an otologist or at a diagnostic centre. In the case of young applicants, it may be useful to have access to the results of audiometry performed by school medical services.

It has been suggested that if pre-placement testing shows an average loss of more than 15 dB at 500, 1000 and 2000 Hz, or if there is any unusual irregularity—particularly an abrupt loss beginning at 2000 Hz—
the potential employee should be referred for specialist otological examination. In general, with reference to standards, one view is that those applying for employment in noisy areas should not have impairment in either ear exceeding 20 dB in the 500-2000 Hz range, 30 dB in the 3000 Hz range, and 40 dB at 4000 Hz. Applicants with binaural loss of 20%-70% should not be employed in noisy areas. In some work situations, however, the existence of a severe hearing loss may constitute an actual advantage (Shone, 1958; Barron & Love, 1955). Because hearing losses are widespread one must have adequate medical justification—quite apart from the important sociological considerations that are present—before rejecting an employee as otologically unsuitable for a given noisy task.

The purpose of follow-up tests is to detect early signs of impairment. It is not easy to make precise recommendations on the frequency for such testing as the development of noise-induced hearing loss is usually insidious. Some authorities consider that, except when the over-all noise level is very high—over 120 dB—yearly examinations suffice. In general, this might be satisfactory were it not for the existence of noise-susceptible persons, for whom the first repeat audiogram must be made much earlier. Other authorities recommend follow-up testing at 7, 30 and 90 days after initial placement (Committee of Consultants, 1953). Yet others are content to wait for 90 days unless there is long and continuous exposure to sound levels above 100 dB, tinnitus, or excessive temporary threshold shift. If the changes at the first follow-up audiogram are less than 15 dB, it should suffice to repeat tests at yearly intervals, unless otherwise indicated; if the loss exceeds this figure at one or more of the six recommended frequencies, steps should be taken to conserve hearing. The guide issued by the American Academy of Ophthalmology and Otolaryngology (1957, 1964) contains specific recommendations concerning follow-up tests of hearing ability.

Screening tests

Partly because audiometry takes time, which may provoke some management resistance, rapid screening tests have been evolved. The information they yield, though useful, is limited, and further investigation may still be required for some individuals. One such test includes all the frequencies at a fixed intensity level, 15 dB or 20 dB (House, 1957). The 4000 Hz single-frequency screening test is easy to perform, as this frequency is not masked by ordinary environmental noise and can sometimes be carried out in rooms that have not been acoustically treated (Katz et al., 1963). 4000 Hz has been chosen for this purpose because most noise-induced industrial loss initially occurs at this level and because,
if the threshold at this frequency is within normal limits, hearing will be normal for speech in at least 98% of the listeners (Glorig & House, 1958). This test is not reliable if the loss at 4000 Hz exceeds 50 dB (Glorig, 1957). A double frequency test (2000 Hz and 4000 Hz) has also been used; if a subject fails to hear at both frequencies at 20 dB, his exact hearing status should be carefully investigated (Glorig & House, 1958).

Many consider that, in industry, group audiometry is of little practical use.

It may be possible, by the use of automatic audiometers, for employees to save time by carrying out their own tests, the immediate attention of a technician being unnecessary. Their use may present medico-legal difficulties (Carhart, 1956). In large industrial plants a great number of men can be tested simultaneously, using several machines, and one technician is able to supervise the entire operation (Fox, 1960). The evidence suggests that the results obtained are close to those of the classical, individual pure-tone method (Burns & Hinchcliffe, 1957). There are two main types of instrument. In one, the frequency and signal intensity are continuously varied slowly over the range of test frequencies. In the other, the signal is presented at discrete frequencies of 500, 1000, 2000, 3000, 4000 and 6000 Hz rather than being continuously variable (Rosenwinkel, Stewart & Doerfler, 1959b). Automatic audiometers have been adapted to produce direct graphic recording of results.

Diagnostic audiometry is not essential for hearing-conservation purposes. In this procedure, both bone- and air-conduction tests are performed, often by a medically-trained person, to assist in the determination of the cause of a loss.

A speech audiometer is an electronic instrument capable of measuring an individual's ability to hear and understand speech. Though rarely used in industry, speech audiometry is important because hearing is concerned with the ability to repeat or respond correctly to the spoken word (American Medical Association, 1955). The scores obtained depend on many factors, such as the words used, the rapidity of speaking and the dialect employed (Rudmose, 1958). Pre-recorded material has certain advantages in testing over the live voice, and bisyllabic words of spondee accentuation, which are readily identified, are chosen to determine the hearing threshold for speech. Spoken-voice tests are inadequate to evaluate auditory social competence (Glorig, 1958).

HEARING THRESHOLD REFERENCE LEVELS

The present American Standards Association audiometer standard Z24.5—1951 (see Annex 1), states that the normal threshold of hearing
for air conduction at a given frequency is the modal value of the minimum sound pressure, at the entrance to the ear canal, which produces a pitch sensation in a large number of normal individuals between 18 and 30 years of age (Botsford, 1960). The modal acoustic pressures obtained by British observers are appreciably lower than those on which the US standard for the threshold of hearing is based. Consequently, an audiometer calibrated to the American standard shows an acoustic output at the zero hearing-loss reading that is 5-15 dB greater (depending on frequency) than an audiometer calibrated to the British standard (Hinchcliffe & Littler, 1958). There are other international discrepancies. Table 12 sets out the corresponding values of reference hearing threshold levels as laid down by the American Standards Association and those proposed by the International Organisation for Standardisation (J. occup. Med., 1963). Botsford (1963) has discussed the practical problems that will arise if the ISO recommendations are followed. Davis & Kranz (1964) support the concept of International Reference Zero levels for pure-tone audiometers. Stewart & Burgi (1964) are critical of the new reference zero, considering that emphasis should be laid on biological variations in man rather than on the tendencies of groups.

**TABLE 12. COMPARISON OF ASA (1951) AND ISO (1963) REFERENCE HEARING THRESHOLD LEVELS**

<table>
<thead>
<tr>
<th>Frequency, Hz</th>
<th>Reference threshold level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASA (1951)*</td>
</tr>
<tr>
<td>125</td>
<td>54.5</td>
</tr>
<tr>
<td>250</td>
<td>39.5</td>
</tr>
<tr>
<td>400</td>
<td>25.0</td>
</tr>
<tr>
<td>1000</td>
<td>16.5</td>
</tr>
<tr>
<td>1500</td>
<td>16.5</td>
</tr>
<tr>
<td>2000</td>
<td>17.0</td>
</tr>
<tr>
<td>3000</td>
<td>16.0</td>
</tr>
<tr>
<td>4000</td>
<td>15</td>
</tr>
<tr>
<td>6000</td>
<td>17.5</td>
</tr>
<tr>
<td>8000</td>
<td>21.0</td>
</tr>
</tbody>
</table>

*The figures in parentheses are interpolations. Adapted, by permission, from Journal of Occupational Medicine (1963).*
CHAPTER 9

ASSESSMENT OF DISABILITY

Accuracy in determining hearing impairment is limited by the capacities of audiometry. In addition, it may be difficult to decide the degree of psychogenic overlay. Disability may be measured in terms of earning power, or of difficulty in hearing sounds and everyday speech audible to most people, the important frequencies for the latter lying between 500 Hz and 4000 Hz (Davis, 1957a). The questions of monaural or binaural impairment and of the extent of any monetary award are two other important aspects of the problem. It may also be necessary to evaluate the measured loss in terms of social and economic disability, and this is difficult. Listening to speech in an audiology room is very different from listening in a crowded place. Losses of up to 15 dB are within the normal range of hearing and are not usually considered a handicap.

METHODS OF ESTIMATING SPEECH-HEARING LOSS

Because of differences between the results of successive audiograms, the use of the best of three readings taken at least a week apart has been proposed (Bonney, 1962). It is sometimes necessary to allow for presbycusis. The calculated degree of disability depends on the method used (Harris, Haines & Myers, 1956). Some of the procedures will be briefly discussed chronologically.

Fletcher’s method (1929) was intended to yield a figure for percentage speech-hearing loss. The decibel losses at frequencies of 500, 1000 and 2000 Hz were averaged and the result multiplied by 0.8, i.e., a 120 dB loss being equivalent to a 96% impairment.

In 1942 the United States Council on Physical Therapy tentatively suggested that the following decibel losses at the given frequencies represented 100% losses of useful speech hearing (Carter, 1942):

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>128</th>
<th>256</th>
<th>512</th>
<th>1024</th>
<th>2048</th>
<th>4096</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss (dB)</td>
<td>65</td>
<td>80</td>
<td>85</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

— 78 —
The percentage loss is the average of the losses for the two ears taken separately and weighted in the ratio of 7 to 1. This was slightly modified in 1947, when the last four test frequencies were weighted somewhat differently and more importance was accorded to the loss of a given number of decibels in the middle of the intensity range than to corresponding losses from very weak or very strong sounds (Council on Physical Medicine, 1947). This is fairly satisfactory for calculating percentage capacity to hear speech for persons with conductive hearing losses, in whom the losses are not very different for differing frequencies. But for persons with nerve deafness the results often conflict with the clinical evidence.

Possibly the most valid way to measure ability to hear speech correctly is to use selected words and sentences as standard test material. In 1956(a) and 1957 Fox set forth his own views and the approach of the Wisconsin Industrial Commission to occupational hearing loss. He recommended that the pure-tone conduction losses for 500, 1000 and 2000 Hz should be averaged to obtain the percentage compensable hearing loss. A little later the Commonwealth of Australia devised a hearing impairment table which made an allowance for presbycusis and contained a formula for calculating the binaural percentage hearing loss—namely, multiplying the loss of the better ear by four, adding the worse ear percentage and then dividing by five (Murray, 1962). In 1959 the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology recommended averaging the same three losses that Fox had earlier proposed, and it observed that, if the average loss did not exceed 15 dB, there was no impediment to hearing everyday speech under everyday conditions. On the other hand, an average loss of 82 dB would imply that impairment was total (Lierle, 1959). The Academy also recommended a formula to convert the monaural impairment into a binaural percentage. Guides to the evaluation of permanent impairment have been published (J. Amer. med. Ass., 1961; Kryter, 1963b). The latter suggests that impairment for the understanding of speech should be estimated from the average hearing level at 1000, 2000 and 3000 Hz. Others consider it undesirable to restrict the upper frequency to 2000 Hz and suggest that 4000 Hz should be included (Davis & Silverman, 1959).

For compensation purposes some American States still rely solely on "medical testimony" (Drop Forging Association, 1961).

The assessment of binaural hearing loss is not as straightforward as might appear at first sight, and various formulae have been proposed. One reason for this is that total deafness in one ear does not cause a 50% handicap if hearing in the other ear is within normal limits. Until recently, it was thought that the handicap amounted to only 10% but
the currently accepted figure is around 20% (Glorig, 1958). There is no generally agreed method for determining the binaural handicap for those with different degrees of loss in both ears.

Table 13 is a classification of hearing loss, exclusive of any assistance from hearing aids or lip-reading. The calculation used, the three-average method, has weaknesses because it does not allow for the poor consonant discrimination that results when the hearing loss is considerably higher at 2000 Hz than at 1000 and 500 Hz; in these circumstances a man may be able to hear but not understand (Glorig, 1958).

**TABLE 13. HEARING LOSS CLASSIFICATION TABLE**

<table>
<thead>
<tr>
<th>Class</th>
<th>Degree</th>
<th>Average decibel loss at 500, 1000, 2000 Hz in better ear</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Normal</td>
<td>Less than 15 dB</td>
<td>Within normal limits</td>
</tr>
<tr>
<td>II</td>
<td>Near normal</td>
<td>15-25 dB</td>
<td>No difficulty with ordinary conversation at distances up to 20 ft (6m)</td>
</tr>
<tr>
<td>III</td>
<td>Mild loss</td>
<td>25-40 dB</td>
<td>Difficulty with ordinary conversation when distance exceeds 5 ft (1.5m)</td>
</tr>
<tr>
<td>IV</td>
<td>Moderate loss</td>
<td>40-65 dB</td>
<td>Difficulty with loud conversation when distance exceeds 5 ft (1.5m)</td>
</tr>
<tr>
<td>V</td>
<td>Severe loss</td>
<td>65-75 dB</td>
<td>Difficulty with shout when distance exceeds 5 ft (1.5m)</td>
</tr>
<tr>
<td>VI</td>
<td>Profound loss</td>
<td>75-85 dB</td>
<td>Difficulty with shout at less than 5 ft (1.5m)</td>
</tr>
<tr>
<td>VII</td>
<td>Practically total loss</td>
<td>More than 85 dB</td>
<td>Loss of practical hearing for speech</td>
</tr>
</tbody>
</table>

Adapted, by permission, from Glorig (1958).

The point at which a person first notices disability depends on several factors. The impact of the loss is partly objective and partly subjective or psychological. What matters is his ability to hear ordinary speech under average conditions. At 30 dB average loss, the handicap becomes evident to him. When the loss exceeds 45 dB the handicap is decidedly noticeable, and he needs help if he is to carry on without serious inefficiency. At losses of 85 dB he is totally incapacitated for speech communication.

**CLINICAL ASPECTS**

It should be possible to reduce the prevalence of occupational deafness considerably through the assessment of working conditions and
with the cooperation of managements and men. There are many causes
of impaired hearing, and early diagnosis and evaluation are of prime
importance. Efforts must be made to determine the extent, if any, of
associated functional hearing loss. The diagnosis once made, it may be
necessary to decide whether the individual should be allowed to continue
working in a noisy environment. Each case must be judged on its merits,
but there are some important general considerations.

It is neither logical nor desirable for industry to perform pre-employ-
ment hearing tests if the discovery of a loss means automatic rejection or
removal of the employee from his work, with a possibly serious fall in
earning power. The noise may be reducible to a safe level by engineering
modifications, further loss may be preventable with ear-protectors, or the
extent of hearing loss may be such that little or no additional impairment
can accrue even with prolongation of exposure. At least for certain
types of noise there appears to be no medical contra-indication to a
man's continuing to work in noise up to the intensity that caused his
permanent loss, although, if transferred to a noisier environment, an
increase in permanent impairment might be expected (Glorig, Ward &
Nixon, 1961). Some authorities, however, do not consider it safe to say
that anyone who has worked in a noisy environment for ten years or
more can be left there without risk of further loss (Lawrence, 1963).
The United States Air Force (1956) has detailed procedures to be adopted
for varying degrees of impairment.

It is not necessarily true that a man who has already suffered a loss
from noise will be more susceptible to subsequent exposure; indeed,
conductive hearing loss tends to protect against noise-induced loss rather
than to increase susceptibility (Davis, Hoople & Parrack, 1958). It is
conceivable that certain middle-ear defects may protect the inner ear
from the effects of noise that would damage the organ of Corti in an
intact ear; there are limits as to their possible protection (Chadwick,
1963). Goldner (1955) has discussed the effect of associated aural
disease on prognosis. Opinions are not unanimous.

Continued hazardous exposure may, therefore, be quite permissible
in some types of impairment and circumstances, though strongly contra-
indicated in others. A qualified otologist can best decide. Presbycusis,
in this connexion, does not affect susceptibility but merely elevates the
threshold (Davis, Hoople & Parrack, 1958).

It is unfortunate that there is, as yet, no satisfactory treatment for
persistent noise-induced hearing loss. Some deaf persons acquire com-
 pensatory skills based on sight or kinaesthetic abilities. Others are
helped by hearing aids, lip-reading and auditory training. The latter is
da desirable, though not always necessary, preliminary to the use of an
aid. Although, in general, hearing aids are not as useful for inner-ear
hearing loss as for conductive loss, they may be worthy of trial. Their selection and use require a critical assessment of the tests applied and possibly some experiment with several different types of aid under similar environmental conditions. It may be necessary to increase the amount the sufferer is able to hear, or to improve his speech comprehension, or both (Rupp, 1963).

Rehabilitation is as important for those suffering from hearing impairment as it is for any other type of disability. However, relatively speaking, as noise-induced loss rarely causes total deafness, rehabilitation may not be quite as important as with some other types of deafness. Before a person can begin adjusting to his disability, there must be some perception of the loss, which must be put into perspective, and then motivation must be developed to cope with the handicap and living in general. The otologist is an important person in such a programme (Hoople, 1951). The importance of a realistic job assessment should not be overlooked.

Placement problems do not concern only the patient's doctor and employer; there may be a question for consideration at governmental level if there appears to be need for legislation protecting those disabled by hearing impairment. Particular attention should be accorded to deaf juveniles entering industry for the first time; some come on to the labour market at a later age than usual and may have missed any statutory medical examination for fitness for employment (New Zealand, Board of Health, 1962).
A damage-risk criterion specifies the maximum sound-pressure level of a noise, usually as a function of frequency, to which persons may be exposed if the risk of significant hearing loss is to be avoided (Harris, 1957). There may seem to be a broad analogy here with the maximum allowable concentration of dusts and gases widely used by industrial hygienists; but noise is a more complicated problem, because it may interfere with communication, annoy, or cause deafness, and there is no single limit applicable for all three. Some degree of empiricism is inevitable.

There are many difficulties in arriving at practical limits (American Standards Association, 1954). We know too little about the relation between temporary threshold shift and permanent noise-induced hearing loss. Limits can aim only at protecting the majority; it is often impracticable to allow for the noise-susceptible. Cochlear damage may result from causes other than noise, and in such cases differentiation may be difficult. It is often difficult to be precise about the extent and nature of exposure. In some situations, as when working in the neighbourhood of aircraft, quite small head movements can change the noise level at the ear by 10 dB or more (Eldred, Gannon & von Gierke, 1955). Again, many of the suggested criteria relate to the effects of long-term exposure to relatively continuous broad-band noises and are not applicable to other forms, such as impact noise. Presbycousis has to be allowed for. Finally, there is lack of agreement as to what constitutes hearing impairment and what degree of risk, if any, is acceptable. To prevent loss over the entire audible range may be economically impossible.

Expert opinion on maximum safe intensity levels is therefore anything but unanimous (Sterner, 1952; Eldredge, 1960; Bonney, 1962). Some of the several criteria proposed are not precise limits and can be regarded only as general guides. The difficulties of incorporating damage-risk criteria concepts into legislation are considerable. In consequence, some authorities favour keeping such standards out of governmental
acts and regulations and relying instead on the voluntary efforts of employers to keep exposures within tentative limits (Cohen, 1963). Nevertheless, present knowledge is such that it is not usually difficult for a competent investigator to give a useful opinion with regard to many specific hazards or situations, and current research will probably permit the future appraisal of border-line exposures to be made more accurately than is now possible.

A damage-risk criterion is a statistical concept applicable to a group of workers and makes no allowance for the individual. To protect everyone, it would be necessary to set noise levels so low that, in many cases, industry could neither achieve nor financially afford them. The boundary separating harmless from harmful noise has been variously called the critical noise level, or maximum safe intensity level, because of the assumption that intensity was the sole factor determining the hazardous quality of the noise (Sataloff, 1957). Earlier literature abounds in statements concerning safe over-all levels (Bunch, 1942; Davis, 1945; McLaren & Chaney, 1947). But it is now agreed that it is not possible to specify potentially damaging levels in terms of an over-all sound-levelmeter reading alone. Nevertheless, exposure to 150 dB sound-pressure level, or above, irrespective of duration and type of ear protection should not be allowed. Many of the criteria refer to levels to which employees should not be exposed during their working lives. The importance of audiometry as a monitor of the effectiveness of the particular damage-risk criterion finally adopted in any factory can be readily understood.

It may well be the case that all frequencies of the noise spectrum are not equally damaging, and that any criterion must allow for both intensity and frequency. The "critical-band" concept assumes that, if a wide band of masking noise is taken at the minimum intensity required to mask a pure tone located at the middle of the frequency range, this band can be symmetrically reduced in width towards that tone without reduction in masking effectiveness until the critical bandwidth is reached, when the energy in the narrowed band equals that in the pure tone. Many consider that, for long and intermittent exposure, any sound frequency (or narrow band not exceeding the critical width) that is not more than 85 dB above 0.0002 dyn/cm² will not cause temporary or permanent deafness. For brief exposures of up to an hour, the intensity necessary to cause impairment is, in general, of the order of 100 dB above 0.0002 dyn/cm² for any frequency or critical band (Kryter, 1950). Table 14 sets out the criteria proposed by some authorities. It is apparent that Kryter's figure of 85 dB comes nearer to 95 dB for the octave bands 300-600 Hz and higher.

Cohen (1963) has surveyed public opinion and the degree of acceptance of many of the various criteria. Many contours should not be
<table>
<thead>
<tr>
<th>Source of information</th>
<th>Sound-pressure level in octave band level equivalents (dB)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20-75</td>
<td>75-150</td>
</tr>
<tr>
<td>Kryter (1950)</td>
<td>81</td>
<td>85</td>
</tr>
<tr>
<td>Kryter (1950)</td>
<td>125</td>
<td>115</td>
</tr>
<tr>
<td>Hardy (1952)</td>
<td>104-115</td>
<td>100-112</td>
</tr>
<tr>
<td>Strasberg (1952)</td>
<td>115</td>
<td>110</td>
</tr>
<tr>
<td>(a) repeated exposure</td>
<td>125</td>
<td>120</td>
</tr>
<tr>
<td>(b) occasional exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rosenblith Stevens (1953)</td>
<td>110</td>
<td>102</td>
</tr>
<tr>
<td>(a) continuous-spectrum noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) narrow-band noise</td>
<td>110</td>
<td>102</td>
</tr>
<tr>
<td>Lindeman (1955)</td>
<td>110</td>
<td>102</td>
</tr>
<tr>
<td>United States Air Force (1956)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) continuous-spectrum noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) narrow-band noise</td>
<td>105</td>
<td>102</td>
</tr>
<tr>
<td>American Academy of Ophthalmology and Otolaryngology (1957)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>continuous-spectrum noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USSR (Tentative standards and regulations for restricting noise in industry)</td>
<td>100</td>
<td>95</td>
</tr>
</tbody>
</table>
taken too literally. For some criteria, applicable up to a lifetime's exposure in working days, deviations of 1 or 2 dB in either direction can probably be disregarded, and contours 10 dB lower would involve negligible risk—although 10 dB higher represents a significant rise in risk. The Workmen's Compensation Board in New York stated, in 1953, that most persons exposed to noise of over 120 dB for several hours daily will, in a matter of months, suffer permanent hearing damage—regardless of the composition of the noise. Many of those exposed for long to most industrial noises at an over-all level of 100-120 dB daily will suffer permanent damage, the proportion increasing as the noise level approaches the upper figure. A few susceptible persons may suffer permanent damage after many years' exposure to certain noises between 90 dB and 100 dB (Committee of Consultants, 1953).

In 1955, Eldred, Gannon & von Gierke made known their criteria relating to short-time exposure of personnel to high-intensity jet-aircraft noise.

When, in 1956, the United States Air Force published its criteria for continuous spectrum and narrow-band noises, shown in Table 14, it instituted a hearing-conservation programme with the goal of preserving hearing threshold levels of 15 dB or better for pure tones at the test frequencies of 500, 1000 and 2000 Hz (Eldredge, 1960). The "equal energy rule" assumes that equal quantities of acoustic energy entering the ear are equally harmful, regardless of how the energy is distributed in time, provided the intensity of this energy exceeds 85 dB (Marchbanks & Stack, 1958). Ward, Glorig & Sklar (1959a) consider that this assumption overprotects. It will be seen from Table 14 that more stringent criteria are suggested for narrow-band than for continuous-spectrum noise. This may not be necessary, as recent work has shown that the critical-band concept is not relevant at high intensities (Yaffe & Jones, 1961). It has been suggested that damage-risk criteria for pure tones should be developed empirically by measuring temporary threshold shifts directly, rather than by attempting to modify existing criteria for octave-band noise (Ward, 1962c).

In 1957, a group of internationally known authorities presented curves from which it is possible to determine the sound-pressure level, for different frequency bands, at which hearing-conservation procedures are recommended for persons exposed, during a lifetime, daily for various durations from 0.5 to 500 minutes (American Industrial Hygiene Association, 1958).

While in 1957 the American Academy of Ophthalmology and Otolaryngology stated that "our knowledge of the relations of noise exposure to hearing loss is much too limited for us to propose 'safe' amounts of noise exposure", in 1964 they were able to state that knowledge
now “permits us to propose guide lines for establishing standards for preventing significant noise-induced hearing loss in the majority of exposed persons.” The standards recommended are, in brief modified form, those proposed by the International Organisation for Standardisation (see page 89). This publication of the American Academy of Ophthalmology and Otolaryngology (1964) should be read by both employers and trade-union officials. It gives useful information on how to organize, conduct and monitor a practical hearing-conservation programme. The three main components of the latter are listed in addition to the four major factors that characterize noise exposure. The role of the physician is also briefly discussed. The members of the committee that produced the document, recognizing that much remains to be learnt, appeal for further research and for data on existing hearing-conservation programmes to be made available for study by their Research Center.

In 1957, a Japanese authority proposed the following maximum values with the object of ensuring that the average net hearing loss in the speech frequency range should not exceed 25 dB after 20 years’ service (Katsuki, 1957):

<table>
<thead>
<tr>
<th>Predominant frequency band (Hz)</th>
<th>100-200</th>
<th>200-3200</th>
<th>3200-6400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold limit (dB per octave band)</td>
<td>95</td>
<td>90</td>
<td>85</td>
</tr>
</tbody>
</table>

It has also been tentatively suggested that the following criteria, if not exceeded during the working day, can be expected not to cause deafness in an unspecified majority of persons (Littler, 1958):

<table>
<thead>
<tr>
<th>Frequency band (Hz)</th>
<th>75-150-300-600-1200-2400-4800-150</th>
<th>300</th>
<th>600</th>
<th>1200</th>
<th>2400</th>
<th>4800</th>
<th>10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound-pressure level in band (dB above 0.0002 dyn/cm²)</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>75</td>
<td>75</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

Universally acceptable criteria for safe exposure to impulse noise have not yet been formulated. Any impact noise, such as riveting and forging, that causes temporary hearing loss noticeable after several hours exposure is potentially dangerous to hearing; and no one should be exposed to such noise without the application of hearing-conservation measures (Glorig, Ward & Nixon, 1961; Cohen, 1963). Intense pure tones also should be regarded as potentially more damaging than steady-state noise.

A French technical committee, appointed by the Ministry of Public Health, recommended the use of a curve showing maximum levels at different frequencies that should not be exceeded for eight-hour exposures to a complex noise (International Occupational Safety and Health Information Centre, 1961).
When healthy young Russian men engaged in heavy manual work were exposed for 110 minutes to noise levels of 80, 70 and 65 dB in the frequency range 1250-2500 Hz, it was found—for high-frequency noise of 80 dB—that muscular performance deteriorated and that there were disturbances of cortical and autonomic nervous functions. On this basis, it has been suggested that the permissible level for industrial noise should be reduced to 65/70 dB (Orlovskaja, 1962). Many would consider this limit unrealistic and industrially impracticable.

Kryter's damage-risk criteria (1963b, 1965) allow any exposure which on average does not produce a temporary threshold shift, measured two minutes after exposure, of more than 10 dB at 1000 Hz or below, 15 dB at 2000 Hz, and 20 dB at 3000 Hz and above. The damage-risk contours that meet these criteria are shown in Fig. 9.

FIG. 9. HEARING-CONSERVATION CRITERIA FOR BROAD-BAND NOISE

The graph gives, for a range of centre-band frequencies, the sound-pressure levels (in octave bands and one-third octave bands) at which hearing-conservation procedures are recommended, for various daily exposures.

Reproduced, by permission, from Kryter (1963b).

The International Organisation for Standardisation (1963a) proposed in June 1963 the use of a noise-rating number $N$ to identify noise-
rating curves. Many aspects and details of the 1963 document are still being discussed. The noise-rating number for the octave band whose mid-frequency is 1000 Hz is numerically equal to the sound-pressure level (in decibels) of that octave band. For purposes of conservation of hearing, and when exposure to broad-band noise is habitual and continuous for five or more hours during the working day, the values of $N$ corresponding to the sound-pressure levels in the three octave bands whose mid-frequencies are 500, 1000 and 2000 Hz are determined. The rating of the noise in question is the highest of these three values. In brief, $N85$ is proposed as a limit for conservation of hearing because

<table>
<thead>
<tr>
<th>$N$ (dB)</th>
<th>On-time in minutes per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>more than 120</td>
</tr>
<tr>
<td>90</td>
<td>less than 120</td>
</tr>
<tr>
<td>95</td>
<td>less than 50</td>
</tr>
<tr>
<td>100</td>
<td>less than 25</td>
</tr>
<tr>
<td>105</td>
<td>less than 16</td>
</tr>
<tr>
<td>110</td>
<td>less than 12</td>
</tr>
<tr>
<td>115</td>
<td>less than 8</td>
</tr>
<tr>
<td>120</td>
<td>less than 5</td>
</tr>
</tbody>
</table>

This table is reproduced from the Draft Secretariat proposal for noise rating numbers with respect to conservation of hearing, speech communication and annoyance (ISO/TC 43 (Secretariat 194) 314). It is emphasized that this document is in draft form only and does not constitute an officially recognized standard of the International Organisation for Standardisation.

habitual exposure to such a noise for 10 years may be expected to cause negligible hearing loss in the average person. In general, the corresponding sound-pressure levels are considered "just allowable". With habitual exposure to continuous broad-band noise for less than five hours a day, the permissible value of $N$ is obtainable from Table 15. When the exposure to broad-band noise is intermittent and habitual during the working day, the rating permissible when the noise is being produced may be obtained from Fig. 10, which expresses the relationship between the duration of the "on-time", the intervals between noise bursts, and the permissible rating number (solid curves).

For various reasons, approximate measurements are sometimes desirable. Whenever the noise in question is loud enough to make conversation difficult even when shouting loudly at a distance of 1 ft (0.3 m) from the listener's ear, detailed studies are indicated as set out
above, and the same is required whenever the reading of the sound-level meter minus 4 dB and using weighting with fast response (curve A) exceeds the appropriate noise-rating number.

FIG. 10. NOISE-RATING NUMBERS FOR INTERMITTENT NOISE EXPOSURE

The graph shows the relationship between the duration of the "on time" and the duration of the "off time" of the intermittent noise. The continuous curves are the loci of constant noise-rating numbers. The broken curves represent the permitted number of exposures to the intermittent noise per day.

This graph is reproduced from the Draft Secretariat proposal for noise rating numbers with respect to conservation of hearing, speech communication and annoyance (ISO/TC 43 (Secretariat 194) 314). It is emphasized that this document is in draft form only and does not constitute an officially recognized standard of the International Organisation for Standardisation.
The draft secretariat proposal of the ISO (1963a) to use noise-rating numbers in hearing-conservation work is based partly on the fact that (according to the best prediction) the final hearing level at 4000 Hz is, in general, numerically equal to the temporary hearing level measured two minutes after the cessation of five hours’ continuous exposure to the noise in question.

To determine whether a particular noise is permissible, the temporary threshold level produced at 2000 Hz and measured two minutes after the end of five hours’ continuous exposure should be compared with a threshold level that has been selected as "just permissible". The selection of this just-permissible threshold level depends upon a prior decision on what constitutes a significant permanent impairment of hearing. The selection may be different for different purposes or under different

**FIG. 11. NOISE-RATING NUMBERS FOR SHORT-TERM NOISE EXPOSURE**

The curves represent constant noise-rating numbers as given on the right-hand side of the graph.

This graph is reproduced from the Draft Secretariat proposal for noise rating numbers with respect to conservation of hearing, speech communication and annoyance (ISO/TC 43 (Secretariat 194) 314). It is emphasised that this document is in draft form only and does not constitute an officially recognized standard of the International Organisation for Standardisation.
administrative jurisdictions. The noise-rating numbers proposed for
the different kinds of exposure described are based on a permissible
temporary threshold shift of 12 dB at 2000 Hz; for other choices of this
permitted TTS, Fig. 11 should be consulted. Not all the propositions
made by the ISO are well supported by experimental data (International

The British Medical Association has stated that it is generally accepted
that conditions involving continuous exposure throughout working
hours to noise whose intensity exceeds 85 dB in any octave band in the
speech range of 250-4000 Hz could cause permanent hearing impairment
(Committee on the Problem of Noise, 1963). Arkad'evskij (1964) has
produced a curve for continuous industrial noise on the basis of various
physiological criteria.

The preceding chronological itemization is not a comprehensive one.
CHAPTER 11

LEGISLATIVE CONTROL OF NOISE, AND COMPENSATION FOR NOISE-INDUCED HEARING LOSS

In many countries compensation legislation originally provided only for accidental injuries. Even today some legislation makes no specific reference to diseases arising in the course of employment, so that noise-induced hearing loss may or may not be accepted as an accident and thus become eligible for compensation. In some countries a common-law suit is the only means of redress. Cohen (1963) has compared the differing aspects of noise-compensation legislation in the American States. In the USA, consideration has been given to a model compensation and rehabilitation law (Dane, 1963). Many difficulties arise because of the insidious onset of noise-induced hearing losses. Mature thought must be given to the provisions of legislation since haste, perhaps resulting from inappropriate public pressure, may result in unsatisfactory compromises and provisions.

Because of the accrued liability of certain industries, legislation may contain provisions aimed primarily at containing the over-all problem within practical economic considerations.

The law may specify that, for purposes of entitlement, the injury shall be deemed to have occurred either at the date of the accident causing injury, or at the time of the claim, or when the worker first became aware of his disability. In some countries the employee must be absent from work for a specified number of days before he can claim (Drop Forging Association, 1961). In one American State, the date of disability is the last day of the six-month period following separation from employment in which the employee was exposed to harmful noise (Davis, 1960). Alternatively, the date of disablement may be related to the last day of work, rather than to the last day of injurious exposure (Hayes, 1958). In an attempt to avoid unnecessary claims, some legislatures require that compensation shall not be payable unless the employee has been occupationally exposed for a minimum period, amounting in some cases to 90 days.
Some relevant considerations are the noise levels at which hearing loss occurs, the impairment—if any—before beginning employment, the hearing tests to be used, the evaluation of susceptibility and disability, the allowance to be made for presbycusis, and problems of differential diagnosis (Fox, 1956b). One of the chief causes for dispute results from the lack of reliable records establishing hearing status at the start of employment. The legislative position, considered both nationally and internationally, remains fluid, and whatever is written on this subject may be soon out of date. The legal, medical, scientific and technical factors involved, as applicable to the USA, have recently been summarized (American Mutual Insurance Alliance, 1964). It is unfortunate that some employers resist taking any preventive measures, such as the institution of audiometry, that might possibly, directly or indirectly, result in paying compensation. Yet in some countries it is a demonstrable fact that companies with active hearing-conservation programmes face fewer compensation claims than those that make no attempt to abate noise or to follow their employees' hearing status (Glorig, 1961a).

In 1961, in almost all of the American States in which occupational hearing loss was compensable, the number of claims was negligible (Drop Forging Association, 1961). However, although it is true to say that some of the industrialized countries have no specific legislation, many of them are becoming increasingly aware of, and alive to, the problem (Davies, 1962). Thus, in the State of California, only four hearing-loss claims were processed under workmen's compensation law in 1952, whereas 352 claims were filed ten years later (H. M. Mitchell—personal communication, 1963). In 1961, occupational hearing loss was compensable in 22 of the 50 American States, and traumatic hearing loss in almost every one. The impact of standards on compensation claims for loss of hearing has been discussed by Frazier (1965). In Great Britain, if occupational deafness were to be a "prescribed" disease the occupation would also have to be prescribed, i.e., deafness would have to be treated as a particular occupational risk. From time to time the list of prescribed diseases is extended as new evidence comes to hand (Hunter, 1964). Provisions vary in different countries: in Costa Rica (1956), diseases due to physical agents, including noise, are defined as occupational diseases giving entitlement to compensation. In Norway, impairment of hearing caused by noise from machines or tools is included in the list of occupational diseases classified as accidents entitling the victim to accident-insurance benefit. In Japan, compensation is established when, at the time of retirement, hearing losses due to industrial noise exceed 60 dB in the speech-frequency range (Katsuki, 1957).

In 1948, the New York State Court of Appeals held that compensation for partial noise-induced hearing loss was allowable even though
there had been no loss of wages—an important decision since in general it was contrary to the traditional principle that compensation should provide for loss of earnings and medical costs only. However, this concept is not really new since for a long time many awards have been made every year for disfigurement, loss of function of limbs, or visual impairment where there has been no loss of earnings and where it is not anticipated that these defects will cause such a loss in the future (Goldner, 1955).

Some Canadian Provinces will not compensate unless there has been a loss of earning capacity; in others awards are not made until deafness has become a social handicap. In 1961, Canadian Workmen’s Compensation Boards adopted a uniform rating designed to assess the loss of earning capacity. A formula was applied in cases of binaural loss whereby, after averaging the hearing thresholds at 500, 1000 and 2000 Hz and, for claimants over 50 years of age, deducting 0.5 dB for each year exceeding that age, the hearing loss in decibels is translated into a scheduled disability rate. The combined disability in the two ears is determined by multiplying the percentage disability in the better ear by nine, and then adding this to the percentage disability in the poorer ear.

Some authorities hold the view that no substantial injustice is done if no presbycusis correction is made when judging the percentage impairment for which compensation is to be paid—a small omission favouring the worker (Glorig & Davis, 1961). Other authorities, and legislatures, apply corrections (Fox, 1956a; Kalmykov, 1960).

The compensation payable should be a joint medical, legal and administrative decision and, as such, may vary from time to time. Within a country there may be very great local differences in the maximum amounts payable, e.g., from $22,500 in Hawaii to $3500 in Virginia, USA (Drop Forging Association, 1961). In some countries, a fixed sum is payable for certain scheduled degrees of impairment, regardless of absence from work. Where legislatures require that benefits be paid on a schedule rather than on a wage-loss basis, it has been advocated that a reduced schedule of benefits should be applied; this helps to keep industrial liability within bounds, since hearing loss seldom produces industrial disability in the legal sense. Industry cannot reasonably assume sole responsibility for hearing loss when a substantial element is common to the population at large, regardless of occupational exposure (American Foundrymen’s Society, 1958). Industry must be protected against claims it is unable to meet, and non-occupational losses must be distinguished as far as possible from those arising from other causes. Without some control measures, the potential liabilities of industrialists could be astronomical (Glorig, 1961a).
The introduction of a waiting period is sometimes used to limit the number of claims an organization may have to face in a given period. However, if the employee should die during this interval of time, any potential award should not be jeopardized if audiometric or otological evidence existing before death proves a causal relationship (Symons, 1958). Symons, in addition to Hayes (1958), has detailed many of the important problems relating to compensation. If compensation were paid for any loss deviation from the audiometric zero, large numbers of workers would be entitled even though their hearing was still within the normal range. Some legislation allows for this by providing that compensation is not payable unless the average loss exceeds 15-17 dB (J. occup. Med., 1963). In some countries no consideration is given to any improvement in speech comprehension made possible through the use of a hearing aid.

Occupational hearing impairment is usually the outcome of many years' exposure, during which the employee may have held several posts. This is why pre-placement examination is so important in the apportionment of disability and why the prospective employer should, within a given time, notify the findings to the previous employer (Hayes, 1958). In some States of the USA, the latter is not liable if the last preceding harmful exposure was more than three years before the date of such notification (Symons, 1958).

To allow for temporary threshold shift, i.e., for auditory fatigue, it may be advisable for the first examination to be made not less than 48 hours after removal from the noisy environment (Fox, 1956a).

If audiometric examinations are to become more widely used, legislation should preferably specify the standards and conditions for testing and perhaps state who is responsible for the costs. Enacted legislation should encourage employers to employ, in certain jobs, those suffering from noise-induced losses. Similarly, industry must not be penalised for engaging in abatement measures; legislation should encourage employers to reduce or modify the noise in their factories, thereby protecting themselves against future claims. Compensation enactments should also contain provisions designed to encourage research to solve difficult problems.

**LEGISLATIVE CONTROL OF INDUSTRIAL NOISE**

Public health administrators must consider whether there is a need for specific legislation on noise hazards. If so, its form will be influenced by the degree of industrialization and the social and political characteristics of each country. In some countries there is no statutory control
because it is felt that persuasion achieves better results. This may work well during full employment but not in periods of economic difficulty, and there are always some employers who will shirk their responsibilities. Broad condemnations of manufacturing processes that produce potentially harmful amounts of noise are not always easy to substantiate in detail with regard to particular cases in courts of law.

Where an inspector is empowered to require management to carry out such specific control measures as he considers necessary, the advantages of flexibility and adaptability to individual conditions are present. The employer, in his turn, should have a legal right of appeal. Sometimes authority is delegated to a specially constituted board with technical advisers. In certain countries, such as the USSR, the acts and regulations are very detailed and specific.

Legislation alone is of limited value without an informed public opinion, in this case industrial. Its value is also limited if there is insufficient staff to enforce it, to carry out the necessary assessments, and to give the required technical advice. This type of legislation is generally administered by either the Department of Health or the Department of Labour. In some countries, factory inspectors have to carry out a wide range of activities and duties, not all of which are related to improvement of the work environment; therefore the time available for noise control may not be great. It is important for the non-technical inspector to know enough about noise hazards to be able to decide whether there is a problem in a particular factory. For every medically or technically qualified person on the central-control-agency staff there are usually many lay inspectors; the former need well equipped laboratories so as to be able to provide the necessary technical support for their lay colleagues and to carry on appropriate research. The scientist may be required to provide measurements and analyses on which legal proceedings will be based.

The noise-control measures of different countries deal with such aspects as pre-employment and in-employment hearing tests, methods of measuring noise, audiometric examinations, and protective measures. These vary from country to country. Some are more detailed than others, and some nations have no legislation at all. Some points of interest may be selected for notice.

In Austria very noisy machines or manufacturing processes must be physically separated from other places of work, and in certain circumstances the authorities may require specialized control measures (Böse, 1960). In Czechoslovakia, it is recommended that, wherever possible, risks should be reduced by the introduction of automation and remote control. Low noise levels are considered an index of quality in factory operation, and acoustics and vibration experts must advise on factory
construction. Machines, etc., may not be imported if they exceed allowable noise limits. In Finland, if a harmful noise cannot be adequately dealt with otherwise, the process must be intermittently reduced or interrupted. The Agricultural Association of the Federal Republic of Germany issues directives for the approval of agricultural machinery (Freidank, 1962). The International Labour Office (1951) recommends measures to reduce noise in offices from the many possible sources. Turkey prohibits the entry of those not directly involved into noisy machine rooms.

Some American States require noise control at source. Detailed regulations proposed in the USSR cover numerous important matters such as the design and operation of machines, vibration control, replacement of percussive operations by non-percussive ones, sound-proof cabins, sound-absorbing materials, methods of measuring noise, calibration of instruments, permissible levels, medical examinations and ear defenders. The technical impossibility of lowering a noise level must be proved before a commission. In the Netherlands, test methods are laid down to determine the hearing ability of ships' officers and crews, with particular regard to their ability to understand spoken orders.

India has no statutory requirements, although certain industrial undertakings require employees to undergo audiometry before starting work, e.g., aircraft mechanics. Italy (1956) specifies certain operations or classes of worker for annual hearing testing; and in Japan certain industries are listed whose operatives must undergo pre-employment and periodic in-employment audiometry. In a number of countries, including New Zealand (1957), Denmark (1955) and France (1935), it is compulsory for doctors to notify cases of deafness of occupational origin. The Brazilian legislation classifies any noise above 80 dB as hazardous enough to justify a higher salary—an incentive to employers to reduce the hazard. Other countries incorporate noise limits in their legislation e.g., for offices in Czechoslovakia and for ships of the Federal Republic of Germany (Seamen's Mutual Accident Insurance Association, 1962). In some countries, for example Finland, semi-official limit values are used (Lehtinen, 1963).

In many countries, such as Australia, Denmark and Norway, special organizations or committees have been established to investigate noise problems (Australia, 1948).

Some national legislation, such as that of Austria (1951) and Canada, requires the provision of ear-defenders and hearing aids. The International Labour Office (1949) has discussed the use and maintenance of defenders. Recent legislation in California (United States, State of California, 1963) not only specifies when earplugs are to be worn—namely, when exposure equals or exceeds certain stated levels—but also
stipulates the need to instruct those who use them. In connexion with the use of ear-defenders, Italian legislation specifies the respective obligations of employers and workers (Italy, 1956).

It may thus be seen that there are important variations in enacted legislation. The need for "model" legislation is briefly discussed in a later chapter.
CHAPTER 12

COMMUNITY NOISE

"Britain should be considerably quieter than it is... unless something is done the situation will soon become intolerable." 1

This is a statement that could well be applied to many countries. The causes of community noise are many: surface and air transport; ground testing of aircraft; construction noises; amusement areas; electrical substations and air-conditioning systems; animals; sources within the home such as radio and television sets; and, by no means least, industry. Even rural peace is often shattered. In many countries, there is an increased awareness of the problems of community noise, if only because cities are becoming steadily noisier; for example, in Birmingham, England, 33 complaints were received by the authorities in 1957, 54 in 1960, and 182 in 1962 (Millar, 1963). A similar increase has occurred in Sydney, Australia. City noise in the USA is said to be increasing at the rate of 1 dB every year (Noise Control, 1961). Community noise has been studied in many cities, such as London (Burgess, 1961) and Tokyo (Miura, 1961). Transport noise is becoming increasingly important (Purkis, 1964).

In evaluating community-noise problems, it is sometimes essential to know how the community in question has developed, its economic basis, and the attitudes of its members. One may have to blend physics with psychology and with political appreciation. The difficulties of assessing individual annoyances are usually magnified when dealing with a community, and sometimes accentuated by motivations that are difficult to measure. What is acceptable to one person or group is unpleasant to others. Some protest violently against the noise of construction work, others accept it as a symbol of prosperity and employment. A community's complaints about noise are conditioned by many factors—whether it is a residential or an industrial area, the community's wish to attract or discourage industry, the standards of house construction, the

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1 The Times, London, 3 July 1963.
location of schools and hospitals, the times when noise occurs or recurs, the characteristics of the noise, topography, the effects of noise on property values, and whether noise is a reminder of the possibility of accidents.

The relations between industry and the community are also important. Originally, it was more important to get factories into operation than to worry about the control of such hazards as air pollution and noise; and because silence costs money, control measures have too often been ignored. The picture is changing now, partly because of successful legal processes, partly because the general public is expecting to be nuisance-free. Residents are likely to be more sympathetic if they feel that industry is doing its best to reduce the nuisance. A good public-relations department will see that there are apologies and explanations for temporary annoyances, that the noise is kept at a minimum, and that operational staff take the trouble to acquaint neighbours with conditions and progress. It may be that delivery trucks and ancillary processes within factory buildings are as much the source of complaints as the basic manufacturing processes themselves; men shouting at night may cause more disturbance than machines. The list is almost endless.

In a free field, the intensity of propagated sound diminishes proportionately to the square of the distance from the source, and so the space between factories and houses is important. Other factors may operate, such as the absorption of sound by the air, which, in turn, depends on its temperature and humidity. Propagation from points near the ground to other points at the same level is affected by reflection, wind, temperature gradients, atmospheric turbulence, fog and snow. Wind and temperature gradients may account for the occasional freak reception of sounds over long distances, while places nearer the source hear nothing (Parkin, 1962). If a barrier (a wall or a building) is interposed between a source and a receiving position, the reduction obtained depends on the mutual distances between the three, the height of the barrier, and the wavelength of the sound. It may be possible to calculate the probable reduction in advance.

Table 16 sets out information obtained from persons questioned about the types of noise that disturbed them at home, outdoors, and at work. For people studied in the United Kingdom, more annoyance is caused by intrusive noise when at home than when outdoors or at work. People are much more disturbed in their residences by the noise of passing traffic or of industry than by noise originating in their homes or by noise made by neighbours in adjacent rooms.

The industrial aspects of the problem may be briefly outlined. Some industries, by their nature, are noisy. Yet industry cannot exist without the community where it is sited, and the community cannot be economi-
<table>
<thead>
<tr>
<th>Description of noise</th>
<th>Number of persons disturbed per 100 questioned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When at home When outdoors When at work</td>
</tr>
<tr>
<td>Road traffic</td>
<td>36</td>
</tr>
<tr>
<td>Aircraft</td>
<td>9</td>
</tr>
<tr>
<td>Trains</td>
<td>5</td>
</tr>
<tr>
<td>Industry/construction works</td>
<td>7</td>
</tr>
<tr>
<td>Domestic/light appliances</td>
<td>4</td>
</tr>
<tr>
<td>Neighbours' impact noises</td>
<td>6</td>
</tr>
<tr>
<td>Children</td>
<td>9</td>
</tr>
<tr>
<td>Adult voices</td>
<td>10</td>
</tr>
<tr>
<td>Radio/television</td>
<td>7</td>
</tr>
<tr>
<td>Bells/alarms</td>
<td>3</td>
</tr>
<tr>
<td>Pets</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
</tr>
</tbody>
</table>

Adapted, by permission, from Committee on the Problem of Noise (1963).

Cally healthy without industry. The problem of arranging for industry to function economically without infringing the community's reasonable requirements for living conditions is not insoluble, but calls for co-operation all round. There is some risk here that well organized vociferous minorities may succeed in imposing unreasonable restrictions on industry. Many authorities have discussed the over-all problem of the community and industrial noise (Burns, 1962).

**THE CONTROL OF RESIDENTIAL NOISE OF INDUSTRIAL ORIGIN**

**Policy**

Plant management cannot be entirely successful in controlling plant or residential industrial noise without the fullest policy and financial support from the top executives. All levels of management should be informed of any decisions, and it is often advisable for near-by residents to be told something of a factory's aims and methods. Much can be done by arrangements within the plant. Machines can be so located as to cause the minimum of noise in near-by houses. The operation of very noisy machines can be limited to certain times of day. Outdoor workers must not be allowed to create unnecessary noise.
Factory design

The materials used in factory construction, the number and position of windows and doors, ducts and pipe-lines, may affect the noise level of the neighbourhood. Regulations, such as the standards proposed in the USSR in 1959, may require that in planning or remodelling structures to house noisy machines measures be taken to prevent the propagation of loud noise beyond the premises to quieter localities, that noisier installations be grouped at points removed as far as possible from offices and adjacent residential buildings, and that insulating materials be used to shield installations so that the existing noise level in adjoining buildings and neighbouring localities is not increased by more than 3 dB. Transmitted vibration and noise must be reduced by suitable mounting or insulation of the source. The outlets of airducts should be equipped with mufflers, rail tracks laid on elastic foundations and junctions welded, main roads within the plant surfaced with asphalt and lined with trees.

If it is possible to control the noise at source, as by engineering modifications to machines, conditions will be improved both within and without the factory.

Town planning and zoning

In 1898, Ebenezer Howard of Great Britain stated that cities should be limited to a size of 50,000 inhabitants and insulated by strips of non-urban land: a green belt of park, forest or agricultural development. A buffer strip of land—often landscaped with shrubs and trees—used to insulate a noisy factory from the surrounding area is a scaled-down version of such a green belt. The high-frequency content of sound is reduced when it passes through a thick hedge, and this has a great effect in reducing the apparent loudness of a source, especially as the latter is also shut off from view (Parkin, 1962). Wind movement of the hedge may produce an acceptable masking noise.

City planning is primarily concerned with the future. A scheme that will make a great difference in the long run may have little initial effect. The results of past lack of forethought are aggravated by situations still developing that will certainly create noise problems in years to come. In some cities today, commercial activity is passing from the centre to the suburbs, which must not be allowed to become the noisy slums of tomorrow. Whenever possible, a noise survey should precede any town-planning scheme.

Zoning is an important part of town planning (Kosten, 1963), and is applicable both to noise and to such other environmental noxae as
vibration and air pollution. The educational value of zoning for noise levels is considerable, and standards may gradually become matters of public interest and debate (Forster, 1962). Originally, many city planners provided for two types of industrial district, heavy and light, a distinction often unsatisfactory in practice. In either category, the range of noise may be very wide. Recently, therefore, planners have reviewed their notions about assigning industries to predetermined areas and have arrived at the idea of performance standards in zoning.

Performance standards are the most scientific approach to city planning for reduced noise. Industry is not confined to particular localities, but can, within limits, be established anywhere provided it does not create a nuisance or devalue the area. Determining suitable performance standards is far from simple. Limits must not be made so liberal that numerous legitimate complaints are still received, or so strict as to discourage industrial development unduly. Ideally, a factory should be required to predict the noise it will produce when in operation, and to live up to these predictions. Factories must be built in such a way as to ensure that they do not propagate noises prominent enough above the background to call forth community complaints. This will sometimes imply that managements may have to obtain the services of acoustic engineers before submitting building plans or control proposals to planning authorities. Ideally, it should be possible to tell, by studying the blue-prints, whether a factory, when built, will meet the noise standards for the area.

Laws must be reasonable and realistic, and there must be an advisory and enforcement agency with trained staff and suitable equipment. Pressure can be applied to builders; thus, in the USA, to discourage the building of homes near certain jet airports, the Federal Housing Administration will not grant mortgage loans on houses so situated (Noise Control, 1961). In Czechoslovakia, factories where the noise level exceeds 100 dB must have a protection belt of 500 metres, and be so sited that the external noise level at the nearest point to any residential area does not exceed 50 dB by day or 40 dB at night. In Osaka City, Japan, where the maximum permissible levels are as set out in Table 17, more than 25% of the residents complained of emotional effects at a level of 40-45 phons, disturbance of daily life at 45-50 phons, and physical effects at 50-55 phons (Miura, 1961). In Chicago, there are performance standards for three main categories of district: restricted, general, and heavy manufacturing districts (Table 18). The city of Warwick, USA, also has noise codes (Schall, 1964), but codes or standards suitable for one area or city may be totally unsuitable for another. Provisional regulations in the USSR state that sites for industrial plant or research institutes using noisy equipment must be selected with regard to the
TABLE 17. OSAKA CITY—MAXIMUM PERMITTED NOISE LEVELS

<table>
<thead>
<tr>
<th>Area</th>
<th>Factory noise (phons)</th>
<th>City noise (phons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day</td>
<td>Night</td>
</tr>
<tr>
<td>Industrial</td>
<td>65-70 7 a.m.-11 p.m.</td>
<td>55-60 11 p.m.-7 a.m.</td>
</tr>
<tr>
<td>Commercial</td>
<td>60-65 7 a.m.-11 p.m.</td>
<td>50-55 11 p.m.-7 a.m.</td>
</tr>
<tr>
<td>Residential</td>
<td>55-60 8 a.m.-8 p.m.</td>
<td>45-50 8 p.m.-8 a.m.</td>
</tr>
</tbody>
</table>

Adapted, by permission, from Miuza (1901).

existing or planned layout of the town or industrial centre; that plants with equipment causing a noise level of over 90 dB should be sited on the leeward side of the nearest residential area (in terms of prevailing winds) and separated from it by an acoustic buffer zone, landscaped and planted with trees, beyond which the total level of emerging sound must not exceed 50 phons; and that certain installations whose noise level exceeds 130 dB must be placed several kilometers outside the city limits.

EVALUATION OF RESIDENTIAL NOISE

The evaluation of residential noise presents many difficulties. The value judgments involved often depend on social, political and other ill-defined considerations. Satisfactory noise limits cannot be, and perhaps never will be, formulated to everyone’s satisfaction, and decisions must be based on average community reactions.

The International Organisation for Standardisation (1963a) made several important proposals, many of which are still being discussed, dealing with noise ratings for “annoyance”; the documents in question discuss measurement techniques and procedures to determine noise-rating numbers. Table 19 sets out the suggested ranges of maximum noise-rating numbers for certain indoor non-residential spaces, and Table 20 shows the probable public reactions to excessive residential

---

1 This document is in draft form only and does not constitute an officially recognized standard of the ISO.
<table>
<thead>
<tr>
<th>Octave band (Hz)</th>
<th>Maximum permitted sound level in decibels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Restricted manufacturing districts</td>
</tr>
<tr>
<td></td>
<td>Along residence district boundaries (A)</td>
</tr>
<tr>
<td>0- 75</td>
<td>72</td>
</tr>
<tr>
<td>75- 150</td>
<td>67</td>
</tr>
<tr>
<td>150- 300</td>
<td>59</td>
</tr>
<tr>
<td>300- 600</td>
<td>52</td>
</tr>
<tr>
<td>600-1 200</td>
<td>46</td>
</tr>
<tr>
<td>1 200-2 400</td>
<td>40</td>
</tr>
<tr>
<td>2 400-4 800</td>
<td>34</td>
</tr>
<tr>
<td>Above 4 800</td>
<td>32</td>
</tr>
</tbody>
</table>
TABLE 19. SUGGESTED RANGES OF MAXIMUM NOISE-RATING NUMBERS FOR NON-RESIDENTIAL INDOOR SPACES

<table>
<thead>
<tr>
<th>Type of room</th>
<th>Noise-rating number (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital, theatre, church, cinema, concert hall, small office, reading room, conference room, lecture room</td>
<td>20-30</td>
</tr>
<tr>
<td>Larger office, business store, department store, meeting room, quiet restaurant</td>
<td>30-40</td>
</tr>
<tr>
<td>Larger restaurant, secretarial office (with typewriter), gymnasium</td>
<td>40-50</td>
</tr>
<tr>
<td>Larger typing hall</td>
<td>50-60</td>
</tr>
<tr>
<td>Workshop</td>
<td>60-70</td>
</tr>
</tbody>
</table>

TABLE 20. ESTIMATED PUBLIC REACTION TO NOISE IN RESIDENTIAL CASES

<table>
<thead>
<tr>
<th>Excess of noise over suggested corrected noise-rating number (dB)</th>
<th>Estimated public reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0</td>
<td>No observed reaction</td>
</tr>
<tr>
<td>0 to 10</td>
<td>Sporadic complaints</td>
</tr>
<tr>
<td>5 to 15</td>
<td>Widespread complaints</td>
</tr>
<tr>
<td>10 to 20</td>
<td>Threats of community action</td>
</tr>
<tr>
<td>More than 15</td>
<td>Vigorous community action</td>
</tr>
</tbody>
</table>

Tables 19 and 20 are reproduced from the Draft Secretariat proposal for noise rating numbers with respect to conservation of hearing, speech communication and annoyance (ISO/TC 43 (Secretariat 194) 314). It is emphasized that this document is in draft form only and does not constitute an officially recognized standard of the International Organisation for Standardisation.

noise; in deriving the data in the latter table a number of correction factors have been applied to the basic rating. Situations vary—for example, a heavily industrialized area might be rated at N55 without complaint, while a residential area with widely separated homes might be rated as low as N30. Hence the composite rating must include corrections for background-noise conditions, corrections which, though arbitrary, are based on the assumption that ambient noise levels are more or less stable. In some cases it may be necessary to measure background
noise in the absence of the alleged nuisance, in order to determine the
relation between irritant and basic environment.

Background noise levels in suburban communities may vary from
time to time; such variations should be taken into account in the drafting
of zoning and nuisance-control statutes (Ostergaard & Donley, 1964).

It has also been suggested by Purkis (1962) that, if the appropriate
basic figure for noise levels is adjusted for the circumstances of the
individual case, the sum of the basic figure and the allowance gives a
noise level above which complaints may be expected. It is possible, on
measuring the actual noise level produced by an offending factory and
comparing it with the criterion as estimated, to predict complaints in
about 90% of cases. The criteria determined relate to noise measured
outside buildings, though complaints themselves generally arise from
persons within them. Other contributions to the subject include that of
Kosten & Van Os (1962).

The study of the reactions of persons to aircraft noise has produced
the concept of perceived-noise level, expressed in units of PNdB, the
measure of noisiness implicit in a listener’s response to aircraft sound
(Kryter, 1959, 1960). This takes into account the distribution of power
as a function of frequency, and the fact that people judge higher fre-
quencies to be the most annoying when factors such as novelty and
adaptation remain constant. The British Ministry of Aviation has
adopted this concept in relation to communities living in the neighbour-
hood of airports. In the United Kingdom there is a limit of 100 per-
ceived-noise decibels in the take-off paths at airports. The perceived-
noise level can be determined by using a nomograph with the A and C
weighted sound-level readings.

OTHER LEGISLATIVE CONTROLS

In the United Kingdom, it is possible to take action against the per-
petrator of a nuisance under common law, the traditional body of case
law. A nuisance, in law, is an act or omission that interferes with a
person’s enjoyment of ownership or occupation of land, and noise is
obviously one such nuisance. But, because a nuisance is often difficult
to establish legally, common law cannot always adequately protect society
against the ever-growing problem of community noise. The phenomenon
is partly subjective, and is often incapable of objective definition.

The 1960 Noise Abatement Act in the United Kingdom widened the
scope of statutory provision, which formerly required a noise to be
hazardous to health before abatement could be enforced. Now, when
a noise is clearly established as a public health nuisance, there are two
methods of attack. Local authorities are given enforcement powers,
and property owners may complain to the magistrates. The effective-
ness of such legislation must hinge on the definition of a nuisance
(Forster, 1962).

The National Institute of Municipal Law Enforcement Officers have
produced a "model ordinance" prohibiting unnecessary noise.

Local (city) ordinances and bylaws may apply to automobile noise—
motor horns, brakes and silencers—and to the conditions and hours of
building work. In some countries, specific control legislation exists;
thus, in Denmark, bicycles with motors may not produce noise exceeding
79 dB measured outdoors at a distance of 7 meters. In Hesse, Germany,
a 1959 ordinance prohibits noisy work between certain defined hours.

There may be some justification for requiring houses close to fac-
tories to conform to certain building codes aimed at reducing the amount
of noise reaching their interiors (British Standards Institution, 1960).
When industry cannot, for technical or financial reasons, reduce its noise
output to acceptable levels, sound-proofing of near-by homes—possibly
with government assistance—may be the best course.

Finally, as in so many public health issues, it is important that the
general public should appreciate the extent and nature of the problem.
Anti-noise campaigns serve a useful purpose in focusing public attention
on the matter; they provoke discussion and are often a stimulus to posi-
tive control measures.
CHAPTER 13
THE POSSIBILITIES FOR
INTERNATIONAL ACTION

The problems of noise are not necessarily identical in developed and
developing nations.

In some industrialized countries, the vigorous application of preventive measures has considerably reduced the incidence of certain occupational diseases and thus accentuated the importance of conditions causing discomfort rather than disease. Rising living standards make for higher demands in relation to working and living conditions. However, it is necessary to remain on the alert, because noise has insidious effects. As a by-product of industrialization, it is too often ignored or considered only on an emotional plane that obscures the real issues and makes logical action more difficult.

In developing countries endeavouring to improve their conditions through industrialization, the control of the lethal and severely incapacitating diseases must take first place in public health measures. But not the only place; production can also be improved by attention to industrial diseases and working conditions. When an occupational-health service is established, noise should be given due consideration from the start, and small special groups of employees, such as airline workers, should not be overlooked. Even if there is no over-all medical service for industry, public authorities should institute noise-control and hearing-conservation programmes for the benefit of the few who do work in noisy areas. L. Schaudinischky (personal communication, 1964) suggests that in some developing countries, some workers "enjoy noise, which increases the danger, the more so because they are not aware of the possible harmful effects".

Noise is but one aspect of occupational health, and occupational health only one aspect of public health. The difficulties in allotting priorities are enormous, and the resources of any international organization are limited.
NOISE

EDUCATION

The educational approaches are various. They include international conferences, demonstrations, and scholarships. A total educational programme on noise must apply to architects, factory inspectors, industrial medical officers, machine designers and manufacturers, suppliers of measuring equipment, engineers, trade-union officials and factory managers. In any international educational programme for noise control, bodies such as the ILO, WHO and ISO need to collaborate. As hearing conservation is basically a medical problem, there are obvious implications for WHO. The aim should be to establish, in each country, a body of experts with a thorough knowledge of the subject, capable of stimulating the development of, and perhaps even directing, control activities.

CONFERENCES AND SYMPOSIA

While there have been several international meetings devoted to noise, none of them has been planned specifically for public health and labour officials. Unless the interest of such officials and authorities is stimulated, cases of occupational deafness will continue to occur. Meetings of interest to these officials would be concerned principally with improvement in conditions of work and with practical means of preventing noise-induced hearing loss, with less emphasis on the more-academic aspects. It would be useful for such meetings to discuss ways of arousing interest in managements, public authorities and workers, to compare experiences of hearing-conservation work, to determine audiometric requirements for different kinds of work, and to recommend methods of assessing disability. However, in drawing up the agenda for such meetings, it would be as well to bear in mind that too broad a representation (consisting, for example, of lawyers, industrialists, engineers, audiologists, insurance executives and factory inspectors) might result in the discussion being confined to generalities.

MODEL LEGISLATION

The structure of model noise-control legislation is a matter of prime importance. There may be difficulties in drawing up a universally acceptable document, and it might be better to compile two model acts—one a detailed example and the other a general document containing only a few basic control requirements.
Among the legislative considerations are a general survey of the problem, including methods, instrumentation and standards; the definition of harmful noise levels by intensity, frequency and duration of exposure; specification of the persons, places and circumstances where the law applies; details of enforcement agencies and penalties for infringements; the principles and practice of engineering noise control; standards and methods for medical examination and action to be taken when noise-induced hearing loss is found; the qualifications of medical and engineering control staffs; and the types of ear-protector, with indications for their use. Some of these items might be better suited to a code of practice, and a document of this kind would be invaluable.

CLASSIFICATION OF NOISY INDUSTRIES

Noise pervades a high proportion of a nation's industries. An up-to-date classification, accompanied, if possible, by some coding of the severity of the risk, would serve a useful purpose. Two similar but differently located industries may have very different noise levels: as far as practicable, such aspects should be considered. Authoritative documents of this kind produced by international organizations are useful in convincing national authorities of the need to devote money and attention to the topic, and their educational value is enormous. They should be written with the factory manager and trade-union official very much in mind.

BIBLIOGRAPHY AND INFORMATION SERVICES

There is need for a wider and freer interchange of knowledge between nations. Apart from certain publications and periodicals of various organizations and societies, the International Occupational Safety and Health Information Centre of the ILO has made a praiseworthy attempt to break down this isolation, but has to cover a very wide field. A detailed up-to-date bibliography, including recommendations, standards and codes, would be most useful. A small permanent committee might be set up, entrusted with the periodic review and summarizing of the world's literature of importance. Since the volume of published material on acoustics is prodigious and spans many disciplines, there is considerable need for some international correlation and for the dissemination of sufficiently detailed abstracts on every aspect of the subject. There is also room for a central clearing-house of information, freely open to postal enquiries.
INTERNATIONAL CO-OPERATION

Although increasing attention is being paid in many countries to health problems arising from noise, in only a few has there been any systematic attempt to assess the extent of the problem on a national scale. It is difficult to obtain reliable and comprehensive data. The statistics obtainable from workmen’s compensation authorities are often of limited value. Neither medical reports of work injury nor industrial accident records are sufficiently complete to determine the magnitude and diversity of the problem. Notification of occupational deafness often amounts to no more than a theoretical obligation. Few workers seek medical attention for possible hearing impairment. In many countries, there are no large-scale audiometric and screening programmes for locating cases.

Whatever the differences in living conditions and legislation, the nature of many industries varies but little in most countries, and an effective step might be to assess the extent of hearing loss in a cross-section of the international industrial community. All surveys are expensive in time and effort and comparatively unfruitful if only small numbers are audiometrically tested and if the scope of measurements is limited. One country might face great difficulties in investigating a hazard that could be studied more easily elsewhere. Hence the advantages that might accrue from a joint programme on noise-induced hearing loss as it occurs in a particular industry selected for detailed investigation in several countries simultaneously. With proper planning, other benefits would ensue, e.g., a wider appreciation of individual variations in hearing loss.

Valid comparisons of populations or industries cannot be achieved without some standardization of techniques. Doctors should be encouraged to carry out hearing assessment and to record the results, by reference to recognized standards. This applies also to the taking of physical measurements. Only thus can international epidemiological surveys acquire a useful meaning.
Although substantial environmental improvement would immediately result if existing knowledge was fully utilized, research is needed to provide the solution of many of the problems associated with noise. Modern instrumentation and techniques, such as the electron microscope and the use of microelectrodes, will enable further substantial advances in knowledge to be made. Any international sponsorship of research should concentrate on those aspects likely to benefit the health of the greatest number of workers. So far, there is little evidence that exposure to excessive noise has much direct effect on working efficiency, and this kind of enquiry should, relatively speaking, perhaps not rate a high priority. Similarly aspects related to annoyance and residential noise of industrial origin may also be accorded low priority by some public health authorities, depending on the social and industrial development of the country. This is not necessarily to belittle the importance of such aspects or to query the proposition that matters directly affecting health are of the highest concern. What is however, of paramount importance is to prevent noise-induced hearing loss. There is much evidence to suggest that such pathology is more widespread than is usually supposed. The need to develop a reliable predictive test is not acute, since the evidence indicates that only a small proportion of the community is susceptible, although it might be valuable to discover whether susceptibility remains stable throughout a lifetime, and whether there is a relationship between intrinsic individual variations in hearing levels and the probable extent of noise-induced losses among individuals.

It has been suggested that efforts might be made to protect workers against certain noises by pre-activating the acoustic reflex, but this also may not be of first importance; there are easier and safer methods, namely the use of ear-protectors, which are effective in most situations where engineering control is not practicable.

Until the mechanisms involved in normal hearing and occupational deafness are fully understood, many problems must remain obscure. It
is essential to be able to distinguish readily between occupational hearing loss and loss from other causes, such as presbycusis. There is also need for agreement on pre-employment hearing standards, and on the advice to be given concerning work placement or continuation of work in noisy surroundings when varying degrees of deafness are encountered. Much has still to be learned about the nature of temporary threshold shift and its relation to permanent losses.

Sometimes, the practical difficulties in carrying out audiometry before the employee starts work in the morning are great; a test is needed that can be performed at any time of day with the minimum of difficulty and with appropriate correction factors. Although some authorities advocate testing before work starts—thus discounting the effects of any residual temporary loss from the previous day’s exposure—it would be much easier, and more convenient, if testing were possible at any time, irrespective of the degree of the preceding exposure.

A major problem, still insufficiently explored, is the evaluation of the effect of impulse or impact noise, including high-intensity peaks in a broad-band noise exposure of lower intensity. The parameters of rise-time, peak-level, rate of occurrence, and fall-time have not been fully studied. Adequate characterization of the short-term or intermittent exposures to steady-state noise situations common in industry is also needed. More information is required on the medical sequelae of exposure to fluctuating noise that varies both in intensity and spectrum.

It would be very helpful, if possible, to develop a small, inexpensive and universally acceptable acoustic dosimeter, analogous to the personal film badge used for measuring exposure to radiation. It may be argued that it is not the noise, as such, that matters but rather its effect on the individual worker, and that it is easy in practice to designate potentially dangerous situations. However, not all employees are exposed to constant known noise-levels, and the availability of a suitable dosimeter would overcome many present difficulties. Care should be taken to ensure that the provision of such an instrument does not prejudice the development of hearing-conservation programmes and that the information obtained is of practical use.

The largest single gap in our knowledge is in the engineering field. The use of ear-protectors is as primitive as the wearing of masks by miners. Better methods of controlling the generation of noise are needed. There are many industrial processes in connexion with which few, if any, systematic efforts have been made to control noise at its point of origin. Machinery made in one country is often sold in another, and the buyer should be able to ascertain its noise-level under specific operating conditions, as tested in an approved laboratory. In practice, however, such information is not so easy to obtain as are the ordinary technical specifi-
cations. "Buy quiet" might be a useful slogan (Börner, 1963; Murphy, 1963).

A keystone in any noise-control programme is the establishment of generally accepted damage-risk criteria based on the fullest available knowledge. Their present multiplicity suggests that the correct answer is not yet known. Cogent arguments in favour of instituting hearing-conservation programmes may be advanced. However, it is possible for employees to work in places where the noise, though exceeding the criterion, does not affect their hearing, and vice versa. Perhaps this is merely a valid reason for further research into suitable criteria.

Meanwhile, in many industries workers must continue to rely mainly on personal protective devices. If a country in process of industrialization decides to make its own protectors, it is imperative that it should be able to obtain the necessary technical advice and assistance without which protection cannot be effective, and it may well be essential for the equipment to be cheap, if it is to be widely used and accepted. The use of ear-defenders under certain unfavourable conditions, such as high humidity or high temperature, merits further study.

A fuller study should likewise be made of groups of persons who are not exposed to the noise of civilization. Their number is becoming progressively smaller and the remaining opportunities for research should be seized before it is too late. Studies of primitive peoples might help to clarify the degrees of loss attributable to social, domestic and occupational causes, and valuable information might be gathered in regard to presbycusis.

It is not at present easy to identify the acoustic research and noise-control measures in progress in different parts of the world, and there should be a centre for the interchange of such information so as to obviate duplication of effort and bring together those working along similar lines.
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Annex 1

STANDARDS RELATING TO NOISE

The following are some of the standards published by international organizations.

INTERNATIONAL ORGANISATION FOR STANDARDISATION

The International Organisation for Standardisation has an active technical committee, ISO/TC43, with the following scope:

"Standardisation in the field of acoustics other than electroacoustics, including terminology, airborne noise, architectural acoustics, medical acoustics, musical pitch, and other subjects as allotted by council of ISO."

Recommendations

R.131—1959 Expression of the physical and subjective magnitudes of sound or noise
R.140—1960 Field and laboratory measurements of airborne and impact sound transmission.
R.226—1961 Normal equal-loudness contours for pure tones and normal threshold of hearing under free field listening conditions
R.266—1962 Preferred frequencies for acoustical measurement
R.354—1963 Measurement of absorption coefficient in a reverberation room
R.357—1963 Expression of the physical subjective magnitudes of sound or noise
R.362—1964 Measurement of noise emitted by vehicles
R.389—1964 Standard reference zero for the calibration of pure-tone audiometers

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Draft recommendations

DR.675 Procedure for calculating loudness level
DR.695 General requirements for the preparation of specifications for measuring the noise emitted by machines
DR.880 Rating of sound insulation for dwellings

ISO/TC43, Acoustics, has a wide programme of work in hand, as indicated by the following working groups (ISO have issued a document reporting on the work of this technical committee for the year 1964):

WG 43-1 Normal Threshold of Hearing
WG 43-3 Architectural Acoustics
WG 43-8 Industrial and Residential Noise
WG 43-9 Measurement of Machinery Noise
WG 43-10 Vocabulary
WG 43-12 Measurement of Aircraft Noise
WG 43-13 Assessment of Aircraft Noise
WG 43-14 Acoustical reference quantities

INTERNATIONAL ELECTROTECHNICAL COMMISSION

The Commission has an active technical committee, IEC/TC29, Electro-Acoustics with the following scope:

"To prepare international recommendations for standardization in the field of electro-acoustics, including generating, transducing, recording and reproducing of sound (including infra-sound and ultra-sound), and other subjects as allotted by IEC Committee of Action.

Provision is made for collaboration between ISO and IEC.

Publications

No. 123 (1961) Recommendations for sound level meters
No. 177 (1965) Pure tone audiometers for general diagnostic purposes
No. 178 (1965) Pure tone screening audiometers
No. 179 (1965) Precision sound level meters
Drafts approved for publication

29 (C.O.) 43  Recommendations for pure-tone screening audiometers
29 (C.O.) 44  Recommendations for pure-tone audiometers for general
diagnostic purposes

Some of the currently active working groups and their projects are:

WG 29-7  Ultrasonics
WG 29-8  Sound Level Meters
Annex 2

FILMS CONCERNING NOISE

The following films dealing with noise have been produced:

*Ear Protection in Noise* (1960), 12 minutes, colour; obtainable from the Central Film Library, Government Building, Bromyard Avenue, London, W.C., United Kingdom

*Gevaarlijk Geluid* (1959), 17 minutes, colour; obtainable from Rijksvoorzichtigadient, Noordeinde 43, The Hague, Netherlands

*Noise and hearing* (3 films) (1957), 90 minutes, colour; obtainable from T.V. Station WZED, 4337 Fifth Avenue, Pittsburgh 13, Pa., USA

*An approved technique for pure-tone, air-conduction audiometry*, 14 minutes, colour; obtainable from the Subcommittee on Noise Research Center, 327 South Alvarado Street, Los Angeles, Calif., USA

*Une Réalisation de Réduction des Bruits sur un Tonneau Dessableur (Fonderie)*, 8 minutes, black and white; obtainable from Institut National de Sécurité, 9 Avenue Montaigne, Paris, France

*Quiet please,* 20 minutes, colour; obtainable from Celotex Corp., Acoustical Department, 120 S. La Salle Street, Chicago, Ill., USA

*Protect your hearing,* 15 minutes, colour; obtainable from Bray Studios, 729 Seventh Avenue, New York, N.Y., USA. (Sound tracks in English, French, Spanish and Swedish).

*Le bruit* (1958), 28 minutes, black and white; obtainable from Institut National de Sécurité, 9 Avenue Montaigne, Paris, France

*Your ear and noise,* 12 minutes, colour; obtainable from the Subcommittee on Noise Research Center, 327 South Alvarado Street, Los Angeles, Calif., USA
11. MATERNAL AND CHILD HEALTH IN THE USSR. Report Prepared by the Participants in a Study Tour Organized by the World Health Organization (1962) 71 pages 5/- 1.00 3.—

12. ROAD TRAFFIC ACCIDENTS. Epidemiology, Control and Prevention. L. G. Norman (1962) 110 pages 6/8 1.25 4.—

13. ASPECTS OF WATER POLLUTION CONTROL. Various authors (1962) 116 pages 6/8 1.25 4.—

14. DEPRIVATION OF MATERNAL CARE. A Reassessment of its Effects. Various authors (1962) 165 pages 10/- 2.00 6.—

15. EPIDEMIOLOGY OF AIR POLLUTION. Report on a Symposium. P. J. Lawther, A. E. Martin & E. T. Wilkins (1962) 32 pages 1/9 0.30 1.—

16. THE SCOPE OF EPIDEMIOLOGY IN PSYCHIATRY. Trung-Yi Lin & C. C. Stanley (1962) 76 pages 5/- 1.00 3.—

17. PAYING FOR HEALTH SERVICES. A Study of the Costs and Sources of Finance in Six Countries. Brian Abel-Smith (1963) 86 pages 5/- 1.00 3.—

18. MEDICINE AND PUBLIC HEALTH IN THE ARCTIC AND ANTARCTIC. Selected Papers from a Conference. Various authors (1963) 169 pages 10/- 2.00 6.—

19. HEALTH EDUCATION IN THE USSR. Report Prepared by the Participants in a Study Tour Organized by the World Health Organization (1963) 69 pages 5/- 1.00 3.—

20. PREPARATION OF THE PHYSICIAN FOR GENERAL PRACTICE. Various authors (1963) 114 pages 6/8 1.25 4.—


22. THE NURSE IN MENTAL HEALTH PRACTICE. Report on a Technical Conference. Audrey L. John, Maria G. Leite-Ribeiro & Donald Buckle (1963) 212 pages 12/- 2.25 7.—

23. URBAN WATER SUPPLY CONDITIONS AND NEEDS IN SEVENTY-FIVE DEVELOPING COUNTRIES. Bernd H. Dieterich & John M. Henderson (1963) 92 pages 5/- 1.00 3.—

24. CARE OF CHILDREN IN DAY CENTRES. Various authors (1964) 189 pages 12/- 2.25 7.—

25. HOUSING PROGRAMMES: THE ROLE OF PUBLIC HEALTH AGENCIES. Various authors (1964) 187 pages 13/4 2.75 8.—

26. DOMESTIC ACCIDENTS. E. Maurice Backett (1965) 138 pages 10/- 2.00 6.—

27. TRENDS IN THE STUDY OF MORBIDITY AND MORTALITY. Various authors (1965) 196 pages 13/4 2.75 8.—

28. ASPECTS OF FAMILY MENTAL HEALTH IN EUROPE. Various authors (1965) 123 pages 8/6 1.75 5.—

29. MASS CAMPAIGNS AND GENERAL HEALTH SERVICES. C. L. Gontales (1965) 87 pages 6/8 1.25 4.—

30. NOISE. An Occupational Hazard and Public Nuisance. Alan Bell (1966) 121 pages 10/- 2.00 6.—