The effects of intense stimulation on auditory thresholds: with especial reference to occupational deafness in industry.

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THE EFFECTS OF INTENSE STIMULATION

ON AUDITORY THRESHOLDS:

With especial reference to occupational deafness in industry.

THESIS SUBMITTED FOR THE DEGREE OF

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S U M M A R Y

Various aspects of intense aural stimulation are reviewed, including several of the investigations from which damage risk criteria have been derived.

The effect of environmental noise on the hearing acuity of exposed personnel has been studied in three factories.

The incidence of noise-induced deafness is considered in relation to the damage risk criteria which would rate the various noise spectra as safe. It was found that application of most of these criteria would rate as non-hazardous many of the noise sources which have been found, in fact, to cause deafness.

It is suggested that, until such time as more information is available, regarding certain aspects of the noise problem, the most stringent of the damage risk criteria, that formulated by Burns and Littler, should be adopted.

Where the expression "the author" appears in the text, the opinions are those of the author of this thesis - J.S.

SECTION 1

INTRODUCTION

The effect on man of prolonged exposure to intense noise has been recognised for some 130 years, the first published account being that of Fosbroke (1) who reported on the extensive loss of hearing among blacksmiths.

Since that time little has been done in this country to estimate the effect on hearing of other industrial noises.

A considerable body of evidence now exists, mainly from American investigations, to indicate that a large proportion of industrial employees are incurring irreversible damage to their hearing during the pursuance of their employment.

The purpose of this present study is to examine the noise levels existing in specified factories and to estimate the effect which exposure to these levels is having on the hearing of the employees. This estimate is based on three lines of investigation: first on consideration of the results of other investigators in this field, and second by the application of theoretical concepts drawn from the results of laboratory experiments and third on the results of direct measurements of the hearing of employees.

Before considering in detail the effects of intense noise on hearing, it is useful to have an overall picture of the main problems which arise from the exposure of man to high intensity noise. No single aspect of the noise problem can be considered in isolation from the rest. Since there is often considerable interaction between the various effects of noise many people have difficulty in determining which particular aspect is the cause of their complaint. For example, there may be complaints concerning a particular noise involving the widely held opinion that noise affects the 'nerves' and causes fatigue. On examination, however, it often transpires that it is the inability to communicate freely in a noisy environment which is the cause of irritation and fatigue. The continual use of raised speech and the necessity to repeat oneself in order to be understood is both tiring and irritating, but this is not a direct physiological effect of noise. If the necessity to communicate verbally is removed, the fatigue and irritation may well disappear, although the noise remains.

In fact, hearing impairment, which is the most serious and widespread aspect of the noise problem is seldom the cause of complaints against the noisy environment, because the traumatic effect of noise is not easily detected in the initial stages of its development and the facts are not widely known or accepted by British industry. Therefore, a brief consideration of some other aspects of the noise problem is appropriate.

The effects, on man, of prolonged exposure to intense noise may be conveniently divided into six categories:-

1. The effect of noise on performance: There is virtually no evidence from the industrial field since Weston's report in 1935 (2) which relates to the effect of noise on the performance of employees. This lack of evidence is due mainly to the difficulty of studying such a problem in the industrial situation.

Weston studied the effect of environmental noise on the performance of weavers and found that a reduction of 15 dB resulted in a $7\frac{1}{2}\%$ increase in efficiency. This was a long-term effect, enduring over several months and showed that, while unprotected employees became accustomed to working in noise without feeling irritation, annoyance, or distraction, nevetheless , the presence of the high level noise reduced their efficiency compared with the noise-protected group.

This valuable study by Weston does not appear to have been followed up by other investigators and by itself, is not sufficient evidence on which to base recommendations to industry.

It has been firmly established in the laboratory that noise does have a detrimental effect on the performance of certain tasks (3,4,5,6). Noise levels in excess of 90 dB have been shown to affect adversely the performance of inspection-type tasks, where the subject is continually alert for the appearance of an unpredictable signal.

Continuous, steady-state noise has little effect on performance, even at very high intensity levels. It is a change in the state of the noise, or the sudden onset or cessation of environmental noise which causes a momentary decline in performance.

2. <u>The effect of noise on the ability to communicate</u>: Before attempting a determination of the way in which noise affects the intelligibility of speech, it is necessary to consider the basic characteristics of speech itself.

Figure 1

Approximate distribution of speech sounds, with respect to intensity and frequency

Relative Intensity of English Sounds (in decibels)

o:	28	u:	24·5	tʃ	16	k	11
a:	27·5	i	24	n	15·5	v	10·5
ʌ	27	i:	23·5	dʒ	13·5	ð	10·5
æ	27	r	23	ʒ	13	b	8·5
ou	26·5	l	20	z	12	d	8·5
u	26·5	ʃ	19	s	12	p	7·5
ei	25·5	ŋ	18·5	t	11·5	f	7
e	25	m	17	g	11·5	θ	—

(Decibels above the sound of least intensity)

TO FACE PAGE 5

Speech sounds consist mainly of frequencies in the range 125- 4K c/s. The intensity range of speech is 40dB, from the quietest sound, THin, to the most intense, HArd. In general, consonants are high frequency, low intensity sounds and vowels are low frequency, high intensity sounds, as shown in figure 1 opposite.

A given sound exhibits its greatest masking effect on signals of a similar frequency. Therefore, noise which contains the frequencies in the speech range will have the greatest masking effect on verbal communication.

From theoretical considerstions of the mechanism of masking, it could be predicted that relatively low level intensity environmental noise, of approximately 60 dB, would reduce the intelligibility of speech to zero. However, because of the redundancy of information in speech, a level of approximately 85 dB of noise can be tolerated before (raised) speech becomes unintelligible (7,8).

3. The 'annoyance' effect of noise: It is difficult to assess the annoyance value of a given noise. (9). Frequently, the cause of the annoyance is not directly attributable to the noise itself, but to one of the better defined side effects of environmental noise.

High frequency noise appears to engender feelings of annoyance and irritation more readily than sounds of low frequency, but intense low frequency environmental noise will seriously affect the intelligibility of speech and consequently may produce discomfort.

Individual tolerance to noise varies greatly, but in general, high frequency noise is more irritating than low frequency noise, when verbal communication is not required.

Intermittant noise is more annoying than steady-state noise, but it is possibly the effect of a constantly changing noise environment on the ability to concentrate which is the causative factor.

4. Physiological effects of exposure to intense noise:

The physiological effects of exposure to intense noise may be conveniently divided into two categories:-

i) The effect of noise on hearing.

Since this is the main subject matter of this report, traumatic deafness and its associated pathology will be dealt with in detail in a later section.

ii) The effect of noise on physiological processes other than hearing.

It has been established, both by laboratory experiments and by field investigations, that exposure to noise levels in excess of 90 dB frequently causes disturbances in the peripheral circulatory system.

An increased vascular resistance occurs in the precapillary blood vessels, resulting in a reduction in the circulation of blood through the peripheral organs. This effect is a function of the intensity and bandwidth of the exposure noise. (10). Pure tones and narrow band noise have little effect, whilst wide band noise in excess of 90 dB, typical of the industrial environment, causes a measurable reduction in peripheral circulation.

Laboratory investigations (11) demonstrate that 95 dB of noise will counteract the normal expansion of peripheral blood vessels which occurs during manual work.

These results were substantiated by a thorough examination of steelworkers.

It is interesting to speculate here on the effects of intense noise on manual workers in a hot environment. Since manual work and a hot environment both cause dilation of the peripheral vessels, the restriction on capillary dilation imposed by excessive noise may well be a cause of symptoms of distress which are usually attributed to the heat alone. In most heat stress situations, an environmental noise level of 90 dB, which is common in industry, may well be a controlling factor. If such a relationship between heat stress and noise intensity exists, the author suggests that the simple expediency of fitting exposed personnel with ear defenders may reduce the undesirable effects of the hot environment.

Damage to vision is another important physiological phenomenon resulting from exposure to intense noise. The early work in this field was by Kravkov (12) and Yakovlev (13), who investigated the effects of noise upon peripheral and colour vision. More recently, Benkö (14) has demonstrated that prolonged exposure to intense industrial noise reduces the field of peripheral vision.

The traumatic effect of noise upon vision has received considerable attention in America, where it has been found that Air Force pilots were developing irreversible 'tunnel vision' due to noise exposure. Serious erros in judgement occurred which were attributable to this visual defect.

This important aspect of the noise problem does not appear to be under investigation in Britain.

If a relationship could be established between the narrowing of the field of vision and the development of traumatic deafness, the problem of the diagnosis and aetiology of cases of advanced deafness in noise exposed personnel would be solved.

Exposure to intense noise has other, less traumatic, physiological effects on man. For example symptoms of vertigo following prolonged exposure to jet engine noise have been reported (15).

5. <u>The effect of noise on industrial safety</u>

The effect of high intensity noise on the incidence of industrial accidents has received some attention from investigators of noise problems, but there is no conclusive evidence to relate a high accident rate to intense environmental noise. (16, page 13).

6. <u>The effect of noise on hearing - occupational deafness</u>

The effect of over-stimulation of the auditory mechanism, has been established beyond the point of controversy, although there remain many contributing factors to be investigated.

Of all the effects on Man attributable to intense noise, loss of hearing acuity and its associated psycho-acoustic pathology is the most serious to the affected individual. The ability to communicate, noise-induced error and feelings of annoyance may all be improved at any point in time by decreasing the environmental noise. Hearing alone may remain irreversibly affected.

Numerous other studies of traumatic deafness have been carried out, since those of Fosbroke in 1830, but the majority of these are laboratory investigations from which attempts have been made to predict the damaging effect of various industrial noise environments. Almost all the laboratory experiments have utilised artificial noise conditions: either pure tone, narrow band or random noise stimulation.

The main reason for the lack of evidence from the industrial scene is the difficulty of controlling the many contributing factors. To yield statistically reliable results, such an investigation must be on a nation-wide scale. A study of this nature is at present being carried out by the Medical Research Council, in conjunction with the National Physical Laboratory. A mobile team of investigators, comprising physicists, otologists and technicians is examining the hearing of all factory entrants in a large number of industries. Employees with normal hearing and no history of aural disease or relevant hereditary factor receive regular hearing checks following commencement of employment. In this way, using a very large sample, reliable information will be obtained about the traumatic effect of the noise environments studied.

Another difficulty which detracts from the value of individual industrial investigations is the lack of standardisation of method. For this reason it is of little value to attempt a comparative study of the results.

The effects of noise on hearing is the main concern of this report and will be considered in detail in Section 2.

SECTION 2

The Effects of Noise On Hearing

For the purpose of this report, the effects of intense stimulation on the auditory mechanisms will be divided into two main categories:-

(A) Temporary effects, where auditory functions return to normal after cessation of the stimulus, and (B), Permanent effects, involving irreversible damage to the nerve structure of the inner ear.

(A). Temporary Effects of Aural Stimulation - A review of some experimental studies of the effects of intense stimulation.

The account which follows, of temporary auditory effects, is restricted to those which bear some relation to the permanent effects caused by over-stimulation, and which may contribute to a closer understanding of the principles involved in traumatic deafness.

The broad facts which are known about the transient effects of intense stimulation upon auditory functions have been well established by numerous investigators, but controversy still exists concerning the finer details.

When attempting to review the literature relating to this subject, the formation of definite conclusions is hampered by the conflicting nature of the available evidence. Many investigators report findings which differ considerably in detail. In all cases slight differences in experimental technique are present which may account for the divergent results.

These temporary aural phenomena will be divided into two categories, according to the nature of the stimulus, (i) pure tone and (ii) complex sound. It is the essential differences between the effects on hearing of these two types of stimuli which is of particular interest when considering the traumatic effect of industrial noise. It is becoming increasingly apparent that an environmental noise which has a high concentration of energy in a restricted part of the spectrum may affect hearing to a greater degree and possibly, in a different way from noise with an equal energy distribution. Such a noise appears to function in a manner similar to pure tone and narrow band stimulation and therefore, the results of laboratory investigations into the different effects produced by varying the band width of the stimulus may have considerable bearing on the problem of industrial deafness.

The results of various investigations are summarised in Table 7, pages (49-51).

There are three main effects on hearing which may be measured when the ear is subjected to intense stimulation, namely, (a) a decrease in hearing acuity, as measured by a shift in absolute threshold (b) a decrease in the sensation of loudness and (c) a change in the sensation of pitch. Of these, the first is the index most commonly used to demonstrate the presence of auditory fatigue. The term 'auditory fatigue' is used to denote a temporary decline in function of the auditory mechanisms caused by over-stimulation.

(i) Pure Tone Stimuli Investigations

A comprehensive survey of the effects of stimulation on the ear's sensitivity was published by Hood in 1950 (17). He measured two aspects of fatigue, comprising changes in loudness perception which occur during stimulation, which he termed per-stimulatory fatigue and shifts in absolute threshold which were present after cessation of the stimulus, termed post-stimulatory fatigue.

Hood demonstrated that the frequency at which maximum fatigue occurs is a function of the stimulus intensity. When the ear is stimulated by a 60 dB pure tone, the maximum fatigue is found to be for a frequency very close to that of the stimulus. At a level of 89 dB stimulus intensity, the fatigue effect has spread to involve higher tones and the maximum moved away from the stimulus frequency. When a stimulation of 100 dB is applied, further involvement of higher frequencies occurs and the maximum fatigue is located at a frequency half an octave higher than that of the stimulus. At all intensity levels, the spread of fatigue was towards the higher frequencies. Fatigue did not increase for frequencies below the stimulus as the stimulus intensity was raised. There was very considerable variation in individual susceptibility to fatigue, as demonstrated by the degree of fatigue produced, but the pattern of results was the same in all cases.

Hood found that irrespective of total duration of exposure time, fatigue reaches its maximum value as determined by the stimulus intensity after approximately three minutes stimulation.

He therefore concluded that it is the stimulus intensity and not the exposure time which is the critical factor in determining the extent of fatigue.

This, of course, relates only to the relatively short exposure times measured in the laboratory, where fatigue is not measurably increased by extending the stimulus duration beyond three minutes. However, it may be that if the exposure time were increased so as to be comparable with those encountered in the industrial noise situation, an increase in fatigue might occur. It is, of course, impossible to test this assumption in the laboratory, but it may account for the conflicting views held by various investigators on the role played by duration of exposure in determining the extent of fatigue produced by a given stimulus.

In 1951 Theilgaard (18) published the results of investigations into auditory fatigue and found that the spread of frequencies affected by fatigue as the stimulus intensity was increased followed the same pattern as that described by Hood (17). But, in direct contradiction to Hood's findings, Theilgaard states that the degree of fatigue is dependent upon the stimulus duration and reports an increase in temporary threshold shift from 53 dB, after 5 minutes stimulation with a 100 dB tone, to 79 dB at the end of one hour's exposure. However, in his paper, which is a summary of a doctoral thesis, the precise experimental details are not given, and differences in technique may account for the results conflicting with those of Hood.

Theilgaard also studied the pattern of the ear's recovery from fatigue and found that fatigue diminishes in the reverse order of frequency involvement as occurs during its onset. That is, the highest frequencies affected, which were the last to be involved, recover first, then those nearer to the stimulus frequency and finally, the regions showing greatest fatigue, i.e. those situated half an octave higher than the stimulus frequency.

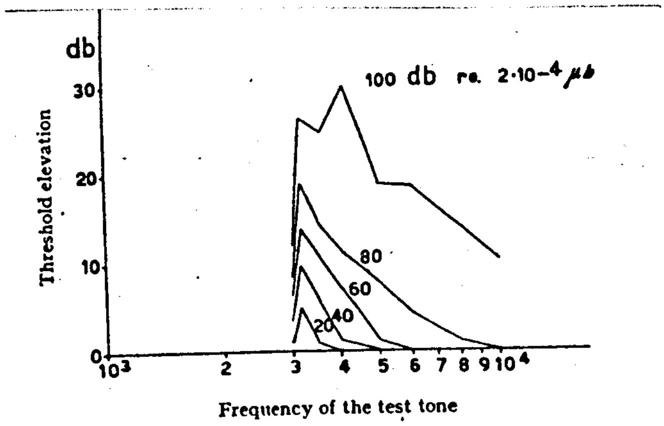
Theilgaard states that there is wide variation in the extent of fatigue produced in different individuals exposed to a given tone. He also found that subjects varied as to the stimulus frequency which caused the greatest fatigue. This suggests that there is no one frequency which is universally more susceptible to fatigue than the rest, as might be assumed when considering the differential susceptibiliby of the 4 K c/s region when the ear is exposed to wide spectrum noise.

The pattern of cochlea fatigue reported by Hood and Theilgaard was further substantiated by Zwislocki and Pirodda (19) in 1952. This latter paper gives emphasis to the existence of two separate phenomena, adaptation and fatigue, which co-exist at high levels of stimulus intensity.

Adaptation is the spontaneous fall in acuity which occurs, to some extent, at all stimulus intensity levels. Adaptation is characterised by an initial rapid decrease in discharge of nervous impulses, sometimes called the 'on effect', of a duration of a fraction of a second.

FIGURE 2

THE PATTERN OF THE SPREAD OF ADAPTATION



——-Spread of adaptation to the neighbouring frequencies of the stimulating tone for its different intensities (average values of 6 persons with normal hearing). Frequency of the stimulating tone = 3150 c. s.

If the stimulus is continued, a slow decline in the frequency of impulses occurs, during the subsequent 4 minutes stimulation. The ear has then reached a state of equilibrium and no further decrease in threshold occurs with continued stimulation. The total threshold shift is dependent upon stimulus intensity and as the intensity is increased there is gradual spread of adaptation to involve frequencies higher, but not lower, than the stimulus frequency. The maximum effect of adaptation is always at the frequency of the stimulating tone. Recovery from adaptation is always rapid and complete and is only slightly dependent upon the intensity and duration of the stimulus.

Fatigue only appears when the stimulus intensity is greater than 80 dB. The intensity used by Zwislocki and Pirodda was 100 dB at which level a new maximum in threshold shift was observed which occurred at a frequency one half an octave higher than the stimulating tone. This appeared in their results as an additional peak in threshold shift, superimposed upon the pattern determined by adaptation, as may be seen in Figure 2 opposite.

At high intensity levels, the greatest threshold elevation may be measured at the stimulus frequency, provided the measurement is made immediately after cessation of the stimulus. The rapid recovery from adaptation reveals the presence of the more enduring fatigue threshold shift for the frequency one half an octave higher when the measurement is made at a time interval greater than 0.1 seconds after cessation of the stimulus.

Fatigue appears to be dependent upon both the intensity and the duration of the stimulus. This was indicated by the results obtained by Zwislocki and Pirodda using an intermittent stimulus. They found that such a stimulus applied to the ear, at intensities below 80 dB, causes a threshold shift denoting adaptation, which does not increase if the train of impulses is prolonged. When the stimulus intensity is greater than 80 dB, the ear does not recover during the silent period between impulses and the fatigue effect is cumulative, depending upon the total stimulus duration. If stimulation is continued beyond the point of maximum threshold shift, then the recovery rate is affected and, eventually, permanent trauma occurs.

The differing effects of adaptation and fatigue are summarised in Table 1, page 17.

TABLE 1

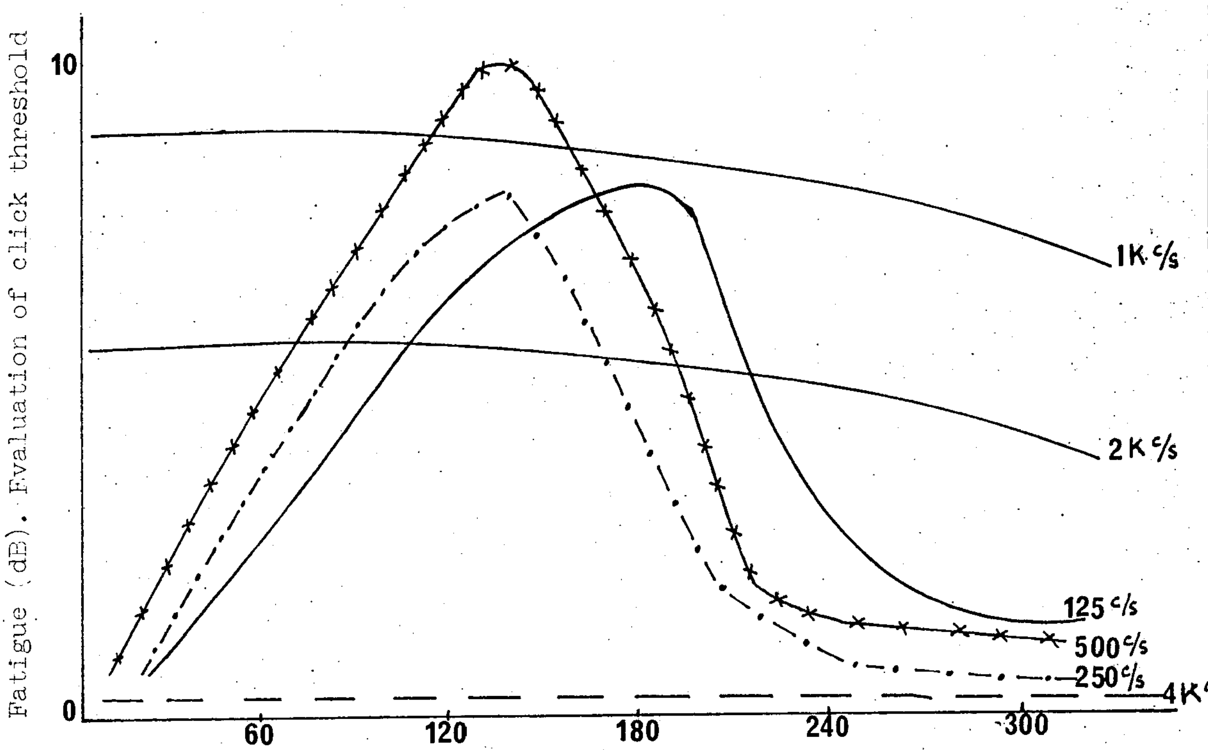
COMPARISON BETWEEN ADAPTATION AND FATIGUE

	Adaptation	Fatigue
Stimulus intensity required to initiate temporary threshold shift.	Occurs to some extent at all levels of stimulus intensity.	Greater than 80 dB.
Frequency at which maximum threshold shift occurs.	At frequency of stimulating tone.	Half an octave higher than frequency of stimulating tone.
Rate of onset of threshold shift.	Rapid and complete within 4 minutes.	Slow.
Rate of recovery of threshold shift.	Rapid.	Slow.
Factors governing rate of recovery of threshold shift.	Slightly dependent upon intensity and duration of stimulus.	Largely dependent upon intensity and duration of stimulus.
Extent of recovery of threshold shift.	Always complete, independent of intensity and duration of stimulus.	Varies from complete recovery to permanent loss in acuity, depending on intensity and duration of stimulus.

Figure 3

From Hirsh and Ward (20)

Recovery of click threshold following 3 minutes stimulation by pure tones.



Time after cessation of stimulating tone (secs)

Parameter = frequency of fatiguing tone.

In 1952, Hirsh and Ward (20) studied the pattern of recovery of the ear from stimulation by intense pure tones and bands of noise. Although this section is primarily devoted to the effects of pure tone and narrow band noise, Hirsh and Ward's results using wide band noise will be included here since they form an integral part of their paper.

Hirsh and Ward used a multiple frequency click as the test stimulus and measured the recovery of threshold for this click after the ear had been exposed to a variety of fatiguing stimuli.

In their first series of experiments the recovery click threshold was measured following stimulation by pure tones of frequencies 125 c/s, 250 c/s, 500 c/s, 1 K c/s, 2 K c/s and 4 K c/s. There were considerable individual differences in the absolute threshold. shift of subjects, but Hirsh and Ward showed the results to be reliable by repeated testing of each subject over a period of several days. Figure 3 opposite is a simplification of Hirsh and Ward's results and is only an approximation of the actual values obtained, drawn here to illustrate the diphasic nature of the recovery curves for stimulating tones of 125 c/s, 250 c/s, and 500 c/s.

Hirsh and Ward then examined the click threshold recovery pattern when the ear is stimulated by bands of noise of various widths. These results are summarised in Table 2, overleaf.

TABLE 2

T.T.S. RECOVERY PATTERN OF CLICK THRESHOLD

Fatiguing Stimulus	Pattern of recovery of click threshold
Low frequency narrow band 160 c/s - 67- c/s	Diphasic. Similar to recovery pattern after exposure to low frequency pure tone.
Low frequency wide band 160 c/s - 1420 c/s	Monophasic.
Broad band noise 160 c/s - 6600 c/s	Monophasic.

Clicks stimulate the entire basilar membrane and therefore it may be that the threshold shift of that portion of the membrane which was least fatigued was being measured in these experiments. This supposition is supported by the fact that Hirsh and Ward's subjects reported distortion of the quality of the clicks following stimulation by pure tones. In particular, the 4 K c/s stimulus, which produced little subsequent elevation in click threshold, resulted in distortion of the click to a 'thudlike' sound, indicating that, although there was no threshold shift for the lower frequency components of the click, reception of the higher frequencies was impaired. This supports other evidence (27, 28, 29) that intense stimulation results in maximum fatigue for frequencies higher than that of the stimulating tone.

Hirsh and Ward carried out a further series of experiments designed to study the recovery of the pure tone threshold from intense stimulation by pure tones and noise. They found that white noise produced more fatigue for high frequencies than for low frequencies.

All observers exhibited a frequency of maximum fatigue, but this varied, between subjects, from 4 K c/s to 8 K c/s.

When the fatiguing stimulus was a pure tone, diphasic recovery occurred mainly for the test frequencies greater than that of the fatiguing frequency, recovery for lower frequencies being uniform. As the frequency of the fatiguing tone was increased the diphasic nature of the threshold recovery was diminished and for a fatiguing frequency of 4 K c/s the recovery pattern was monophasic for all frequencies of threshold shift.

The diphasic quality of threshold recovery was much less pronounced after white noise stimulation than it was following pure tone stimulation.

The diphasic type of recovery pattern appears to occur only for frequencies higher than that of the fatiguing tone, so that as the frequency of the fatiguing tone is raised, the recovery 'bounce' is pushed further and further along the basilar membrane until it disappears when the fatiguing tone is approximately 4 K c/s.

When the fatiguing frequency was 500 c/s, the residual temporary threshold shift was roughly constant for all test frequencies, but there was a shift maximum at 700 c/s. This substantiates the findings of many other workers who have also found the maximum residual fatigue to occur half an octave above the fatiguing frequency. These results are briefly summarieed in Table 3, overleaf.

TABLE 3

T.T.S. RECOVERY PATTERN OF PURE TONE THRESHOLD

Fatiguing Stimulus	Pattern of Pure Tone Threshold Recovery
500 c/s pure tone intensity = 100 dB	Diphasic for all frequencies higher than 500 c/s.
1 K c/s pure tone intensity = 100 dB	Diphasic for all frequencies higher than 1 K c/s.
2 K c/s pure tone intensity = 100 dB	Diphasic for all frequencies higher than 2 K c/s.
4 K c/s pure tone intensity = 100 dB	Slightly diphasic at 5400 c/s, recovery monotonic for all other frequencies.
White noise intensity = 100 dB	Diphasic for all frequencies below 4 K c/s

The results of Hirsh and Ward's work indicate that the ear does not recover from stimulation fatigue in a simple linear fashion, but that the recovery curve is dependent upon the frequency of both the fatiguing stimulus and of the test tone. This indicates the recovery rate varies in different areas of the frequency reception mechanism.

The existence of this diphasic 'bounce' in recovery from fatigue suggests the importance of the time factor when making measurements of temporary threshold shift. In order to make an accurate assessment of threshold shift, the time which has elapsed since cessation of the stimulus must be carefully controlled, so that the diphasic threshold 'bounce' is taken into account.

Thompson and Gales (21) in 1961, examined the temporary threshold shift produced by pure tones and bands of noise in order to determine if the amount of fatigue is dependent upon the stimulus band width. They used two basic frequencies of fatiguing stimulus, 500 c/s and 3200 c/s, and measured the threshold shift for a pure tone of 4 K c/s.

Four bandwidths were used, pure tone, 5 c/s band, 1/3 octave band and octave band, centering about the stimulus frequency.

It has been suggested that the critical stimulus for fatigue is the intensity level in an aural critical band and from this assumption one would predict that a pure tone and band of critical width would cause equal temporary threshold shifts, more than the fatigue arising from exposure to octave band noise, where most of the noise energy is contained in frequencies outside the aural critical band. However, Thompson and Gales found no significant difference in the temporary threshold shift produced at 4 K c/s by varying the bandwidth of the fatiguing stimulus, from pure tone to one octave. They point out that, since they did not use identical frequencies for the fatiguing stimulus and the tone at which the temporary threshold shift was measured, it is doubtful whether the concept of the aural critical band could be applied.

In general support of Hirsh and Ward's findings (20) Thompson and Gales' results disclosed the presence of diphasic recovery patterns in most of their subjects and for both frequencies of exposure stimulus. They found the 'bounce' in 4 K c/s threshold recovery was not dependent upon the stimulus bandwidth or frequency.

In 1945, Rüedi and Furrer (22) published the results of an investigation into the changes in absolute threshold and pitch perception which occurred after intense stimulation by pure tones. Since the prime objective of their work was to examine the hypothesis that a dual mechanism exists for the perception of pitch and loudness, their results will not be considered in detail here, but a brief summary follows of their findings, relevant to the study of acoustic trauma.

Rüedi and Furrer used pure tone stimuli, the frequency range 270 c/s to 7 K c/s, at intensity levels of 130 dB to 140 dB. They measured both the temporary threshold shift in extent and duration, and also changes in pitch. Their results are given briefly in Table (4) below.

TABLE 4

RECOVERY TIMES AND PITCH DISTORTION FOLLOWING INTENSE STIMULATION

STIMULUS	INTENSITY	DURATION	EFFECT MEASURED	
			T.T.S.	Pitch Distortion
270 c/s	135 dB	5 mins.	Complete recovery after 2 minutes	Pitch raised
400 c/s to 7 K c/s	130 dB - 140 dB	2 to 4 minutes	25 dB to 70 dB T.T.S Recovery period ranged from 1 hour to several days.	Frequencies below 4 K c/s pitch raised 4 K c/s - no pitch change frequencies above 4 K c/s pitch lowered

In common with many other investigators, Rüedi and Furrer found that the spread of fatigue, with increasing intensity, always involves frequencies higher, but not lower, than that of the fatiguing stimulus. They also noted that recovery from pitch distortion occurs simultaneously with recovery from threshold shift.

The author feels that the anomalous behaviour of 4 K c/s in relation to pitch distortion is of particular interest. There is an increasing body of evidence which indicates that this region of the basilar membrane is, in some way, critically different from other areas. This is of essential importance in relation to traumatic deafness, since it is the 4 K c/s region which is most susceptible to trauma.

A summary of the unique aspects of 4 K c/s stimulation is given at the end of this section, page 41 .

Davis, et al (23) in 1950, studied four aspects of the effect of intense stimulation by pure tones and wide spectrum noise, namely shifts of absolute threshold, changes in loudness perception, distortion of pitch and speech intelligibility. Their results are reported in full in their paper which contains details of each subject's performance.

Davis, et al, examined the effect, on threshold shift and perception of loudness and pitch, of varying the frequency, intensity and duration of the stimulus. They used pure tones of frequencies 500 c/s, 1 K c/s and 4 K c/s and found that the threshold shift incurred was dependent upon the frequency of the stimulus in the following order of increasing effect: - 500 c/s, 1 K c/s, and 2 K c/s, 4 K c/s.

Hearing loss developed rapidly during the initial exposure, with a maximum threshold shift for tones one half an octave higher than the stimulus, after which there was more gradual involvement of increasingly higher frequencies .

Recovery from fatigue followed the same frequency involvement pattern as occurred during its onset, i.e. there was rapid recovery for frequencies close to the exposure tone and a more gradual recovery of higher frequencies.

Both the extent of threshold shift and the spread of frequency involvement was found to be dependent upon exposure time, a fact which has been disputed by other authors.

Some individuals were found to be more consistently susceptible to intense stimulation than others and two cases of permanent deafness arising from these investigations are reported.

Davis et al, also used wide spectrum noise stimuli, at an intensity of 130 dB, to measure the effects of stimulus duration. They found that threshold shift, with an average maximum for 4 K c/s, continued to increase with increasing duration of exposure, up to 60 minutes, which was the limit of the experiment.

Pitch distortion was found following pure tone stimulation with maximum distortion corresponding to the frequency of maximum fatigue, i.e. one half an octave higher than the stimulating tone. Distortion was not caused by the wide spectrum noise.

Recovery from noise exposure was similar to that following pure tone stimulation, the lower frequencies recovered rapidly, with a more enduring threshold shift for the higher frequencies.

The investigation into the effect of intense stimulation on the sensation of loudness produced complex results which indicate that a slowing-down of the normal increase in loudness with increasing intensity occurs for low sensation levels, while at higher sensation levels a reaction similar to that of loudness recruitment occurs.

From the mass of data they obtained, Davis et al, produced the Table of Equinoxious Exposures, which is reproduced on page 27. This suggests combinations of frequency, intensity and duration which give rise to the specified temporary threshold shift, given as average hearing losses over a two octave band. It will be seen that wide band noise is comparable in its effect to pure tones of 500 c/s and 1 K c/s.

The three hearing loss values, 30, 40 and 50 dB, are those which were found to require respectively less than 24 hours, 24 hours, and more than 24 hours for complete recovery.

The author feels that one of the most significant results of Davis' work, in relation to present problems concerning acoustic trauma, is the change reported in temporary threshold shift with increasing exposure time. The pattern of fatigue which occurs closely resembles the initial stages of traumatic deafness, where there is an initial sharply localised threshold shift, which gradually spreads to involve higher frequencies as the duration of exposure is increased. This same sequence of events appears to occur when either the stimulus intensity, or the duration of exposure is increased.

In 1953 Alexander and Githler (24) studied the threshold shifts produced by over stimulation by direct measurement of cochlea potentials in guinea pigs. Their technique involved producing a controlled loss in sensitivity, in all cases, of 60 dB. They achieved this by using a constant stimulus intensity, but a variable exposure time.

The stimuli employed were pure tones of low and high frequency, 300 c/s and 5 K c/s. Cochlea potentials were measured immediately before and after stimulation and again after a period of three weeks. The cochlea were then studied histologically.

TABLE 5

EQUINOXIOUS EXPOSURES

Average (2-octave) hearing loss	Cycles	dB	Min.
30 dB	500	110	> 60
		120	50
		130	20
	1000	110	32
		120	24
		130	6
	2000	110	30
		120	7
		130	4
	4000	110	12
		120	3
		130	2
	band spectrum	120	26
		130	10
40 dB	500	120	> 60
		130	30
	1000	120	42
		130	10
	2000	120	15
		130	10
	4000	110	20
		120	6
		130	3
	band spectrum	120	52
		130	20
50 dB	500	130	45
	1000	120	> 60
		130	16
	2000	120	30
		130	15
	4000	110	35
		120	10
		130	5
	band spectrum	120	60
		130	30

The results of these experiments indicate that when a fatigue of 60 dB has been established, recovery is more complete when the stimulating frequency is 3 K c/s, than when the fatigue is produced by the lower frequency, 300 c/s, tone.

Alexander and Githler found that, immediately following stimulation the 300 c/s tone produced fatigue involving equally all frequencies up to 5 K c/s with greater impairment for tones of higher frequency. With the 5 K c/s stimulus, the threshold shift was equally distributed for all frequencies. After a period of three weeks, recovery occurred, to a varying extent, in all cases exposed at 5 K c/s, but the 300 c/s injury was more permanent. They conclude, from this, that "at equal sound pressures, a low tone stimulus is much more effective in producing injury than a high tone stimulus".

This appears to contradict the findings of other workers who report higher frequencies to cause more fatigue than the lower frequencies . However, in these latter studies the duration of the exposure stimulus was kept constant and the resulting fatigue was measured as a function of the frequency. It may be that different principles are involved here, whereby a low frequency stimulus is slow to produce fatigue, but that the threshold shift, once produced, is of a more permanent nature. There is insufficient evidence at present to suggest that the duration and frequency of the stimulus are interchangeable in their effects and that the resultant fatigue may be predicted by a simple addition process. Short exposure to high frequencies may have a very different effect from long exposure to low frequencies, even though the initial threshold shift is the same.

Alexander and Githler's histological examinations of the noise exposed cochlea showed patterns of injury which were not consistent with a place theory of pitch perception. Lesions in the basal turn of the cochlea were found although there was no corresponding loss in sensitivity in the region of 3 K c/s. Also, in cases where there was no evidence of cochlea damage, there was loss in sensitivity throughout the frequency range.

In 1955, Wever and Lawrence (25) measured the changes in cochlea potential caused by over stimulation. Their stimuli were pure tones in the range 100 c/s to 10 K c/s and measurements were made of the effect of intense stimulation on both loss in sensitivity and of the maximum response. Their results showed that absolute sensitivity was affected to a greater degree than was the maximum response of the cochlea, a result which appears to be in agreement with the 'recruitment' type of phenomenon reported in several investigations into the effect of high intensity stimulation on loudness functions. Maximum response is more seriously affected for low tones than for high, but Wever and Lawrence found that high intensity stimuli caused wide-spread damage, involving all areas of the cochlea, irrespective of the frequency of the stimulus. They suggest that certain hair cells which respond mainly to high intensity stimuli, are the most susceptible to damage from over-stimulation. Their results are tabulated in their paper to show the effect of a given stimulus upon the sensitivity and maximum response of the range of test frequencies. These results indicate that a low frequency injuring tone has a severe and equal effect upon all test frequencies.

In no instance is there evidence of the localised maximum loss in sensitivity which appears so clearly in studies of temporary threshold shift. All the stimulation frequencies appear to have a wide-spread effect upon absolute sensitivity. However, as in the experiments of Alexander and Githler, mentioned above, the duration of the over-stimulating tone was not kept constant and. also the intensity was varied so that there is no basis for comparison of the results of injury produced by different stimuli. The author feels that the argument put forward above also pertains here, namely, that intensity, frequency and exposure duration are not interchangeable factors and may well exert different influences on the extent and transiency of the resulting fatigue.

The results of a study of auditory adaptation were published by Jerger in 1957 (26) in which he examined the effect of varying the intensity and duration of the stimulus. All measurements were made at the frequency of the stimulus and were taken during stimulation, thus giving results comparable with Hood's work (17) on "per-stimulatory fatigue".

Jerger found that the degree of adaptation, for a given intensity of fatiguing stimulus, was a function of frequency. There was comparatively little adaptation for the lower frequencies, a sharp increase occurring as the frequency was raised from 125 c/s to 1 K c/s, but adaptation became stabilised above 1 K c/s and increasing the frequency to 8 K c/s caused little further adaptation.

Hood reported maximum adaptation to be achieved after a stimulus duration of only $3\frac{1}{2}$ minutes. These results are in agreement with those of Jerger, but only apply to the limited lower range of frequencies examined by Hood, 500 c/s, 1 K c/s and 2 K c/s.

Jerger found that the stimulus duration at which maximum adaptation is attained is a function of both frequency and intensity. At low frequencies, 125 c/s, 250 c/s and 500 c/s maximum adaptation occurs after only 3 minutes stimulation, but higher frequencies, 1 K c/s to 8 K c/s, only reach their maximum value during this period when the intensity is low. At high intensities, high frequency stimulation caused a continually increasing adaptation during the whole of the test period, 5 minutes.

The growth of adaptation had been measured previously by Jerger for an 80 dB, 4 K c/s tone and he found that adaptation did not reach a maximum until exposure duration was 7 minutes.

These results give further support to the concept that noise induced fatigue is dependent upon at least three factors, intensity, frequency and exposure time.

(Jerger did not examine the effect of duration of exposure on recovery from fatigue).

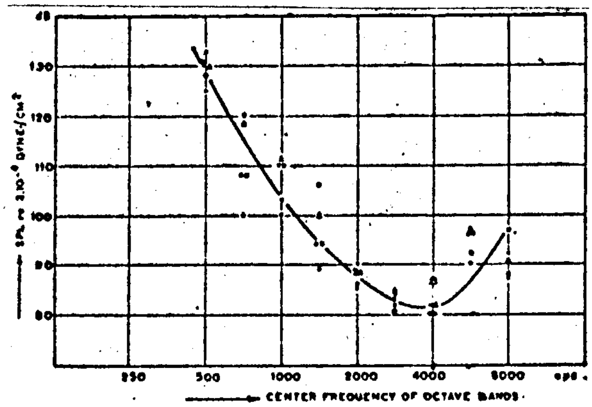
Plomp et al (27) in 1963, examined the fatiguing effect produced by octave bands of noise. From their data, they produced isotraumatic lines to illustrate the variations in temporary threshold shift, as a function of frequency, for a given intensity. They assume, from consideration of the results of an investigation by Ward and Glorig (28) which will be considered in detail in Section 2C (page 79), that temporary shifts in threshold may be used as a reasonable indication of permanent trauma.

Threshold measurements were taken immediately before and after 3 minutes stimulation and the recovery pattern traced for 9 minutes following cessation of the stimulus.

FIGURE 4

From Plomp et al
(27, page 1237)

Curve of equal threshold shift

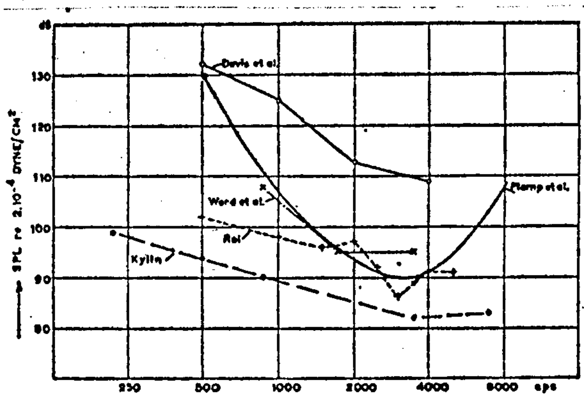


Sound-pressure levels of octave bands of noise which gave 3 min after exposure for 3 min a threshold shift of 5 dB at a frequency one-half octave above the center of the noise band. The different signs represent 5 test subjects.

FIGURE 5

From Plomp et al
(27, page 1239)

Iso-traumatic lines



Comparison of some isotraumatic lines,

A sharp initial recovery was followed by a slower recovery rate, after one or two minutes. Threshold measurements taken 3 minutes after cessation of the stimulus were used as an index of fatigue.

It is interesting to note that Plomp et al found only a very slight indication of the diphasic recovery pattern reported by Hirsh and Ward (20) and others. The experimental conditions of Hirsh and Ward are comparable with those of Plomp et al, since the former measured fatigue at a variety of frequencies other than that of the fatiguing stimulus.

Plomp et al found that an octave band, with a centre frequency of 500 c/s at 130 dB intensity produced the same threshold shift (5 dB) as a 4 K c/s octave band at an intensity of 82 dB. An octave band centering around 8 K c/s required an intensity of approximately 90 dB. These results are reproduced in figure 4 opposite.

Although the minimum sound pressure level required to produce the 5 dB threshold shift appears at 4 K c/s, it will be seen that this is the centre frequency of the octave band which produces the threshold shift for a frequency one half an octave higher. Therefore, the minimum intensity required to produce equal threshold shift really applies to 6 K c/s, and similarly, with all other points on the graph.

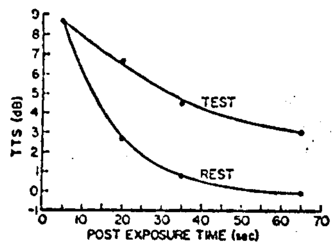
Plomp et al compare the results from their investigations with those of other workers in a graph which is reproduced in figure 5 opposite.

They assume the differences in position of these lines to be due to differences in experimental conditions, for example, exposure time and degree of threshold shift taken as an index of fatigue.

FIGURE 6

From Bell & Fairbanks
(29, page 1731)

Pattern of recovery from T.T.S



———— Mean time course of recovery from TTS. All frequencies and levels pooled. As in Fig. 6, the upper curve shows recovery during continuous threshold tracing following exposure; the lower shows recovery when silence is interposed before testing. The difference between the curves may be interpreted as estimating the retardation caused by testing.

All the above lines show the same trend, indicating that exposure to high frequency stimuli has a greater effect on threshold shift than does low frequency exposure.

An interesting point arises here - Plomp et al suggest that the differences in the slope of the isotraumatic lines cannot be explained by differences in experimental technique, although this would obviously affect the absolute values obtained. The author has found evidence, from the literature, to suggest that duration of exposure might have a different effect on low frequencies than it does on high frequencies (page 28). If this is so, then it would explain why, within the same set of experimental conditions, the slope of the isotraumatic line would be a function of the duration of exposure, as indicated by the way different results were obtained by Kylin's 2 hour exposure and Plomp et al's 12 minutes.

The results of this investigation are treated so as to suggest a possible application to damage risk criteria and this aspect of the paper will be considered in section 2C, page .

A paper by Bell and Fairbanks (29) published in 1963, gives the results of an investigation into the threshold shift produced by relatively low intensity pure tone stimuli. The main purpose of their work was to examine theeffect, on threshold recovery, of the audiometric technique employed. They found that continuous audiometry considerably retards the return to pre-exposure sensitivity. These results are reproduced in figure 6 opposite.

Fatigue measurements were made, at the frequency of the test tone, at intensity levels varying from 10 dB to 60 dB. The frequencies used were 1 K c/s, 2 K c/s and 4 K c/s.

The rate of recovery from temporary threshold shift increased as the initial fatigue also increased, as the exposure stimulus level was raised from 10 dB to 60 dB. A low intensity stimulus appears to cause a smaller, but more enduring threshold shift than does a high intensity stimulus.

It is interesting to note that, at stimulus levels of 10 dB and 20 dB, threshold shift was not a function of frequency. At the higher intensity levels, fatigue increased with increasing frequency.

A laboratory investigation which differs from those so far considered and which may be especially relevant to the problem of establishing a realistic damage risk criteria, is one by Wright (30) published in 1959. Wright measured the adaptation of the ear to pure tone stimuli in the presence of noise. A summary of his results is given in Table 6.

TABLE 6

ADAPTATION OF THE EAR TO PURE TONE STIMULI IN THE PRESENCE OF NOISE

Experiment Number	Stimulus Intensity and Frequency of 7 minutes duration.	Test tone used to measure adaptation.	Maximum ADaptation after 7 mins. stimulation.	Residual Adaptation After 3 mins. Recovery.	Remarks
1.	250 c/s) at 1 K c/s) 90 4 K c/s) dB S.P.L.	250 c/s 1 K c/s 4 K c/s	12 dB 17 dB 25 dB	5 dB	Adaptation increases with increasing frequency.
2.	250 c/s at 80 DB 1 K c/s at 59.4 dB 4 K c/s at 59.3 dB	250 c/s 1 K c/s 4 K c/s	8 dB 25.0 dB 22.5 dB	3 dB	Less adaptation at this lower intensity level than in expt. 1.
3.	90 dB tone + 60 dB noise 250 c/s 1 K c/s 4 K c/s	250 c/s 1 K c/s 4 K c/s	15 dB 32 dB 32 dB	5 dB	Adaptation increases with addition of noise.
4.	60 dB noise alone	250 c/s 1 K c/s 4 K c/s	8 dB 10 dB 0 dB	4 dB 2 dB 0 dB	Slight adaptation for lower frequencies, none at 4 K c/s.

(Contd. overleaf)

TABLE 6 (Contd.)

Experiment Number	Stimulus Intensity and Frequency of 7 minutes duration.	Test tone used to measure adaptation.	Maximum adaptation after 7 mins. stimulation.	Residual Adaptation after 3 mins. Recovery	Remarks
5.	No continuous fat-iguing tone. Simultaneous dichotic loudness balance between tone in control ear and tone + noise in experimental ear.	250 c/s 1 K c/s 4 K c/s	2 dB 0 dB 8 dB	0 dB 0 dB 5 dB	Interrupted stimulus increases adaptation at 4 K c/s only.
6.	(a) sustained noise of 60 dB followed by (b) sustained noise of 60 dB and sustained tone of 90 dB. 250 c/s 1 K c/s 4 K c/s	250 c/s 1 K c/s 4 K c/s	11 dB 26 dB 38 dB	3 dB 5 dB 5 dB	Adaptation at 4 K c/s greatly increased.
7.	(a) sustained noise, 60 dB followed by (b) sustained noise 60 dB + pure tone only at 1 min. intervals for dichotic loudness balance. 250 c/s 1 K c/s 4 K c/s	250 c/s 1 K c/s 4 K c/s	) 2 dB (all three)	) 0 dB (all three)	Virtually no adaptation caused by continual exposure to noise alone.

It will be seen that experiment 3 produced more adaptation than either experiments 1 or 2. If adaptation in noise was related to the sensation level of the stimulating pure tone, then the results should be the same as in experiment 2, where the intensity of the stimulus was adjusted so as to equal the effective sensation level of the same tone in the presence of noise. In other words, the presence of a masking noise does not reduce the amount of adaptation of a stimulus, even though it does reduce the sensation level.

If the noise had no effect upon the adaptation of the pure tone stimulus, the results of experiment 3 should be equivalent to those of experiment 1. However, it appears that noise increases the amount of adaptation.

Experiment 4 measures the adaptation produced by noise alone. 60 dB of noise was presented for the same fatiguing period as previously, namely for seven minutes and the amount of adaptation measured, at one minute intervals, by simultaneous dichotic loudness balance. The table of results above shows the rather surprising fact that 60 dB of noise produces adaptation for the frequencies 250 c/s and 1 K c/s but not for 4 K c/s.

In experiment 5 there was no sustained fatiguing stimulus, the experimental run consisting of simultaneous dichotic loudness balances between the pure tone in the control ear and tone-plus-noise in the experimental ear. The results under these conditions show a complete reversal of those of experiment 4, indicating a greater effect at 4 K c/s than at the other, lower frequencies. Wright suggests that there may be a cumulative fatiguing effect for the 4 K c/s tone which does not occur at the lower frequencies, but the author finds it difficult to accept the idea that an interrupted stimulus, at intervals as great as one minute, would result in more adaptation than a continuous stimulus. (This appears to be another example of the facilitation effect, noticed in Wright's later experiments, of noise on adaptation for a 4 K c/s tone).

In experiment 6, Wright first fatigued the experimental ear with sustained noise, measuring the adaptation produced, then with the noise continuing, he added the sustained pure tone, measuring the growth of adaptation over the usual seven minute period of stimulation. This procedure was designed to measure the adaptation which was directly due to a sustained tone in the present of noise. The assumption was that the ear had already adapted fully to noise and the additional adaptation produced by introducing the sustained tone was attributable to the tone itself. This series of experiments produced a far greater degree of adaptation than any of the previous ones.

In order to determine whether the adaptation in experiment number 6 was due to the increased duration of exposure to the sustained noise, experiment 7 consisted of measuring the adaptation for this duration of noise only, without the addition of the seven minute sustained tone. This produced virtually no adaptation, therefore, in experiment 6, the high degree of adaptation appears to be due to some kind of facilitation produced by prior exposure to noise which, in itself, does not cause adaptation, but which increases the degree of adaptatinn of a subsequent exposure to pure tones.

The following general conclusions are reported by Wright:

<u>Initial rate of adaptation</u>

The initial rate of adaptation is increased in the presence of noise at 4 K c/s, but not at 250 c/s or 1 Kc/s

Asymptotic level

The asymptotic level of adaptation at 4 K c/s is increased by the addition of noise, but 250 c/s, 1 K c/s are not affected.

Residual level

Although the addition of noise appears to have a slight effect on the residual adaptation for 4 K c/s, Wright reports that there was no statistically significant difference between the residual adaptation levels at any of the test frequencies, at the end of each of the different experiments. Hence, the sustained noise, while increasing both the initial rate and asymptotic level at 4 K c/s, did not affect the recovery of the ear from adaptation.

This investigation by Wright, into the effect of noise on the ear's adaptation to pure tones, has been considered in some detail because the author feels that Wright's results are particularly relevant to the effects of industrial noise. Wright's study shows that broad band noise itself causes little adaptation, but when added to a pure tone stimulus, the combined effect is far in excess of the sum of the two separate adaptation levels. Of the three frequencies investigated by Wright, 250 c/s, 1 K c/s and 4 K c/s, this effect was only apparent for 4 K c/s.

It has been shown that industrial noise, most of which contains definite maxima in intensity, causes a maximum threshold shift at 4 K c/s, and that flat-spectrum noise results in a slight overall threshold shift.

The author suggests that industrial noise may be operating in a manner similar to Wright's experimental noise-plus-tone situation, namely, the basic wide spectrum industrial noise may be facilitating adaptation to the pure tone (or narrow band) constituents. Wright only measured adaptation at the frequency of the stimulus. It would be illuminating to discover whether any pure tone, in a background of noise, caused adaptation at 4 K c/s, or whether the effect is specific to that frequency.

If Wright's experiments were extended to cover the effect, on adaptation at 4 K c/s, of other pure tones in the presence of noise, our present scanty knowledge of the importance of frequency peaks in wide spectrum noise would be considerably enlarged.

PHENOMENA UNIQUE TO THE PERCEPTION OF A 4 K c/s TONE

There is now considerable evidence to show that frequencies in the region of 4 K c/s exhibit phenomena associated with stimulation which differ in many respects from those of all other frequencies. These are of particular interest in the study of industrial deafness, since the first indication of permanent trauma is loss of hearing acuity for pure tones in the region of 3 K c/s to 6 K c/s, with a sharp maximum for 4 K c/s.

Summarised below are some phenomena in which stimulation of the 4 K c/s area of the basilar membrane is unique in its effects.

SUMMARY OF THE UNIQUE EFFECTS OF STIMULATION OF THE 4 K c/s BASILAR AREA

Pattern of recovery from fatigue (Hirsh and Ward, 20)

All fatiguing stimuli below 4 K c/s produce diphasic recovery patterns. At and above 4 K c/s, recovery is monophasic for all frequencies.

Changes in pitch perception following intense stimulation (Ruedi and Fürrer, 22)

Fatiguing stimuli below 4 K c/s cause pitch to be raised.

Fatiguing stimuli of 4 K c/s cause no change in pitch.

Fatiguing stimuli above 4 K c/s cause pitch to be lowered.

Region of maximum temporary threshold shift (Davis et al, 23)

Wide spectrum stimulation caused maximum threshold shift for 4 K c/s.

The facilitation of adaptation by the addition of noise to a pure tone stimulus (Wright, 30)

Adaptation to a pure tone of 4 K c/s is greatly increased by the addition of a noise stimulus. This effect does not occur at other frequencies.

(ii) Complex Sound stimuli investigations

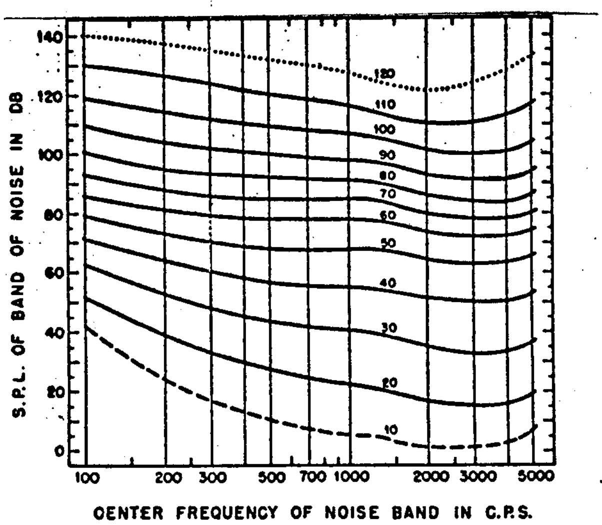
Conclusions drawn from investigations which employ multiple frequency stimuli would appear to be more directly applicable to the problems arising from exposure to high intensity environmental noise, than are experiments using pure tones. However, with an increase in the complexity of the experimental stimulus there arises the addition of further variables to confuse the interpretation of the results. Also, knowledge of the ear's reactions to both simple and complex stimuli is required before one can hope to estimate the traumatic effect of a noise which may contain elements of both pure tone and wide spectrum noise.

In 1952, Pollack (31) measured the sensation of loudness produced by complex noise of varying bandwidth and found the results to be comparable with those obtained for pure tones. Mid-frequency noise, of a given intensity, produced a greater sensation of loudness than either low or high frequency noise. Pollack also found that, at medium intensity levels, a greater sensation of loudness was produced when the frequency range of the stimulus was increased. For the highest levels measured, however, (100 dB and 110 dB), increasing the stimulus frequency range did not affect the loudness sensation. This suggests that, at high intensity levels, excitation has spread to involve all frequency receptors and loudness is no longer a function of bandwidth. It would be interesting to compare these results with the loudness of pure tones in order to determine whether there is a critical bandwidth which produces this spread of loudness perception.

FIGURE 6 A

From Pollack(31, page 534)

Equal Loudness Contours for Bands of Noise



Equal-loudness contours for bands of noise (band width about 250 to 300 mels) as a function of the center frequency (geometric mean of upper and lower cut-off frequencies) of the noise band.

Pollack's equal loudness contours for bands of noise are reproduced in figure 6Aopposite.

It will be seen that the relationship between frequency and intensity, to give equal loudness, changes as the overall intensity is increased. This is a further indication that the behaviour of the ear under low intensity stimulation may not be ussd to indicate the likely effect of high intensity stimulation.

Jerger (32) in 1955 studied a different aspect of the recovery of the ear from intense stimulation. For threshold stimuli there is a critical stimulus duration, below which the stimulus fails to elicit a response. For stimuli of duration shorter than approximately 175 milliseconds, the intensity must be raised above normal threshold to maintain threshold response. This relationship between stimulus intensity and duration at threshold is disturbed in cases of perceptive deafness, where the lesion is in the cochlea, and shortening the stimulus duration below the critical time does not require such a large intensity increase as in the normal ear, before the threshold response is re-established. Jerger examined this stimulus duration to intensity relationships in ears which had been fatigued by a two minute exposure to thermal noise, of 110 dB intensity. The test tone was 4 K c/s. He found that during recovery from fatigue the ear behaved in a manner similar to that of the pathological ear, indicating that in this respect, at least, permanent trauma is analogous to temporary fatigue.

An implication which may be drawn from Jerger's work is that the explanation for this phenomenon may lie in the physical nature of short tone impulses. When a pure tone is of very short duration it no longer consists of a single frequency, there is considerable spread of complexity. Therefore, since Jerger was using a short duration pure tone of 4 K c/s and this is the region affected most by complex noise exposure, it may be that the increase in the complexity of the 'pure tone', with decreasing stimulus duration, elicited a response from a relatively unfatigued area of the basilar membrane. This assumption could be tested by measuring the affect of the stimulus duration of a complex noise, instead of a pure tone, when an increase in complexity caused by shortening the duration would not substantially alter the spectrum.

The diphasic nature of recovery from auditory fatigue, was apparent in Jerger's results and the 'bounce' occurred during the post-exposure period between one and three minutes, in close agreement with Hirsh and Ward's results (20).

Carterette (33), in 1955, used continuous and interrupted wide band noise to measure several aspects of per-stimulatory fatigue. Using a technique similar to that of Hood (17), dichotic median plane localisation, he studied the effect, on adaptation, of varying the rate of interruption per second of the fatiguing stimulus.

Thermal noise was used throughout the experiments, therefore shortening the duration of the stimulus would not substantially alter the spectrum, as may have affected the results of Jerger's experiments, reported above.

The total energy of the fatiguing stimulus was kept constant for all interruption rates, i.e, as the interruption rate was increased, so the total energy per burst was decreased, with a constant time fraction of 0.5 seconds, therefore the resulting adaptation was a true measure of the interruption rate, and not a function of the total energy presented.

Two sets of measurements were made, viz:-

a) Continuous thermal noise stimuli, presented at various sound levels.

Stimulus duration to reach maximum fatigue = 7 minutes. (twice that reported by Hood for pure tones).

Fatigue increased with increasing stimulus intensity.

b) Interrupted thermal noise stimuli, presented at a fixed intensity (90 dB.)

Rate of interruptions per second varied.

Fatigue increased with increasing rate of interruptions per second.

The results showed that less fatigue was caused by the interrupted noise, even at the highest rate of interruption, 12.5 i.p.s, than by continous noise of an equivalent overall intensity level. It appears that, since the amount of fatigue was dependent upon the stimulus interruption rate, at slow interruption rates, recovery occurs between bursts of noise and there is little residual fatigue. At higher rates of interruption, the silent intervals between bursts is less than the time required for complete recovery and, therefore, fatigue may be demonstrated.

Another interesting study by Carterette was p ublished in 1956 (34) was an extension of his previous work on adaptation. He examined the effect of varying the bandwidth and intensity of the stimulus on adaptation, as measured by the method of dichotic median plane localisation.

Carterette suggests that adaptation is a function of both the loudness and intensity of the stimulus. If this is so, then, since loudness increases with increasing bandwidth, the adaptation caused by wide band noise should be greater than that of narrow band noise. This supposition was supported by his results, which are summarised below.

<u>Stimuli</u> - Pure tone of 1500 c/s

Thermal noise - 100 c/s to 5 K c/s.

Bands of noise, varying width, with centre frequency of 1500 c/s.

<u>Results</u> - a) Adaptation is greatest for pure tone stimuli (1500 c/s) being 8.5 dB greater than the maximum adaptation for any bandwidth at any sound pressure level.

b) Adaptation is small and rapid (complete in 1 minute) for all bands at 50 dB sound pressure level.

c) At 70 dB and 90 dB, the time taken for maximum adaptation increases. Wider bands cause greater adaptation than the narrower bands.

d) At 90 dB, stimulus intensity, there is an obvious trend in the results. As the bandwidth increases, so does the time required for maximum adaptation to be stabilised and also the maximum amount of adaptation increases.

Carterette does not distinguish between adaptation and fatigue, as do some other investigators, and the author feels that the results obtained with relatively low-intensity stimuli, at 50 dB where 'adaptation' was found to be of rapid onset, reaching its maximum within one minute, might correspond to the adaptation measured by Hood (17) and others.

The results obtained at higher intensities have the characteristics of the fatigue phenomenon, with a slower onset. Carterette did not measure recovery rates, or the frequency at which maximum 'adaptation' occurred, so the argument cannot be pursued further.

A very interesting result is the fact that a pure tone has a greater (8.5 dB greater) effect on adaptation than any of the bands of noise, with the same centre frequency as that of the pure tone. It appears to the author that a separate mechanism must be in operation here, since, with the bands of noise, adaptation is a function of the bandwidth. It is difficult to understand why there should be a sudden drop in adaptation caused by the addition of a few more frequencies, unless, perhaps, these additional frequencies caused a shift in the frequency of maximum adaptation which was not apparent with the experimental technique used

To summarise the inter-relationships demonstrated by Carterette's experiments in complex tones, loudness adaptation is a function of stimulus duration, bandwidth, intensity and loudness.

The experimental technique used by Carterette in both the papers reviewed above (33 and 34) is not, of course, measuring threshold shift, but is an indication of the loss of loudness caused by intense stimulation. Since loudness is a function of bandwidth, and Carterette's measurements are essentially those involving loudness changes, the author wonders whether these results, which suggest that adaptation itself is a function of loudness, may be extended to include all aspects of adaptation, such as the effect on absolute threshold, or whether they should be confined to supra-threshold phenomena only.

This is a further indication of the difficulty of applying results obtained from laboratory experiments to the industrial situation, where the prime consideration is to determine the permanent threshold shift of a complex noise. However, experiments such as those of Carterette indicate that the effects of intense stimulation are indeed widespread and do not confine themselves to a simple elevation of absolute threshold.

Several other experiments on the effects of complex noise on hearing are reviewed in section 2.C, "Damage Risk Criteria", page 69, since the authors of these have studied aspects of the fatigue phenomena as being directly applicable to the determination of the maximum permissible noise exposure levels for hearing conservation.

Summary of Research Reports Reviewed in Section 2A

It becomes increasingly apparent from studying the many investigations into the effect of intense stimulation, that the conclusions drawn by the individual investigators are largely dependent upon the experimental techniques employed. For example, the time which elapses between cessation of the stimulus and the measurement of temporary threshold shift is critical, if recovery from stimulation follows the diphasic pattern reported by Hirsh and Ward (20) and others. Again, the study by Bell and Fairbanks (29) indicates that the use of continuous audiometry to measure temporary threshold shift considerably retards the ear's recovery from stimulation.

The various papers which have been reviewed here are summarised in Table 7 overleaf. The results and conclusions are those of the authors specified in column one of the table.

TABLE 7

SUMMARY OF REPORTS ON THE EFFECTS OF INTENSE STIMULATION

Author	Stimulus	Measurement Technique	Results and Conclusions
Hood (17)	Pure tones	Dichotic median plane localisation & temporary threshold shift.	Fatigue is a function of stimulus intensity, independent of stimulus duration. Frequency of maximum fatigue is a function of stimulus intensity.
Theilgaard (18)	Pure tones	Temporary threshold shift.	Fatigue is a function of stimulus intensity & duration. Frequency of maximum fatigue is a function of stimulus intensity. Recovery follows reverse order of frequency involvement as does onset of fatigue. Individual variations in frequency, exhibiting greatest fatigue effects.
Zwislocki & Pirodda (19)	Pure tones	Temporary threshold shift.	Pattern of fatigue as found by Hood & Theilgaard. Distinction made between adaptation & fatigue.
Hirsh & Ward (20)	Pure tones, bands of noise & wide spectrum noise.	Temporary threshold shift.	Pattern of recovery from fatigue is a function of both the stimulus & test frequencies, being diphasic under certain conditions.
Thompson & Gales (21)	Pure tones & narrow bands of noise.	Temporary threshold shift at 4 K c/s	Fatigue was not increased by increasing the stimulus bandwidth.
Rüedi & Furrer (22)	Pure tones	Temporary threshold shift & Pitch distortion.	Spread of fatigue, with increasing intensity, always involves frequencies higher, but not lower than stimulus frequency. Recovery from pitch distortion occurs simultaneously with threshold recovery.

TABLE 7 (CONTD.)

Author	Stimulus	Measurement Technique	Results & Conclusions
Davis & al (23)	Pure tones & wide spectrum noise.	Temporary threshold shift, loudness, pitch & speech intelligibility	Fatigue increases as the stimulus frequency is raised. Both the extent of fatigue & of frequency involvement is a function of stimulus duration. The pattern of pitch distortion corresponded to pattern of fatigue. Distortion did not occur following wider spectrum stimulation.
Alexander & Githler (24)	Pure Tones	Cochlea potentials	For a given threshold shift, low frequency stimuli produce a more enduring effdct than do high frequency stimuli.
Wever & Lawrence (25)	Pure Tones	Cochlea potentials	Maximum response is more seriously affected than is absolute sensitivity by low frequency stimulations.
Jerger (26)	Pure Tones	Median plane localisation	Degree of adaptation, for a given stimulus intensity, is a function of frequency. Adaptation increased as frequency was raised from 125 c/s to 1 K c/s, but was stable from 1 K c/s to 8 K c/s. Stimulus duration at which maximum adaptation occurs is a function of both frequency & intensity.
Plomp et al (27)	Octave bands of noise.	Temporary threshold shift.	High frequency exposure causes greater threshold shift than does low frequency exposure.
Bell & Fairbanks (29)	Pure tones	Temporary threshold shift.	For low stimulus intensities, fatigue is not a function of frequency. Continuous audiometry techniques retard recovery from fatigue.

TABLE 7 (CONTD.)

Author	Stimulus	Measurement Technique	Results & Conclusions
Wright (30)	Pure tones, & pure tones + noise	Simultaneous dichotic loudness balance.	The addition of noise to a pure tone stimulus facilitates adaptation for 4 K c/s.
Pollack (31)	Noise of various bandwidths.	Binaural loudness balance.	At sensation levels, below 100 dB, loudness is a function of bandwidth. At higher sensation levels loudness is independent of bandwidth.
Jerger (32)	Thermal noise	Time-intensity relationship of interrupted threshold. stimulus	Fatigue from thermal noise caused improvement of threshold for short-duration stimuli, similar to the effect found in recruiting deafness.
Carterette (33)	Thermal noise - continuous and interrupted.	Dichotic median plane localisation.	Stimulus duration to reach maximum fatigue $\approx$ 7 minutes. For a given intensity (90 dB) fatigue increases with increasing rate of stimulus interruption. Maximum fatigue caused by continuous stimulus.
Carterette (34)	Various bandwidths of noise	Dichotic median plane localisation.	Pure tones cause greater adaptation than noise of any bandwidth. In complex tones, adaptation is a function of stimulus duration, bandwidth, intensity and loudness.

SECTION 2B

Permanent Effects of Aural Stimulation - A Review of Industrial Noise Surveys

Introduction: Traumatic Deafness

The term 'deafness' used to describe the result of over-stimulation of the auditory mechanisms, is a misleading one, unless it is qualified by the prefix 'perceptive'. However, the distinction between perceptive and conductive deafness is not usually appreciated by the layman, the popular conception of deafness being that of a person who only hears when shouted at. This is readily apparent when one observes someone meeting a deaf person for the first time. They speak with a raised voice, causing discomfort to the conductively deaf patient with a hearing aid and distortion of hearing to the one with perceptive deafness. The alternative descriptive prefix 'nerve' deafness, while accurately assigning the site of the lesion to the nervous system, has an unfortunate association, for many laymen, with psychopathic disorders.

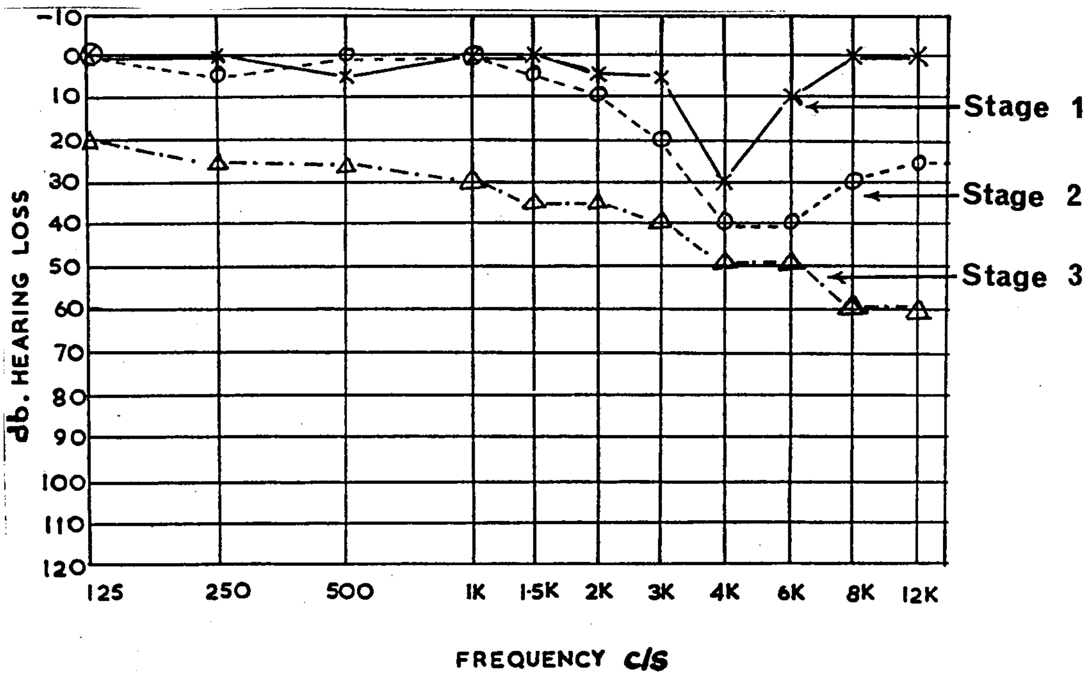
It is often said of a perceptively deaf patient that 'he hears when he wants to', because the partially deaf may only understand when giving their full attention to the speech and facial movements of the speaker. Most of our everyday listening to speech is a passive rather than an active occupation. We communicate frequently with our faces turned away from the listener, through open doors and often against considerable background masking noise. This we accomplish partly because of the redundancy of information in speech. To the partially deaf, there is no redundancy of information; they must make use of every particle of information which they can perceive, and fill in the gaps from previous experience of speech and from an expectation of the most likely words to appear in a particular context.

Perceptive deafness, whatever the origin, has the effect of isolating the sufferer, cutting him off from a society which has neither understanding nor patience with his affliction. The handicap of partial sight is more readily understood by society and does not impose the restriction on verbal communication which limits the social life on the partially deaf.

There is no satisfactory classification of degrees of deafness since the definition of deafness itself is dependent on many conditions, apart from the measurable loss in hearing acuity for pure tones. If one considers the hypothetical case of a hearing loss of 40 dB throughout the frequency range, the extent to which such a loss will constitute a serious handicap depends upon such factors as whether the deafness is conductive or perceptive, the age at which it was acquired and the degree of pitch distortion and recruitment present. In most cases of deafness, the pattern of frequency involvement is not linear and while a hearing loss of 40 dB for frequencies above the speech range will cause little inconvenience, a 40 dB loss for the frequencies 125 c/s to 3 K c/s will render normal speech unintelligible.

FIGURE 7

The Development Pattern of Progressive Traumatic Deafness



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Deafness caused by overstimulation of the cochlea is the only instance in which loss of acuity follows a definite pattern of frequency involvement. There are three recognisable stages in the development of occupational deafness: -

1. Loss of acuity for a narrow range of frequencies centering around a sharp maximum loss for 4 K c/s.
2. Loss of acuity for frequencies higher than those involved in stage 1.
3. Loss of acuity for frequencies lower than those involved in stages 1 and 2.

This pattern is summarised in Figure 7 opposite.

The presence of the typical 4 K c/s 'notch' is only detected by pure tone audiometry. Involvement of the higher frequencies, in stage 2, is rarely noticed by the subject and it is not until stage 3 is reached that deafness becomes apparent.

It is often stated by noise-deafened subjects that deafness occurred suddenly. This is rarely the case, unless the traumatising noise was of sufficient intensity to rupture the ear drums. What really occurs is that deafness is slowly progressing, unnoticed until the speech frequencies are involved snd it is at this point that the subject suddenly becomes aware of impaired hearing.

Occupational deafness, in common with other forms of perceptive deafness, is irreversible. The damaged hair cells cannot be made to respond normally. It is therefore of vital importance that occupational deafness should be diagnosed in its early stages, before irreparable damage has been done to the cochlea cells responsible for the reception of the speech frequencies.

Measures can be then taken to ensure that no further deterioration in hearing occurs.

Controversy still rages over the maximum permissible exposure to intense noise. It seems fairly certain that duration of exposure plays some part in determining the extent of hearing loss incurred, but this and many other factors still remain undecided.

Industrial Noise Surveys

There is a considerable volume of literature relating to the effects of industrial noise on the hearing of employees, mostly emanating from the U.S.A. The task of sifting through the mass of evidence is a formidable one and the hope of reaching any definite conclusions is remote.

The difficulties in this particular retrospective investigation are twofold - firstly the individual populations studied by the various investigators differ widely with respect to occupation and hence spectrum of traumatising noise. Secondly, there has been no attempt at a standardised method of investigation in order to minimise the effects of the many uncontrollable variables which beset all such field investigations. We therefore possess a mass of data which relates only to the traumatic effects of a given noise on a specific population. It is impossible to predict with accuracy, from the available data, the effects of exposure to occupational noises which differ in intensity and/or frequency.

In this country, interest in the problem of industrial noise has aroused national interest only during the last decade. A committee was set up in 1960 under the Chairmanship of Sir Alan Wilson F.R.S., to investigate many aspects of the noise problem including that of noise in industry, and the final report of the committee was published in 1963 (16).

The committee recommended a full investigation into the effects on hearing of high intensity industrial noise, with the result that a large-scale survey is at present being conducted by the National Physical Laboratory in collaboration with the Medical Research Council. During the course of this investigation, a longitudinal study is being made of deterioration in hearing acuity of young factory entrants with clinically normal hearing.

The results of this survey should yield sufficient information on which to base the first really reliable damage risk criterion available in this country and will also form the basis for future leglislation.

Although there are a great many publications on the effects of industrial and other environmental noises, it becomes apparent upon a close study of these reports, that there is comparatively little original field work. The majority of published works contain reviews of investigations carried out by other workers with an attempt to evaluate the somewhat slender evidence available.

Coles and Knight (35) in 1958 examined the hearing acuity of 111 young recruits for the Royal Navy. A history of their previous occupations revealed that 81 men had, at some time been engaged in work where a noise hazard possibly existed. The results show the permanent damage to hearing which has arisen through exposure to industrial noise to young men within three years of leaving school. This hearing loss, although not yet of a severity to cause social disability, is permanent and cumulative. Further exposure to a noise hazard would inevitably lead to social inadequacy.

The results of this work give some indications of the present incidence of traumatic deafness in the (unprotected) working population.

Van Leeuwen (36), examined the hearing acuity of 300 employees exposed to 12 different types of noise. He concludes that in the sample tested definite trauma, attributable to noise exposure, occurs at a total intensity level of 90 dB or 150 sones or 35 sones maximal in one octave band. Van Leeuwen suggests that the noise intensity is the determining factor in the extent of hearing loss and not the duration of exposure and that possibly the maximum hearing loss is acquired shortly after commencement of exposure. The temporary threshold shift measured during this survey was found to be greater during the first three months of noise exposure and possibly forecasts the extent of future permanent damage. Among older workers, the hearing loss is stabilised and temporary shifts of only 5 dB occur.

Powell (37) in 1956 published the results of a survey of the environmental noise of seven collieries. 100 different machines were measured and analysed and some were found to have noise levels of between 100 and 130 phons. The higher noise levels were not encountered at the coal face, but, here the relatively low noise intensity may be dangerous due to the masking of strata movements and other danger signals. Powell concludes from the results of this survey that several operations in the mining industry constitute a hazard to hearing and he reports that an audiometric survey was to be carried out in the future.

In 1954 a committee under the chairmanship of W. A. Rosenblith (38) published its findings after a thorough and carefully controlled investigation into the traumatising effect of noises of different spectra on the hearing of 200 carefully selected employees. The resulting data was treated to demonstrate the effect on hearing, at a given frequency, of various selected octave bands of each noise, with increasing exposure time. The aim of this procedure was to be able to predict the effect on hearing, for a given frequency, of specified intensities of any selected octave band of noise.

The committee found there was close agreement, using this method, between predicted and measured hearing loss, but they issue a warning that these findings may only apply to the noises measured and tested in their survey. It was suggested that the methods used in the investigations, if extended on a large scale to include many more types of industrial noise, may well yield the information required to be able to predict, with accuracy, the effect any given noise would have on hearing.

It is interesting to note that the results of the Committee's Survey show that, after an initial sharp decline in hearing acuity during the first few years of exposure, hearing continues to deteriorate as a function of exposure time. These results were corrected for the effects of presbycusis and are therefore in contradiction to the suggestion of Van Leeuwen (36) that noise intensity, and not duration of exposure, is the determining factor in assessing the possible traumatising effect of a given noise hazard.

Rosenblith in an earlier study (39) on the deafening effects of environmental noise in several factories, found the maximum hearing loss to occur at 6 K c/s. The subjects tested were drawn from various employments, and therefore, were exposed to different noise spectra. This finding is not in agreement with other comparable surveys where the maximum loss occurs at 4 K c/s and it is difficult to account for the discrepancy. The results reported by Rosenblith include both the permanent and temporary hearing loss with the 'notch' at 6 K c/s. Rosenblith also found, in common with other investigators, that the short-term effects of excessive stimulation of the cochlea, as evinced by temporary threshold shift, are more pronounced in previously unexposed ears than in ears with a permanent partial deafness.

There is some evidence from both Rosenblith's results and those of other workers, that temporary threshold shift, while giving some indication of an ear's susceptibility to trauma, may result from different mechanisms than those causing permanent damage.

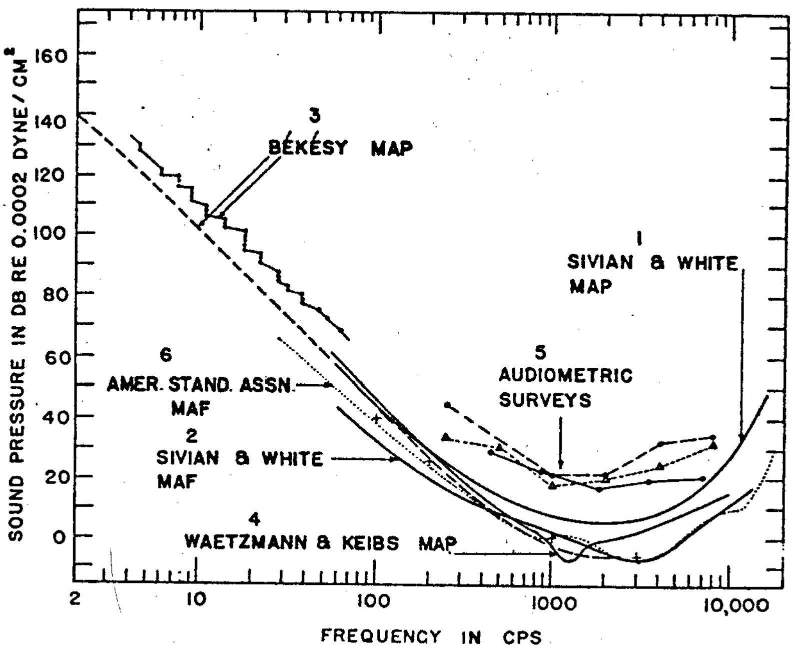
An important fact which is stressed in Rosenblith's Survey is that the region of the basilar membrane which is affected by gross stimulation is not dependent upon the noise spectra of the stimulus. Hearing loss is always predominantly high frequency, while the causative noise usually has a relatively equal intensity distribution over the whole spectrum.

It is suggested by the author that a fruitful line of investigation would be one in which the frequency components of white noise were examined to ascertain which were responsible for the highly selective damage which results from exposure to the entire spectrum.

It is known (see Section 2.A "The Effects of Noise on Hearing") that intense pure tones and narrow bands of noise, cause a temporary threshold shift, which is maximal for a frequency ½ octave higher than the stimulus. At present, other investigators have examined the effects of pure tones and narrow-band noise and wide spectrum noise and have found a complete dichotomy in the resulting effects. The first two produce the same sharply regional threshold shift thelatter, the typical 'notch' in hearing at 4 K c/s. The author believes these divergent results should be investigated further to ascertain at what spectrum width of the stimulus the effect becomes localised at 4 K c/s.

FIGURE 8

Chart of Comparative Minimum Audible Field Pressures



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It is desirable to know whether the 4 K c/s hearing loss is attributable to such a factor as resonance within the structure of the ear, or whether it is, in fact, caused by the ear's susceptibility to tones in the region of $3\frac{1}{2}$ K c/s, as would result from a stimulation of a pure tone of that frequency.

The issue is further confused by the conflicting values, given by different investigators, of the minimum audible sound pressure over the audible spectrum. For example it might be expected, from inspection of the Churcher and King equal loudness contours (40) that the most sensitive area for hearing damage would be between 2 K and 3 K c/s. The loudness contours published by Fletcher and Munson (41) indicate the position of the ear's most acute hearing as occurring between $1\frac{1}{2}$ K and 2 K c/s. Waetzmann and Keibs (42) demonstrate a sharp decrease in minimum audible sound pressure at $1\frac{1}{2}$ K c/s, but Sivian and White (42) and the American Standards Association (42) both specify 3 K c/s as the most sensitive area of hearing acuity. See figure 8 opposite. Obviously the area of greatest sensitivity lies somewhere in this mid-frequency range and a thorough investigation of the available data, or re-evaluation of the minimum audible sound pressures over the entire spectrum is required before the apparent discrepancies between the results of various investigators can be accounted for.

It has been stated by many investigators that high frequency noise is more damaging than is low frequency noise, (for example, Hirsh and Ward, (20)), but the statement has never been more specific than this.

It would be valuable to know whether wide-spectrum noise, with mid-frequency components, with especial attention to $3\frac{1}{2}$ K c/s, filtered out would still produce a maximum threshold shift for the reception of 4 K c/s. If it could be thus determined whether it is, in fact, all the higher audible frequencies or only the mid-range which is responsible for hearing damage, the task of protecting industrial personnel might be greatly simplified.

Another problem which urgently requires further investigation is the role played in noise induced hearing loss by duration of exposure time. Some investigators, for example Van Leeuwen (36) suggest that the maximum hearing loss occurs, almost entirely, during the initial period of exposure to noise and one might assume from this, that the extent of damage to hearing is not a function of the duration of exposure. However, other investigators, for example, Schneider et al (43) classify the hazardous nature of a working environment according to both the analysis of the noise and the duration of exposure time.

Johnson (44) in 1952 examined the hearing of 191 employees of three factories. Hearing was measured by pure tone audiometry, air conduction only and by assessing the hearing loss for speech at conversation level. As with many of such investigations, the number of uncontrollable variables such as the length of exposure times, previous history of noise exposure, present age, spectrum of environmental noise, makes the resultant data of little use when trying to establish a damage risk criterion for any set of circumstances other than those examined. Even then, as Johnson points out, the subdivision of his subjects into the various work categories, reduces the number of results for each type of noise to a point where precise conclusions are difficult to establish.

Johnson, in common with many investigators, quotes the relevant noise levels in phons, but also uses only the overall noise level with no regard for frequency distribution, when deciding on the possible maximum safety level. The frequency analyses of the noises he studied are not included in his paper and it would be interesting to compare the spectra of the noises which he rates as safe and unsafe. A loudness level of 105 to 108 phons is suggested as the level above which hearing damage is likely to occur. More recent evidence (see page 84, ref. 61) suggests that not only the intensity, duration and frequency distribution must be considered but also the relative intensities of the various frequency components. It has been suggested that a noise level which contains a narrow frequency range having a large proportion of the sound energy concentrated in these frequencies, may be more damaging to hearing than a noise of equivalent overall sound energy with a more equal frequency distribution. Pure tones of a given intensity certainly cause a greater temporary threshold shift than a wide-spectrum noise of equal sound energy (26 and 34) and it is possible that sharp peaks in intensity occurring in a wide-spectrum noise may function in a way similar to pure tones.

Most noise encountered in industry has a fairly equal frequency distribution. The author suggests that a study should be made of the effect on hearing of selected environmental noises which have a large proportion of the sound energy concentrated in a narrow band of frequencies.

In this case, it may well be that the region of maximum hearing loss would be found to be more closely related to the frequency distribution of the noise and not concentrated at 4 K c/s as occurs in noise spectra with an equal intensity distribution.

To return to Johnson's paper, it is interesting to note his comments on the adaptation of hearing to speech in the presence of noise. An improvement in hearing for speech when the background noise level is high, is a common feature of conductive deafness. This occurs because a speaker will naturally raise his voice until its clearly audible to himself above any masking noise. In this situation the conductively deaf person is at an advantage over those with normal hearing, because for him, the signal to noise ratio is greater. In cases of perceptive deafness, including of course, occupational deafness, the presence of loudness recruitment will ensure that the high intensity masking noise is heard with normal loudness, and therefore there is no improvement in hearing in a noisy situation.

It is frequently found, however, that workers in a noisy environment are able to communicate verbally when the unaccustomed visitor finds intelligibility nil. Johnson reports that this phenomenon exists even in noise-deafened personnel, where it applies only in the working environment and is not extended to other types of masking noise. He suggests therefore, that it is central in origin.

The author finds this suggestion difficult to accept, in view of the evidence on the peripheral nature of masking. Neither can this be a learned process, based on the understanding of partially heard speech, since this ability to communicate verbally in accustomed noise is lost after even a few days away from the noise.

Yaffe and Jones (45) in 1962 investigated the incidence of noise induced hearing loss in a population of 1,952 men employed in Federal Prison industries. They report a high incidence of defective hearing, attributable to noise exposure. The main purpose of the report was to examine the hearing losses and noise spectra in relation to existing D.R.C. and this aspect will be considered in the section relating to D.R.C.

Yaffe and Jones conclude that a shift in threshold for the frequencies 3,000, 4,000 and 6,000 c/s will occur during the first few months of exposure if the environmental noise is severe enough to cause an eventual loss of hearing for speech. This suggests that measurements of temporary threshold shift at these three frequencies could be used to predict the hazardous nature of a given occupational noise environment. Yaffe and Jones also state that permanent hearing loss becomes established over a period of time and infer that permanent damage is failure of the ear to recover from temporary threshold shift which suggests that permanent damage is merely an extension, or consolidation of the effects of temporary exposure. This view is not held by other investigators (page 59) who suggest that temporary and permanent shifts in threshold are caused by different physiological mechanisms and, therefore, that an assessment of the one may not be used to predict the other.

In an analysis of 72 cases of traumatic deafness, Weiss (46) states that complete recovery of hearing occurs when the initial hearing loss is slight or moderate in extent. In severe cases, the loss is usually permanent and constant, but sometimes a progressive loss in hearing may occur even when the subject is no longer exposed to the damaging stimulus. These findings appear to be related to only the noise intensity and are independent of duration of expqsure time.

One of the main problems of the effects of noise on hearing which remains to be solved is that of the importance of length of exposure time as a contributing factor. Some investigators (see Section 2.C, "Damage Risk Criteria") maintain that it is the total energy to which the ear is exposed that determines the hazardous nature of an environment, while others believe that maximum damage occurs during the initial exposure period, the extent of the hearing loss being determined only by the intensity and frequency characteristics of the noise. It is difficult to compare the results of the various investigators holding these opinions, since the noise stimuli all have different characteristics, and the reason for the divergency of opinion may well lie in the variations in energy distribution throughout the spectrum.

In this section on industrial noise surveys, brief mention will be made of the effects of aircraft noise on the hearing of personnel, since there is some indication that jet-aircraft noise may have an effect which differs from that found in industry. Jet aircraft noise has a continuous spectrum, similar to random noise, with the energy uniformly spread throughout the frequency range. Most industrial noise, while giving the general appearance of uniformity has at least a small concentration of energy in selected bands.

It has been reported by Coles and Knight (47) in 1959, that exposure to jet aircraft causes hearing loss which differs in two respects from industrial deafness, namely, in degree and in the frequency region of maximum loss.. The degree of hearing loss measured was less than would be expected from consideration of industrial noise-induced hearing losses which result from exposure to a similar overall intensity. Also, the mid-range of frequencies was found to be the area most affected, in contrast to the typical 4 K c/s 'notch' in hearing encountered so often in industrial surveys.

Similar mid-frequency hearing losses were reported, in 1948, by Finkle and Poppen (48). Whereas Coles and Knight had examined the hearing of flight-deck personnel after exposure to jet aircraft noise, Finkle and Poppen reproduced the noise, under experimental conditions. The noise analysis they submit in their findings could be described as uniform over most of the spectrum, but there were sharp peaks in intensity in the very high frequency range of 21,700 c/s, 27,400 c/s and 29,600 c/s. Another interesting fact reported by Finkle and Poppen was the absence of diplacusis after exposure to jet noise.

A survey by Ward (49) in 1957 on the hearing of naval aircraft maintenance personnel again indicates the presence of an unexpectedly mild hearing loss for the mid-range of frequencies. Since this was a field study, the presence of many uncontrollable variables makes an exact evaluation of the results difficult, but the general trend is in close agreement with that reported by Coles and Knight and Finkle and Poppen.

A report published in 1961 by Witwer and Cole (50) gives detailed noise analyses of several different aircraft, operating under different conditions. The main purpose of the report was to determine which noise levels were likely to constitute a hazard to hearing and the damage risk criterion adopted for the evaluation was that proposed by the United States Air Force (51). Hearing tests were not included in the data published and the main reason for including the paper in this account of industrial noise surveys is that the jet aircraft spectra published by Witwer and Cole appears to be substantially different from those mentioned by other investigators (47, 48 & 49) showing a rise in intensity with increasing frequency. The three other papers reviewed above describe jet aircraft spectra as having a uniform distribution of intensity throughout the frequency range. It is unfortunate that Witwer and Cole do not publish any audiometric data to enable a comparison to be made with the 'flat' hearing losses reported in references 47, 48 & 49.

SECTION 2.C Review of Damage Risk Criteria Estimations

In this section will be included general accounts of damage risk criteria in current use and also details of publications which show how some of these criteria were derived. Table 14 (page: 88) at the end of this section lists several damage risk criteria for comparison.

Although the contribution to hearing damage of the duration of exposure is still highly controversial, many damage risk criteria are based on a computation of spectrum analysis, intensity and exposure duration, as though the three factors were closely interrelated and an increase in one could be compensated by a decrease in another. It is obvious, from a study of the literature, that no such simple relationship exists, and the author feels that the common procedure of estimating the damaging effect of a noise according to the total energy to which the ear is exposed is unjustified.

In 1949, a regulation was issued by the Medical Service Department of the United States Air Force (51) for the purpose of establishing "a programme to minimise the undesirable effects of noise on Air Force Personnel". Table 8 below details the intensity level, for various octave bands, which should not be exceeded during continuous (8 hours per day) exposure.

TABLE 8

LIMITING OCTAVE BAND SOUND PRESSURE) LEVELS

Levels: Broad-band noise (jet type); continuous daily exposure, 8 hours, (480 minutes).

Octave Band	Band Pressure Level	Action Required
300 - 600 c/s 600 - 1200 c/s 1200 - 2400 c/s 2400 - 4800 c/s	85 dB 85 dB 85 dB 85 dB	Use of ear protection is recommended when any one of the band levels equals the value shown.
300 - 600 c/s 600 - 1200 c/s 1200 - 2400 c/s 2400 - 4800 c/s	95 dB 95 dB 95 dB 95 dB	Use of ear protection is mandatory when any one of the band levels equals the value shown.

It is stated categorically in the Regulations that these exposure intensities may be exceeded provided the exposure time is reduced and a method of computing permissible combinations of exposure duration and intensity is given. The same principles are applied to noise which has a high concentration of energy in restricted parts of the spectrum. In this case, it is stated that the permissible level for the peak value narrow band is 10 dB less than for the equivalent band in a uniform spectrum.

The following quotation gives the definition of narrow band components as specified in the United States Air Force criteria - "16 g. Limits for pure tone or narrow band components: (1) Identifying "pure tone" components - The limits on noise exposure in the preceeding paragraphs apply only to broad band type noise, where the noise energy is distributed rather uniformly in all octave frequency bands. However, the noise energy in such noises as the compressor whine of a jet engine at "Idle" is concentrated in one or more frequency components., called pure toneor narrow band components. These components may be in one octave band or they may spread through several octave bands. A noise of this type sounds rather like a musical note or a "pure tone", in contrast to the roaring sound of a broad band noise. The sound pressure level of the octave band with the pure tone component will usually be 3 dB or more higher than the levels of the other adjacent bands. If the pure tone components are an octave apart, the sound pressure levels in two or three adjacent pure tone octave bands will not differ more than 1 or 2 dB; however, they will usually be 3 dB or more higher than the levels of the other adjacent bands.

In many cases, the octaves containing the pure tone can be identified simply by listening to the sound and examining data on the octave band sound pressure level."

Unfortunately, the origin of the data on which these recommendations were made is not given.

In 1950, Kryter (52) stated that the prevalence of the 4 K c/s 'notch' in hearing, typical of occupational deafness, may be explained by the predominance of high frequency components in industrial noise and is not due to there being a localised region of increased susceptibility to trauma. Although this assumption gains support from the pattern of hearing loss resulting from exposure to 'flat' spectrum aircraft noise, the author feels that there is now sufficient evidence from other sources to support the concept of a differentially sensitive sound receptor mechanism.

Kryter suggests that from the evidence available, 85 dB (relative to 0.0002 dynes/cm^2) should not be exceeded, in any one aural critical band. This estimate applies to prolonged or continuous exposure.

Beranek (53) in 1950, published two criteria, one modified from Kryter's, stating maximum safe intensity levels for pure tones and continuous spectrum noise, the other lists speech interference levels for various distances and voice intensities. These are reproduced in Table 9.

TABLE 9

CRITERION FOR NO DAMAGE TO HEARING

(After Kryter with modifications)

Octave Band Frequencies in Cycles per Second	Levels not to be exceeded to assure no permanent damage to hearing. (Decibels re 0.0002 Microbar)	
	Continuous Spectrum Noises	Pure tones
20 - 75	110 *	110*
75 - 150	102 *	99*
150 - 300	97*	90*
300 - 600	95	86
600 - 1200	96	85
1200 - 2400	97	85
2400 - 4800	98	85
4800 - 9600	99	85

* These three levels are not as reliably established as the other five.

TABLE 10

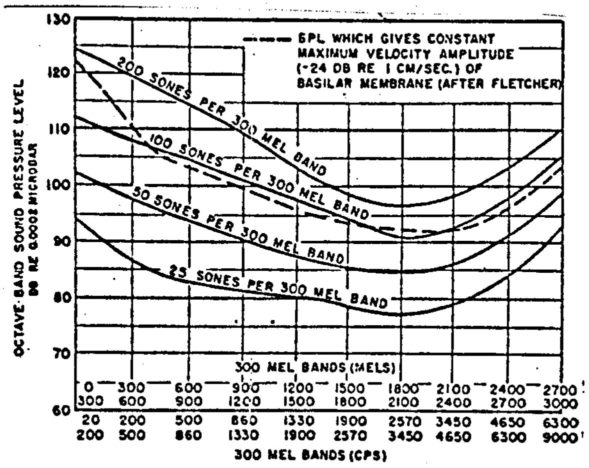
SPEECH INTERFERENCE LEVELS

Voice Level / Distance (Feet)	Normal	Raised	Very Loud	Shouting
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61

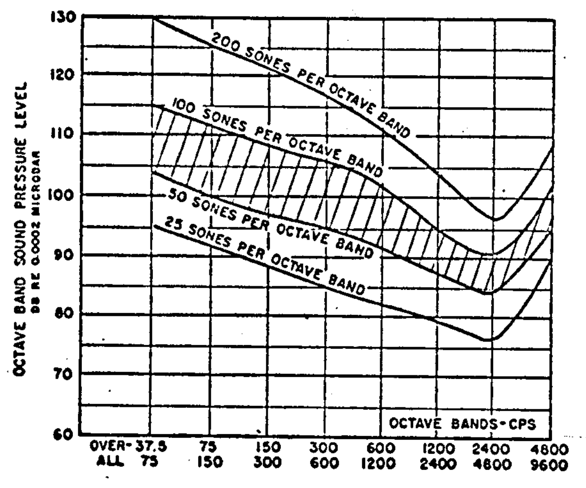
Speech interference levels (in dB re 0.0002 microbar) which barely permit reliable conversation at the distances and voice levels indicated.

FIGURE 9 From Hardy (54, page 75)

Curves of Equal Sensation



Equal sensation curves for broad-band noise in 300 mel bands as calculated by Beranek's equivalent tone method from the Churcher-King curves. The dotted line gives the sound pressure level necessary to give a constant maximum velocity amplitude of the basilar membrane.



Equal sensation curves for broad-band noise in octave bands. The 50-sone and 100-sone curves are suggested by this paper to be the limits which bracket the damage risk for long time daily exposure to broad-band noise.

To face page 74

Hardy in 1952 (54) published a damage risk criterion based on theoretical considerations of various functions of the hearing mechanism. The basic assumption is that fatigue, which is the precursor of trauma, is a direct function of the energy stimulus of the basilar membrane. It is shown that the curve for maximum energy density on the basilar membrane closely follows the curves for equal sensation of loudness and Hardy therefore suggests that loudness is a function of energy stimulus and not directly a function of frequency. Two of Hardy's graphs are reproduced in figure 9 opposite, one showing the relation between maximum energy density and the sensation of loudness over a wide range of frequency bands. The other graph illustrates the proposed damage risk criterion.

The lower level, 50 sones, per octave band, indicates Hardy's proposed maximum for complete safety of hearing based on data from industrial surveys by several investigators.

In contrast to Kryter's assumption that no frequency area of especial sensitivity exists, Hardy accepts the prevalence of 4 K c/s trauma as additional proof of his concept of the relationships between equal loudness functions and the fatigue (or maximum energy density) curve. It is obvious, from the graph reproduced opposite, that the area of maximum sensitivity to loudness corresponds to the frequency region which would result in selective fatigue for 4 K c/s. (i.e. at approximately $3\frac{1}{2}$ K c/s).

Since Hardy's conclusions are based on considerations of the loudness function his damage risk criterion is in subjective units, sones, the author feels that a more workable criterion would be obtained if these units were converted back into intensity levels, rather than using the specified levels in their present form, which would necessitate conversion of all industrial noise analyses data. The author prefers the use of physical units, since a considerable degree of accuracy is lost when these are converted into subjective units. It is frequently overlooked that all subjective units are based on observer judgements, the results of which vary considerably according to the experimental technique involved. Added to this source of variation is the additional factor of inter-subject variation, which extends over a wide range in all measurements of loudness. The single figure which may be given to represent the loudness of a sound is, therefore, a mean value, with a large standard deviation, and all such loudness values should be used with caution.

Sterner, in 1952 (55) published a short review of thirteen damage risk criteria in order to demonstrate the wide variation in the noise levels designated as 'safe' by different investigators. No evaluation of the various criteria is offered by Sterner, but it is interesting to note that, prior to 1952, the majority of criteria specified a single intensity level, with no frequency weighting.

In 1954, the report of a committee of the American Standards Association (38) was published, in which average hearing losses, for specified frequencies, were related to continuous exposure to octave bands of noise. Trend curves were developed to show the hearing loss which might be expected for frequencies of 1 K c/s, 2 K c/s and 4 K c/s, from continuous exposure to steady noise. The Committee found that, using these trend curves, predicted hearing loss was in close agreement with measured hearing loss, but they issue a warning that the curves are only applicable to noise which comes within the limits of the exposure times and spectra of their investigations. They make no attempt to derive a damage risk criterion from the results of the investigations, and suggest that insufficient evidence was available at that time (1954) for a criterion to be established which would be applicable to the wide variety of noise environments encountered in industry.

There is very little evidence published on the effect on hearing of impulsive noise, due no doubt, to the technical difficulties involved in making accurate noise measurements of this type. It is interesting to note, therefore, that the Committee report that the greatest threshold shifts, as a function of time, occurred in the hearing of drop-forge operators.

In 1956, Jerger and Cahart (56) attempted to establish a relationship between fatigue as measured by temporary threshold shift, and susceptibility to permanent trauma. As an index of pre-exposure fatigue, they measured the recovery rate from experimentally induced fatigue.

Pure tone audiograms and pre-exposure fatigue measurements were made on 178 subjects, who were then engaged in work with a high noise level. Eight weeks following the end of the noisy work period, the subjects were examined for permanent hearing loss and the extent of the loss related to susceptibility to the experimentally induced fatigue.

The index of pre-exposure fatigue was taken as the recovery rate of an interrupted tone (500 milli sec. duration) of 4500 c/s, following one minute's fatiguing stimulus of 3000 c/s. It seems to the author that this is an unnecessarily complex way of measuring fatigue, depending as it does upon the recovery rate from fatigue, rather than on the total fatigue induced. This procedure pre-supposes a direct relationship between recovery rate and total fatigue present, a relationship which may well exist, but which does not appear to have been established.

Jerger and Cahart's results give some indication that temporary threshold shift may be an index of susceptibility to noise trauma. Unfortunately, they do not publish details of the spectrum of the traumatising environmental noise to which their subjects were exposed, beyond stating that it consisted of jet-engine noise. Several other investigators (47, 48 and 49) have suggested that under certain conditions, jet-engine noise is atypical in its effects on hearing.

Glorig (57)in 1957, published "Guide for the conservation of hearing in noise" which will only be considered briefly here, since most of the contents relate to methods for hearing conservation. The damage risk criterion which Glorig proposed at that time, in 1957, was that hearing conservation should be considered for continuous exposure to environmental noise which exceeds 85 dB in either of the octave bands 300 - 600 c/s and 600 - 1200 c/s. Glorig bases his choice of octave bands on the assumption that, since speech is contained within the lower frequencies of the spectrum, noise which contains high levels of these frequencies will have the greatest damaging effect on speech intelligibility. This assumption again indicates the controversy which exists concerning the relationship between the spectrum of the traumatising noise and the nature of the induced hearing loss. Some investigators consistently find maximum loss for high frequencies, especially in the 4 K c/s region, while others report a closer relationship between noise spectrum and hearing loss pattern.

In 1957, Burns & Littler (58) proposed a damage risk criterion based on the data supplied by the Committee of the American Standards Association (38) as follows: -

TABLE 11

SUGGESTED SPECIFICATION OF MAXIMUM SOUND PRESSURE LEVELS FOR AVOIDANCE OF OCCUPATIONAL DEAFNESS

Frequency band c/s	Maximum permissible spl in band (dB)	
Below 150	100	
150 - 300	90	
300 - 600	80	x
600 - 1200	75	
1200 - 2400	70	x
2400 - 4800	70	
above 4800	70	

Burns & Littler state that the above criterion is only applicable if the noise spectrum closely resembles one of those from which the data was derived, namely, with a pattern of decreasing intensity for the higher frequencies. The two octave bands marked with a cross, 300 - 600 c/s and 1200 - 2400 c/s, were derived directly from the data of the Committee. For noise spectra which are flat, or which contain a preponderance of higher frequencies, the other octave bands in the above table must be taken into consideration.

In 1959, Ward and Glorig (28) specified a damage risk criterion as a result of their investigations into temporary threshold shift. Table 12 below summarises their experimental conditions.

TABLE 12

SUMMARY OF EXPERIMENTAL CONDITIONS OF WARD & GLORIG

STIMULUS	-	Frequencies at which growth and recovery of T.T.S. was measured
Frequency range of octave bands	Intensity Levels	
300 - 600 c/s	105 dB	1 K c/s . 2 K c/s
600 - 1.2 K c/s	95, 100, 105 dB	1.5 K c/s . 2 K c/s
1.2 K - 24 Kc/s	90,95,100,105 dB	3 K c/s . 4 K c/s
2.4K - 4.8 K c/s	85,90,95, 100 dB	4 K c/s . 6 K c/s

From their results, Ward & Glorig derived equations for the estimation of the T.T.S. which could result from exposure to any of the above octave bands of noise. They tested experimentally, the validity of their equations and found that there was close agreement between calculated and measured T.T.S.

Two facts which emerged as a result of their experiments are: -

1) That the time taken for complete recovery from fatigue is dependent upon the initial amount of threshold shift, and,

2) When the T.T.S. reaches the value of 50 dB, recovery is considerably slower than was expected. It is suggested that an induced T.T.S. of 50 dB is probably the critical level at which threshold shift loses its temporary nature and assumes permanence.

In applying their results to the formulation of a damage risk criterion, Ward & Glorig suggest that, since no T.T.S. is produced by any octave band at an intensity below 80 dB, this level will probably not produce any permanent trauma, even after prolonged exposure. They consider that the intensity level of an octave band which produces the "critical" 50 dB T.T.S. is the intensity at which permanent hearing loss will result from continual exposure. In order to avoid the possibility of <u>any</u> permanent trauma, they base their criterion on the octave band intensity levels which produce 40 dB T.T.S., i.e. 10 dB less fatigue than the "critical level" The intensity levels which will result in 40 dB T.T.S. are summarized in Table 13 below.

TABLE 13

OCTAVE BAND INTENSITY LEVELS WHICH CAUSE 40 dB T.T.S.

OCTAVE BAND	INTENSITY WHICH WILL RESULT IN 40 DB T.T.S.
/300 - 600 c/s	102 dB
600 - 1.2 Kc/s	108 dB
1.2 K - 2.4 K c/s	95 dB
2.4 K - 4.8 K c/s	95 dB

Ward & Glorig in referring to the noise safety levels specified by the United States Air Force (51) which makes hearing protection obligatory if intensity levels exceed 95 dB in any octave band, make the following statement: - "A continuous 8-hour exposure to a noise with 85 dB in all octave bands would produce a T.T.S. of about 20 dB at 6 K c/s, 35 dB at 3 K c/s, 15 dB at 2 K c/s and about 10 dB at 1 K c/s The same limits are prescribed for all octave bands, which means that less T.T.S. is permitted at low frequencies than at high. However, it must be considered that a given permanent loss at 1 K c/s is probably more 'important' than one at 4 K c/s. That is, while a 40 dB loss at 4 K c/s will hardly be noticed, a 40 dB loss at 1 K c/s will seriously interfere with perception of speech. It is therefore eminently sensible to provide a greater margin against permanent loss in the low frequencies than in the high, until we know more about the relation between T.T S. and permanent loss".

The author doubts the validity of the assumption that industrial noise behaves like a collection of octave bands. It appears from a study of the literature, that the following factors should be taken into consideration: -

(a) The effect of low frequency noise may be governed by a different set of determining factors from those which cause the more rapidly acquired fatigue at higher frequencies.

Exposure time may be a more important contributing factor than is intensity level for these low frequencies. (see page 28).

(b) The <u>relationship</u> between the various frequency components of environmental noise may be an important factor in determining the resulting trauma (see page 39-40)

(c) The difference between the traumatising effects of 'flat' spectrum jet noise (see page 67) and the more uneven spectrum of most industrial noise, would appear to lend further support to the author's contention that the effects of complex noise cannot be deduced by a simple addition of the sum of the separate effects of the component octave bands.

In a further study by Glorig et al (59) in 1961, a more conservative estimate is made of safe environmental intensity levels. They report that noise-induced permanent threshold shift follows a definite pattern, with increasing exposure time. 4 K c/s is affected first and then progressively lower frequencies are involved as exposure time increases. After about 10 years exposure, there is no further decline in the 4 K c/s threshold except that caused by presbycusis. Glorig et al suggest that a damage risk criterion should be based on the combination of intensity level and exposure time which will result in no permanent damage to the most vulnerable of the speech frequencies, that is, the highest frequencies in the speech range. They conclude that if hearing for 2 K c/s is preserved, there will be no spread of trauma to involve the lower speech frequencies.

FIGURE 10 FROM GLORIG (59, pag

CURVES FOR RATING SHORT-TERM NOISE EXPOSURE

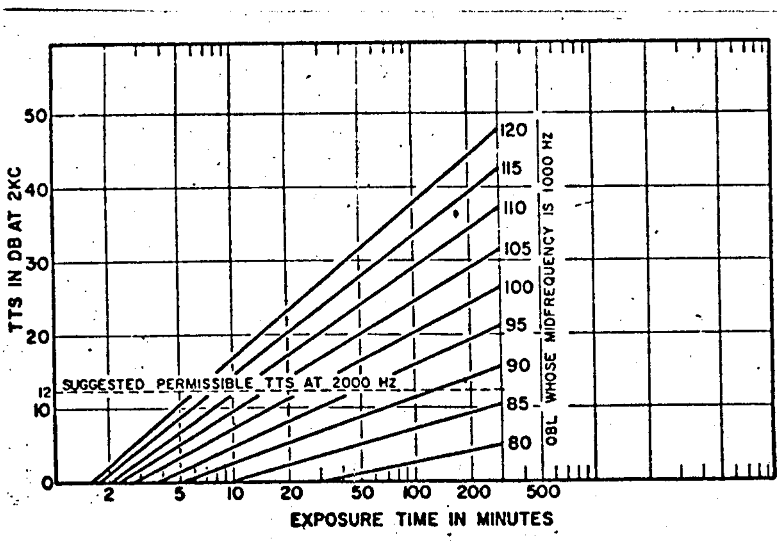
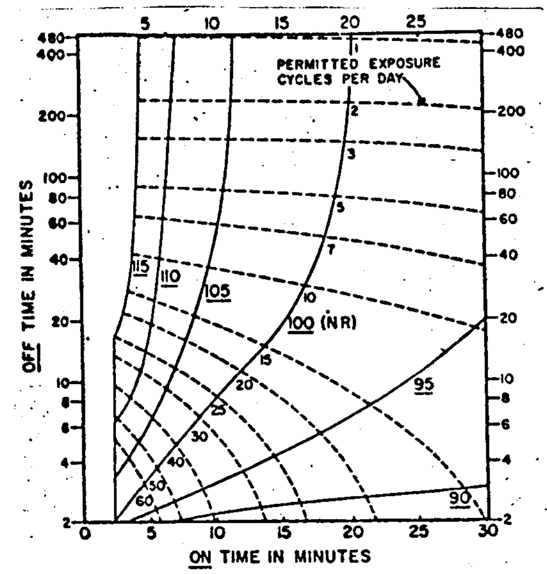


FIGURE 11 FROM GLORIG (59, page

CURVES FOR RATING INTERMITTENT NOISE EXPOSURE



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In their previous paper (57) Glorig et al suggested that intensity levels which produce less than 40 dB T.T.S. would not result in permanent damage to hearing if exposure is prolonged. In this paper (59) they propose a much lower level, 12 dB as the maximum permissible temporary shift in threshold. They summarise their findings by stating that hearing conservation should be considered if a given noise produces more than 12 dB temporary threshold shift. in hearing for 2 K c/s. From the results of their experimental work and field observations, they suggest that, for continual exposure to steady-state noise, the intensity level should not exceed 85 dB in the octave band 600 c/s - 1.2 K c/s. Figures 10 and 11 opposite, reproduced from their paper, give the 'safe' exposure time for various intensity levels of the octave band 600 c/s - 1.2 K c/s.

The curves in figure 10 give the combination of exposure time and intensity level of the octave band 600 c/s - 1.2 K c/s which cause the temporary threshold shift in hearing for 2 K c/s specified along the ordinate.

Figure 11 relates the intensity level of the octave band 600 c/s - 1.2 K c/s to the number of exposure cycles per day of intermittent noise which will result in no more than 12 DB temporary threshold shift for 2 K c/s.

Brief reference will be made here to an article by Bonney (60) published in 1962, which, while it contains no original material, does give a useful account of the controversy in the United States of America concerning the choice of damage risk criteria. It is apparent that in 1962, there was considerable disagreement among various investigators on the following points: -

a) What constitutes hearing impairment?

(b) The desirable definition of hearing safety, i.e. should there be no permanent threshold shift, or is a loss of frequencies beyond those of the speech range acceptable?

(c) The relationship between band-width and threshold shift.

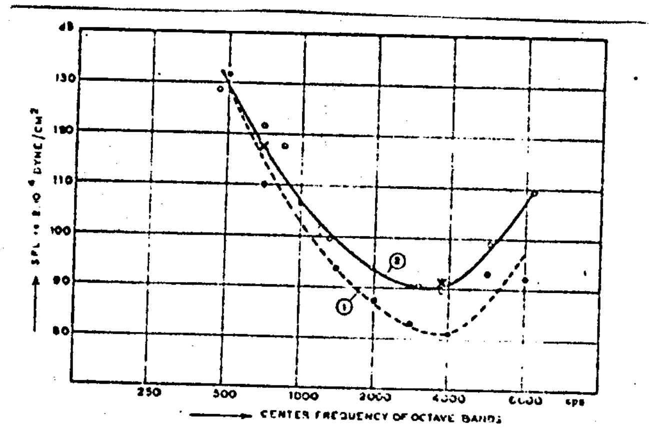
(d) The exact specification in terms of intensity, frequency and exposure time, of damage risk criteria.

In 1962, Ward (61) extended the investigations of Thompson and Gales (21) into the effect on T.T.S. of varying the stimuli bandwidths. Thompson and Gales had found that T.T.S. was independent of bandwidth, over the range from pure tone to octave band, at intensity levels up to 110 dB. Ward measured the T.T.S. produced by a wider range of intensity levels, using a pure tone of frequency 1650 c/s and an octave band comprising 1200 - 2400 c/s. He reports that, at intensity levels up to and including 115 dB (5 dB higher than the maximum used by Thompson and Gales) the pure tone and octave band produced equal amounts of threshold shift. At intensity levels above 115 dB, more threshold shift resulted from pure tone stimulation than from exposure to the octave band. Relating his findings to damage risk criteria, Ward issues the following warning "a single decibel correction applied to all levels and to any frequency range is a gross over-simplification."

The results obtained by Plomp et al from their study of T.T.S. (27) which was considered in some detail in Section 2.A (i) page 31 of this report, are also relevant to this section on damage risk criteria.

FIGURE 12 From Plomp et al (27, page 1238)

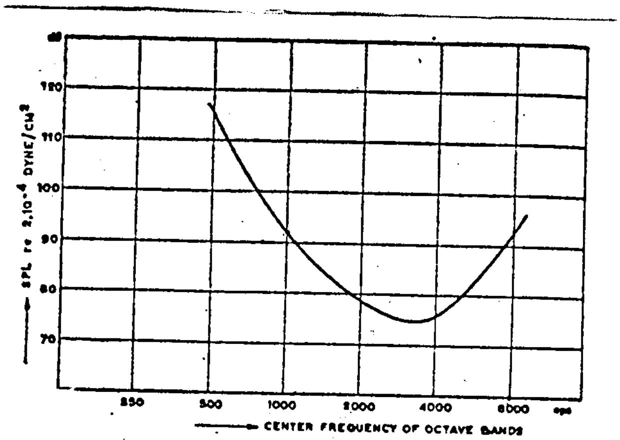
CURVES OF EQUAL THRESHOLD SHIFT FOR OCTAVE BANDS OF NOISE



Sound-pressure levels of octave bands of noise which gave equal threshold shift at one frequency (solid circles) and equal threshold-shift area (open circles), respectively, averaged for 2 test subjects. *X* indicates noise levels giving the same threshold-shift area as for the open circles, being an average for 12 subjects. The curves 1 and 2 give the best visual fit to the points.

FIGURE 13 From Plomp et al (27, page 1240)

PROPOSED DAMAGE RISK CRITERION



Proposed criterion line showing the limit of noise spectra which will not induce permanent hearing losses.

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Figure 4, facing page 32 , gives the intensity level of octave band stimuli which cause a 5 dB T.T.S. for frequencies half an octave higher than the centre of the stimulus band

Plomp et al also measured the T.T.S. produced over a wide frequency range by each octave band and plotted their results in terms of total threshold shift. Figure 12 opposite, illustrates the difference between the curve obtained from these results snd that of figure 4 in which the maximum threshold shift only was plotted.

Plomp et al use the data from curve 2 in figure 12 to specify a damage risk criteria, which is reproduced in figure 13 opposite.

The author feels that further evidence is required on the following points before such criteria can be accepted.

a) The exact nature of the effect of stimulus duration, at various frequencies and intensities on threshold shift, and

b) The effect of the interaction of the frequency components in wide spectrum noise.

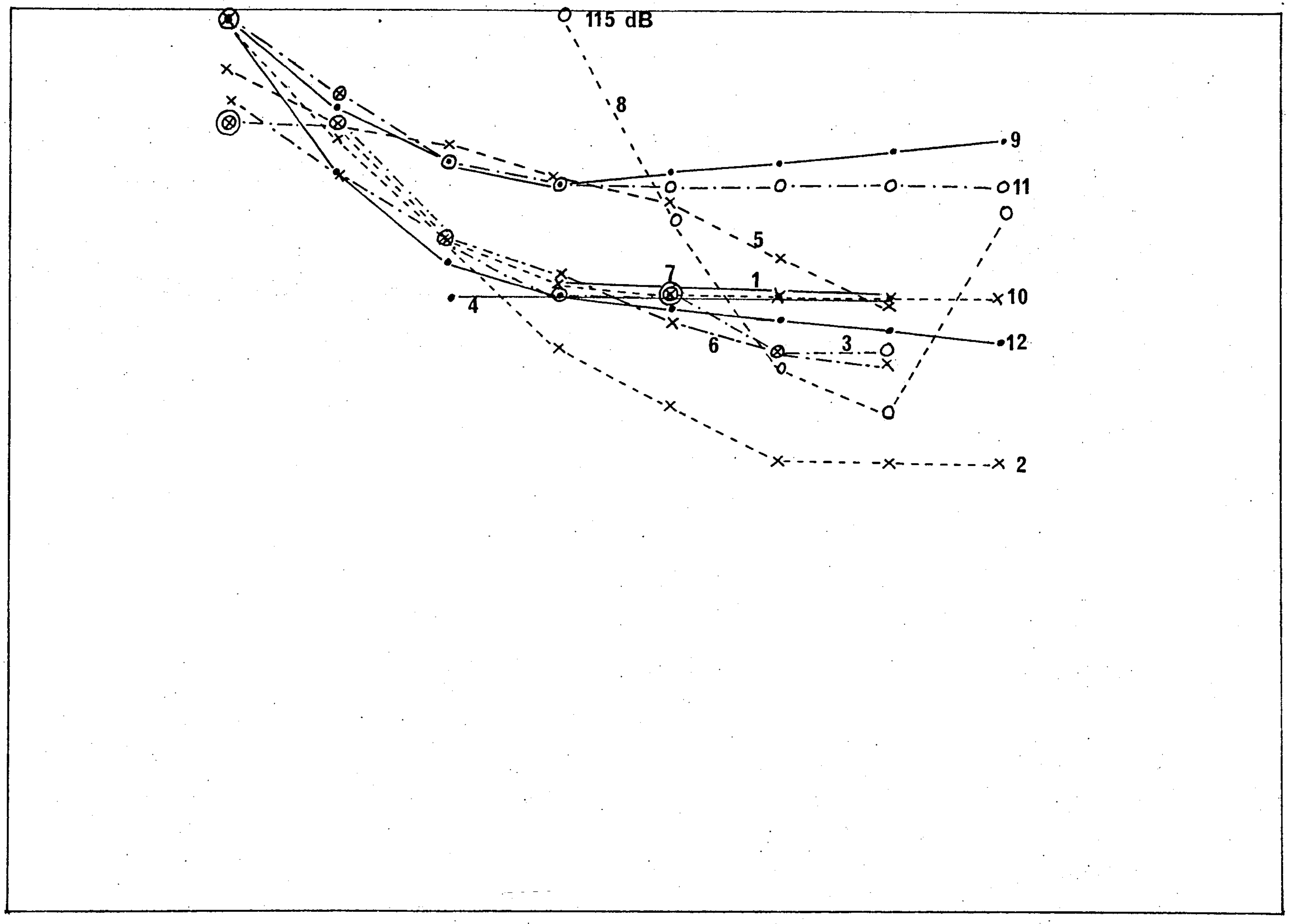
Yaffe and Jones (45) in their study mentioned previously in Section 2.B (page 65) of this report, examined the efficacy of various damage risk criteria in the light of the results of their large-scale hearing survey conducted among workers in Federal prison industries. They found that noise levels which came within the Rosenblith and Stevens (42) specifications for damage risk criteria resulted in little hearing loss. However, their findings did not substantiate the criteria for line spectra formulated by Rosenblith and Stevens snd adopted by the U.S.A.F. regulation 160-3 (51). Yaffe and Jones found that 41.2% of the environmental noise they analysed came within the U.S.A.F. regulation definition of 'narrow band' noise but the measured hearing loss indicated that the hazard to hearing did not justify the use of a criterion based on the relatively low intensity levels specified for narrow band noise.

Yaffe and Jones point out that the decision as to whether or not a noise spectrum qualifies for the description 'narrow band' is largely dependent upon the definition of the term 'narrow band'. If the U.S.A.F. regulation definition (see page 71 of this report) is accepted, then about 50% of all industrial noise comes within it. They feel that this makes for a criterion too stringent for industrial application.

It is apparent from their results, that pure tone components, as defined by the U.S.A.F. regulation, do not contribute appreciably to the hazardous nature of noise exposure. However, this does not exclude the possibility that a concentration of energy within a narrow band of frequencies may, in fact, be more detrimental to hearing than exposure to more evenly distributed noise intensity. It simply means that the definition of 'narrow band' or 'pure tone' components requires more careful consideration.

Yaffe and Jones conclude that the Rosenblith and Stevens criterion gives protection for most of the environmental noise levels they studied. They also state that their data support the U.S.A.F. regulation recommendations that hearing conservation should be instituted when the intensity level of continuous spectrum environmental noise reaches 85 dB in any one

FIGURE 14 DAMAGE RISK CRITERIA NUMBERS 1 TO 12



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octave band. It may be seen from table 14, page 88 of this report that these two criteria differ by 10 dB. It becomes apparent, from a study of the literature, that there is an area of uncertainty between 85 dB and 95 dB within which probably lies the most reliable value for a workable damage risk criterion. This uncertainty is unlikely to be resolved until definitions and methods of investigation are standardised.

Conclusions

It is difficult to draw any definite conclusions from consideration of the various damage risk criteria reviewed in this section, beyond the obvious one that there are still several problems which remain to be solved before a single reliable damage risk criterion can be formulated.

Table 14 below gives details of damage risk criteria which are often quoted in the literature, some of which, presumably are in current use, at least, in America. These are presented in graphical form infigure 14 opposite to illustrate the wide divergence of opinion as to what constitutes the maximum permissible intensity level for the conservation of hearing.

TABLE 14

DAMAGE RISK CRITERIA

	Origin	Centre frequency of octave band c/s 63	125	250	500	1K	2K	4K	8K	Maximum exposure time	Remarks
1.	U.S.A.F. (51)				85 dB	85dB	85dB	85dB		8 hours per day	Protection recommended whenany one band exceeds limit shown
2.	Burns & Littler (58)	100dB	100dB	90dB	80 dB	75dB	70dB	70dB	70dB	8 hours per day	
3.	Burns & Littler (16)	100dB	100dB	90dB	85 dB	85dB	80dB	80dB		8 hours per day	For flat-spectrum noise only
4.	British Medical Assoc. (16)			85dB	85 dB	85dB	85dB	85dB		8 hours per day	
5.	Hardy (54)	105dB	103dB	98dB	95 dB	93dB	88dB	84dB	94dB	Continuous exposure	
6.	I.S.O. Noise Rating No. 85 (62)	102.6 dB	95.9 dB	91dB	87.5 dB	82.8 dB	80.6 dB	79.5 dB		5 hours per day	Protection recommended if intensity is exceeded in any one octave band
7.	Glorig (59)					85dB				Continuous exposure	For the protection of hearing for speech
8.	Plomp et al (27				115dB	92dB	79dB	75dB	93dB	Not specified	
9.	Beranek (53)	110dB	102dB	97dB	95 dB	96dB	97dB	98dB	99dB	8 hours per day	Continuous spectrum.
10.		110dB	99dB	90dB	86 dB	85dB	85dB	85dB	85dB		Pure tones.
11.	Rosenblith & Stevens (42	110dB	103dB	97dB	95 dB	95dB	95dB	95dB	95dB	8 hours per day	Continuous spectrum.
12.			96dB	88dB	85 dB	84dB	83dB	82dB	81dB		Pure tones & critical bands
	Range of variation	110-100 = 10dB	103-96 = 7dB	98-85 = 13dB	115-80 = 35dB	96-75 = 21dB	97-70 = 27dB	98-70 = 28dB	99-70 = 29dB		

SECTION 3

NOISE CONTROL

Two aspects of the control of environmental noise are considered briefly in this section. An outline of noise control methods (A) is followed by a review (B) of the present state of British Legislation against injurious noise.

A. METHODS OF NOISE CONTROL

When a noise hazard is known to exist, the problem of reducing the effective intensity may be approached in two ways. Obviously the most satisfactory solution is to reduce the noise at source, but in many cases, this is not practical. Alternatively, hearing may be protected by instituting a hearing conservation programme. The two methods will be considered separately.

1. Reduction of Noise at Source

There are many ways in which high intensity noise may be reduced to a level compatible with hearing safety, but the technicalities of these are beyond the scope of this report and a brief reference only will be made to the various principles involved.

(Full details of noise control methods are contained in references 42, 62, 63 and 64)

(a) Enclosure of noise source:-

Emitted noise may be greatly reduced by total or partial enclosure of the source. Sound reduction may be achieved by the use of a homogeneous single-layered structure, for which the insulation largely depends upon the weight per unit area of the material. The insulating properties of a solid enclosure vary slightly with frequency, ~~but~~ and are most effective for the higher frequencies. Further insulation of higher frequencies may be achieved by the use of a double-layered enclosure where the two walls are separated by an air cavity.

The sound insulation properties of this type of construction are dependent upon there being the minimum of communicating ties between the two walls, and while high frequency insulation is greater with a compound wall construction, low frequency insulation is reduced. Therefore, very careful consideration must be given to the exact function of the sound insulation barrier. If protection of hearing is of prime importance, a double-layered structure will be effective, but if it is required to improve verbal communication, then a working compromise may be reached by using a single layered barrier of sufficiently massive construction to reduce both high and low frequency noise.

The sound insulating properties of many materials and types of construction are detailed in Handbook of Noise Control (63) which covers all aspects of noise control.

Obviously, total enclosure of a noise source will provide greater sound insulation than partial enclosure, but the size of a machine,or the method of its operation, often prohibits the use of a barrier which completely surrounds the noise source. Considerable noise reduction may be effected by interposing a suitably constructed screen between a localised noise source and the machine operator. The use of sound absorptive materials reduces the intensity of noise reflected from walls and ceilings, but these measures are effective only when a reduction of a few decibels is required, as, for example, when it is desired to improve the intelligibility of speech in a noisy environment. When environmental noise is of an intensity likely to constitute a hazard to hearing, then total enclosure of the noise source, or the adoption of personal protective measures, is usually required to reduce the effective noise level to within the safety limits.

When a noise analysis reveals an equal distribution of energy throughout the spectrum, the overall intensity level can only be reduced by partial or total enclosure of the source. If however, it is found that there is a concentration of energy in discrete octave bands, then the source of these intensity maxima may be determined by a finer analysis of the relevant octave bands. This procedure will enable each component of the noise source to be identified and located precisely and where possible, reduced in intensity.

(b) Maintenance of Machines

The noise emitted by a machine may often be reduced by close attention to maintenance. Worn driving belts and gears contribute unnecessary noise and the overall level may be further reduced by the use of rubber mountings to prevent transmission of structure borne noise.

(c) Process Substitution

It is sometimes possible to reduce a high intensity environmental noise level by replacing the noisy process by a quieter one, for example, welding may be substituted for rivetting.

2. Personal Protection against Noise

When it is not practical to reduce a noise level at source, a hearing conservation programme may be instituted to provide protection against the noise hazard. The success of such a programme depends upon the careful selection of the correct ear defender and supervision of its use. Personal protection often fails to be successful because no further action is taken after the initial issuing of defenders. The following points should be carefully considered when a hearing conservation programme is to be adopted.

a) Selection of the most suitable ear defender

There are two main types of ear defenders, externally worn ear muffs which totally enclose the ears, and insert defenders, which occlude the meatus. The decision as to which type is more suitable in a given noise environment will depend upon both the sound attenuation required and whether other protective headgear is worn.

Ear muffs provide greater protection than insert defenders, having attenuation characteristics of approximately 40 dB for all frequencies, but the disadvantages of their use are their relatively high cost, (about four times as much as a pair of inserts), the reduction they cause in speech intelligibility and the discomfort which may arise through continual use. When protective helmets, hoods or face masks are also worn, the addition of ear muffs may be unacceptable to the employee, although the ear muffs themselves may be successfully incorporated into specially designed protective headgear.

The protection afforded by insert defenders varies greatly with the different types available and it is important to choose one with attenuation characteristics similar to the spectrum of the noise hazard. It is common practice for people to use plugs of cotton wool, a dangerous procedure, since these afford virtually no protection and give the wearer a false sense of security. Most commercial inserts are available in three sizes and each employee should be carefully fitted to ensure that the insert is large enough to occlude the meatus but not so big that pressure on the walls of the meatus causes discomfort or pain.

Insert defenders are also available which have highly selective attenuation characteristics, reducing the intensity of high frequencies only. This enables speech to be heard, while protecting the ear from the more damaging higher frequencies. These inserts are particularly useful when verbal communication is essential in a noisy environment and provide adequate protection against many noise levels encountered in industry.

Noise levels of 120 dB may require the use of a combination of insert and external defenders to reduce the effective intensity level to within the safety limits.

For adequate protection against noise levels in excess of 120 dB the whole head must be covered by a specially designed helmet, because sound vibrations of this magnitude will reach the cochlea, via the bones of the skull, at a dangerously high intensity.

b) Explanation of programme to employees

Most employees are not aware of the damaging effect of high noise intensities. There is no obvious hazard, as there is with most other dangerous situations when safety precautions are accepted by the employee.

The onset of occupational deafness is so gradual that loss of hearing acuity does not usually become apparent until irreversible damage has occurred. Employees need to be educated, therefore, about the danger of exposure to high noise levels and the desirability of taking adequate precautions.

c) Hearing Tests

All employees to be fitted with ear defenders should have an initial hearing test to provide a record of their hearing immediately before protective measures are taken. Thereafter, regular checks of hearing should be made to ensure that the protection provided is adequate.

The author has found that, in the few instances where ear defenders have been issued to employees, none of the above precautions have been taken to ensure that the noise hazard has in fact been reduced to within the safety limits. Consequently, when a noise survey is requested, the report submitted to the management always contains an outline of a hearing conservation programme, together with details of ear defenders which will provide adequate protection.

B. LEGISLATION

English law has been slow to provide protection of the individual from the ever-increasing noise levels of our highly automated society. As in all other aspects of acoustic research and noise control, America is far ahead of England in the sophistication of their legislative procedure.

Until 1960, there was no provision in this country for the protection of the individual against noise nuisance. Prior to this, noise had to be shown to be injurious to health before the Law would enforce abatement. The Noise Abatement Act 1960 brought noise within the scope of the legal definition of a statutory public health nuisance and so opened up the way for private individuals to apply for the abatement of a noise.

The fact that noise is now recognised in Law to constitute a hazard to the health and well-being of the citizen is an excellent, although slow moving, beginning to the urgent need to reduce the dangerous noise levels of our society. However, there is still no legal protection for the employee who is slowly being deafened during the pursunnce of his employment. Again, in this respect, America leads the way in providing machinery through which an employee may sue his employer for damage to hearing incurred as a result of a high noise level working environment.

When legislation was introduced in America, it was made retrospective in its application, and the cost to industry of the many claims for compensation of hearing loss was enormous. The present state of American Law relating to protection of hearing against industrial noise is difficult to assess, since there is no one standardised damage risk criterion applicable to the whole country, each state administering its own industrial safety regulations.

In its final report to the Government, the Committee on the Problem of Noise (16) made various recommendations for the reduction of the high noise levels to which the private citizen is exposed, but states that existing knowledge is insufficient to formulate protective leglislation for industrial employees and urges that further research be carried out.

To quote from the report (page 148): -

"725. We recommend, as immediate steps, that the Ministry of Labour should: -

a) Disseminate as widely as possible existing knowledge of the hazard of noise to hearing:

b) Impress on industry the need to take action to reduce the hazard: and

c) Advise industry on practical measures to this end (paragraph 533). 726. We do not consider the present knowledge of this complex problem provides a sufficient basis for legislation (paragraph 534")

As a result of these recommendations, the Government instituted a programme of research into the effects of existing industrial noise on the hearing of employees (see page 55). Information resulting from this investigation will be used as a basis for the legislation of noise control in industry.

SECTION 4

Investigation into the Effects of Noise on Hearing Acuity - A survey of environmental noise in eight factories

The purpose of this investigation is to examine the environmental noise levels which exist in factories where no previous action has been taken to conserve the hearing of exposed personnel. A detailed assessment was made, where possible, of the hearing acuity of the employees in order to determine the traumatising effects of each noise source.

The size of the sample in relation to the many uncontrollable variables present prohibits the findings from being used to predict the effect on hearing of other environmental noises. Therefore, no attempt will be made to suggest the intensity level, frequency spectrum or exposure time which constitutes a hazard to hearing. Each noise measured will be considered separately in its relation to the specific effects which were found to exist in the hearing of exposed personnel.

EQUIPMENT

Noise Analyses

For most noise neasurements the equipment used was a Bruel and Kjoer Objective noise level meter, type 2203, coupled to the octave filter unit type 1613. The first analyses of this survey were made with a Dawes objective noise meter, type 1405, together with a Dawes octave band analyser, type 1410. In all instances, the overall intensity levels were measured with the weighting network switch to the 'linear'position. Calibration checks were made before the commencement of each industrial survey.

Hearing Assessments

Hearing measurements were made with a Peters audiometer, either the portable or the clinical model. Threshold checks were made on the author's hearing at least once during every test session, for two purposes. Firstly, to ensure that the calibration was correct, and secondly, to assess the masking effect, on normal hearing, of the ambient noise of each testing room.

PROCEDURE

One of the main difficulties encountered during this survey was the high ambient noise level which existed in even the quietest rooms available for testing. These noise levels were measured and the possible effects on the hearing test results will be taken into consideration when assessing the hearing acuity of the personnel examined.

Another difficulty frequently encountered arises from the mobility of labour in the industries examined. A history of previous exposure to high noise levels of many of the personnel precludes the formation of a simple cause and effect relationship between the present noise environment and the measured hearing loss. However, if all personnel who had been exposed to more than one environmental noise were excluded from the sample, the remaining data would be too sparse to permit even the most general conclusions to be drawn. Therefore, in most cases, the author intends to consider the incidence of traumatic deafness as a whole, in each of the industries examined, without attempting to attribute hearing loss to exposure to a specific noise. In a few instances, where a subject has been exposed to only one high intensity noise, it has been possible to suggest a more direct relationship between noise exposure and hearing defect.

All personnel were questioned regarding previous history of aural disease and familial deafness and any subjects who revealed a history of pain, discharge or other relevant factors, have been excluded from the results of this survey.

In order to assess the possible effects of temporary threshold shift on the hearing at the time of testing, the time was noted which had elapsed between the last exposure to noise and the commencement of the audiogram. In some instances, audiograms were repeated when the subject had been unexposed to noise for several days, due to holiday or illness. A comparison of these results with those obtained on testing immediately following noise exposure gave some measure of the temporary shift involved. However, even these comparisons cannot give a final hearing loss value, since all hearing measurements are subject to several factors which cause variations in the results obtained by repeated testing.

The time taken for an assessment of hearing was usually twenty minutes, ten minutes being required to explain the test procedure and to obtain the necessary information and ten minutes for the audiogram. In most factories, this was the maximum time which could be given to each subject. Ideally, all subjects who showed a hearing loss should have been investigated more thoroughly to include bond conduction audiometry. Where conditions permitted, this was done, but, since personnel were usually

DEPARTMENT OF ERGONOMICS AND CYBERNETICS

ASSESSMENT OF HEARING

Date .... Factory ....

Name	D.B.	Works No.	Department

Description of Noise:-

Initial Exposure to present noise ....

Total Exposure to present noise ....

Exposure per day.......................... hrs.

Exposure prior to P.T.A. ....

Previous history of noise exposure ....

....

....

....

Previous history of aural disease ....

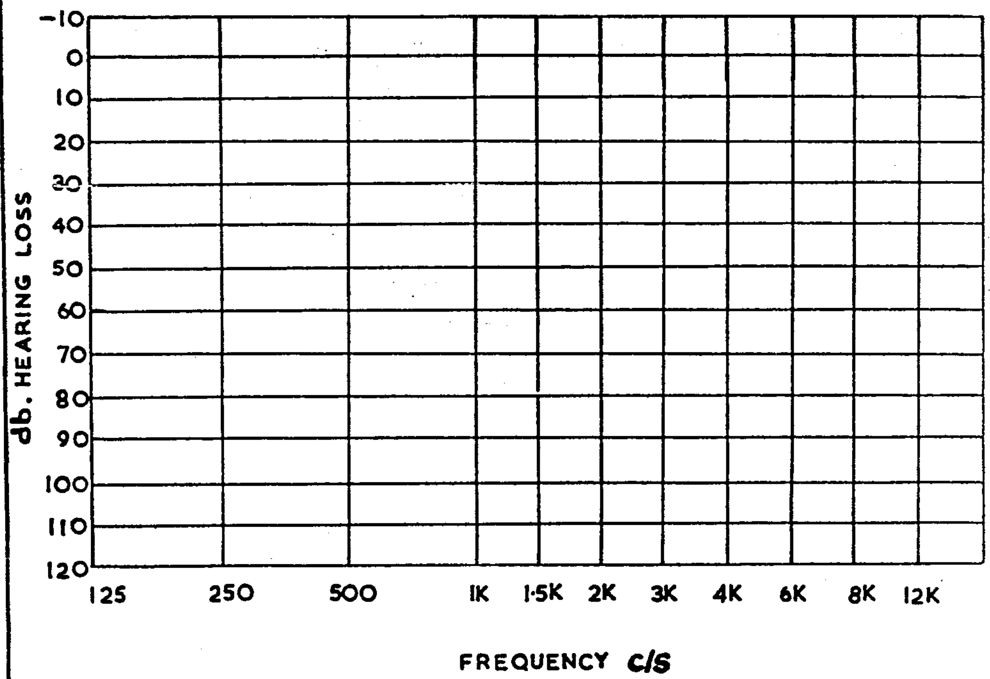
....

Family history of deafness ....

....

....

Audiometer .... AUDIOGRAM Operator ....



A.C. x - x = Left ear
o - o = Right ear

B.C. = Left ear
= Right ear

Masking
A.C. -
B.C. -

engaged on piece work, they were understandably reluctant to spend longer than the minimum twenty minutes away from their work.

The form which was used to record the hearing assessments is reproduced opposite.

Industries which have been investigated have been assured that the results of this survey will be confidential. A code letter has, therefore, been assigned to each factory, which will be used throughout this section.

In order to minimise some of the effects of the many uncontrollable variables abounding in this investigation the noise analyses and hearing assessments of each factory will be considered separately. This procedure will lessen the effect of variations in the noise levels of the various testing rooms. Within each factory, the environmental noise of different departments will be considered separately, in relation to the hearing acuity of the personnel.

Correction for Presbycusis

Hinchcliffe's data (65) on the decline in the threshold of hearing as a function of age is used in this survey.

All subjects exposed to a given noise environment have been divided into the six age groups specified by Hinchcliffe and the hearing acuity of each ear, for eight frequencies, is examined in relation to the values for the normal range of hearing obtained by him.

Hinchcliffe's data, which is reproduced in Table 15 below, gives the twenty-fifth percentile, median and seventy-fifth percentile hearing loss for clinically normal ears.

TABLE 15 From Hinchcliffe (65, page 306)

Twenty-fifth percentile, median, and seventy-fifth percentile hearing loss for clinically normal female ears (together with clinically normal male ears at ages and audio-frequencies where there is no sex difference).

Audio-frequency	Age Group					
	18-24	25-34	35-44	45-54	55-64	65-74 yrs
	dB	dB	dB	dB	dB	dB
125 c/s	-3.9 0.0 4.3	-2.1 1.7 5.5	-1.1 2.6 6.1	1.8 4.8 9.5	4.6 8.7 13.1	6.0 10.1 17.1
250 c/s	-3.4 0.0 2.9	-2.8 1.0 5.3	-1.5 1.7 5.6	0.1 3.2 7.6	2.3 6.5 11.6	4.5 9.6 16.4
500 c/s	-2.7 0.0 4.0	-2.4 0.7 4.1	-2.0 1.7 5.7	0.4 3.9 8.7	2.4 7.0 12.8	4.8 9.7 20.8
1 Kc/s	-3.6 0.0 3.7	-2.4 1.0 4.1	-2.1 1.7 6.4	0.8 4.7 9.5	1.3 5.6 10.0	5.2 12.8 24.7
2Kc/s	-4.2 0.0 4.6	-3.5 0.4 4.8	-0.5 2.5 6.9	1.2 5.5 10.9	4.6 8.7 14.9	9.4 14.6 26.6
3Kc/s	-4.0 0.0 4.6	-2.8 1.5 6.9	0.4 5.5 10.3	4.8 9.9 18.2	8.8 14.8 20.2	10.1 19.8 40.6
4 K c/s	-4.3 0.0 4.3	-0.2 3.8 8.5	1.7 5.3 10.0	6.6 13.2 18.9	8.7 19.4 26.3	12.1 22.2 45.6
6 K c/s	-6.6 0.0 5.8	-0.5 3.6 8.8	0.6 6.2 13.6	3.5 11.2 22.4	11.3 22.3 28.7	17.4 33.9 47.2
8 K c/s	-6.3 0.0 5.6	-5.4 3.3 9.6	-2.3 7.2 15.7	2.6 8.2 28.4	11.0 24.7 39.7	32.2 42.2 52.2

Correction for Ambient Noise

Cox (66) has published data which specifies the maximum ambient noise level, over the test frequency range, which is compatible with accurate testing. These are reproduced in Table 16 below.

TABLE 16

Maximum ambient noise levels for industrial audiometry

(from Cox, 66, page 26)

	Octave Band c/s					
	75-150	150-300	300-600	600-1.2K	1.2K-2.4K	2.4K-4.8K
Maximum Intensity dB	35	43	38	40	48	60

If these noise levels are exceeded, in any octave band, Cox suggests that a correction may be made to the hearing loss value obtained at the affected frequencies. The author doubts the validity of this assumption in view of the fact that both normal hearing and perceptive hearing losses are being measured in an industrial survey. When a conductive defect is present the ambient masking noise will obviously have a smaller effect on threshold measurements than when normal hearing is being tested. However, the presence of a perceptive deafness will have a varying effect on the masking properties of the ambient noise. Masking phenomena are closely associated with the sensation of loudness and if a perceptive recruiting deafness is present, the normal loudness intensity relationship is disturbed. Therefore it seems reasonable to assume that masking will not follow the pattern produced in normal or conductively deaf ears. Hence, the author feels it is a dangerous over-simplification of the problem to apply a single correction factor to all threshold measurements which have to be made against ambient noise levels which exceed those specified by Cox.

It was, therefore, decided to make no correction of threshold measurements, but thresholds measured against levels in excess of Cox's maxima will be excluded from the final data (an exception to this procedure occurs in Factory B).

RESULTS OF NOISE ANALYSES AND HEARING MEASUREMENTS

Eight factories have been surveyed and the results from each will be considered separately. Table 17 below indicates the type of manufacturing process occurring in each factory, and the nature of the investigations carried out.

TABLE 17

Factory code letter	Product	Noise Analyses	Hearing Assessments
A	Knitted clothing	✓	✓
B	Clothing	✓	✓
C	Chemicals	✓	✓
D	Furniture	✓	✓
E	Pharmaceutical	✓	
F	Pharmaceutical	✓	
G	Elastic Webbing	✓	
H	Pharmaceuticals	✓	

All employees in Factory D are either physically or mentally disabled. The hearing tests revealed severe hearing abnormalities which cannot be attributed to the effects of noise alone, therefore these hearing assessments will not be included in this report.

The noise analyses data obtained from Factories D, E, F, G and H are considered on pages 177-179

Each factory has been divided into 'departments' and the analyses of the environmental noise of each department will be considered in relation to the hearing of the departmental personnel.

At the end of each account of a factory survey, the existing noise problem is discussed in relation to the efficacy of existing damage risk criteria.

It was decided originally to assess the hearing acuity of exposed personnel by determining the number of ears which fell outside the 75th percentile specified by Hinchcliffe. This was attempted with the hearing results of one factory, but it became apparent that the ratios obtained, of number of defective ears to total ears, yielded an unrealistic picture of the pattern and extent of hearing loss. No indication was given, using this method, of the area of greatest hearing loss; hearing acuity was either normal, or defective, for different frequencies. In some cases, a 5 dB hearing defect for one frequency would be classed as 'abnormal', along with a 45 dB loss at another frequency. Thus the overall picture would appear to be a hearing loss for both these frequencies, although one is negligible and the other highly significant.

There is as yet, no general agreement among investigators as to the method of classifying hearing losses. Many methods have been tried, but no single expression has been found which specifies the extent and frequency distribution of a hearing defect.

It is also apparent that Hinchcliffe's data may be too stringent for application to the results of a survey of this nature. For example (see table 15, page 101) in the 'normal' age range, 18 to 24 years, the 75th percentile for hearing at 1 K c/s is given as 3.7 dB. Under survey testing conditions, where re-testing is impracticable, and using a 5 dB step attenuater, it is unlikely that such a low threshold will be obtained. Based on long experience of clinical audiometry the author would regard any hearing result which fell within the range from -10dB to + 10dB as 'normal', taking into consideration the many causes of variability in audiometric results. It would seem that the experimental error involved in clinical audiometry is too great to permit the measurement of auditory thresholds with the accuracy necessary for the application of Hinchcliffe's data.

It has therefore been decided to express the hearing results pictorially, to indicate not only deviations from Hinchcliffe's data, but also the exact extent and nature of the measured hearing losses.

The results of hearing assessment will be divided into three main categories, namely: -

A. Hearing within normal limits

B. Hearing loss with no apparent cause other than exposure to environmental noise.

C. Hearing loss attributable to causes other than, or in addition to, environmental noise exposure.

Further sub-divisons will be included where these assist in indicating thepossible cause of deafness.

FACTORY A - Knitted Clothing Manufacturing

The quietest room available for hearing tests had an ambient noise level which was in excess of Cox's maxima for low frequencies. Checks made on the author's hearing curve demonstrated a 15 to 20 dB fall in hearing acuity for the frequencies 250 c/s and 500 c/s. The remainder of the curve was comparable with measurements made in a sound damped room. Therefore, employees' hearing measurements made at 250 c/s and 500 c/s will be excluded from the assessment of noise-induced hearing loss in this factory.

Table 18 below gives an outline of the various manufacturing processes employed in the departments where noise and hearing assessments were made.

TABLE 18

Manufacturing Process	Product	No. of employees tested
1. Flatbed knitting	Stockings	20
2. Circular knitting	Bedsocks	3
3. Circular knitting	Socks	5
4. Winding	Knitting Yarn	5
5. Finishing (1st floor)	Outerwear	5
6. Finishing (ground floor)	Outerwear	4
7. Finishing - linking	Socks & Outerwear	5
		47 employees

Department 1. Flatbed knitting

The highest noise levels measured in Factory A exist in this Department. Assessment of the effect of noise exposure is facilitated here by the stability of the population. Of the twenty employees examined, only three had a history of exposure to alternative noise. The individual length of exposure time varied from 6 years to 44 years, the average being 26 years.

When this survey was commenced, the employees were operating two similar knitting looms. During the course of the survey, the use of these looms was discontinued and many of the same employees are now operating the Reading knitting loom. The octave band analyses of the three looms is given in Table 19 below. It will be seen that the noise levels of the original loom are somewhat higher than the intensity of the Reading machine.

TABLE 19

Centre frequency of octave band, c/s.	Noise Source		
	Loom 1 S.P.L.dB	Loom 2 S.P.L.dB	Reading Loom S.P.L.dB
31.5			73
63	83	84	73
125	82	81	72
250	88	86	78
500	91	87	80
1 K	90	87	80
2 K	96	93	85
4 K	94	93	87
8 K	93	90	85
16 K			77
31.5K			62
Linear	98	98	94

The hearing assessments are analysed in Table 20 below. In this, and in all subsequent tables of hearing assessment, the columns of exposure times relate to the subject's total exposure to the present noise only and does not include exposure to other environmental noise, where this has occurred.

TABLE 20

A Hearing within the normal limits specified by Hinchcliffe's presbycusis data		B Hearing loss attributable to noise exposure. i) no previous history of noise exposure		ii) history of exposure to more than one environmental noise.		C Hearing loss attributable to a multiplicity of factors including noise exposure
Subject	Exposure time	Subj.	Exposure time	Subj.	Exposure time (present noise only)	
A.H2	13 yrs	A.p1	6 yrs			
A.M1	17 "	A.P3	11 "			
		A.G1	15 "			
		A.B.3	,16 "	A.N1	16 yrs	
		A.B.2	16 "			
		A.B1	24 "	A.F1	25 "	
		A.B5	26 "	A.N2	37 "	
		A.P2	26 "			
		A.L1	27 "			
		A.H1	27 "			
		A.S1	28 "			
		A.W1	28 "			
		A.B4	30 "			
		A.G2	34 "			
		A.L2	44 "			
2 subjects		15 subjects		3 subjects		0 subjects

The eighteen subjects in Section B of Table 20 above have hearing losses which are directly attributable to noise exposure. The audiograms of these subjects are reproduced on pages 127 to 129 in order of length of exposure time, to show the extent and frequency distribution of hearing defect.

Consideration of these audiograms reveals no obvious connection between extent of hearing loss and duration of exposure to noise. If a simple relationship between these two factors does exist, it may be masked by differences in individual susceptibility to noise trauma.

It will be seen from the summary of damage risk criteria, Table 14 pages 88 of this report, that the maximum permissible intensities for high frequencies specified by Beranek and Rosenblith and Stevens do not give adequate protection against the noise levels of the looms. The spectra analyses in Table 19 above show high frequency intensities which are below the maximum suggested by these two authors, but the high incidence of deafness, 15 cases directly attributable to the noise of the looms, suggests that the more conservative estimates of the remaining damage risk criteria in Table 14 are more realistic.

Department 2. Circular Knitting (Bedsocks)

The octave band analysis of the environmental noise in this department is given in Table 21 below.

TABLE 21

Centre frequency of octave band, c/s	Sound level dB
31.5	72
63	80
125	81
250	79
500	79
1 K	81
2 K	79
4 K	79
8 K	80
16 K	83
31.5K	56
Linear	91

Table 22 below contains the analysis of hearing acuity of the three employees operating these machines. Several other employees in thisdepartment were originally operating the flat-bed looms in department 1. Subsequent to their hearing tests, the use of the looms was discontinued and they transferred to department 2, but they could not, of course, be included in this section, therefore, only three subjects were available.

TABLE 22

A Hearing within the normal limits specified by Hinchcliffe's presbycusis data		B Hearing loss attributable noise exposure			C Hearing loss attributable to a multiplicity of factors, including noise expos.
		i)no previous history of noise exposure		ii)history of exposure to more than one environmental noise	
Subj.	Exposure time	Subj.	Exposure time	Subj. Expos. time (present noise only)	
A.T1	19 yrs.	A.W2	38 yrs	A.L3 15 yrs	
1 subject		1 subject		1 subject	0 subjects

The audiograms of the two subjects in section B are reproduced on page 131.

It is unfortunate that the sample is too small in this department to permit any conclusion to be drawn. It would be interesting to know if the relatively even distribution of noise intensity, with respect to frequency, of these knitting machines has a lesser effect on hearing than a similar overall intensity having a concentration of energy in a limited area of the spectrum

Department 3. Circular knitting (socks)

Table 23 below gives the octave band analysis of the circular knitting machines.

TABLE 23

Centre frequency of octave band c/s	Sound level dB
31.5	72
63	78
125	82
250	81
500	78
1 K	79
2 K	79
4 K	78
8 K	78
16 K	81
31.5K	63
Linear	90

Five employees in this department had their hearing measured and the results appear in Table 24 below.

TABLE 24

A Hearing within the normal limits specified by Hinchcliffe's presbycusis data		B Hearing loss attributable to noise exposure. 1) No previous history of noise exposure		ii) History of exposure to more than one environmental noise.		C Hearing loss attributable to a multiplicity of factors including noise exposure.
Subject	Exposure time	Subj.	Expos. time	Subj.	Exposure time	
A.M3 A.H3 A.M2	,17 yrs. 21 " 48 "	A.S3	10 yrs			A.S2
3 subjects		1 subject		0 subjects		1 subject

The audiogram of the one subject in Section B of Table 24 is reproduced on page 131.

Subject A S.2 in Section C has a moderate degree of deafness and a history of excessive secretion of wax.

The three subjects in Section A of Table 24 may all be said to have hearing losses if Hinchcliffe's data is to be strictly applied, but since these "losses" are only of the order of 5 to 10 dB at one or two frequencies, they cannot be regarded as a reliable indication of a true hearing defect.

Department 4. Winding

Two main types of winding operations occur in this Department, namely, hank to cone winding and cone to cone winding. The analyses of both machines is given in Table 25 below.

The five employees who were examined are all exposed to the noise from both machines, either separately, or simultaneously.

TABLE 25

(A) Hank to cone winding

Centre frequency of octave band c/s.	Sound level dB
31.5	66
63	78
125	80
250	76
500	73
1 K	73
2 K	74
4 K	74
8 K	70
16 K	62
31.5K	38
Linear	84

(B) Cone to cone winding

Centre frequency of octave band c/s.	Sound level dB
31.5	67
63	74
125	77
250	77
500	80
1 K	81
2 K	84
4 K	85
8 K	83
16 K	79
31.5K	57
Linear	92

Table 26 below shows the distribution of hearing loss among operators, of the two winding machines.

TABLE 26

A		B				C
Hearing within the normal limits specified by Hinchcliffe's prebycusis data		Hearing loss attributable to noise exposure. i)No previous history of noise exposure		ii)History of exposure to more than one environmental noise		Hearing loss attributable to a multiplicity of factors, including noise exposure
Subject	Exposure time	Subj.	Exposure time	Subj.	Exposure time (pres. noise only)	
A.F2	1½ yrs.	A.L5 A.I4	35 yrs 44 "	A.H4	39 yrs	A.B6
1 subject		2 subjects		1 subject		1 subject

The audiograms of the three subjects in Section B of Table 26, reproduced on page 132, show the nature and extent of hearing loss. Subject A.B6, in Column6 has virtually normal hearing, apart from a 30 dB loss, in the right ear for 8 K c/s. There is a history of exposure to gunfire and also of bilateral ear dieease in childhood.

Department 5. Finishing (1st floor)

This Department does not generate its own noise environment, but is exposed to the noise of the linking machines in Department 7, which are also situated on the first floor of the factory.

It is of interest that although Department 5 has one of the quietest noise levels measured, the employees here were the only ones in the whole factory who expressed dislike of their noise environment. This is the only Department in which the personnel are exposed to noise unrelated to their work. Employees in Department 6, who operate the machines producing the noise, did not appear to be upset by it, although the intensity level was, for them, higher.

Table 27 below gives the noise andysis of Department 5, the noise being generated by the linking machines in Department 6.

TABLE 27

Centre frequency of octave band, c/s	Sound level dB
31.5	62
63	61
125	56
250	54
500	56
1 K	54
2 K	53
4 K	49
8 K	44
16 K	33
31.5K	33
Linear	66

Table 28 below shows the incidence of hearing loss in the five employees examined.

TABLE 28

A Hearing within the normal limits specified by Hinchcliffe's presbycusis data		B Hearing loss attributable to noise exposure. i) No previous history of noise expos.		B ii) History of exposure to more than one environmental noise		C Hearing loss attributable to a multiplicity of factors including noise exposure
Subject	Exposure time	Subj.	Expos. time	Subj.	Expos. time (Present noise only)	
		A.P5	35 yrs	A.H5 A.S4 A.B7	1 year 8 years 18 year	A.T2
		1 subject		3 subjects		1 subject

The audiograms of the four subjects in group B are reproduced on page 133. The three subjects in group B (ii) have all been exposed to noise levels in excess of that existing in department 5.

Department 6 - Finishing (ground floor)

The noise in this department is generated by sewing machines which, although in constant use, are operated in bursts of approximately one second duration at intervals of two to three seconds, during which period the operator is adjusting the garment in readiness for stitching.

Two noise analyses were made, measurements being taken during the noise bursts. In one analysis the microphone was placed in the centre of the room to measure the general noise level. For the second analysis the microphone was at machine operator level. The results of the measurements are given in Table 29 below.

TABLE 29

Centre frequency of octave band, c/s	1. Overall noise level. Noise intermittant - Measurements taken with machines running	2. Sewing machine. Operator level. Measurements taken during noise burst
	Sound level dB	Sound level dB
31.5	60 - 64	60
63	65 - 72	65
125	60 - 66	60
250	58 - 66	70
500	60 - 66	78
1 K	60 - 64	70 - 76
2 K	62 - 64	74
4 K	60 - 62	70
8 K	60 - 62	68
16 K	56	64 - 68
31.5K	47	48
Linear	approx. 70	80

The hearing acuity of four machine operators was measured and the results are given in Table 30 below. There was no indication of occupational deafness. Three employees had normal hearing, the fourth showing a slight low frequency loss, with a history of recurrent ear infection and also of familial deafness.

TABLE 30

A Hearing within the normal limits specified by Hinchecliffe's presbycusis data.		B Hearing loss attributable to noise exposure.				C Hearing loss attributable to a multiplicity of factors including noise exposure
		i)No previous history of noise exposure		ii)History of exposure to more than environmental noise		
Subject	Exposure time	Subj.	Expos. time	Subj.	Expos. time	
A.A2 A.B8 A.T3	5 weeks 3 months 40 years					A.P6
3 subjects		0 subjects		0 subjects		1 subject

Department 7. Finishing (linking)

The linking machines are situated in the open-plan first floor of the factory and as mentioned previously, are the source of environmental noise in department 5.

Table 31 below gives the results of an analysis, taken at operator level, of one linking machine.

TABLE 31

Centre frequency of octave band, c/s	Sound level dB
31.5	62
63	64
125	62
250	59
500	61
1 K	59
2 K	57
4 K	54
8 K	47
16K	41
31.5K	24
Linear	71

Five employees had their hearing tested and Table 32 below shows incidence of deafness.

TABLE 32

A Hearing within the normal limits specified by Hinchecliffe's presbycusis data		B Hearing loss attributable to noise exposure. i) No previous history of noise exposure.		ii) History of expos. to more than one environmental noise.		C Hearing loss attributable to a multiplicity of factors including noise exposure
Subject	Exposure time	Subj.	Expos. time	Sub.	Expos. time	
A.S5	4 yrs	A.M4	40 yrs			
S.M5	18 "					
A.C1	20 "					
A.P4	35 "					
4 subjects		1 subject				0 subjects

The audiogram of the one subject in group B (i) is reproduced on page 133.

Summary of results in Factory A

In every department examined with the exception of department 6, there is evidence of noise-induced hearing loss, although in all departments the sample is too small for statistical tests of significance to be applied.

In Department 1, eighteen of the twenty subjects examined show a hearing loss due to noise exposure and fifteen of these cases are directly attributable to the present environmental noise.

The hearing assessment results of employees in departments 1 to 7 are summarised in table 33 below.

TABLE 33

Department	No. of cases of hearing loss attributable to noise exposure.		No. of cases of hearing loss attributable to multiplicity of causes.	No. of cases of normal hearing	Total No. of subjects examined
	Single source of noise exposure	Multiple noise exposure			
1	15	3	0	2	20
2	1	1	0	1	3
3	1	0	1	3	5
4	2	1	1	1	5
5	1	3	1	0	5
6	0	0	1	3	4
7	1	0	0	4	5
TOTAL	21 subjects	8 subjects	4 subjects	14 subj.	47 subjects

It will be seen from Table 33 above, that of the 47 subjects examined in Factory A, 21 have a hearing loss for which there is no known cause other than exposure to their present environmental noise. A further 8 subjects have deafness attributable to noise exposure, but while the noise environment of this factory may well have contributed to the extent of their hearing losses, previous exposure to alternative noise prevents the formation of a direct cause and effect relationship. Therefore, 29 subjects show noise induced hearing damage, while 14 subjects show normal hearing and the remaining 4 subjects have deafness which may have been caused by a combination of factors.

Table 34 below shows the departments which are not protected by the various damage risk criteria reviewed in Section 2C of this report, (table 14 on page 88 gives the details of these criteria), together with the ratio of the number of cases of deafness directly attributable to each departmental noise environment, to the number of subjects tested.

TABLE 34

Damage risk criteria	Departments unprotected	No. of cases of deafness/ total subjects tested
1. U.S.A.F.	Dept. No. 2	1/3
	" No. 3	1/5
	" No. 4	2/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
2. Burns & Littler	" No. 5	1/5
	" No. 7	1/5
3. Burns & Littler	" No. 2	1/3
	" No. 3	1/5

TABLE 34 cont'd.

Damage risk criteria	Departments unprotected	No. of cases of deafness/total subjects tested
3. continued	Dept. No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
4. B.M.A.	" No. 2	1/3
	" No. 3	1/5
	" No. 4	2/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
5. Hardy	" No. 2	1/3
	" No. 3	1/5
	" No. 4	2/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
6. I.S.O. 85	" No. 2	1/3
	" No. 3	1/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
7. Glorig	" No. 2	1/3
	" No. 3	1/5
	" No. 4	2/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
8. Plomp	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
9. Beranek - continuous spectrum noise.	" No. 1	15/20
	" No. 2	1/3
	" No. 3	1/5
	" No. 4	2/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5

Table 34 contd.

Damage risk criteria	Departments unprotected	No. cases of deafness/total subjects tested
10. Beranek. Noise containing pure tones.	Dept. No. 2	1/3
	" No. 3	1/5
	" No. 4	2/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
11. Rosenblith. Continuous spectrum noise.	" No. 1	15/20
	" No. 2	1/3
	" No. 3	1/5
	" No. 4	2/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5
12. Rosenblith. Noise containing pure tones.	" No. 2	1/3
	" No. 3	1/5
	" No. 5	1/5
	" No. 6	0/4
	" No. 7	1/5

The noise analyses data of departments 1 to 7 are shown graphically on pages 126 to 127. The twelve damage risk criteria are supplied as transparencies in order that a quick assessment may be made of their relative levels of protection.

The only results which demonstrate a clear relationship between environmental noise and incidence of deafness are those obtained in department 1, where eighteen of the twenty subjects examined have some degree of deafness, fifteen of whom have no previous history of noise exposure. It may be seen from Table 34 that most damage risk criteria would give protection against this noise spectrum, the exceptions being the criteria of Beranek (No. 9) and Rosenblith (No. 11).

However, these criteria were designed forapplication to continuous spectrum noise only and the noise of department 1, which has a concentration of energy in the 2 K to 4 K c/s region of the spectrum, is in excess of the modified criteria (Nos. 10 & 12) of these authors which relate to noise containing pure tone elements.

There were insufficient subjects in departments 2 to 7 to yield reliable information on the effects of the noise environments, but there is some indication of the incidence of deafness being related to the type of exposure noise. Table 35 below shows the overall noise level of each department, together with the shape of the noise spectrum and the number of cases of deafness.

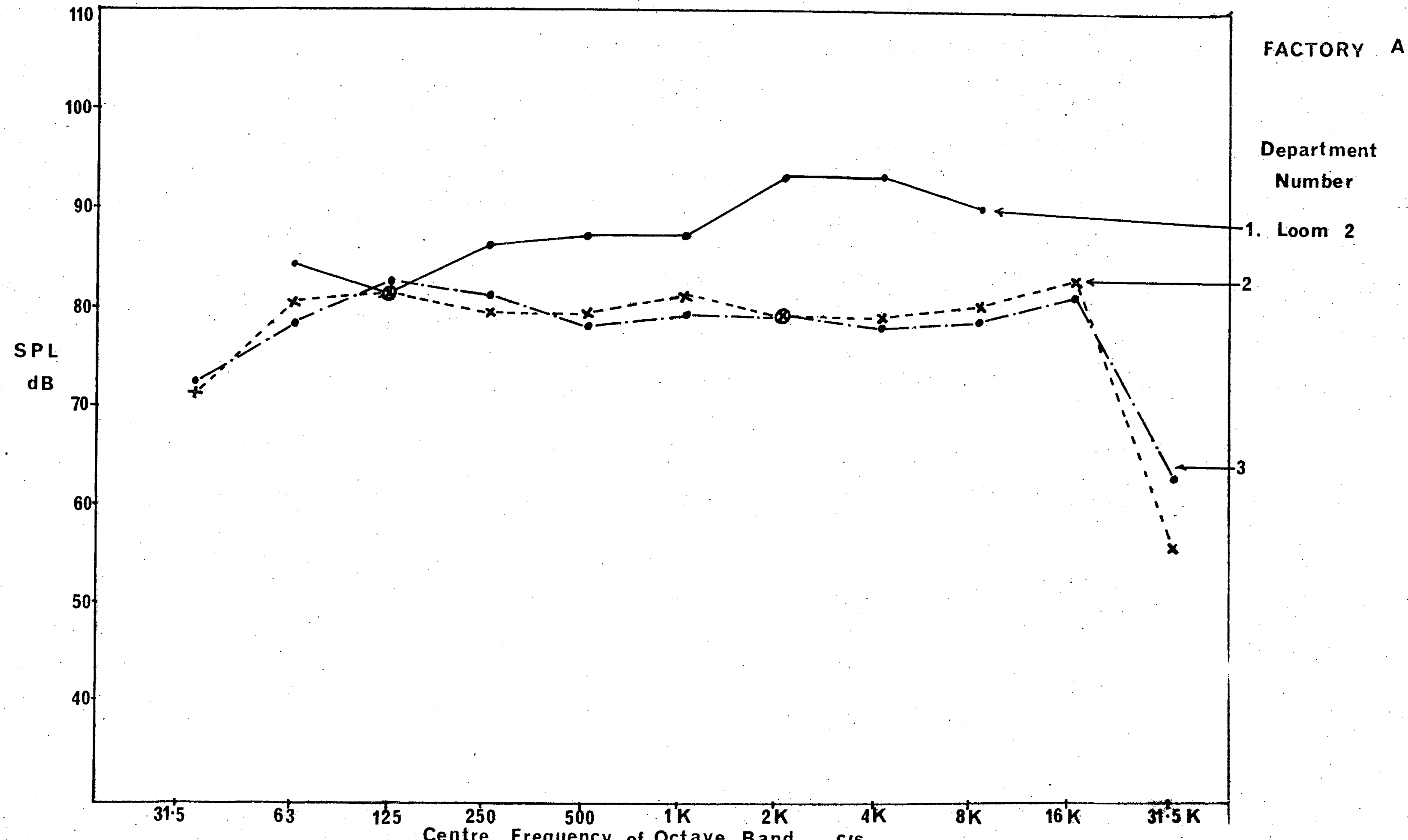
Consideration of Table 35 below suggests two general relationships between the incidence of deafness and the nature of the noise environment - firstly departments 3 & 4 have overall S.P.L. of 90 dB and 92 dB respectively. There are only two possible cases of traumatic deafness in department 3, which has a flat spectrum noise, one of which is directly attributable to the departmental noise alone and shows a slight, but typical noise induced hearing loss (page 131, subjectA.S.3). The 92 dB noise spectrum of department 4 has a sharp peak at 4 K c/s and there are four possible cases of traumatic deafness, two directly caused by the departmental noise, one by exposure to additional noise environment and the third caused by general factors, possibly including noise exposure. The two cases in group B (i)(page 132, subjects A.L.5 and A.L.4) both show fairly severe loss of hearing acuity for high frequencies.

TABLE 35

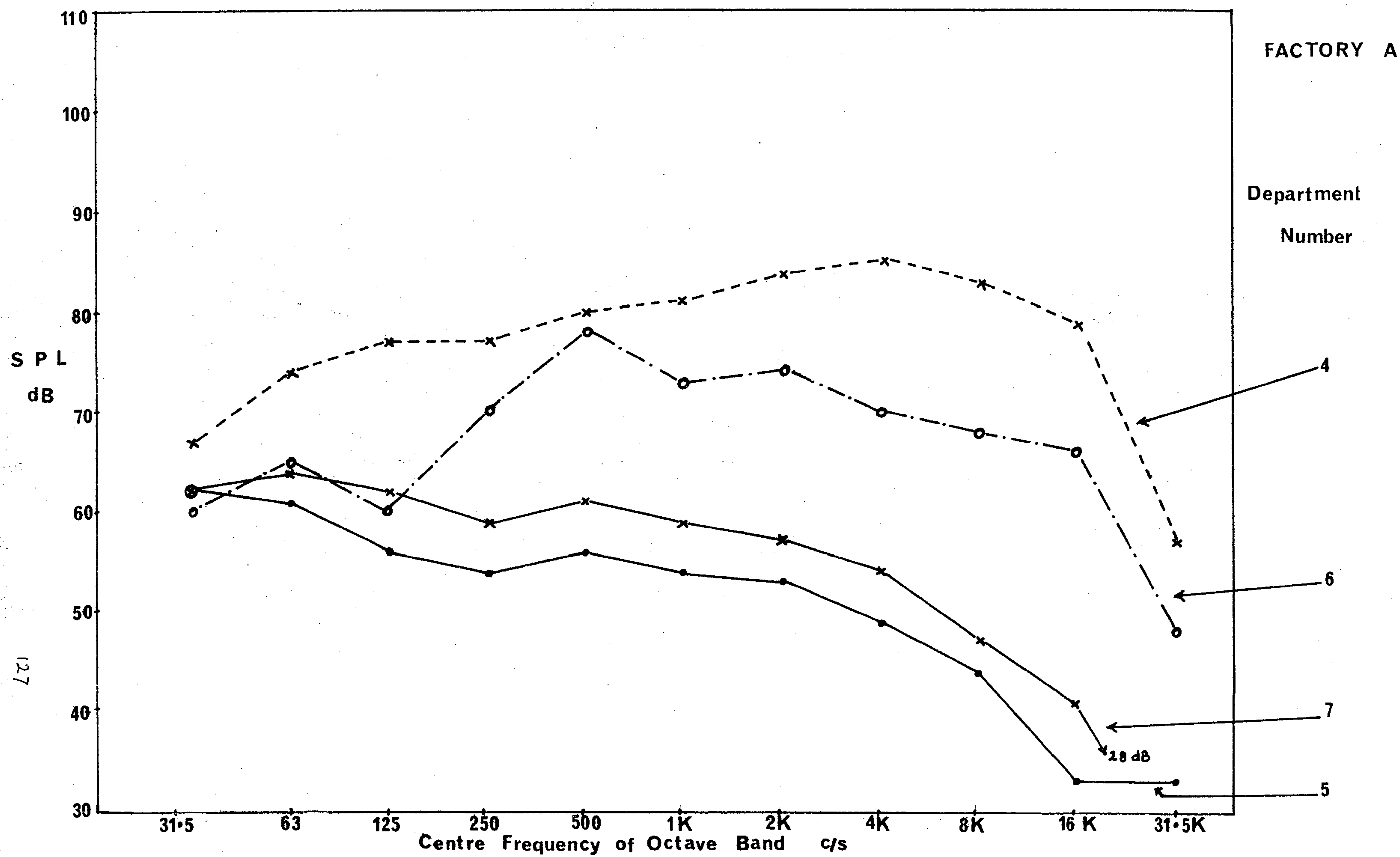
Dept.	Overall S.P.L. dB	Shape of spectrum	Total No. subjects	Total cases of deafness	Cases attributable to present noise alone	Cases of noise exposure and other factors	Normal hearing
1.	98	Peaks at 2 K c/s and 4 K c/s	20	18	15	0	2
2.	91	Flat-peak at 16 K c/s	3	2	1	1	1
3.	90	Flat	5	2	1	1	3
4.	92	Peak at 4 K c/s	5	4	2	2	1
5.	66	No sharp peaks. Intensity decreases with increasing frequency.	5	5	1	4	0
6	80	Noise intermittent (sewing machines)	4	0	0	1	3
7.	71	No sharp peaks. Intensity decreases with increasing frequency.	5	0	1	0	4

While these results substantiate the hypothesis that narrow concentration of energy in the noise spectrum may be more damaging to hearing than an equal energy distribution, it must be stressed again that the subject sample is far too small to allow conclusions to be drawn.

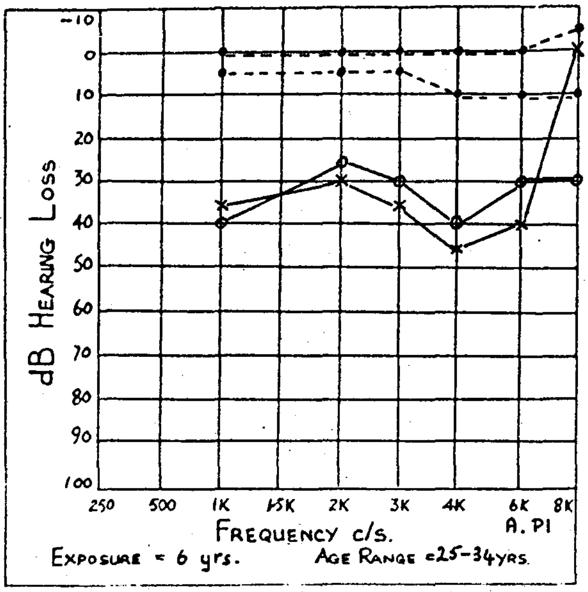
Secondly, it is of interest that, in department 6, with an overall S.P.L. of 80 dB there is no case of deafness which may be attributed to noise exposure alone. The noise in intermittent and it may be that the quiet phases are of sufficient duration to permit recovery from temporary fatigue effects, so avoiding permanent trauma. Whereas, in the low-intensity, but continuous, noise environment of department 7, 71 dB, there is one case of high frequency deafness for which there is no apparent explanation other than exposure to this noise (page 133, subject A.M.4)

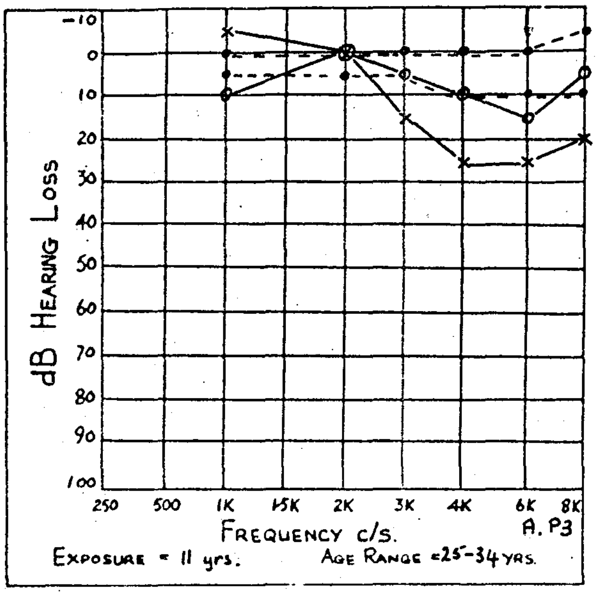


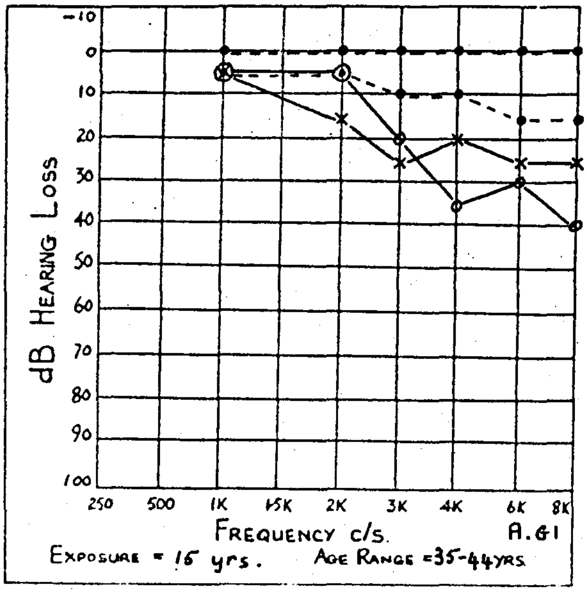
FACTORY A
Department Number
1. Loom 2
2
3
SPL dB
110
100
90
80
70
60
50
40
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5K
Centre Frequency of Octave Band c/s

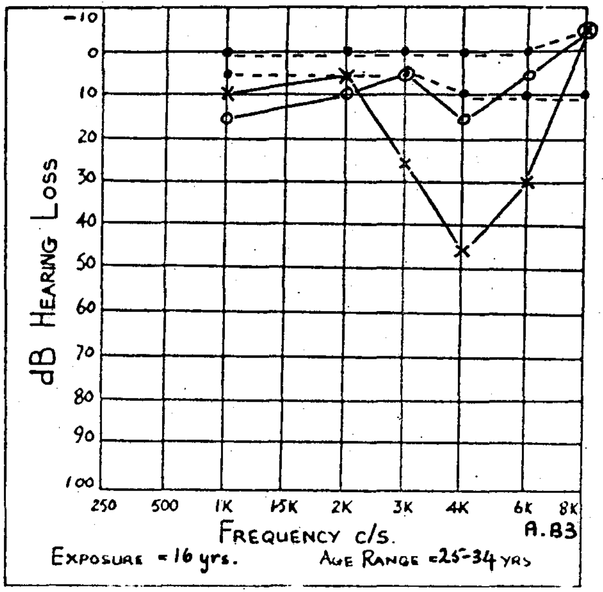

FACTORY A
Department
Number
4
6
7
5
28 dB
S P L
dB
110
100
90
80
70
60
50
40
30
31·5
63
125
250
500
1K
2K
4K
8K
16 K
31·5K
Centre Frequency of Octave Band c/s

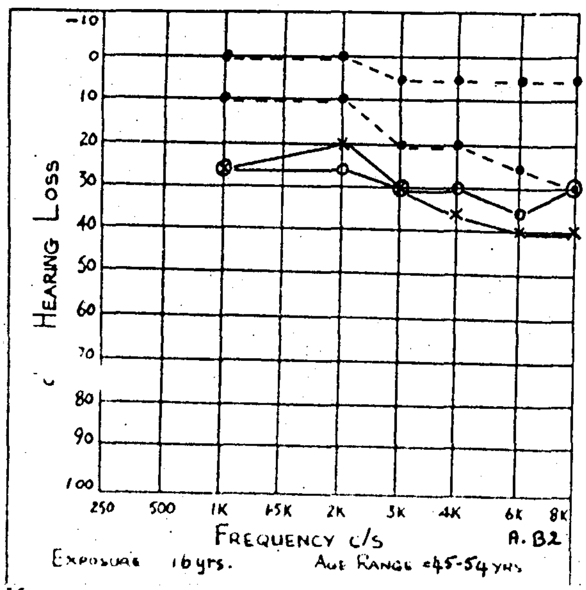
Audiograms of subjects in Section B(i) of Table 20, page 108.

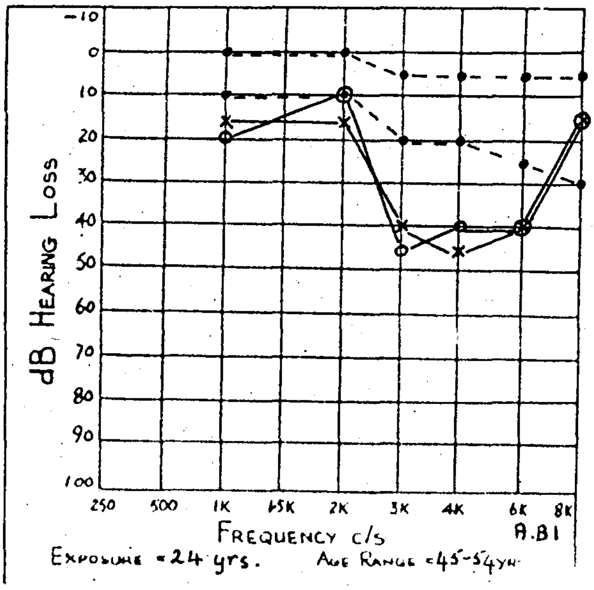












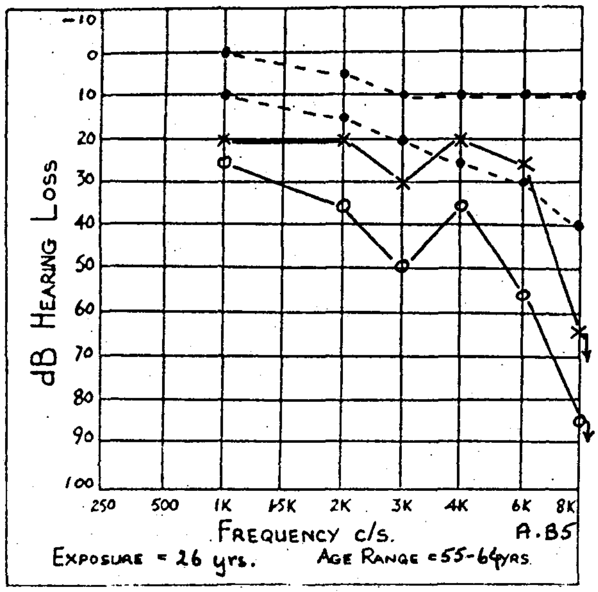
Key

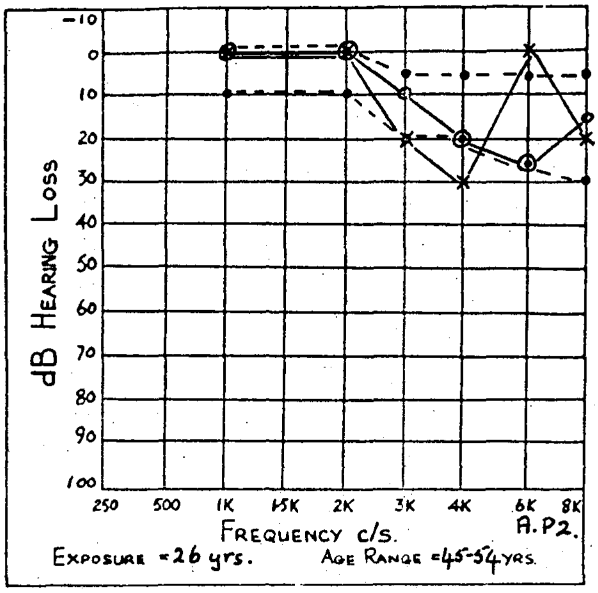
Air conduction o—o = right ear. x—x = left ear.

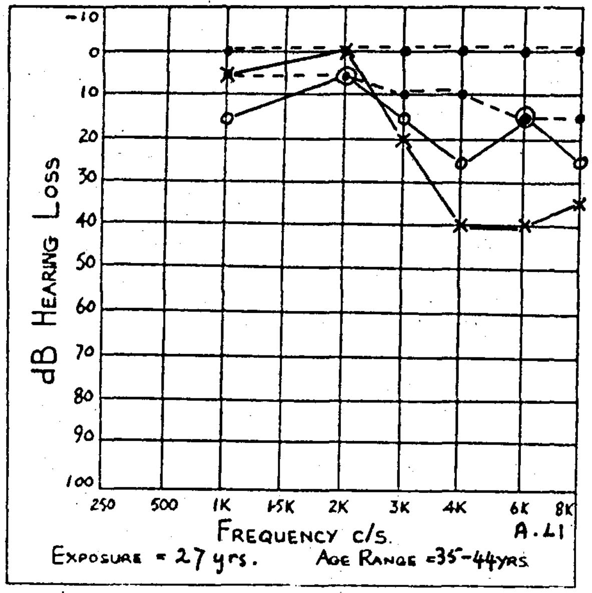
Age range •------• limits of 25 th and

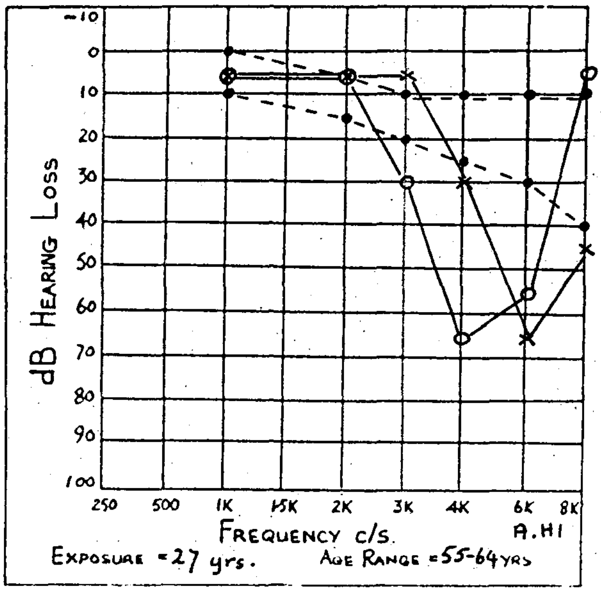
•------• 75 th percentile. (Hinchcliffe's data)

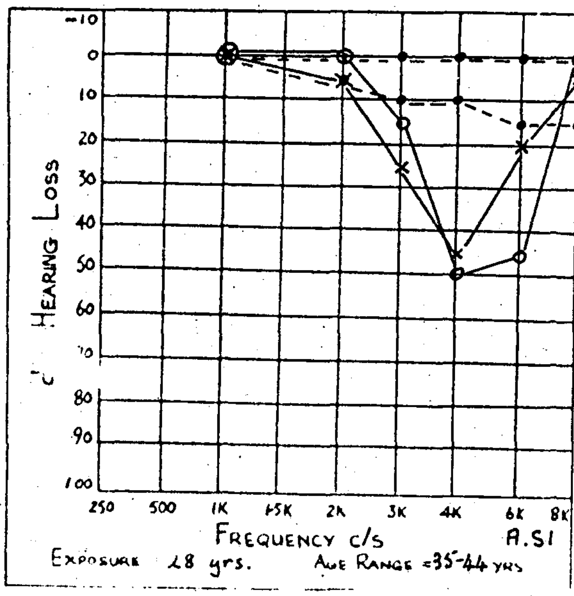
Audiograms of subjects in Section B(i) of Table 20, page 108.

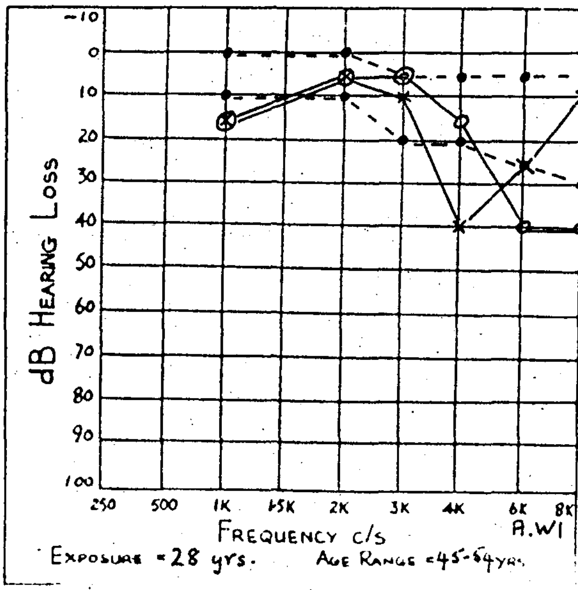












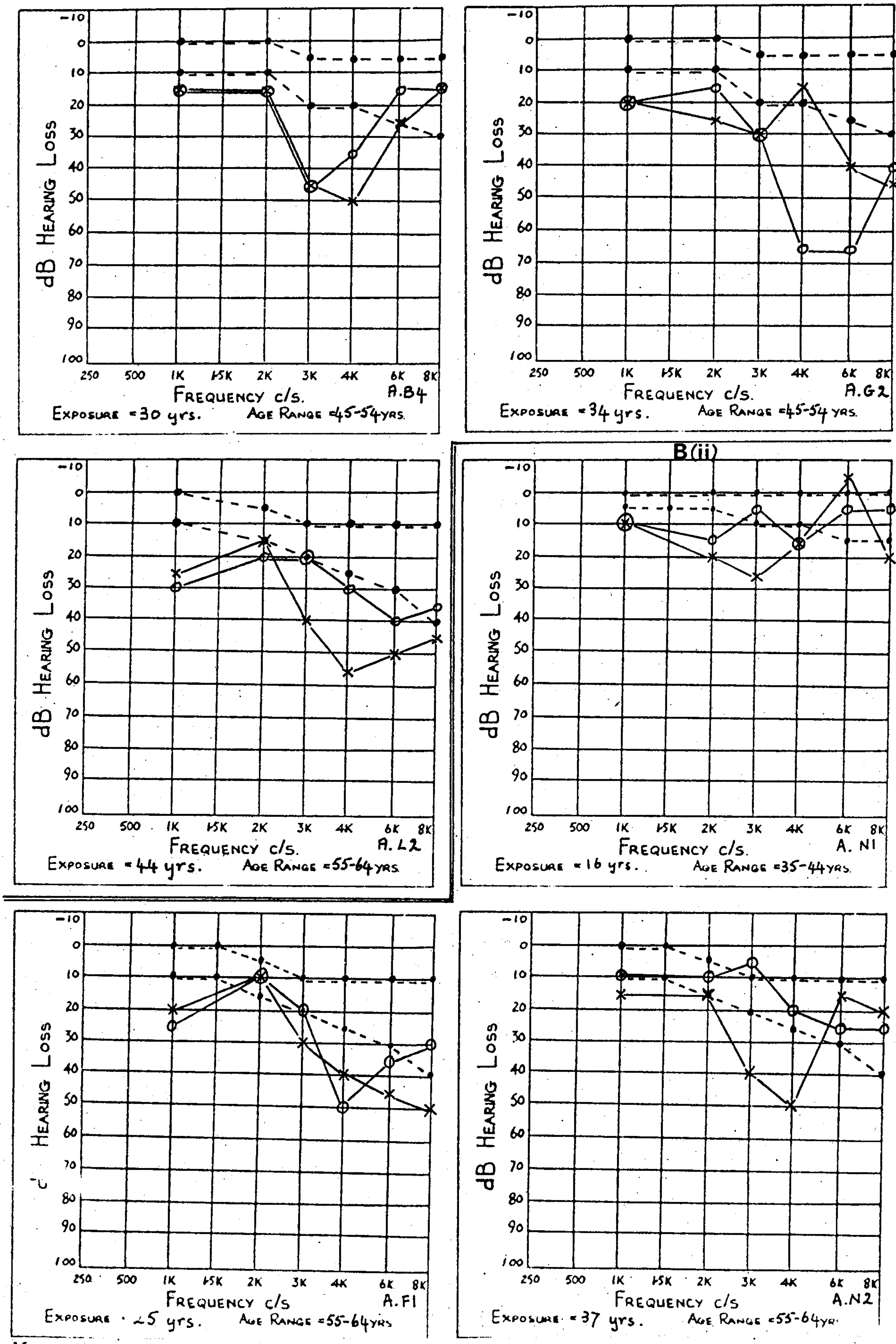
Key

Air conduction o—o = right ear. x—x = left ear.

Age range •-----• limits of 25 th and

•-----• 75 th percentile. (Hinchcliffe's data)

Audiograms of subjects in Section B(i) and B(ii) of Table 20, page 108.



Key

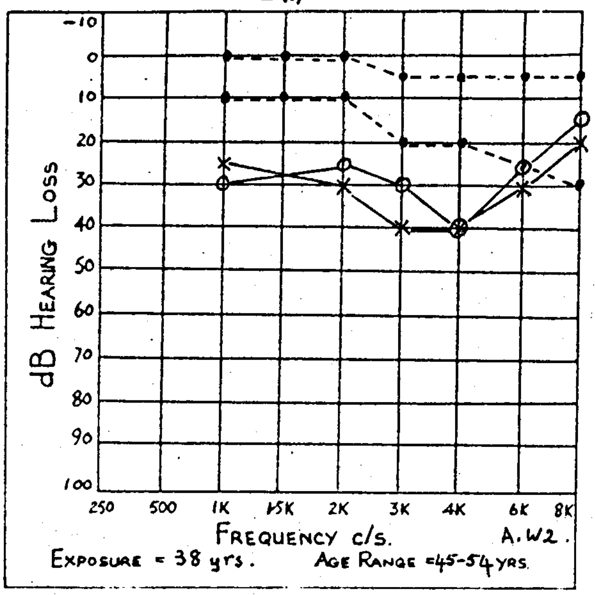
Air conduction o—o = right ear. x — x = left ear.

Age range •-----• limits of 25 th and

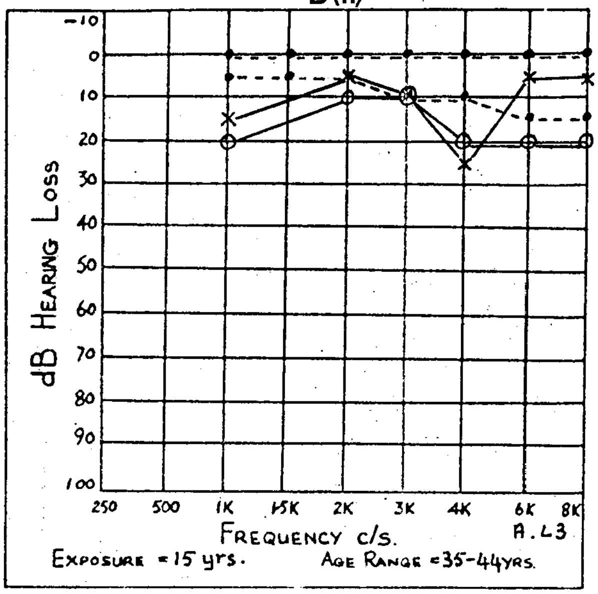
•-----• 75 th percentile. (Hinchcliffe's data)

Audiograms of subjects in Section B(i) and B(ii) of Table 23, page 111.

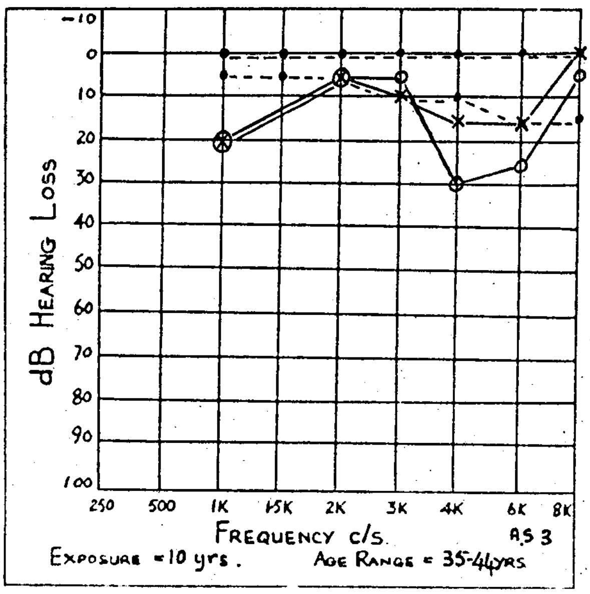
B(i)



B(ii)



Audiograms of subject in Section B(i) of Table 24, page 112.



Key

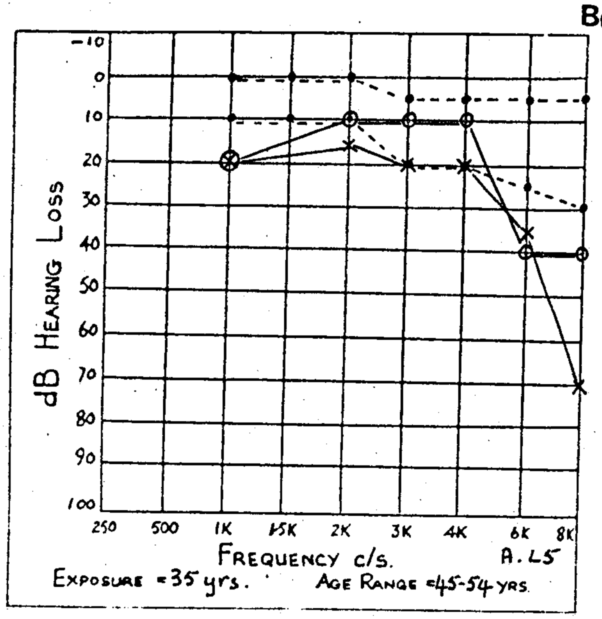
Air conduction o——o = right ear. x——x = left ear.

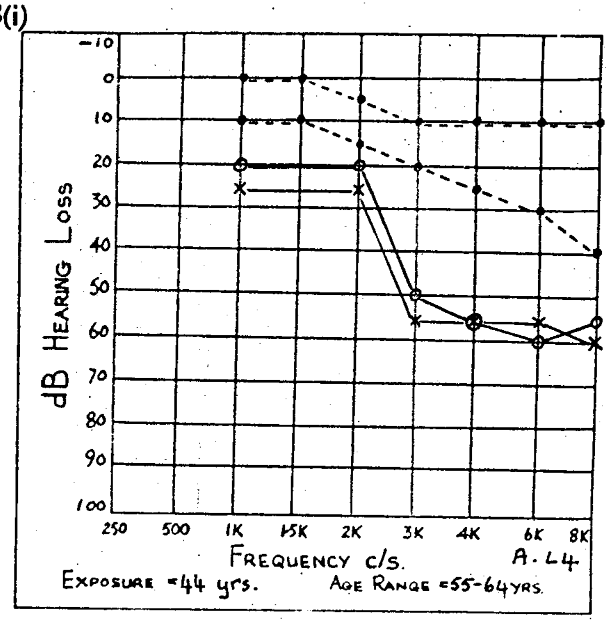
Age range •-----• limits of 25 th and

•-----• 75 th percentile. (Hinchcliffe's data)

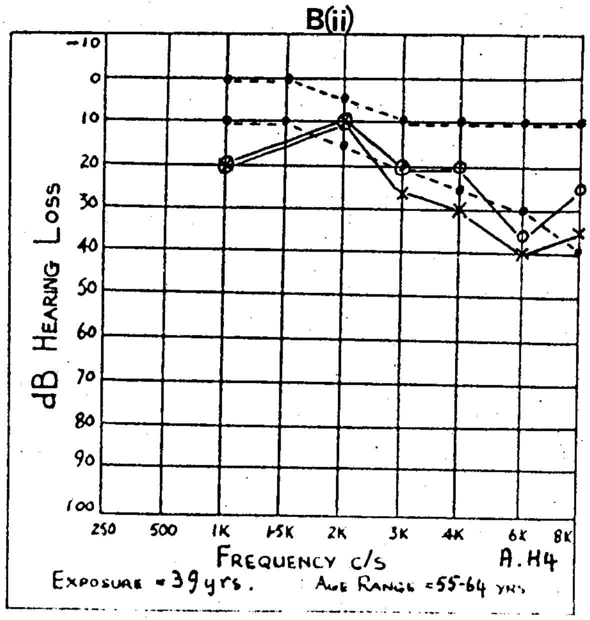
Audiograms of subjects in Section B(i) and B(ii) of Table 26, page 114.

B(i)





B(ii)



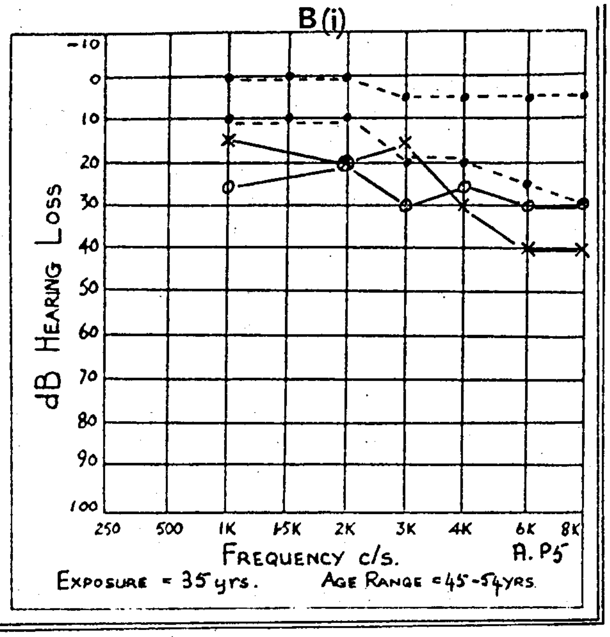
Key

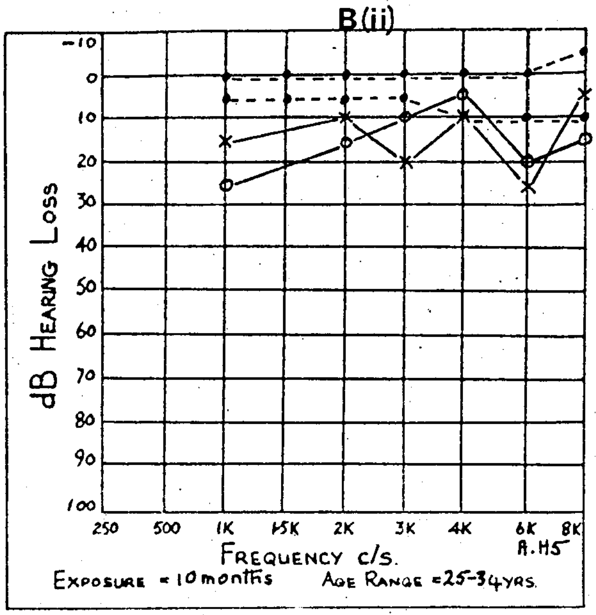
Air conduction o——o = right ear. x——x = left ear.

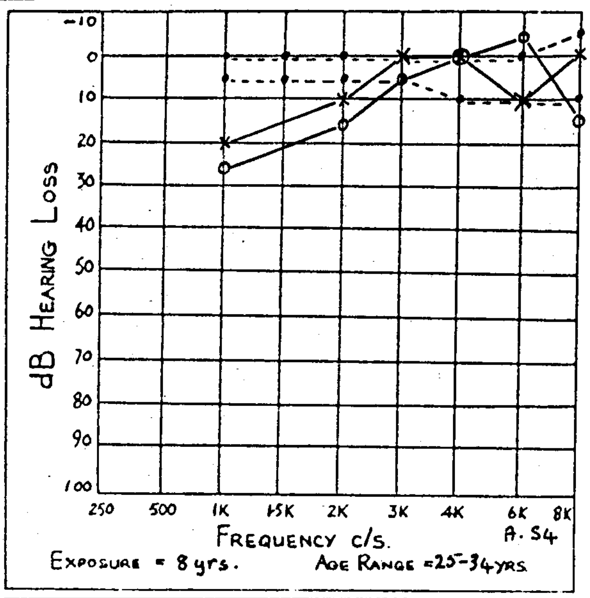
Age range •------• limits of 25 th and

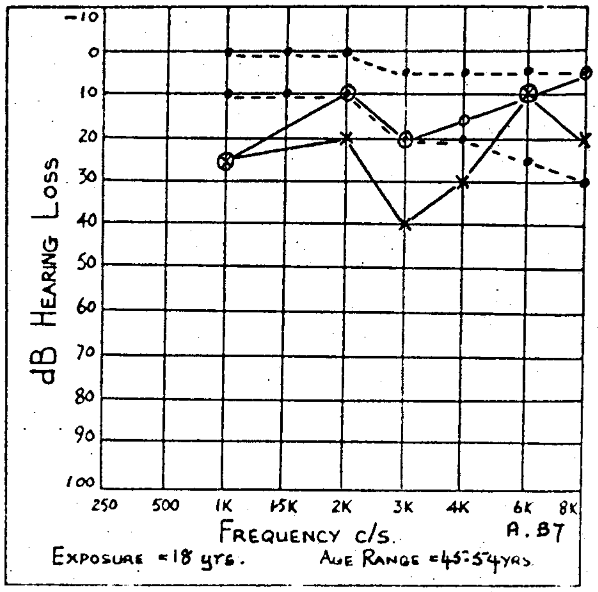
•------• 75 th percentile. (Hinchcliffe's data)

Audiograms of subjects in Section B(i) and B(ii) of Table 28, page 115.

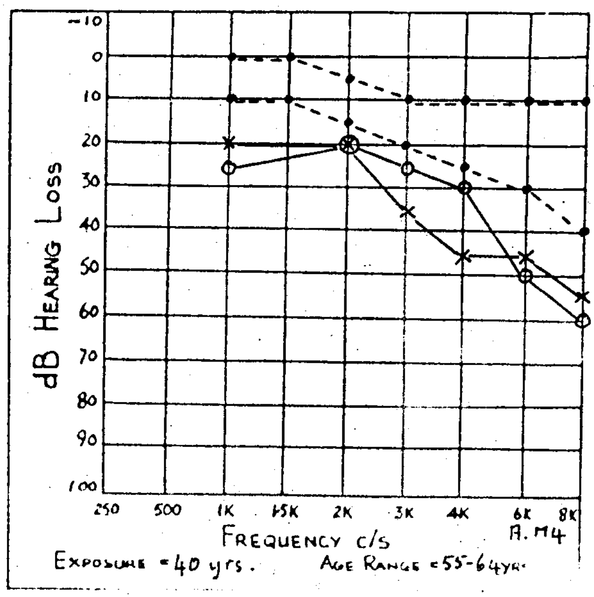








Audiogram of subject in Section b(i) of Table 32, page 118.



Key

Air conduction	o——o = right ear.	x——x = left ear.
Age range	•------• limits of 25 th and	
	•------• 75 th percentile. (Hinchcliffe's data)	

FACTORY B - CLOTHING MANUFACTURING

Hearing tests were carried out in the medical centre of this factory, where the background noise level was slightly in excess of Fox's recommended levels, for low frequencies. Frequent tests on the author's hearing showed a 10 dB drop (normally 5 dB, reading 15 dB) in acuity for the frequencies of 250 c/s to K c/s inclusive. The noise level and the masking effect on normal hearing were stable throughout the entire hearing survey, therefore the audiograms of noise-exposed subjects will be reproduced in full. The masking effect of the ambient noise cannot be more than 10 dB and that only for subjects with audiometric readings of between 0 dB and 15 dB. Therefore, allowing for the maximum possible masking effect, all hearing losses for the frequencies of 250 c/s, 500 c/s and

1 K c/s will have 10 dB subtracted from the measured reading before a decision is made regarding the presence of a true hearing loss for these frequencies. The audiometric data will be reproduced ~~in the form in which it was recorded~~, with the correction factor ~~superimposed~~.

Noise analyses and hearing tests were carried out in two departments, and Table 36 below gives details of the noise sources in each.

TABLE 36

Department	Noise Source	Number of subjects tested
1.a)	Superlock machine	9
b)	Lace attach "	2
c)	Welting "	2
d)	Covering "	1
e)	Flat lock "	9
f)	Lockstitch "	5
g)	Strapping "	1
2.	Winding	24

Department 1

This is a large open-plan department where several different finishing processes are carried out. Two conveyor-belt transporters have been installed to facilitate the delivery and collection of work to the individual operators, several of whom have complained of the additional noise. Measurements were made of the general background noise and these are reproduced below. It will be seen that the transporter contributes little to the noise level, except at the frequencies 63 c/s, 125 c/s and 250 c/s.

TABLE 37

Background Noise Analyses

Octave band c/s	Sound level dB	
	Transporter Silent	Transporter operating.
31.5	64 - 70	64 - 70
63	70	80
125	70 - 74	81 - 85
250	68 - 71	75 - 77
500	74 - 76	76 - 79
1 K	71 - 74	74 - 78
2 K	70 - 72	70 - 72
4 K	64 - 66	64 - 66
8 K	58 - 60	58 - 60
16K	44 - 52	44 - 52
31.5K	24 - 32	20 - 31
Linear	80 - 82	87 - 88

An alternative explanation for the employers dissatisfaction is that, since the necessity to fetch and return their own work is removed, they now remained seated in one position for a considerable length of time.

The background noise was measured and analysed from several locations and was found to vary very little, the overall reading always being 80 - 82 dB and the spectrum shape flat, with intensity decreasing towards the higher frequencies. A typical reading is given below.

TABLE 38

Centre of Room - Background Noise

All machines operating

Octave band c/s	Sound level dB
31.5	60 - 70 - 75
63	68 - 74
125	68 - 74
250	69 - 72
500	72 - 75
1 K	72 - 75
2 K	66 - 70
4 K	63 - 67
8 K	58 - 62
16K	46 - 50
31.5K	21 - 26
Linear	80 - 82

It will be seen that these readings are very similar to those taken near the transporter.

All the machines in this department are operated intermittently. Bursts of noise, of varying time length, alternate with periods of 'quiet' (containing background noise), while the operator adjusts the garment under the machine.

The seven machines listed in Table 36 will be considered separately. All noise analyses were made at operator level.

(a) Superlock machine

TABLE 39

Noise Analysis

Centre of frequency of Octave band, c/s	Sound level dB
31.5	74 - 76
63	80 - 82
125	74
250	76
500	74
1 K	74
2 K	75
4 K	74
8 K	70
16K	60
31.5K	40
Linear	84

The hearing assessments are analysed in Table 40 below.

TABLE 40

A Hearing within the normal limits specified by Hinchecliffe's presbycusis data.		B Hearing loss attributable to noise exposure. i)No previous history of noise exposure.		ii)History of exposure to more than one environmental noise.		Hearing loss attributable to a multiplicity of factors including noise exposur
Subject	Exposure time	Subj.	Expos. time	Subj.	Expos. time	
M.W5	6 months	M.T2	6 yrs			M.G2
M.D2	6 "	M.G3	7 "			M.P1
M.W6	13 "	M.W7	7 "			
		M.L4	47 "			
3 subjects		4 subjects		0 subjects		2 subjects

Table 40 above shows that four of the nine subjects examined have some degree of hearing loss which is directly attributable to the present noise environment. The audiograms of these subjects, group B (i) are reproduced on page 155 .

(b) Lace-attach machine

TABLE 41

Noise Analysis

Centre frequency of Octave band c/s	Sound level dB
31.5	74 - 76
63	76 - 78
125	76
250	75
500	76
1 K	74
2 K	76
4 K	75
8 K	72
16K	65
31.5K	44
Linear	84

Two subjects only were available for examination. Both were seventeen years old and had been exposed to the noise for one year and one and a half years respectively. There was no indication of any hearing abnormality in either case.

(c) Welting Machine

TABLE 42

Noise Analysis

Centre frequency of Octave Band, c/s	Sound level dB
31.5	70 - 72
63	74 - 78
125	80
250	80
500	84 - 85
1 K	83 - 84
2 K	84 - 85
4 K	80
8 K	76
16 K	68
31.5K	42
Linear	82

The hearing assessments are analysed in Table 43 below.

TABLE 43

A Hearing within the normal limits specified by Hinchcliffés presbycusis data.		B Hearing loss attributable to noise exposure. i) No previous history of noise exposure		ii) History of exposure to more than one environmental noise.		C Hearing loss attributable to a multiplicity of factors including noise exposure.
Subject	Exposure time	Subject	Expos. time	Subj.	Expos. time	
		M.R1 M.P2	1 year 14 "			
0 subjects		2 subjects		0 subjects		0 subjects

The audiograms of the two subjects examined both show hearing losses due to noise exposure and are reproduced on page 156.

(d) Covering Machine

TABLE 44

Noise Analysis

Centre frequency of Octave Band, c/s	Sound Level dB
31.5	74 - 76
63	80 - 82
125	78
250	80
500	84
1 K	82
2 K	82
4 K	79
8 K	78
16K	67
31.5K	50
Linear	90

Only one subject was available for testing and hearing was within normal limits. Total exposure to the noise was 15 years.

(e) Flat lock machine

TABLE 45

Noise Analysis

Centre frequency of Octave Band, c/s	Sound Level dB
31.5	74
63	74 - 78
125	74 - 75
250	80
500	76
1 K	80
2 K	77
4 K	74 - 76
8 K	73
16K	61
31.5K	38 - 40
Linear	88

Nine operators of this machine were examined and Table 46 below shows the distribution of hearing loss. The three audiograms in group b(i) appear on page 156.

TABLE 46

A		B				C
Hearing within the normal limits specified by Hinchcliffes presbycusis data.		Hearing loss attributable to noise exposure. i)No previous history of noise expos.		ii)History of exposure to more than one environmental noise.		Hearing loss attributable to a multiplicity of factors including noise exposure.
Subject	Exposure time	Subject	Exp. time	Subj.	Expo. time	
M.G6	$1\frac{1}{2}$ years	M.T1	17yrs			
M.L1	$2\frac{1}{2}$ years	M.K2	25 "			
M.B8	3 years	M.W8	30 "			
M.F1	6 years					
M.D1	11 years					
M.C3	12 years					
6 subjects		3 subjects		0 subjects		0 subjects

(f) Lockstitch Machine

TABLE 47

Noise Analysis

Centre frequency of octave band, c/s	Sound level dB
31.5	76
63	84 - 86
125	80
250	80
500	84
1 K	82
2 K	80
4 K	78
8 K	74
16 K	67
31.5K	40 - 42
Linear	90

The hearing of the five subjects tested is analysed in Table 48 below.

TABLE 48

A Hearing within the normal limits specified by Hinchcliffe's presbycusis data.		B Hearing loss attributable to noise exposure. i)No previous history of noise exposure		ii)History of exposure to more than one environmental noise		C Hearing loss attributable to a multiplicity of factors including noise exposure.
Subject	Exposure time	Subj.	Expos. time	Subj.	Expos. time	
M.S3 M.L2 M.K1	3 years 20 " 20 "	M.H3	11 years			M.G5
3 subjects		1 subject		0 subjects		1 subject

The audiogram of subject M.H3 in group B (i) is reproduced on page 156.

(g) Strapping Machine

TABLE 49

Noise Analysis

Centre frequency of Octave Band c/s	Sound level dB
31.5	74 - 78
63	82 - 84
125	79
250	80
500	78
1 K	77 - 79
2 K	78 - 79
4 K	74 - 75
8 K	67 - 69
16K	55 - 57
31.5K	30 - 32
Linear	88 - 89

Only one subject was available for testing. The total exposure time to this machine was four years but there was a history of 40 years exposure to various machines in the same department. Hearing was within normal limits.

Department 2. Winding

Two noise analyses were made in this Department, one in the centre of the room and one at operator level.

TABLE 50

Noise Analyses

Centre frequency of Octave Band, C/s	Sound level dB	
	Centre of room	Operator level
31.5	67 - 72	67 - 74
63	66 - 68	67 - 68
125	68 - 69	71 - 72
250	76	79
500	82	82
1 K	84.5	855
2 K	87 - 88	88
4 K	85	84
8 K	79	80 - 81
16 K	71	73 - 74
31.5K	50	55 - 56
Linear	91 - 92	92

Hearing assessments were carried out on twenty-four subjects and Table 51 below gives the distribution of hearing loss.

TABLE 51

A Hearing within the normal limits specified by Hinchcliffes presbycusis data.		B Hearing loss attributable to noise exposure. i) No previous history of noise exposure		ii) History of exposure to more than one environmental noise		C Hearing loss attributable to a multiplicity of factors including noise exposure.
Subject	Exposure time	Subj.	Expos. time	Subj.	Expos. time (present noise only)	
M Y1	5 years	M.B4	4 mnths			M.L3
M.W1	18 "	M.B1	4 years			
M.B2	23 "	M.G1	4 years	M.B3	2 weeks	
M.W4	29 "	M.P2	$4\frac{1}{2}$ "	M.G4	3 mths	
M.O1	34 "	M.C1	8 "	M J1	2 yrs	
		M.B5	14 "	M.W2	12 "	
		M.M3	15 "	M.W3	14 "	
		M.C2	17 "			
		M.M4	17 "			
		M.H1	21 "			
		M.S1	21 "			
		M.M2	22 "			
		M.M1	30 "			
5 subjects		13 subjects		5 subjects		1 subject

In addition to the above 24 subjects, six employees were tested, all of whom had a severe degree of deafness resulting from an established pathological condition. There were five cases of chronic supperative otitis media, three of whom had had unilateral mastoidectomy, and one case of severe congenital deafness. Since severe deafness, in all these cases, was established before noise exposure occurred, they have not been included in Group C of Table 51 above.

The audiograms of the 18 subjects in Group B of Table 51 are reproduced on pages 157to159.

Summary of results in Factory B

There is evidence of noise-induced hearing loss in both of the departments investigated. The hearing assessment results are summarised in Table 52 below.

TABLE 52

Department	No. of cases of hearing loss attributable to noise exposure.		No. of cases of hearing loss attributable to multiplicity of causes.	No. of cases of normal hearing	Total No. of subjects examined
	Single source of noise exposure.	Multiple Noise exposure			
1. a	4	0	2	3	9
b	0	0	0	2	2
c	2	0	0	0	2
d	0	0	0	1	1
e	3	0	0	6	9
f	1	0	1	3	5
g	0	0	0	1	1
2.	13	5	1	5	24
TOTAL	23	5	4	21	53

Table 52 above shows that of the total 53 subjects tested, 23 have a measurable hearing loss which may be directly attributed to exposure to their present working environmental noise. A further 5 subjects have hearing losses which may have been caused, wholly or partly, by exposure to additional high-intensity noise.

The total number of cases of noise-induced hearing loss is, therefore, 28. Four subjects have deafness which may have been caused by noise exposure in addition to other factors and the remaining 21 subjects have normal hearing.

Table 53 below indicates which departments would <u>not</u> be protected if the damage risk criteria listed on page 88 were to be applied. The third column gives the ratio of the number of cases of deafness directly attributable to each departmental noise, to the number of subjects tested.

TABLE 53

Damage risk criteria (see page 88)	Departments unprotected	Number of cases of deafness/total subjects tested
1. U.S.A.F.	1 a	4/9
	1 b	0/2
	1 d	0/1
	1 e	3/9
	1 f	1/5
	1 g	0/1
2. Burns & Littler	Nil	
3. Burns & Littler	1 a	4/9
	1 b	0/2
	1 e	3/9
	1 g	0/1
4. B.M.A.	1 a	4/9
	1 b	0/2
	1 d	0/1
	1 e	3/9
	1 f	1/5
	1 g	0/1
5. Hardy	1 a	4/9
	1 b	0/2
	1 c	2/2
	1 d	0/1
	1 e	3/9
	1 f	1/5
	1 g	0/1
	2	13/24
6. I.S.O. 85	1 a	4/9
	1 b	0/2
	1 e	3/9
7. Glorig	1 a	4/9
	1 b	0/2
	1 c	2/2
	1 d	0/1
	1 e	3/9
	1 f	1/5
	1 g	0/1

TABLE 53 contd.

8. Plomp	1 a	4/9
9. Beranek. Continuous spectrum noise.	1 a 1 b 1 c 1 d 1 e 1 f 1 g 2	4/9 0/2 2/2 0/1 3/9 1/5 0/1 13/24
10. Beranek. Noise containing pure tones.	1 a 1 b 1 d 1 e 1 f 1 g	4/9 0/2 0/1 3/9 1/5 0/1
11. Rosenblith Continuous spectrum noise	1 a 1 b 1 c 1 d 1 e 1 f 1 g 2	4/9 0/2 2/2 0/1 3/9 1/5 0/1 13/24
12. Rosenblith Noise containing pure tones.	1 a 1 b 1 d 1 e 1 f 1 g	4/9 0/2 0/1 3/9 1/5 0/1

The noise analysis data are shown graphically on pages 152-154. The general background noise of department 1 is included, since all employees in this department are continually exposed to this noise, in addition to the sporadic noise of their individual machines.

The damage risk criteria state that the levels specified should not be exceeded. In several instances in this factory, the noise analyses reveal a few frequencies which equal the damage risk maxima, while the remainder of the spectrum falls below the danger level.

These analyses have been omitted from Table 53 since they are, by strict definition of damage risk criteria, below the danger levels. However, since a reading of 0.5 dB more would have qualified them as dangerous noise levels, they are listed in Table 54 below, together with the frequencies which are co-incident with the various damage risk maxima.

TABLE 54

Department	Deafness/Normal ratio	Frequencies co-incident with D.R.C. maxima
1 a	4/9	2) Burns & Littler 4K c/s
1 b	0/2	2) Burns & Littler 2Kc/s, 4Kc/s 8) Plomp 4Kc/s
1 c	2/2	1) U.S.A.F. 500c/s 2Kc/s 4) B.M.A. 500c/s 2Kc/s 10) Beranek 2Kc/s
1 e	3/9	8) Plomp 4Kc/s
1 f	1/5	3) Burns & Littler 2Kc/s 6) I.S.O. 85 1Kc/s 2Kc/s
1, background noise	-	2) Burns & Littler 1 Kc/s
2	13/24	7) Glorig 2 Kc/s

The highest level of environmental noise recorded in factory B exists in department 2, which also yielded the largest number of subjects, 24, available for testing. Thirteen of these subjects demonstrated some degree of deafness which may be attributed to their present noise environment. With the exception of D.R.C. No. 8 (Hardy) the application of all the criteria examined would give protection. Criteria Nos. 9 & 11 for continuous spectrum noise, would not be applicable to this noise, since there is a concentration of energy in the mid-frequency range.

Table 55 below shows the overall noise level in each department, together with the general shape of each spectrum and the incidence of deafness.

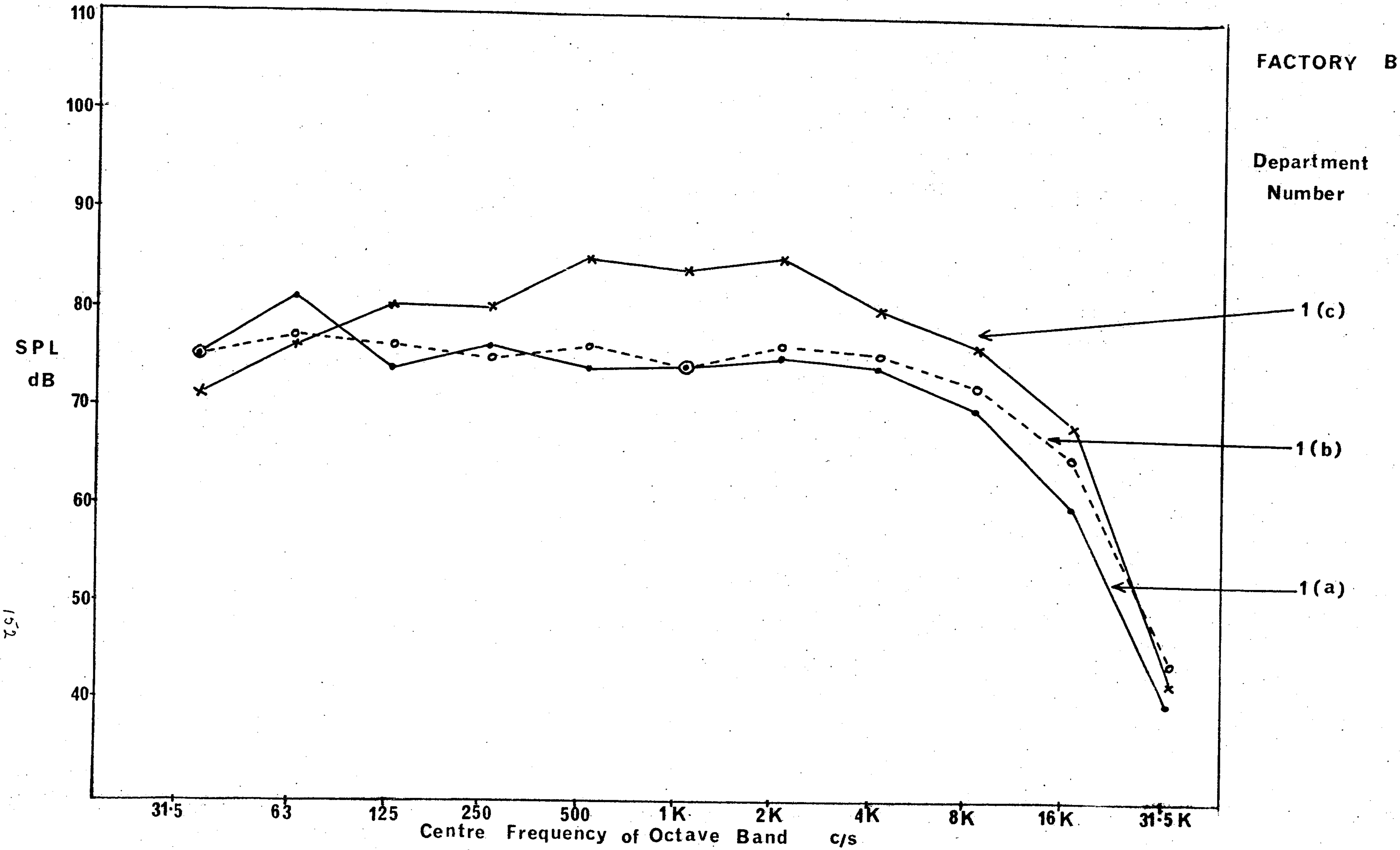
TABLE 55

Dept.	Overall S.P.L. dB	Shape of spectrum	Total No. subjects	Total cases deafness	cases attributable to present noise alone	Cases of noise expos. & other factors	Normal hearing
1 a	84	Flat, with peak at 63 c/s (Intermittent)	9	6	4	-	3
b	84	Flat (intermittent)	2	-	-	-	2
c	82	Peaks at 500 c/s & 2Kc/s (Intermittent)	2	-	2	-	-
d	90	Peaks at 63c/s & 500 c/s (intermittent)	1	-	-	-	1
e	88	Peaks at 250 c/s & 1Kc/s (intermittent)	9	3	3	-	6
f	90	Peaks at 63c/s & 500c/s (intermittent)	5	2	1	1	3
g	88-89	Flat, with peaks at 63c/s (intermittent)	1	-	-	-	1
2	92	Peak at 2Kc/s intensity decreases towards higher & lower ends of spectrum (continuous)	24	19	13	6	5

In department 1, machines (a), (b) and (c) have comparable overall sound levels. Machine (b) has a flat spectrum of 84 dB overall SPL and both subjects tested had normal hearing, after exposures of one year and one and a half years respectively. Exposure to the noise of machine (a), with the same overall S.P.L. of 84 dB, has caused deafness in 4 of the 9 subjects, and possibly has contributed to the deafness of two more. Noise from machine (a) has a peak in the spectrum of 63 c/s. Exposure times are not comparable, since the 4 noise deafened subjects had spent from 6 to 47 years on these machines, and the length of exposure time of the 2 normal-hearing subjects on machine (a) was much shorter.

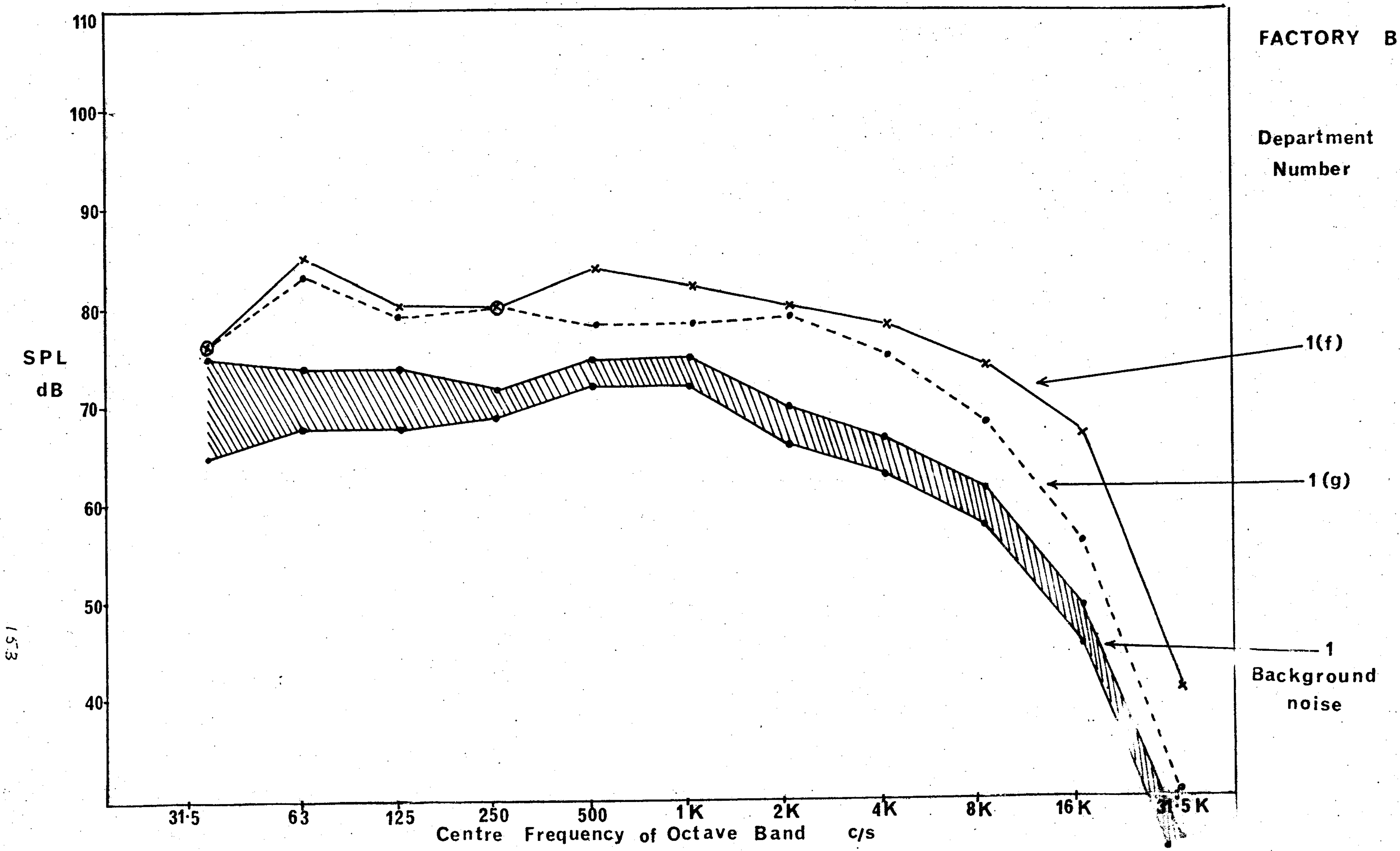
The subjects operating machine (c) with an overall S.P.L. of 82 dB, both show a hearing loss. The spectrum of machine (c) contains two areas of high energy concentration, at 500 c/s and 2Kc/s. One subject has spent one year operating the machine and the other, 14 years.

Thus, noise emitted by machines (a) and (c) both of which produce sharp peaks in the spectrum, has been found to cause deafness, while operators of machine (b), where there is no concentration of energy in any one part of the spectrum, have normal hearing. This is a further indication that noise-induced deafness is a function of the distribution of energy, throughout the spectrum (see factory A, page 123). But, as with these earlier results, the sample is too small to be conclusive.



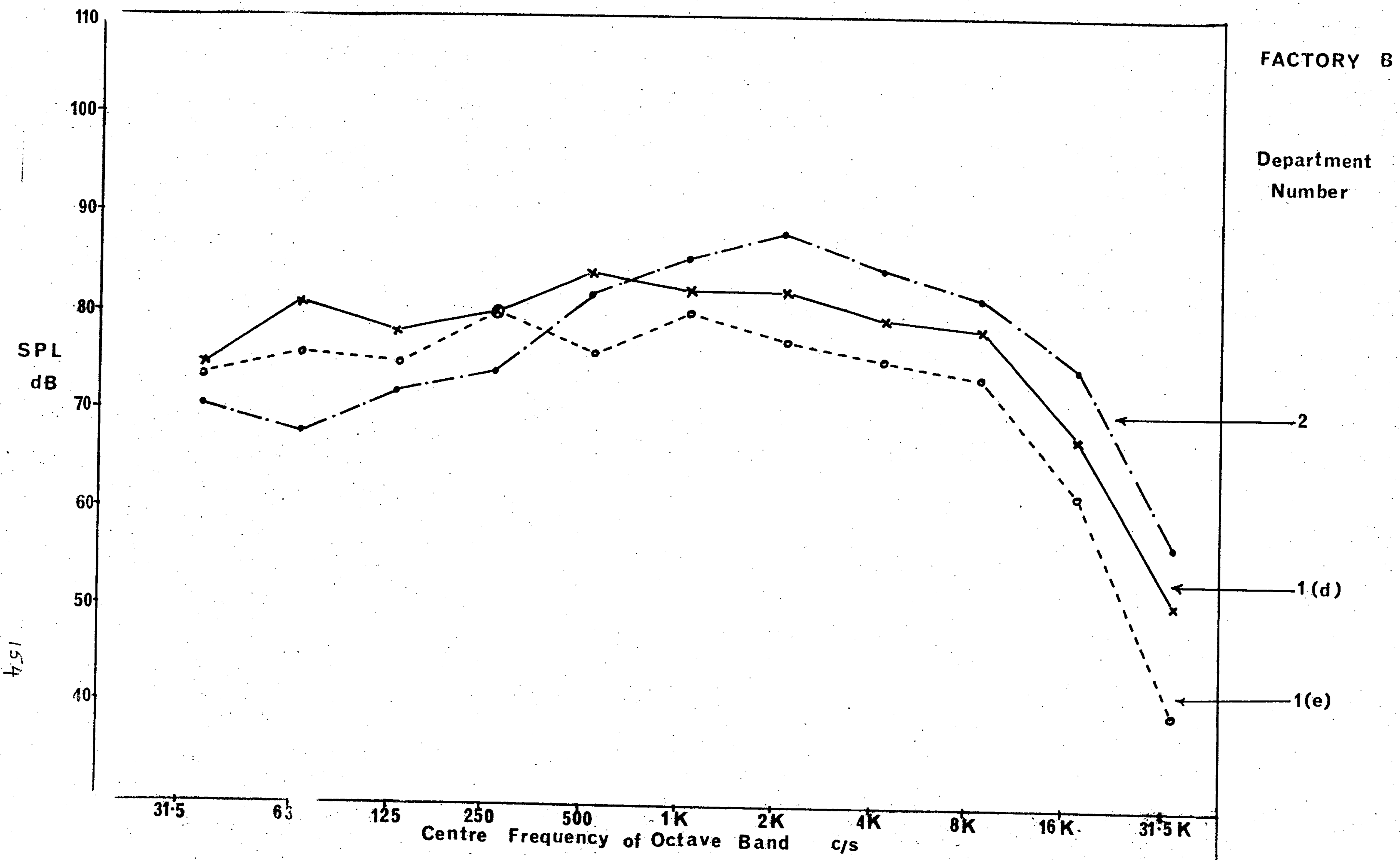
FACTORY B
Department Number
1 (c)
1 (b)
1 (a)
SPL dB
110
100
90
80
70
60
50
40
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5 K
Centre Frequency of Octave Band c/s

152



FACTORY B
Department Number
SPL dB
110
100
90
80
70
60
50
40
1(f)
1(g)
1
Background noise
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5K
Centre Frequency of Octave Band c/s

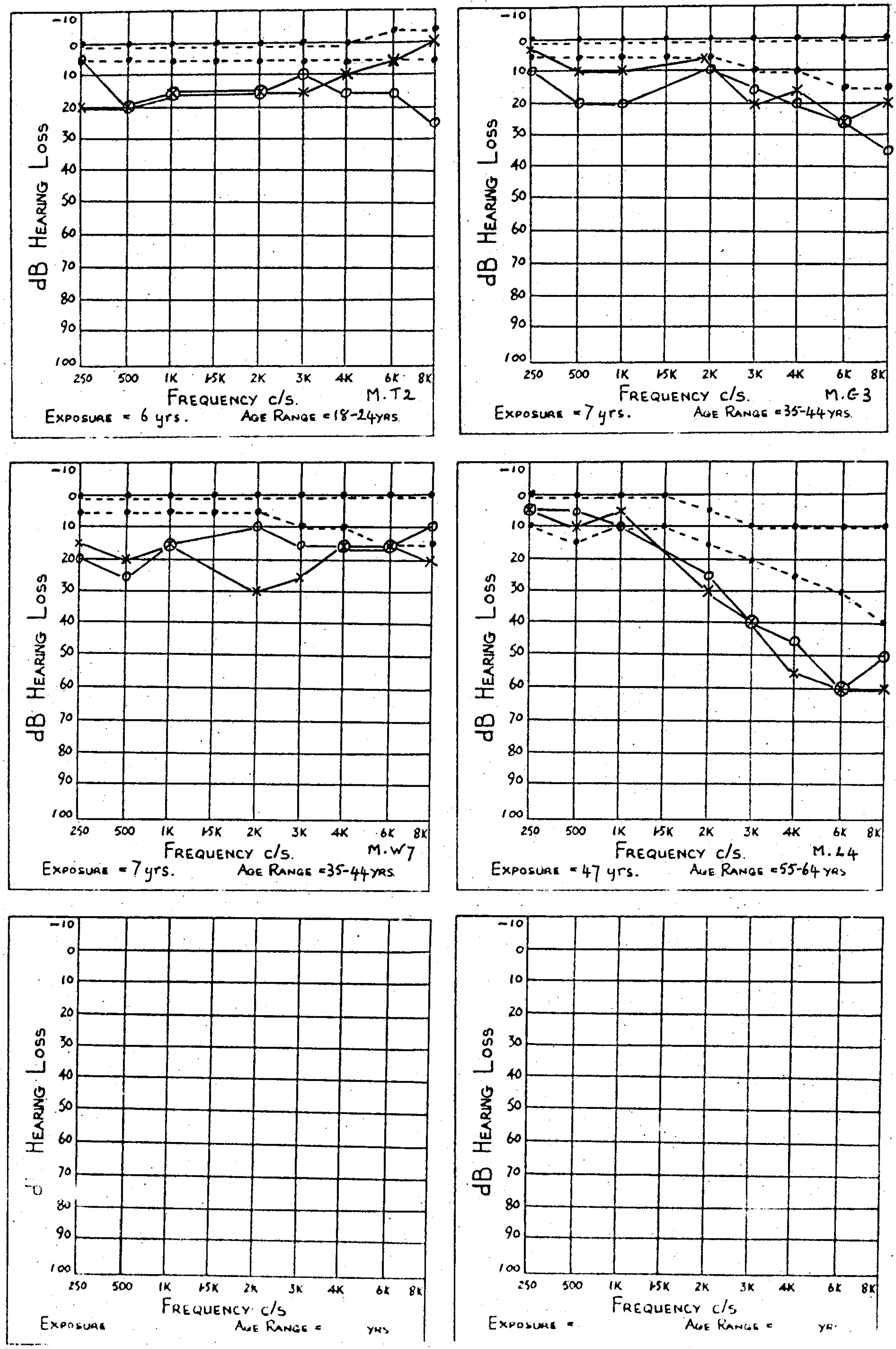
153



FACTORY B
Department Number
SPL dB
110
100
90
80
70
60
50
40
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5 K
Centre Frequency of Octave Band c/s
2
1(d)
1(e)

154

Audiograms of subjects in Section B(i) of Table 40, page 138.



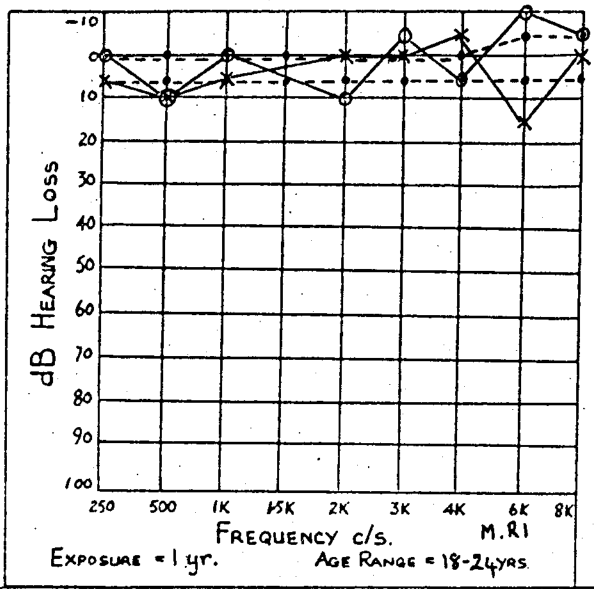
Key

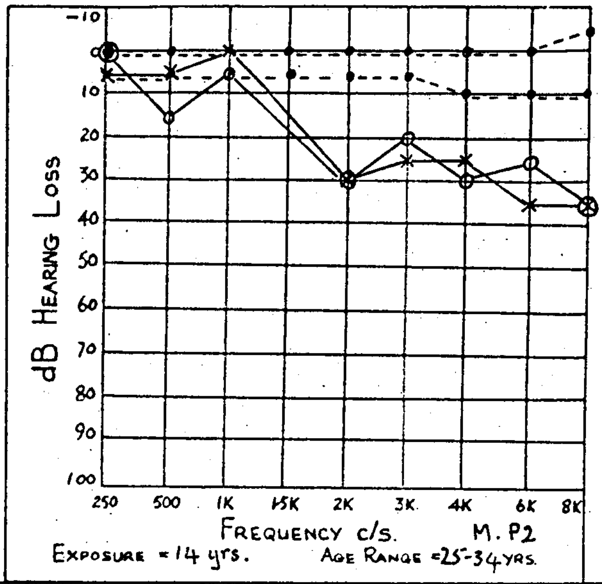
Air conduction o——o = right ear. x — x = left ear.

Age range •------• limits of 25 th and

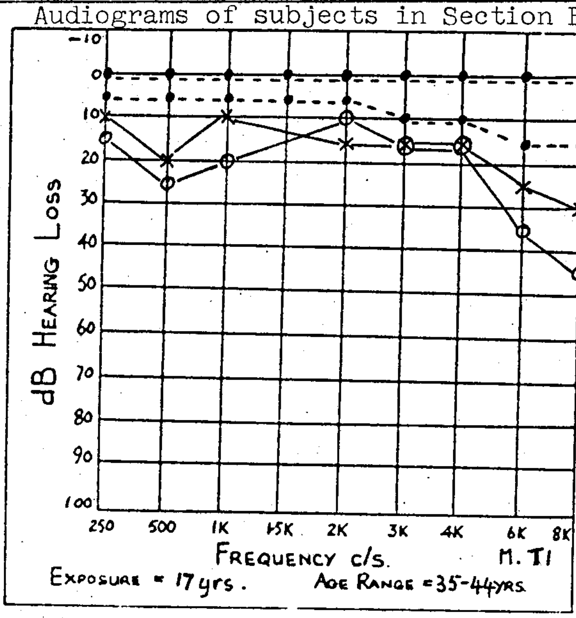
•-----• 75 th percentile. (Hinchcliffe's data)

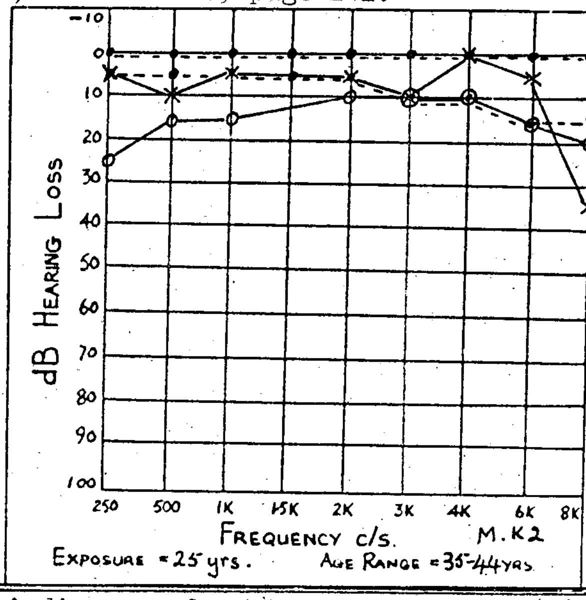
Audiograms of subjects in Section B(i) of Table 43, page 140.

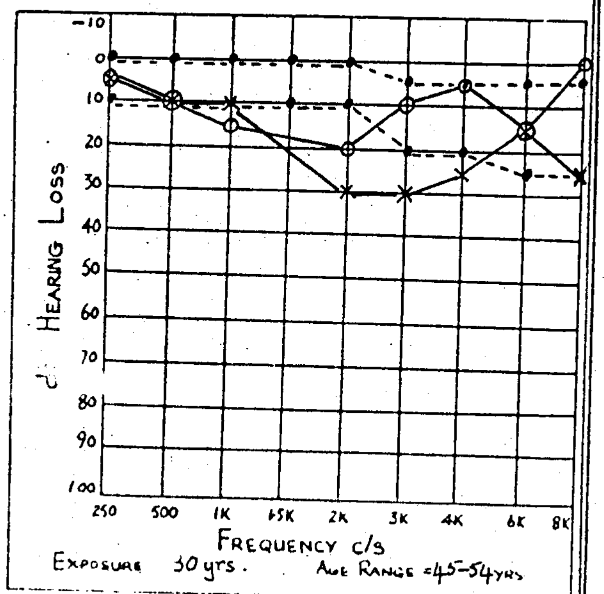




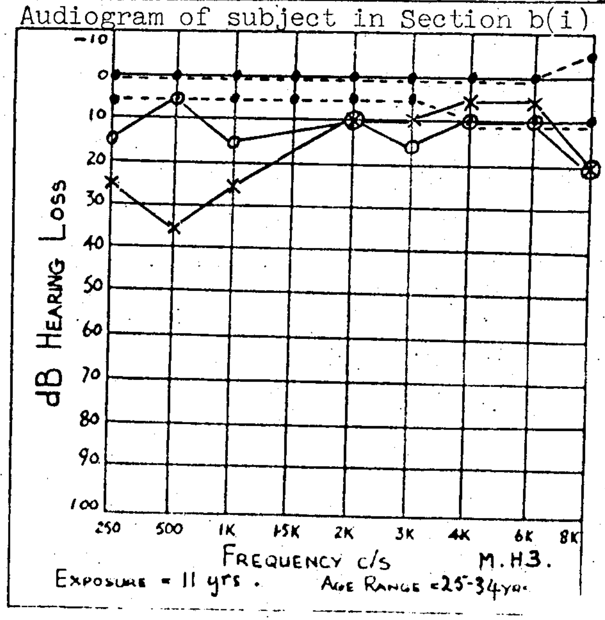
Audiograms of subjects in Section B(i) of Table 46, page 142.







Audiogram of subject in Section b(i) of Table 48 page 143.



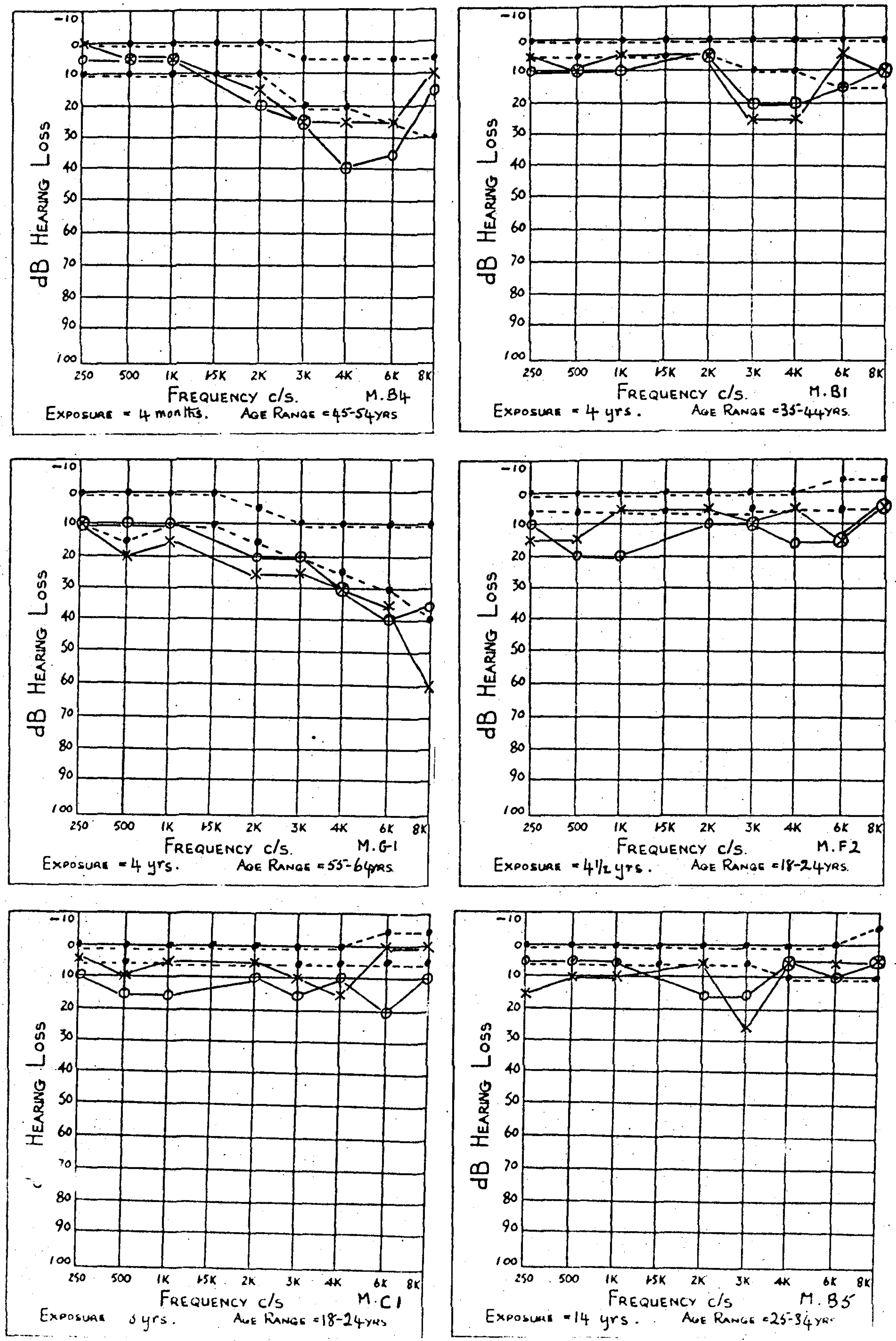
Key

Air conduction o——o = **right ear.** x——x = **left ear.**

Age range •------• **limits of 25 th and**

•------• **75 th percentile. (Hinchcliffe's data)**

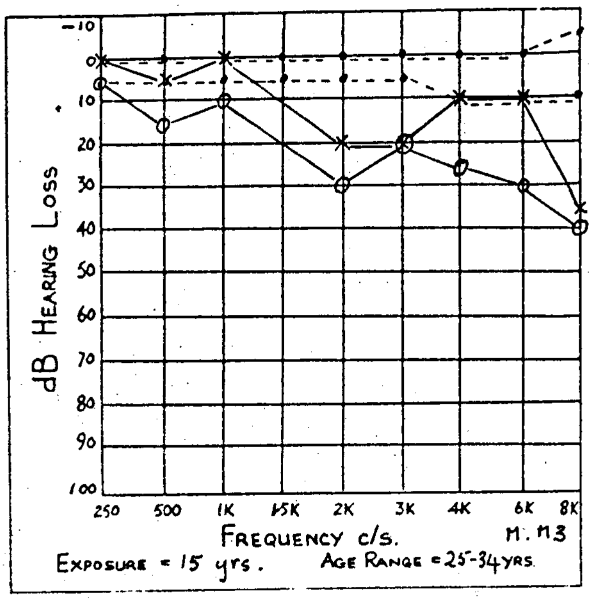
Audiograms of subjects in Section B(i) of Table 51, page 145.

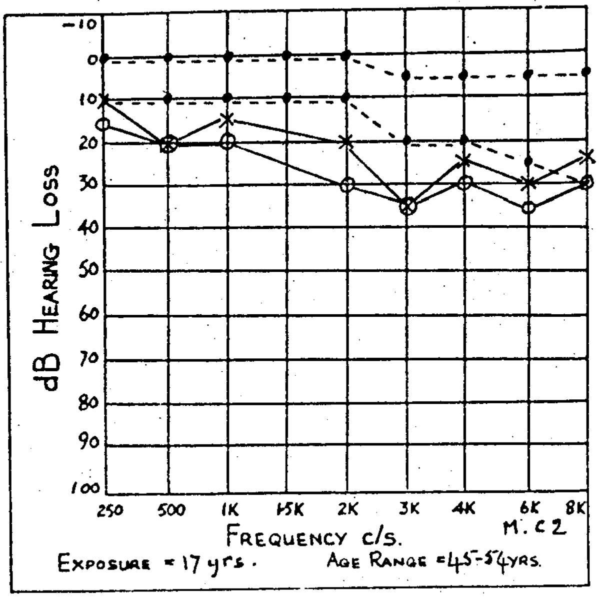


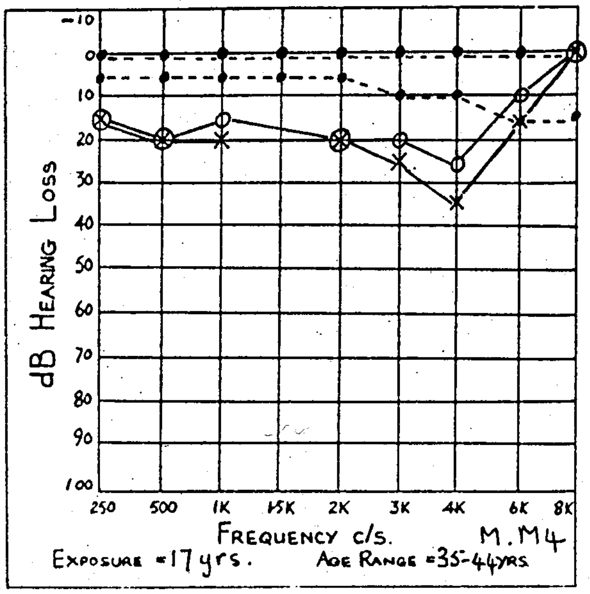
Key

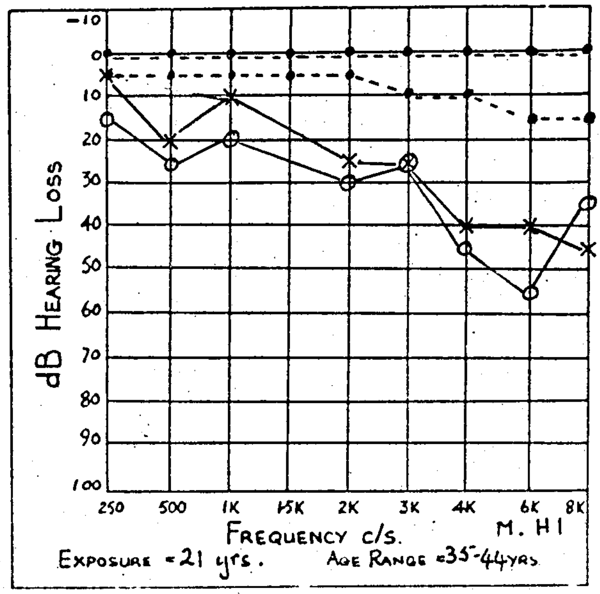
Air conduction	o—o = right ear.	x—x = left ear.
Age range	•-----• limits of 25 th and	
	•-----• 75 th percentile. (Hinchcliffe's data)	

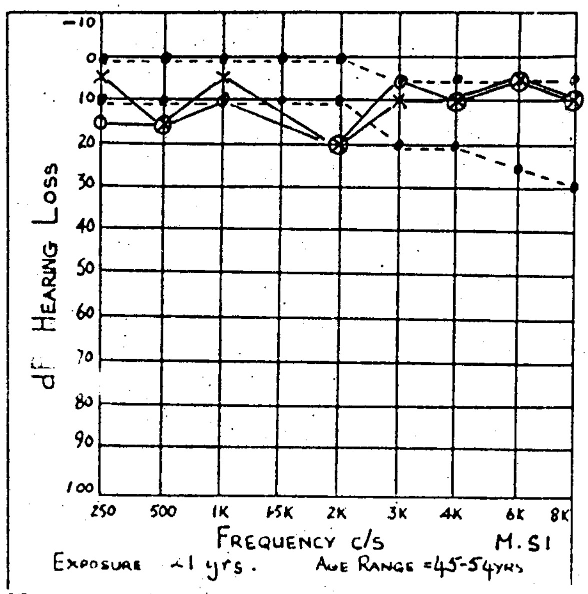
Audiograms of subjects in Section B(i) of Table 51, page 145 (continued)

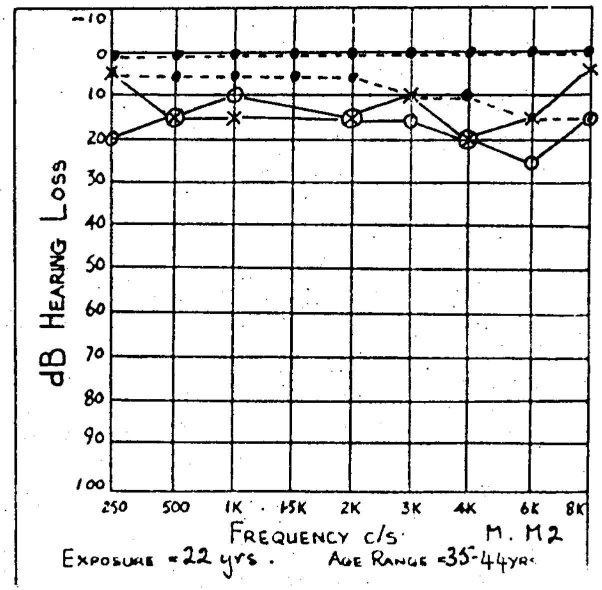












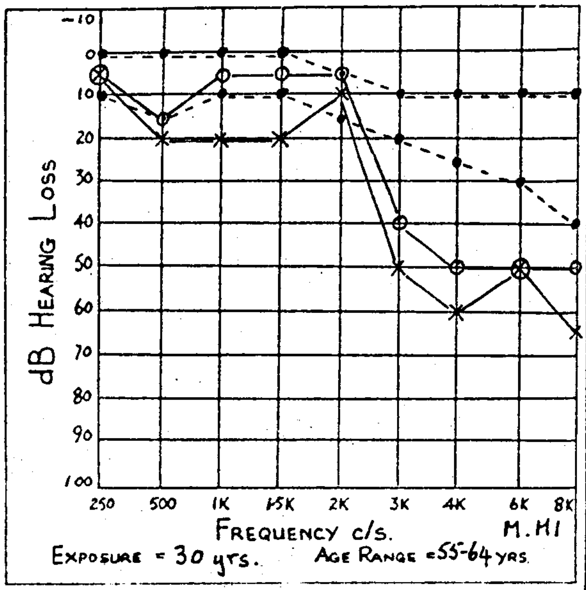
Key

Air conduction o—o = right ear. x—x = left ear.

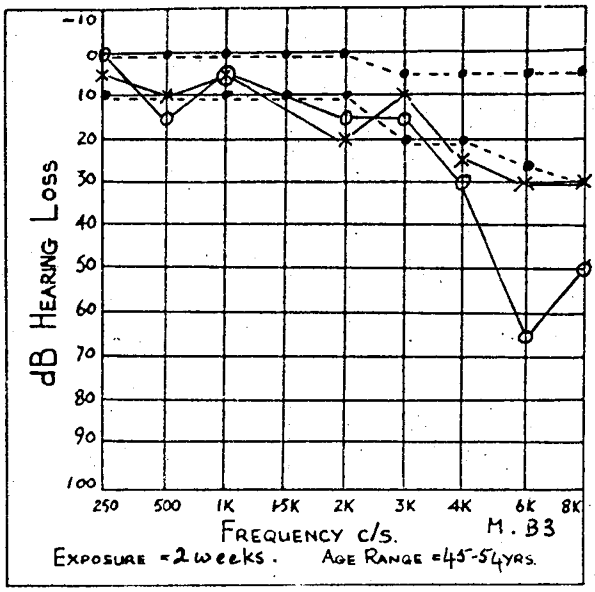
Age range •------• limits of 25 th and

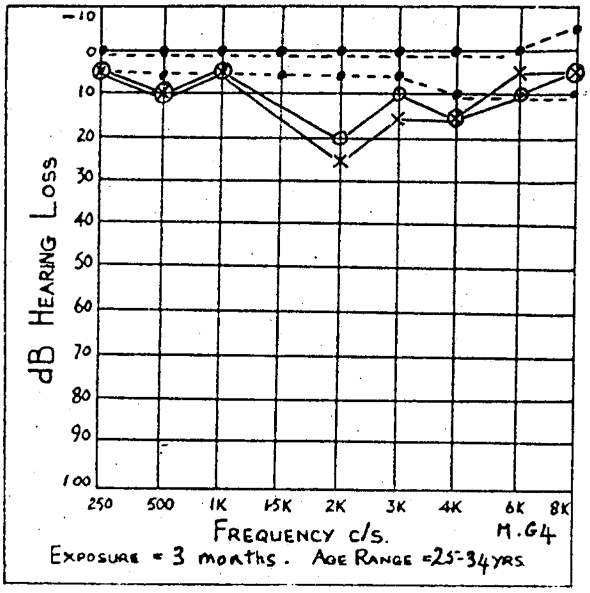
•------• 75 th percentile. (Hinchcliffe's data)

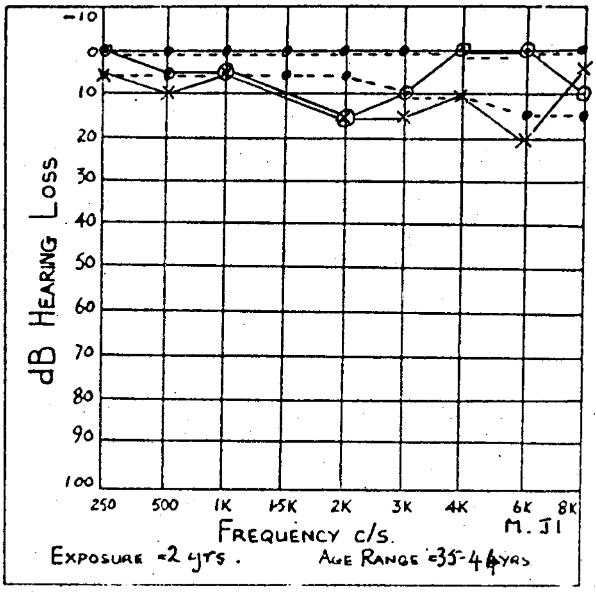
Section B(i), continued.

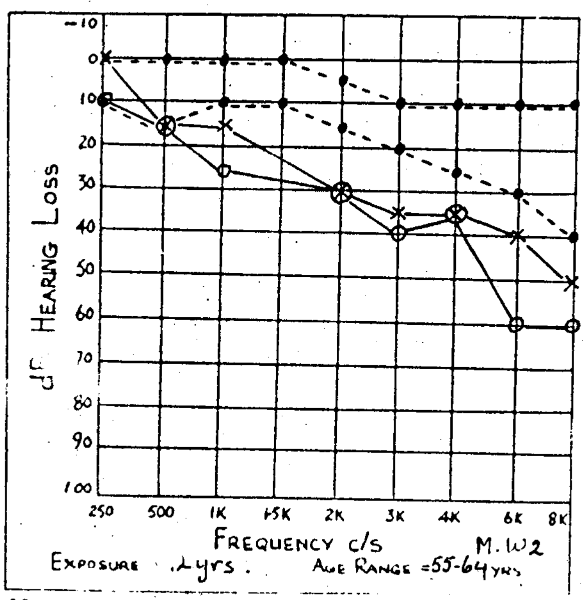


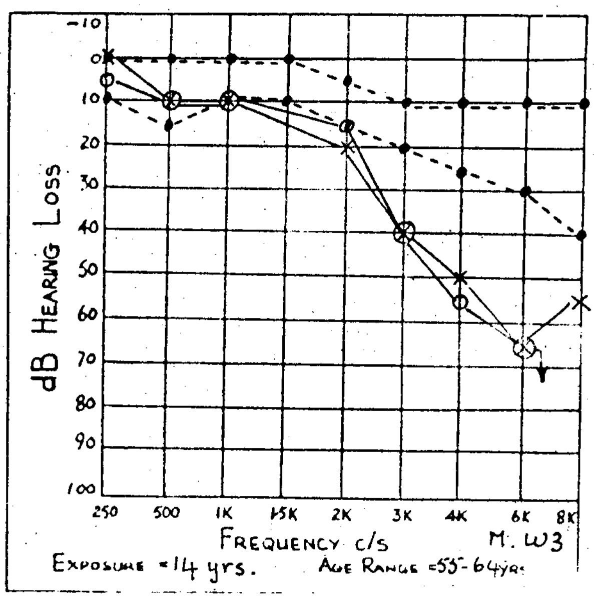
Audiograms of subjects in Section B(ii) of Table 51, page 145.











Key

Air conduction o—o = right ear. ×—× = left ear.

Age range •-----• limits of 25 th and

•-----• 75 th percentile. (Hinchcliffe's data)

FACTORY C - CHEMICAL MANUFACTURING

A survey was carried out, at the request of the Management, of the effects of noise of a grinding mill on the hearing of employees, where it was suspected that the noise level was dangerously high.

All employees who had, at some time, if not currently, operated this mill, were examined for signs of occupational deafness. Several employees had a history of exposure to high intensity noise other than that from the mill. Where this had occurred within factory C, measurements were also made of the noise from the relevant sources.

Employees were brought to the Department of Ergonomics for the hearing assessments and testing was carried out in the Department's sound-damped audiometric laboratory, where the ambient noise level is well below Cox's maxima for all frequencies.

A report on the results of this investigation was submitted to the Management, which included the following: -

Details of noise analyses and hearing assessments.

Recommendations and methods to reduce the noise hazard.

A short account on occupational deafness.

A short account on techniques of audiometry.

An explanatory note on the institution of a hearing conservation programme.

The recommendations were based on the application of only two damage risk criteria, those of Burns & Littler (No. 2) and of the I.S.O. (No. 6) but for the purposes of this present report, the results obtained in Factory C will be assessed in a manner comparable with that used for Factories A and B.

A total of 24 employees were tested, all of whom had been exposed to the noise of the grinding mill. Table 56 below shows the additional noise sources to which some of these employees had been exposed.

TABLE 56

<table>
<tr><td>Grinding Mill</td><td colspan="2">Additional noise sources to which some of these 24 employees were exposed.</td><td>Number of employees with no history of additional noise exposure.</td></tr>
<tr><td rowspan="3">24 employees exposed</td><td>Noise source</td><td>No.employees</td><td rowspan="3">8</td></tr>
<tr><td>Ring drier</td><td>5</td></tr>
<tr><td>Multiple noise exposure</td><td>11</td></tr>
</table>

The eleven employees with multiple noise exposure had either worked in several departments of Factory C where a high noise level exists, or had previously been employed in a noisy occupation. Noise measurements were therefore made in the following departments, to include the noise sources relevant to the investigation, in addition to the Grinding Mills.

Department 1. Grinding Mill (a)

Rotary Vacuum Filter

Ring Drier

Department 2. Grinding Mill (b)

Department 3. General Purpose Gantry

Since all 24 employees had a common source of noise exposure, the Grinding Mills, the noise analyses of the mills and the hearing assessments will be considered first, although the two mills are situated in different departments.

Grinding Mills (a) and (b)

Several noise analyses were made and the results of these are given in Table 57 below.

Two grinding mills (a) and (b) below) are in operation in separate departments, and the noise analyses of these differ considerably. Mill (a) has a sieving device, the screen, attached to it and this intensifies the noise level. The second mill (b) is normally operated without a screen.

TABLE 57

NOISE SOURCE

Centre frequency of octave band c/s	Mill(a) Department 1			Mill(b) Depart. 2
	With screen operator's position	With screen at base of steps.	General back-ground noise. Mill not operating	Without screen operator's position.
	S.P.L.dB	S.P.L.dB	S.P.L. dB	S.P.L.dB
31.5	63 - 66	72 - 76	76 - 78	85 - 87
63	67 - 69	67 - 71	73 - 76	86 - 90
125	93 - 94	97	74 - 76	90 - 93
250	94	93 - 94	73	94
500	101	86 - 88	79 - 80	96 - 97
1 K	100	93	76 - 78	101 - 102
2 K	102	89 - 91	73	102
4 K	104 - 108	96	71	103

TABLE 57 contd.

	S.P.L.dB	S.P.L.dB	S.P.L.dB	S.P.L.dB	
8K 16K 31.5K	101 - 105 100 - 105 89 - 90	98 - 100 92 - 95 78	64 53 30	97 - 98 90 75 - 76	
Linear	111	103	85	108	

Access to the mill is gained from a small platform at the top of a short flight of steps. Measurements were taken from this platform, which is the position of the employee while operating the mill, and also from a point at the base of the steps.

Table 58 below shows the distribution of hearing loss found among the 24 employees.

TABLE 58

A Hearing within the normal limits specified by Hinchcliffe's presbycusis data.		B Hearing loss attributable to noise exposure. i)No previous history of noise expos.		ii)History of exposure to more than one environmental noise.		C Hearing loss attributable to a multiplicity of factors including noise exposure.
Subject	Exposure time	Subj.	Expos. time	Subj.	Expos. time (present noise only)	
C.H3	Very occasional exposure	C.L1	Occasional expos.			C.M1
C.A1	3 months of occasional exposure	C.S2 C.C2 C.W3	2 wks 3 mths 6 mths	C.C1 C.Z1 C.F1	1 day 2 days 2 weeks	C.W4 C.P1 C.R1
C.R2	occasional exposure	C.B1	3 yrs	C.W2	Occasional exposure	
C.H1 C.01	3 weeks 3 months			C.A2 C.A3	" "	

TABLE 58 contd.

Subject	Exposure time	Subject	Exposure time	Subject	Exposure time	
C.B2	4 mnths			C.H2	6 months inter-mittent exposure	
C.W1	6 mnths			C.S1	7 months inter-mittent exposure	
7 subjects		5 subjects		8 subjects		4 subj.

It was not possible to assess the exact duration of exposure for most employees since the mills are not in constant use, and several subjects have operated a mill for short periods, two to three hours at intervals of days or even weeks. These have been termed 'occasional' exposures. Where an employee has only operated the mill for a few hours each day, over a period of several weeks, the term 'intermittent exposure' has been used. Elsewhere, exposure in terms of days or weeks refers to continual, 8 hours per day, exposure.

The audiograms of the 13 subjects in Group B of Table 58 are reproduced on pages 174 to 176.

It may be seen from table 58 that there is no clear relationship between duration of exposure to noiseand the incidence of deafness. With the exception of subject C.B1, with an exposure time of three years the exposure times of the subjects with normal hearing are comparable with those of the subjects with noise-induced hearing loss. This finding has been apparent throughout all the industrial investigations of this report and would appear to be dependent upon individual susceptibility to noise trauma.

One of the problems which urgently requires further investigation is that of the relationship between temporary threshold shift and permanent trauma. If a definite relationship could be established, all employees could be screened before entering a noisy environment and adequate precautions taken to protect the hearing of the noise-susceptible population.

The analyses of the additional noise sources, where these occur within Factory C, to which subjects in column B(ii) of Table 58 have been exposed, are given below.

Department 1

Grinding Mill (a) - see page 162
Rotary Vacuum Filter
Ring Drier

TABLE 59

NOISE ANALYSES

	NOISE SOURCE	
Centre frequency of octave band c/s	Rotary Vacuum Filter. Operator's position.	Ring Drier Operator's position.
	S.P.L. dB	S.P.L. dB
31.5	78 - 80	70 - 73
63	80 - 82	76 - 78
125	82 - 83	87 - 88
250	86 - 87	84 - 85
500	85	95 - 96
1 K	87 ± 0.5	99 - 100
2K	82 - 83	95 - 96
4 K	81	94
8 K	73 - 74	88
16K	60	76 - 77
31.5K	35	63 - 64
Linear	92 - 93	102 - 103

Department 2.

Grinding Mill (b) see page 162 .

Department 3.

General purpose gantry.

TABLE 60

Noise Analysis

Centre frequency of octave band c/s	Sound level dB
31.5	73 - 78
63	69 - 70
125	72 - 75
250	73 - 76
500	78 - 79
1 K	78 ± 0.5
2 K	74 - 76
4 K	68 - 69
8 K	60 - 61
16K	48
31.5K	26
Linear	84 - 85

Summary of results in Factory C

Five of the twenty-four subjects tested have hearing losses which are directly attributable to exposure to the noise of the Grinding Mills. A further eight subjects have noise-induced hearing losses of which the mill noise may be the sole cause, or a contributory factor.

In column C, Table 58, page 163, subject C.M1 has a very slight bilateral hearing loss with a history of multiple noise exposure and bilateral middle ear infection. Subject C.W4 has a slight bilateral hearing loss with a typical 4K c/s notch in the left ear. Possible causative factors are multiple noise exposure, excessive secretion of wax and middle ear infection. Subject C.P1 has a severe bilateral, high frequency deafness. There is a history of bilateral scarring of the ear drums, with intermittent discharge and exposure to heavy artillary noise during the war.

Subject C.R1 spent 6 years operating mills in a brick yard in addition to 2 years with the grinding mill. A moderate conductive deafness in the right ear appears to be caused by excessive wax.

The results of these hearing assessments are summarised in Table 61, below.

TABLE 61

No. of cases of loss attributable to noise exposure.		No. of cases of hearing loss attributable to multiplicity of causes.	No. of cases of normal hearing.	Total No. of subjects examined
Single source of expos.- Grinding Mill	Multiple noise exposure - Grinding Mill + other sources			
5 subj.	8 subjects	4 subjects	7 subjects	24 subj.

Table 62 below shows the damage risk criteria (page 88) which do not give protection against the various noise environments examined in Factory C. Since only subjects who had been exposed to the Grinding Mill noise were tested, it is not possible to assess the ratio of cases of deafness to total subjects tested, as was done in other factories, for the additional noise sources. This ratio, for exposure to the Grinding Mills (a) and (b) combined, is 5 to 24.

TABLE 62

Damage Risk Criteria	Sources of Noise Unprotected
1. U.S.A.F.	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.3 - General Purpose Gantry
2. Burns & Littler	All noise sources are in excess of this criterion.
3. Burns & Littler	Dept.No.3 - General Purpose Gantry
4. B.M.A.	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.3 - General Purpose Gantry
5. Hardy	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.1 - Rotary Vacuum Filter Dept.No.3 - General Purpose Gantry
6. I.S.O. 85	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No. 3- General Purpose Gantry
7. Glorig	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.3 - General Purpose Gantry
8. Plomp	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.3 - General Purpose Gantry
9. Beranek - continuous spectrum noise.	Dept. No.1 - General background noise - Mill (a) not operating. Dept.No.3 - General Purpose Gantry
10. Beranek - noise containing pure tones.	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.3 - General Purpose Gantry
11. Rosenblith - continuous spectrum.	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.1 - Rotary Vacuum Filter Dept.No.3 - General Purpose Gantry
12. Rosenblith - noise containing pure tones.	Dept.No.1 - General background noise - Mill (a) not operating. Dept.No.3 - General Purpose Gantry

It will be seen that application of any one of these criteria would give protection against the noise emitted by the two Grinding Mills and Ring Drier. The noise of the Rotary Vacuum Filter is in excess of most criteria. The criterion of Burns and Littler (No. 3) classes all the noise sources measured in Factory C as hazardous.

The noise analyses data are shown graphically below. on pages 172 & 173.

In the author's report to the Management, recommendations based on the application of the Burns and Littler (No. 3) and I.S.O. 85 (No. 6), were made that employees exposed to the following noise sources should be protected.

Department 1. Grinding Mill (a)
Rotary Vacuum Filter
Ring Drier

Department 2. Grinding Mill (b)

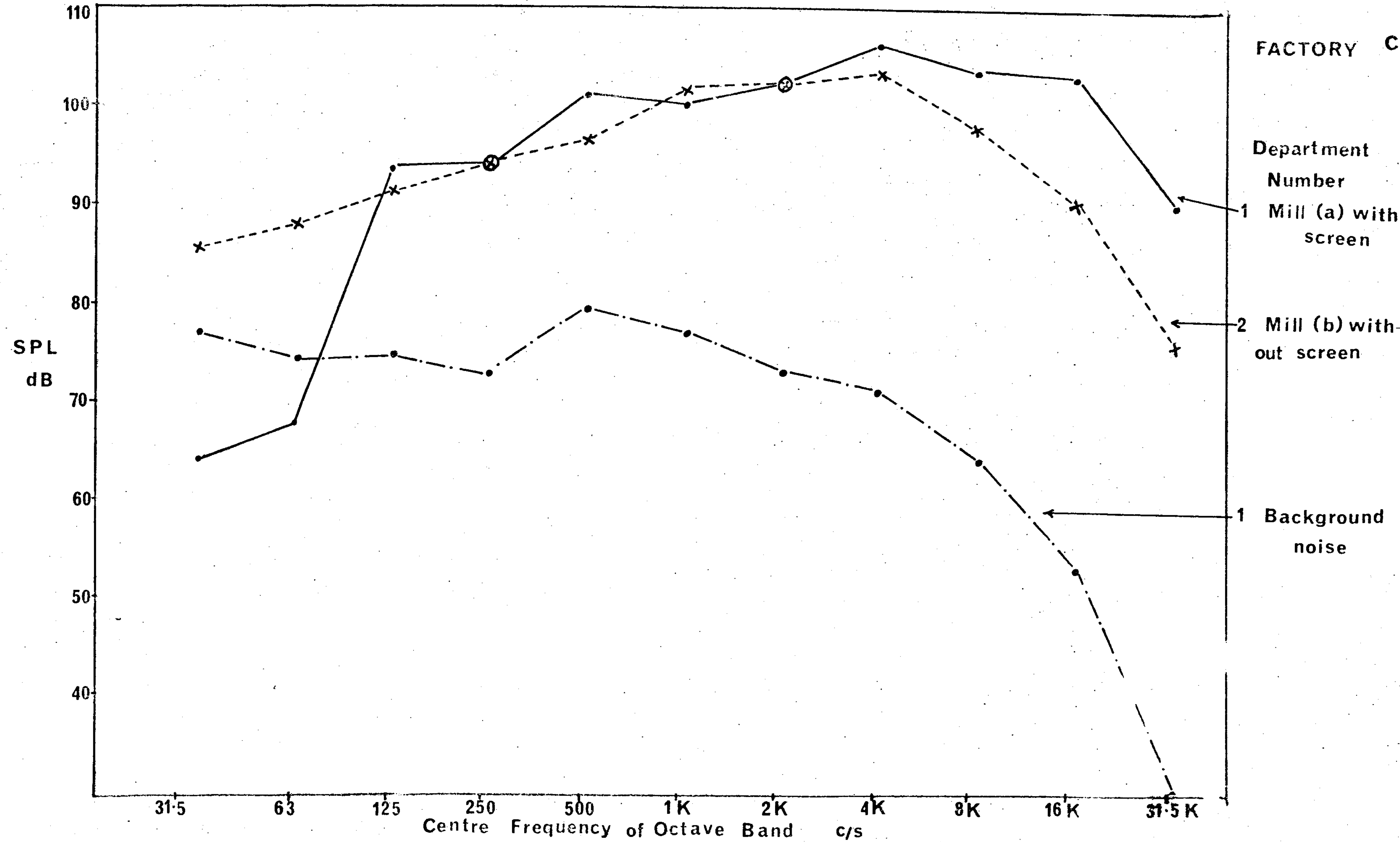
It was suggested that protection should be effected either by reduction of the noise at source or by the institution of a hearing conservation programme.

Table 63 gives a general picture of the various noise sources measured in Factory C, and in the case of the Grinding Mills, of the distribution of hearing loss among the employees.

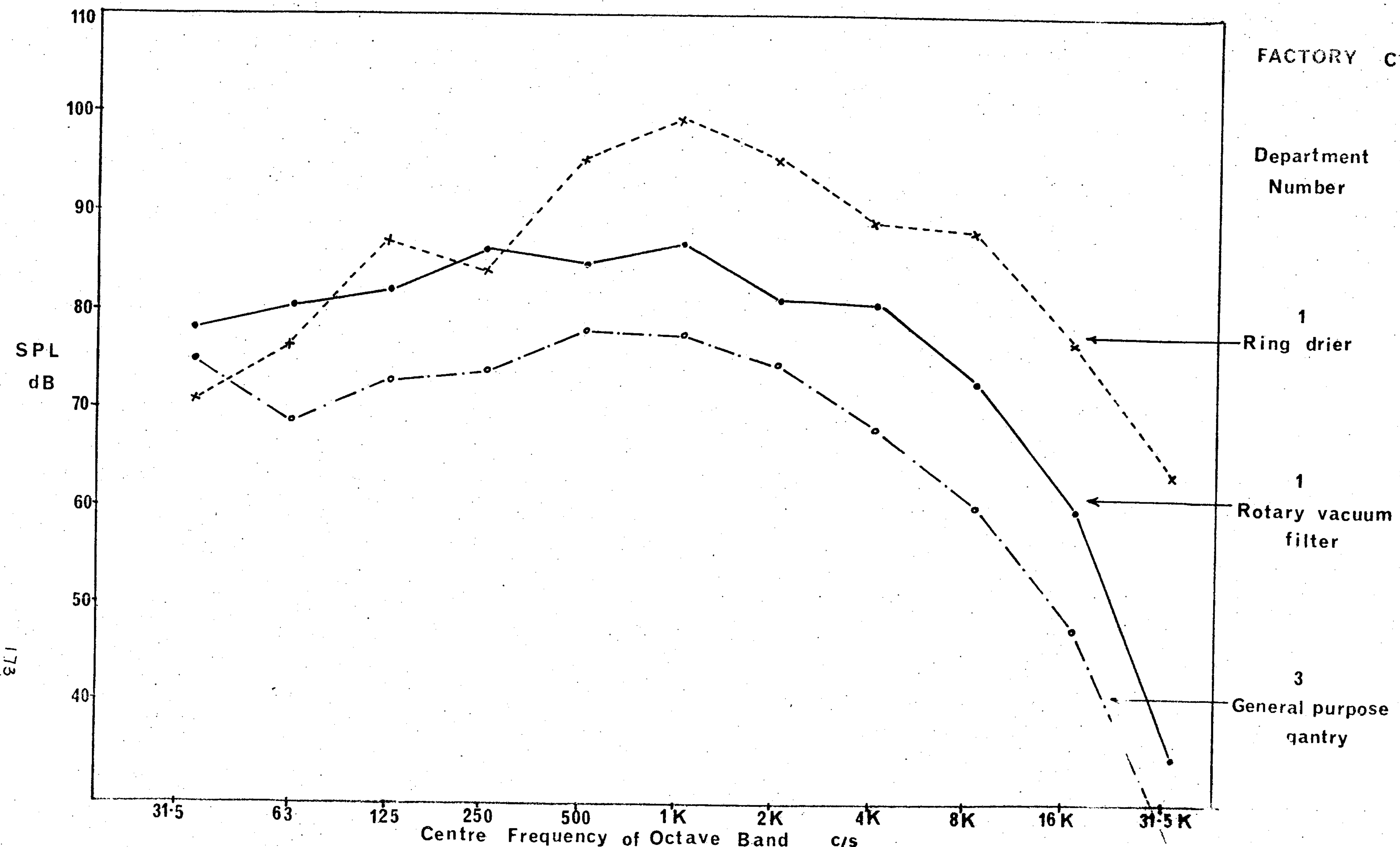
TABLE 63

Dept.& noise source	Overall S.P.L. dB	Shape of spectrum	Total No. subjects	Total cases deafness	Cases attributable to present noise alone	Cases of noise expos. & other factors.	Normal hearing
1.Rotary Vacuum Filter	92-93	Peaks at 250c/s & 1Kc/s					
1.Ring Drier	102-103	Concentration of energy between 250c/s & 4Kc/s with peak at 1Kc/s					
1.Grinding Mill(a)	111	Peaks at 500 c/s & 4Kc/s	24	17	5	4	7
2.Grinding Mill (b)	108	Energy decreases beyond 4Kc/s					
3.General Purpose Gantry	84-85	No sharp peaks. Intensity decreases with increasing frequency.					

Two factors which preclude the comparison of these results with those of factories A and B are the unsimilarity of the noise spectra and the wide variation in duration of exposure of employees to the Grinding Mills. The noise levels of the mills are well in excess of any measurements made in the previous factories. Duration of exposure which was fairly consistent during an eight-hour day in Factories A and B, varied here from one day to three years continual exposure, with many cases of intermittent and occasional exposure. However, it is interesting to note that among the 5 employees who have a deafness directly attributable to the Mills, very short duration exposure of a few weeks or months was sufficient to cause permanent deafness. In all these cases, sufficient time had elapsed since the last exposure prior to testing to eliminate the effects of any temporary threshold shift.


FACTORY C
110
100
90
80
70
60
50
40
SPL
dB
31·5
63
125
250
500
1 K
2 K
4 K
8 K
16 K
31·5 K
Centre Frequency of Octave Band c/s
Department Number
1 Mill (a) with screen
2 Mill (b) without screen
1 Background noise

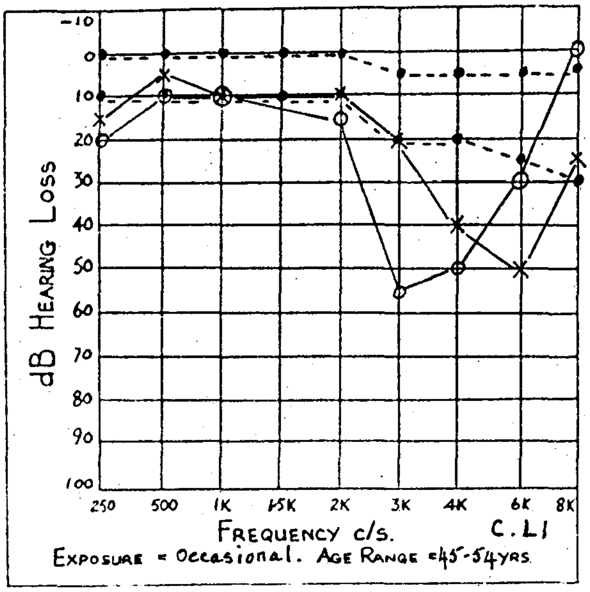
172

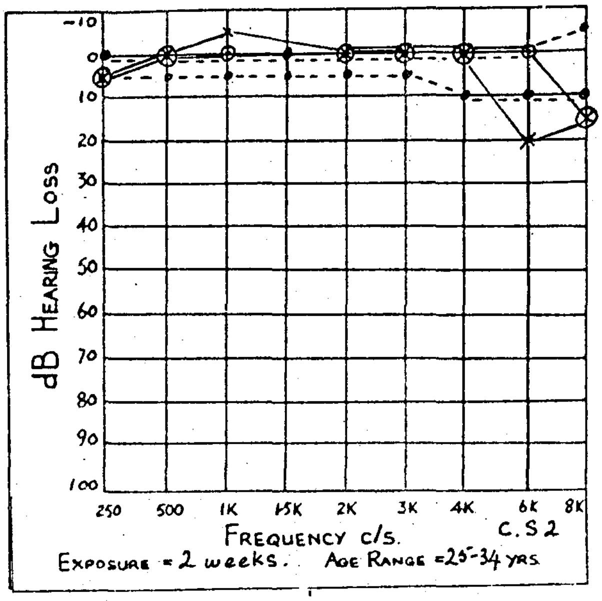


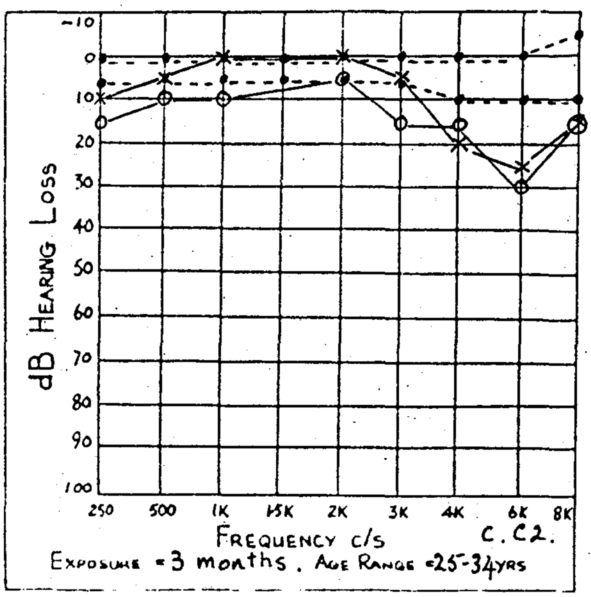
110
100
90
80
70
60
50
40
SPL
dB
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5 K
Centre Frequency of Octave Band c/s
FACTORY C
Department
Number
1
Ring drier
1
Rotary vacuum
filter
3
General purpose
gantry

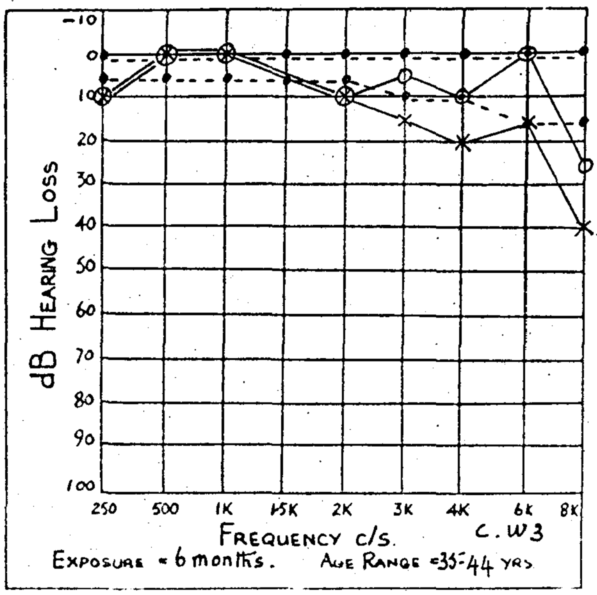
173

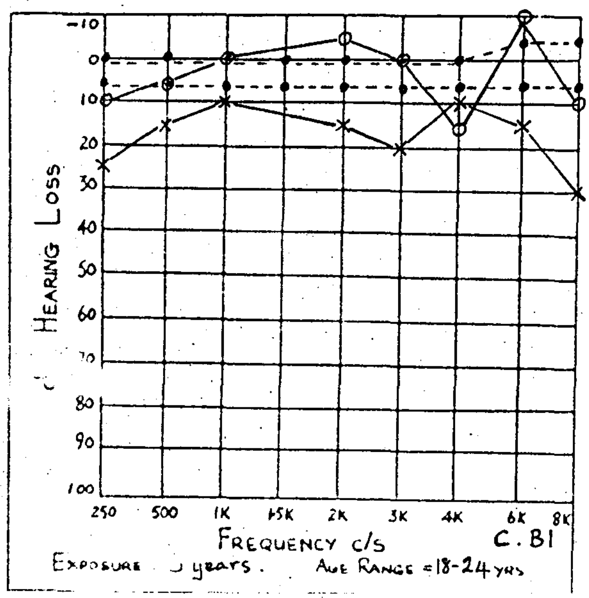
Audiograms of subjects in Section B(i) of Table 58, page 163-164.

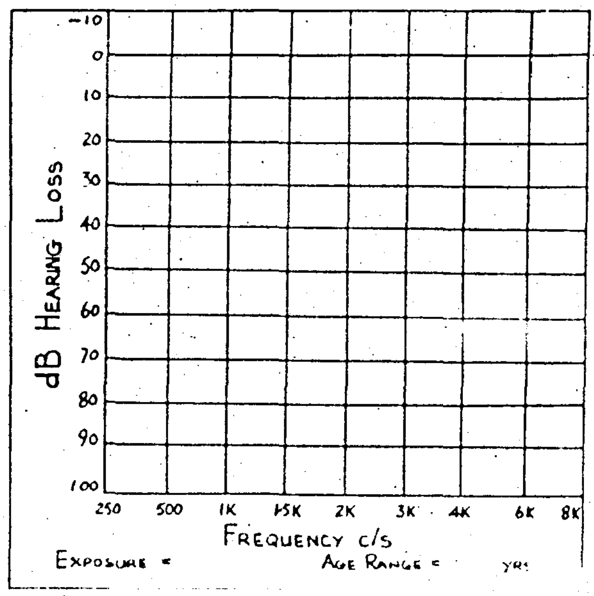












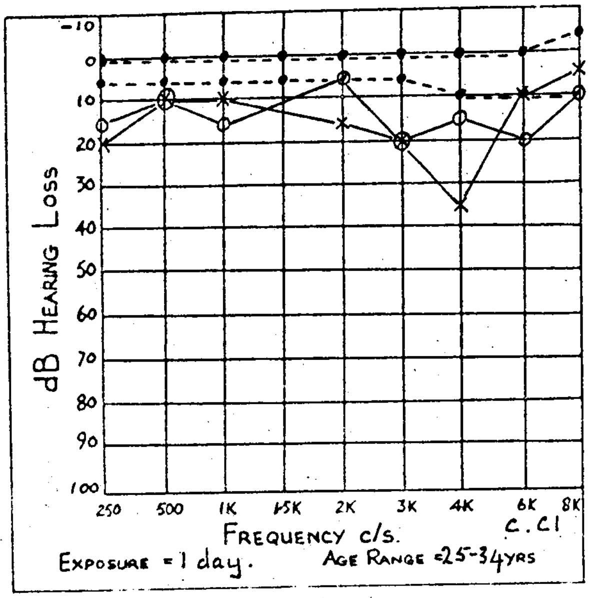
Key:

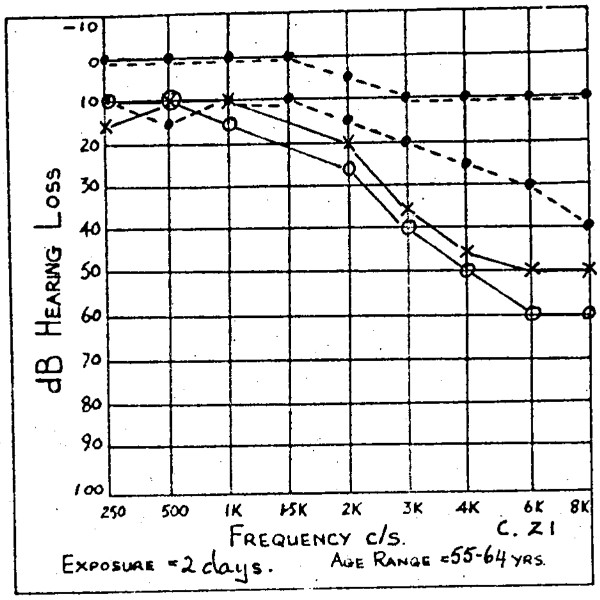
Air conduction o—o = right ear. x—x = left ear.

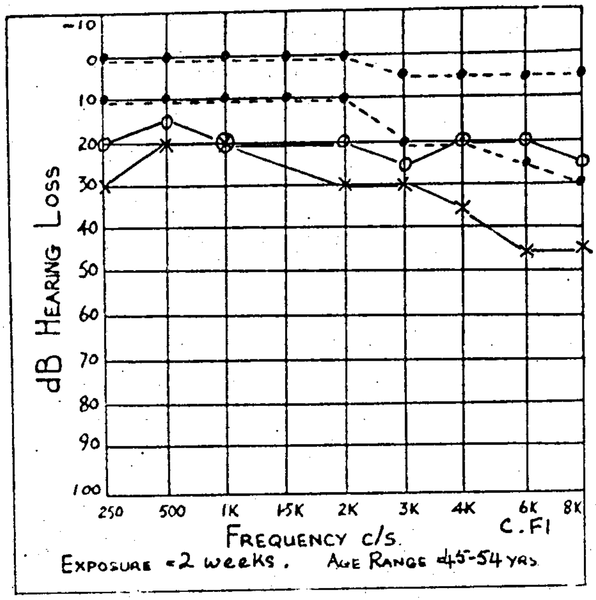
Age range •-----• limits of 25 th and

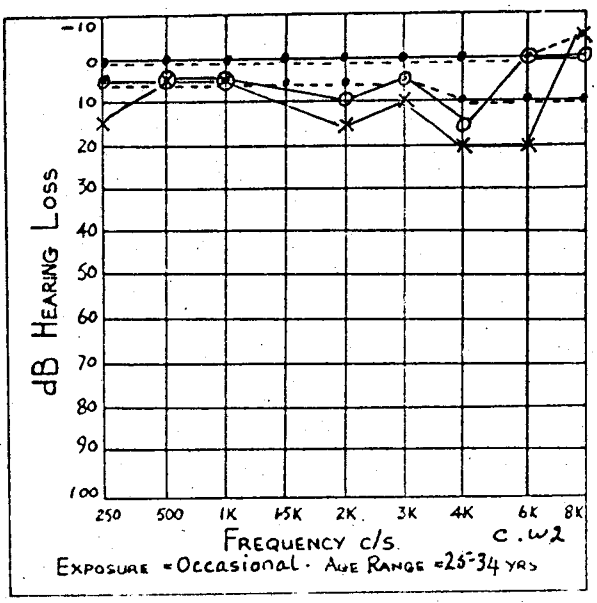
•-----• 75 th percentile. (Hinchcliffe's data)

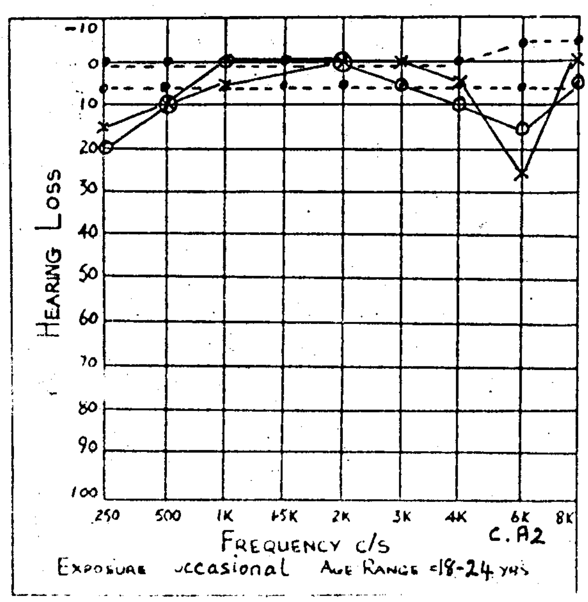
Audiograms of subjects in Section B(ii) of Table 58, page 163-164.

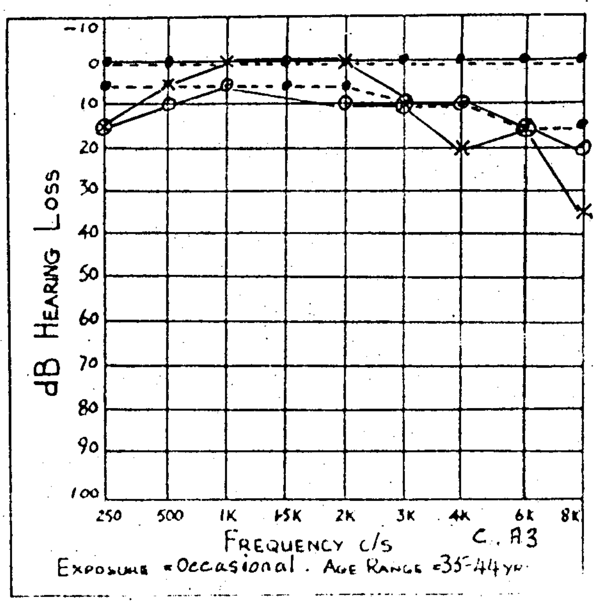












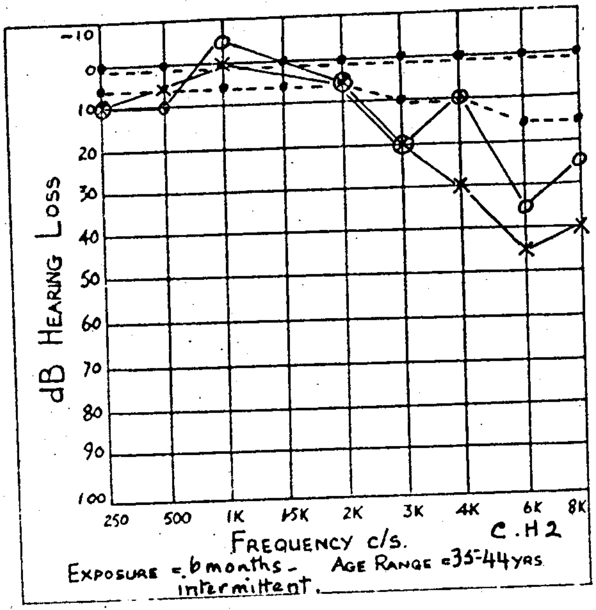
Key

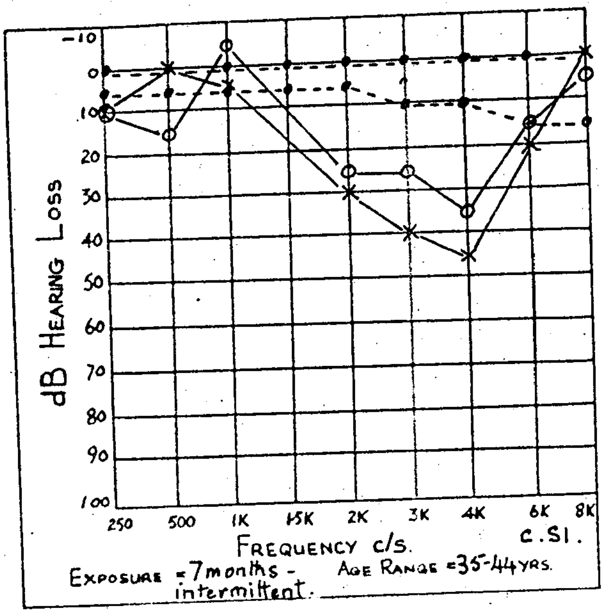
Air conduction o—o = right ear. x—x = left ear.

Age range •-----• limits of 25 th and

•-----• 75 th percentile. (Hinchcliffe's data)

Audiograms of subjects in Section B(ii) of Table 58, pages 163-164 (continued)





Key

Air conduction — o—o = right ear. x—x = left ear.

Age range — •-----• limits of 25 th and 75 th percentile. (Hinchcliffe's data)

The data obtained from investigations into the noise levels of the remaining five factories in this survey consist of noise analyses only. Although the lack of hearing data excludes the results from these factories from the final assessment of the effect of factory noise on hearing, a review of these noise sources gives a further indication of the high level environmental noise which exists in many factories where employees are unprotected.

FACTORY D - Furniture manufacturing

Noise analyses were made in an open plan department where manufacturing processes were carried on at one end and assembly work at the other end. The results are given in Appendix 1. It may be seen from these results that all noise sources measured are in excess of the Burns and Littler damage risk criterion.

FACTORY E - Pharmaceutical manufacturing

A large number of noise meaaurements were made in this factory and eleven of these have been selected to represent those most likely to constitute a hazard to hearing.

Noise analyses graphs of the following processes are given in Appendix 1, for comparison with the damage risk criterion transparencies.

1. Powder packaging.
2. Bottle filling (1)
3. Bottle Filling (2)
4. Pill manufacturing - pressing machines
5. Pill manufacturing - sugar coating drums
6. Powder manufacturing - vibrating sieve
7. Ointment packaging - filling machine
8. Tablet manufacturing - pressing machines
9. Powder manufacturing - tablet presses
   vibrating sieve
   mixer.
10. Tablet manufacturing - 3 sugar coating drums
11. Main tablet manufacturing department

FACTORY F. Pharmaceutical manufacturing

Noise measurements were made in five departments, as follows:-

Department 1 Antibiotics factory

(a) Vacuum filter
(b) Biozan extractor
(c) Diesel compressors
(d) Fermentors

Department 2 Insulin Manufacturing

Scott-Rietz Disintegrator

Department 3 Kiln room

Department 4 Soap manufacturing

(a) Soap cruster feeder
(b) Stripper

Department 5 Medical confectionery manufacturing

(a) Barley sugar stick machine
(b) Cutting Machine

The noise analysis data are reproduced graphically in Appendix 1. It may be seen that some criteria afford protection against these environmental noise levels, but that the criterion of Burns and Littler is exceeded in all departments

FACTORY G. Elastic webbing manufacturing

Noise measurements were made in the following departments.

Department 1 Winding and weaving.

(a) Winding machines
(b) Looms, large machines weaving many small strips of webbing.

Department 2 Weaving

(a) Northrop looms. Small machines, weaving single strip of wide fabric.

Department 3 Winding

Department 4 Rubber covering

Department 5 Inspection room

Department 6 Dying room

The noise analyses from these departments are reproduced in Appendix 1. Comparison of these graphs with the damage risk criteria transparencies shows that many noise levels in this factory are in excess of the various criteria.

FACTORY H. Pharmaceutical manufacturing

Noise analyses were made of the following machines: -

Sugar coating drum
Vibrating sieve
Comminuting Mill

These results are given in Appendix 1 and it may be seen that all excede the damage risk criteria.

CONCLUSIONS

The review of published work and the investigation into factory noise will be considered separately.

Review of the literature

A study of the literature, relating to both laboratory and field investigations, has revealed several facts which may contribute towards a fuller understanding of the effects of industrial noise on hearing.

The effect which a stimulus has on hearing acuity, when considered as a function of the stimulus intensity, falls into one of three distinct groups, as follows: -

a)	Adaptation	:Adaptation occurs to some extent at all levels of stimulus intensity.
b)	Fatigue	:Stimulus intensities greater than 80 dB give rise to fatigue.
c)	Trauma	:At some intensity level yet to be determined, permanent threshold shift occurs.

Unfortunately, there is no direct evidence to relate fatigue, as measured by temporary threshold shift, with permanent hearing loss. It appears that maximum temporary threshold shift occurs during the first three months of exposure to noise (see page 57) and some investigators believe that there is a critical combination of noise intensity and exposure time which determines whether loss of acuity will be temporary or permanent.

In addition to intensity and duration of exposure, there are other factors, involving the frequency characteristics of the stimulus, which influence the loss in acuity due to stimulation.

These have been considered in some detail in this report and will be only briefly summarised here.

The results of the investigation carried out by Wright (see page 34) suggest that the fatigue caused by pure tone stimuli and by complex stimuli is determined by different mechanisms. Complex stimulation causes the greatest fatigue for 4 Kc/s while the fatigue resulting from pure tone stimulation is closely related to the stimulus frequency.

Further evidence of a dual mechanism appears in the work of Carterette (see page 46) who showed that fatigue is independent of bandwidth when the stimulus is complex. If pure tone and complex sound fatigue are caused by the same mechanism, it would be expected that there would be an increase in fatigue as the stimulus bandwidth is increased from pure tone to complex tone. However, it was found that a pure tone caused a greater degree of fatigue than any combination of tones, from narrow band to white noise.

Fatigue in Carterette's experiments, was measured as a loss in loudness function, for stimulus intensities of up to 90 dB. Ward's investigations (see page 84) however, measuring reduction in acuity, show that fatigue is independent of bandwidth, over the range of pure tones to octave band for stimulus intensities of up to 115 dB. Above this level, a pure tone was found to cause greater temporary threshold shift than an octave band centering on the pure tone frequency.

It appears from this evidence, not only that a dual mechanism may exist, but that its effect upon the absolute threshold, as measured by temporary threshold shift and upon loudness perception are initiated at different levels of stimulus intensity.

Wright also found that when a pure tone is added to a complex stimulus, the resultant fatigue is greater than would be predicted from knowledge of the fatigue caused by the two stimuli operating separately. This facilitation effect applies to 4 K c/s only and the author suggests that this finding may be relevant to the study of industrial hearing loss for the following reason: - Exposure to noise in which the energy is uniformly spread throughout the spectrum has been found to produce a slight permanent threshold shift for all frequencies, unlike the typical hearing loss, with its maximum at 4 K c/s which is so prevalent among industrial personnel.

Since industrial noise invariably contains pure tone components, it may be that the difference in the nature of the threshold shift produced by 'flat' spectrum and by 'peaked' spectrum noise results from the facilitation effect, of noise + tone, which was demonstrated by Wright.

Wright's experiments were measuring loss in loudness function and before one could speculate further on the application of his findings to problems of industrial noise, it would be necessary to determine whether temporary threshold shift is also affected in a similar manner by the addition of a pure tone component to a broad band stimulus.

From the evidence of the experiments of Ward and Carterette, it appears that loss in loudness function and temporary threshold shift may be determined by the same conditions of stimulus spectrum, but the effect appears at different levels of stimulus intensity. That is, any given frequency, or combination of frequencies, may produce a similar affect upon temporary threshold shift as appears in loss of loudness function, but the effect on loudness appears at a lower level of stimulus intensity than that required to initiate a similar effect on threshold shift.

The various damage risk criteria which are reviewed in Section 2C of this report are summarised on page 88 . The differences in the experimental techniques and interpretation of results employed in these investigations is reflected in the wide range of variation in the recommended levels of maximum intensity for hearing conservation. An intensive investigation into the effects of pure tone and complex sound stimulation, carried out under the same experimental conditions is required before it can be determined whether the results of laboratory experiments are applicable to the problems of industrial noise.

A study of environmental noise in factories

The most obvious conclusion to be drawn fromthis small study of environmental noise is that there is a considerable incidence of noise-induced hearing loss in factories where noise has never been considered as a hazard to health. It appears that one of the most urgent problems to be solved in order to reduce this unnecessary impairment of hearing is that of educating both management and employees in the effects of noise and in the methods of noise control.

Table 64 below summarizes the results of the hearing surveys in Factories A, B & C.

TABLE 64

Summary of Results from Factories A, B & C

Total number of subjects examined.	Number of subjects with normal hearing.	Hearing loss attributable to noise exposure.		Hearing loss attributable to noise expos.& other factors
		Single source of exposure	Multiple expos.	
Factory A. 47	14	21	8	4
Factory B. 53	21	23	5	4
Factory C. 24	7	5	8	4
TOTAL 124	42	49	21	12

Total number of cases of noise-induced deafness = 70

56.4% of all employees examined have some degree of noise-induced hearing loss. A further 9.7% have deafness where the contribution of noise exposure is obscured by the presence of other causative factors. Only 33.9% employees have hearing within normal limits.

At the end of each factory survey a table is given which relates the incidence of deafness resulting from a specific noise exposure, to the damage risk criteria which would rate the relevant noise sources as non-hazardous. Table 65 below summarizes this data from each factory, giving an overall picture of the incidence of industrial deafness which might be expected if these damage risk criteria were to be applied.

TABLE 65

Damage risk criteria which would rate the noise environment as non-hazardous.	Total number of cases of deafness, directly attributable to the present noise environment alone, which occur in departments not protected by the relevant Damage Risk Criterion.
1. U.S.A.F.	14
2. Burns & Littler	2
3. Burns & Littler	11
4. B.M.A.	14
5. Hardy	49
6. I.S.O. 85	11
7. Glorig	16
8. Plomp	6
9. Beranek *	44)
10. Beranek	14
11. Rosenblith*	44)
12. Rosenblith	12

* Damage risk criteria numbers 9 and 11 refer to flat spectrum noise only. Application of criteria 10 and 12 gives a more realistic picture of these authors recommendations.

It may be seen that the Burns & Littler criterion, number 2, above, gives the greatest protection from noise. On the basis of the figures obtained in this investigation, application of this criterion should result in the number of cases of occupational deafness, due to a single source of exposure, falling from 49 to 2.

It must be stressed here that, due to the unpredictable nature of individual susceptibility to noise trauma, this estimated improvement in the incidence of deafness can only be approximate.

There will be a few individuals in each factory who would still incur a certain degree of deafness even if the noise level is reduced below the Burns and Littler criterion. This is obvious from the fact that there are two cases of deafness attributable to noise exposure levels which fall below the criterion.

The draft recommendation of the International Standards Organization, Noise Rating Curve 85 (Number 6 in the tables of damage risk criteria) is widely quoted in the literature as an acceptable damage risk criterion. However, it is clearly stated by the International Standards Organization that the noise rating curves with respect to hearing conservation, interference with speech communication and annoyance, are only a tentative estimate and are not intended to be regarded as an International Standard.

The I.S.O. 85 is based on a 'permissible' level of 12 dB deafness for 2 Kc/s for the average population. This means, due to the pattern of the progression of noise-induced deafness, that there will be a considerably larger permanent threshold shift for frequencies higher than 2 Kc/s, but the aim of the I.S.O. 85 curve is to protect hearing for the speech frequencies only. The I.S.O. state that the exact deterioration in hearing which is to be regarded as 'permissible' is one of the factors which has yet to be decided before a damage risk criterion is formulated as a Standard.

The author feels that although hearing loss for frequencies higher than those of the speech range, causes little disability, the aim of a damage risk criterion should be to protect all employees against any loss of hearing which may lead to reduced intelligibility of speech. A 12% loss in hearing for 2Kc/s may only slightly reduce speech intelligibility, but this figure applies to the average of the population and the I.S.O. states that there is considerable deviation from this average. Therefore, application of noise rating curve 85 would result in the majority of the population, exposed to noise levels below curve85, suffering from some degree of social inadequacy which would increase with the addition of presbycusis and some being more seriously handicapped.

It appears that on the limited evidence available the first criterion specified by Burns and Littler should be adopted until our knowledge is increased in the following aspects of the effect of noise on hearing: -

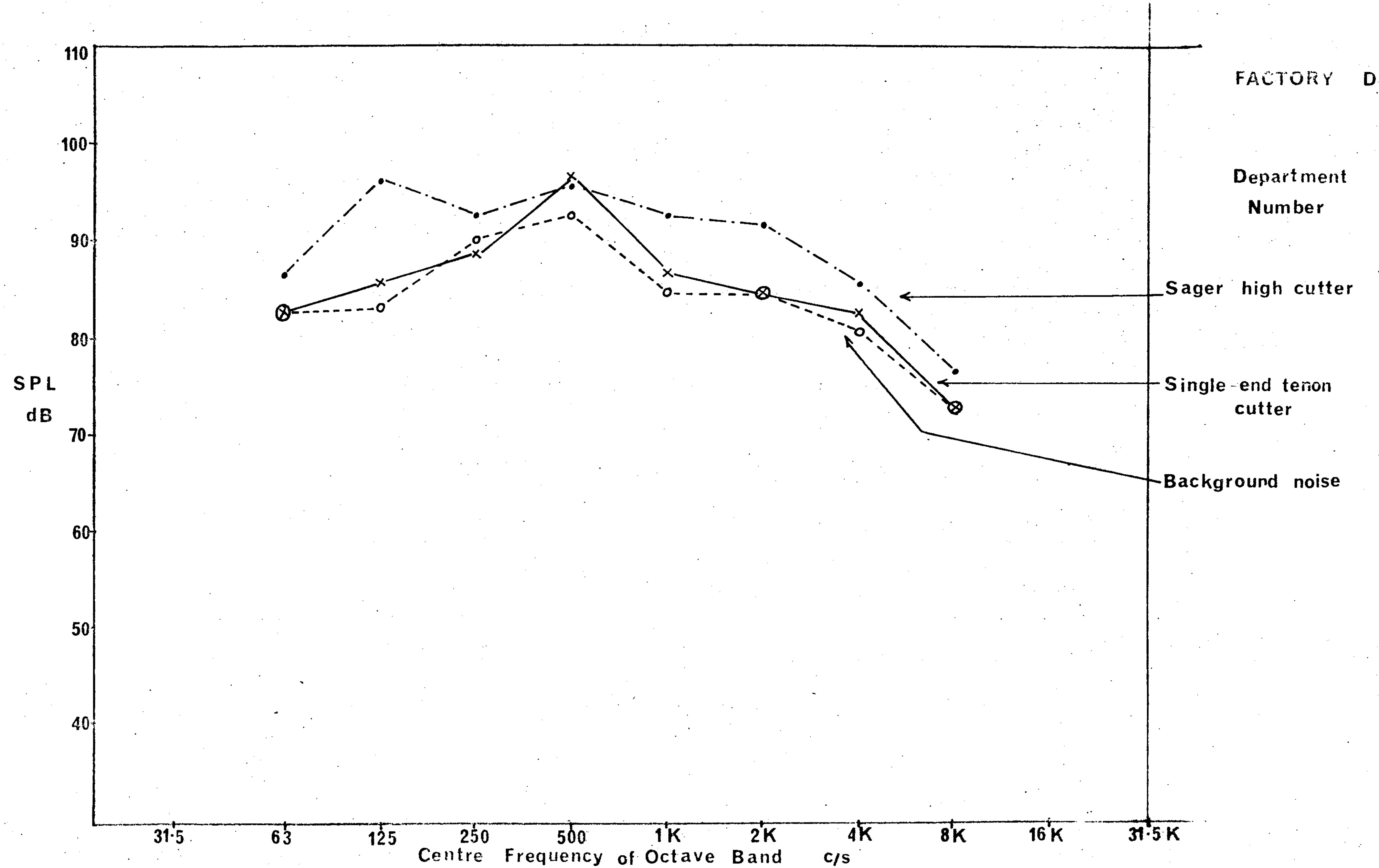
a) Duration of exposure.
b) Distribution of energy throughout the noise spectrum.
c) Relationship between temporary threshold shift and permanent, noise-induced deafness.
d) Individual susceptibility to both temporary and permanent noise-induced threshold shift.

If noise reduction is to be attempted at all in a noisy environment, it is desirable to aim for the maximum possible protection by adopting the Burns and Littler criterion, rather than to apply one of the less stringent criteria and so leave a considerable proportion of the population at risk.

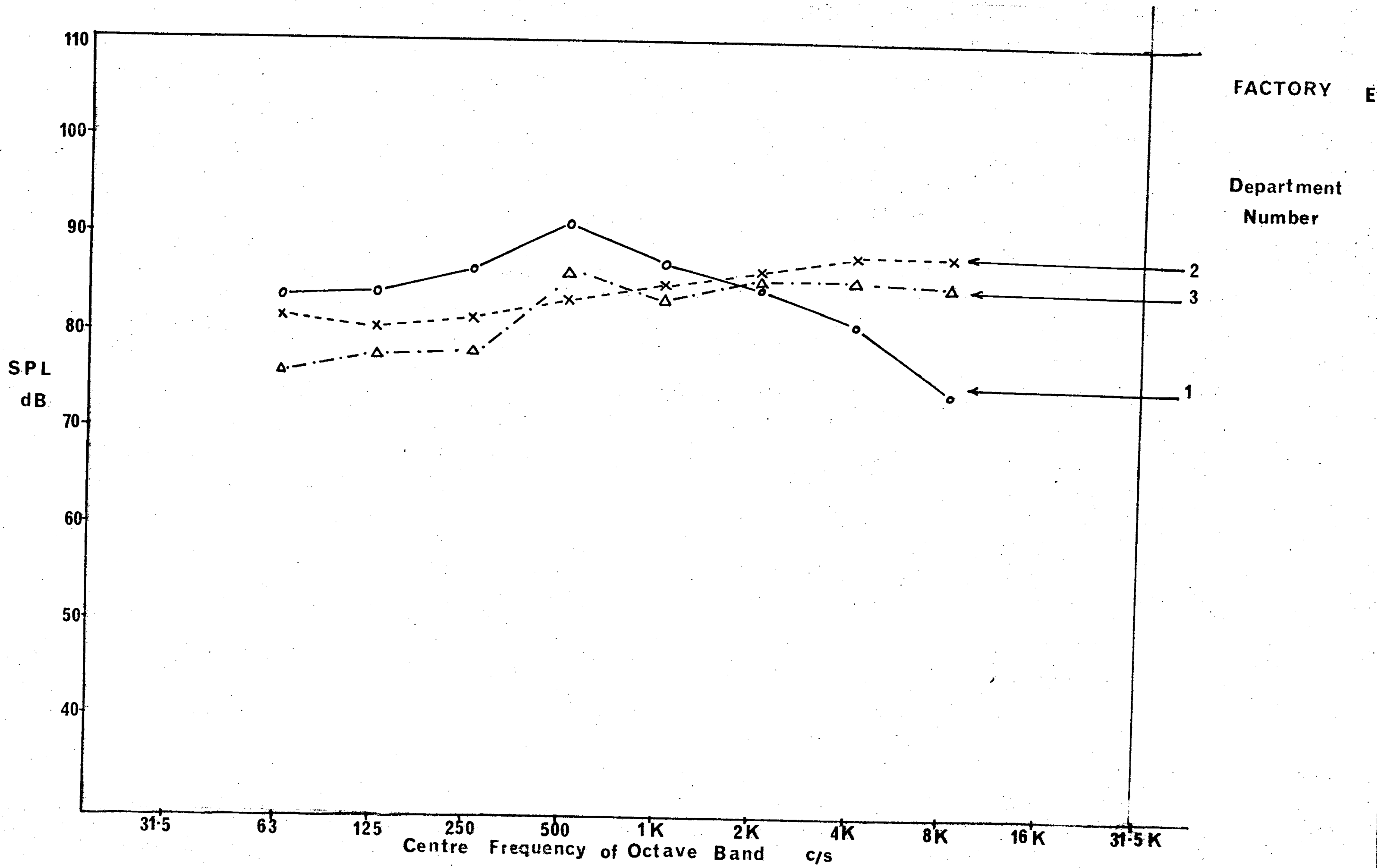
APPENDIX 1

NOISE ANALYSIS DATA

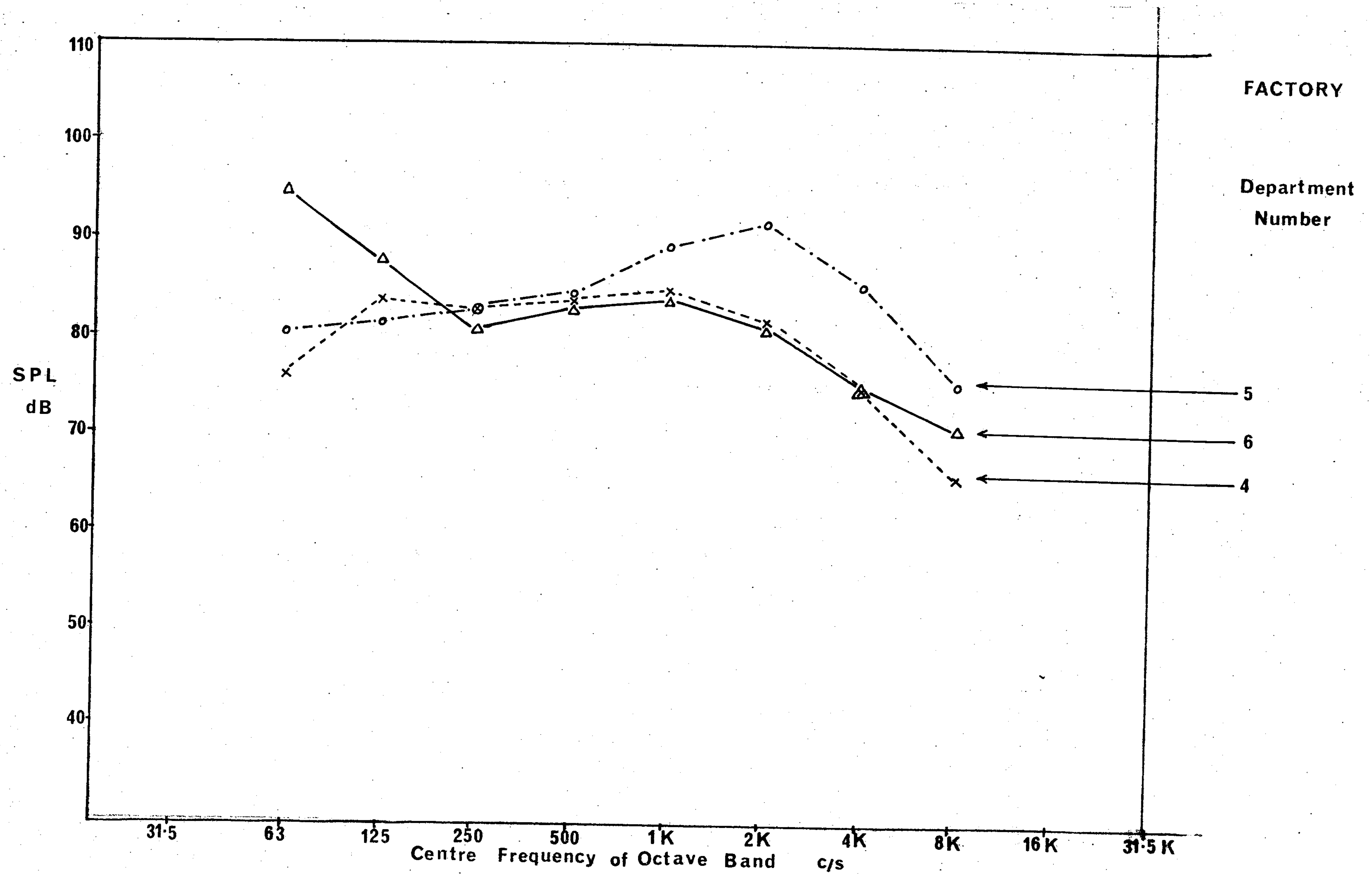
FACTORIES D,E,F,G & H



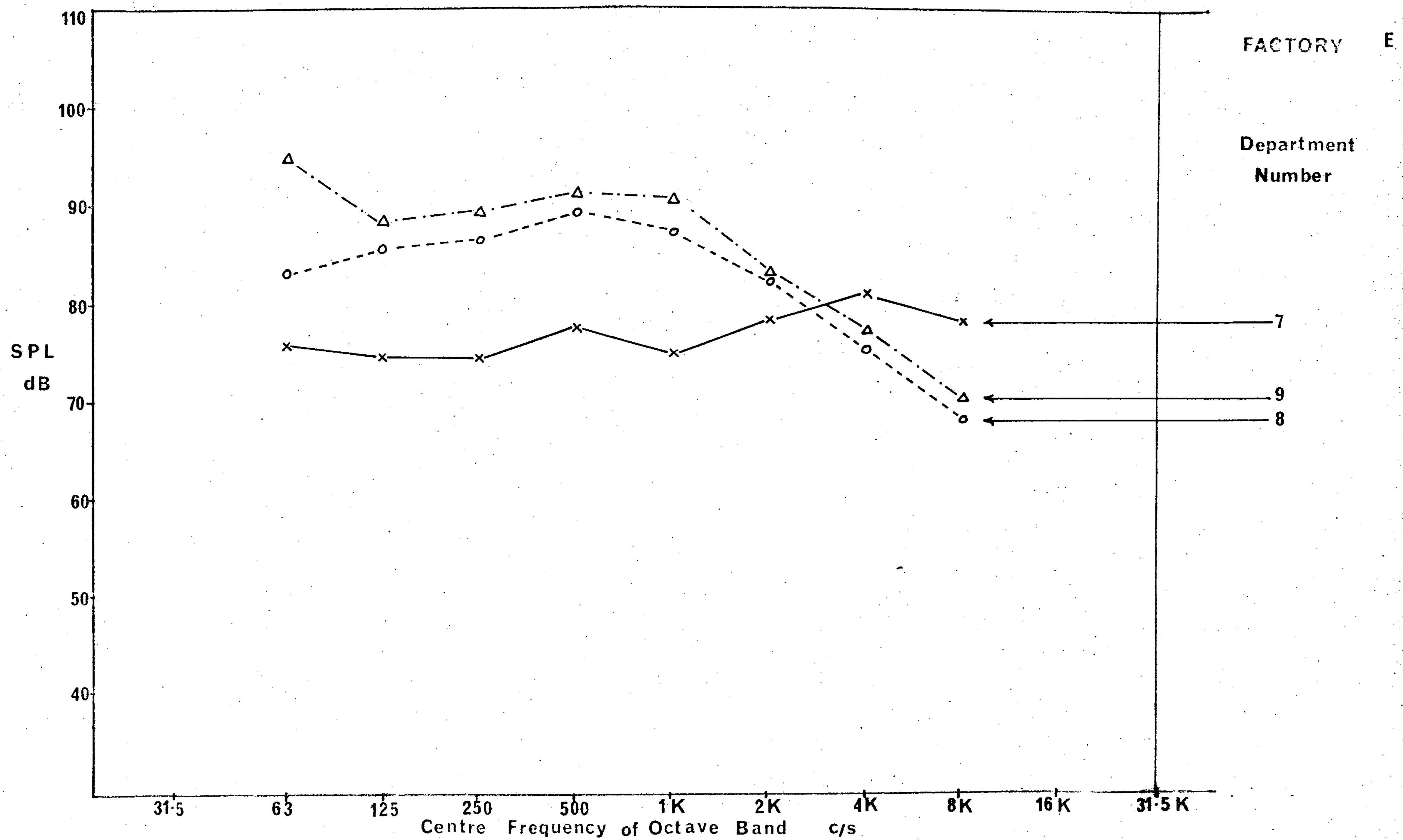
FACTORY D
Department Number
Sager high cutter
Single-end tenon cutter
Background noise
SPL dB
110
100
90
80
70
60
50
40
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5K
Centre Frequency of Octave Band c/s

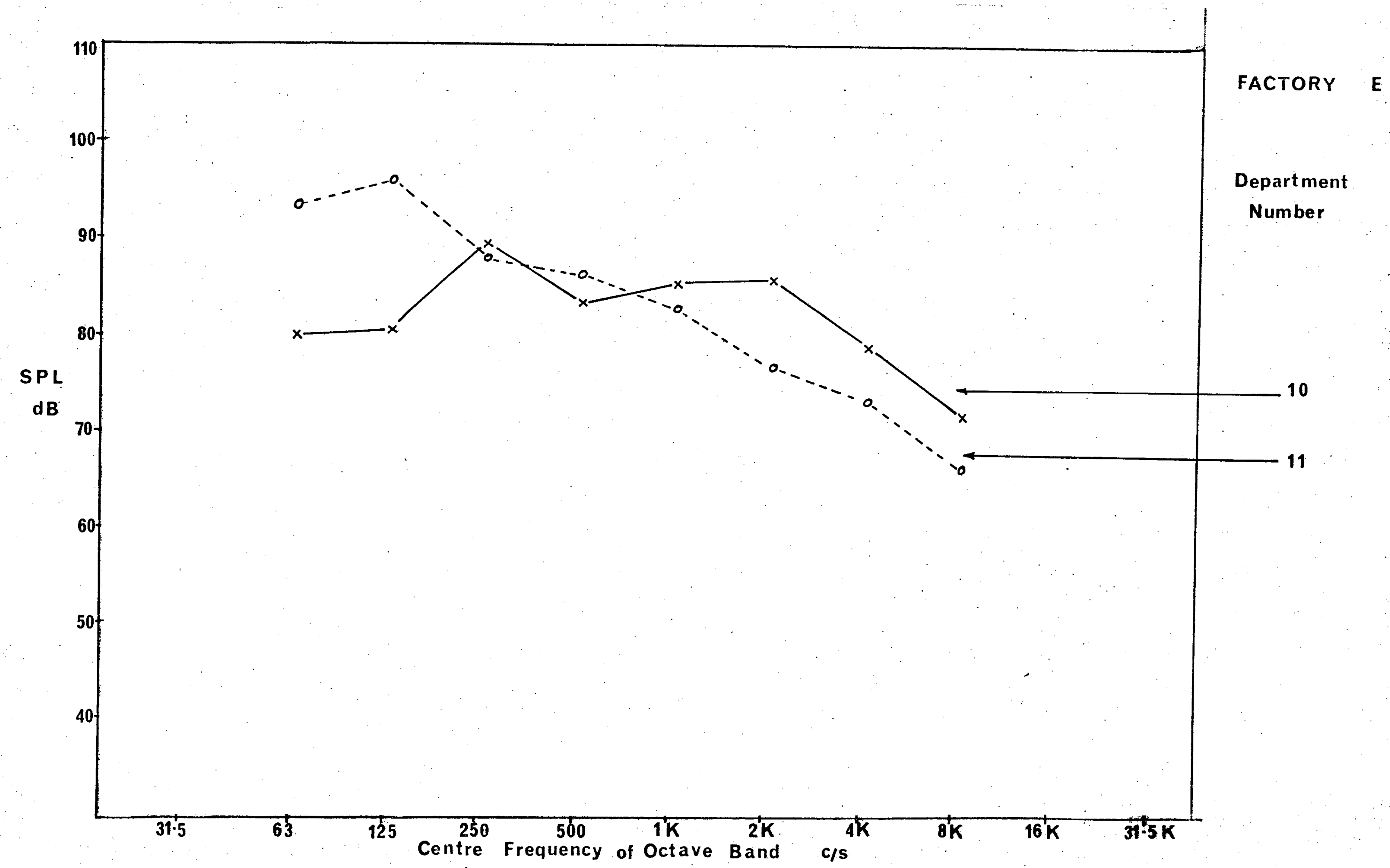


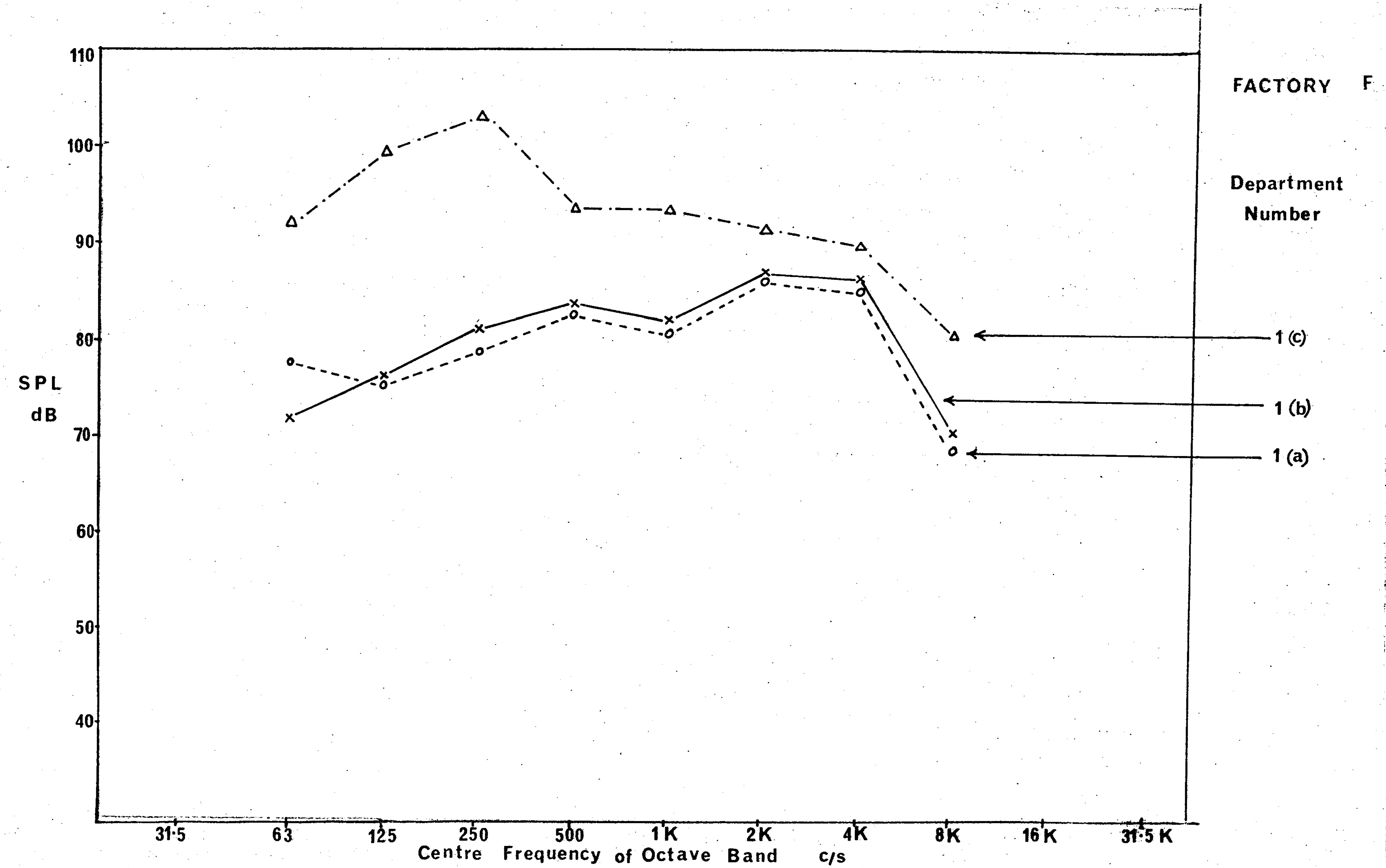
FACTORY E
Department Number
SPL dB
110
100
90
80
70
60
50
40
2
3
1
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5K
Centre Frequency of Octave Band c/s

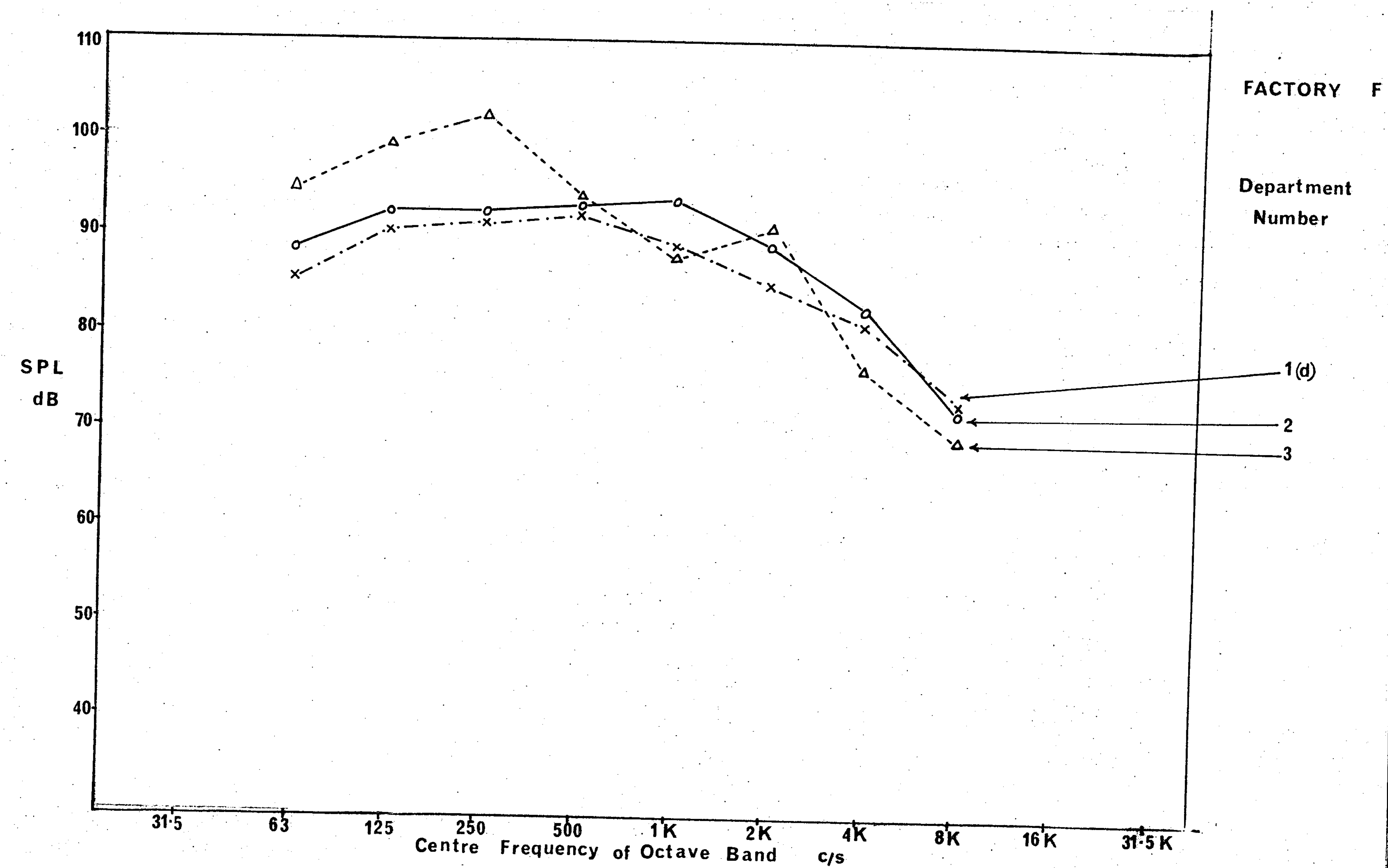


FACTORY E
Department Number
SPL dB
110
100
90
80
70
60
50
40
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5K
Centre Frequency of Octave Band c/s
5
6
4


FACTORY E
Department Number
SPL dB
110
100
90
80
70
60
50
40
7
9
8
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5 K
Centre Frequency of Octave Band c/s


FACTORY E
Department Number
10
11
SPL dB
110
100
90
80
70
60
50
40
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5K
Centre Frequency of Octave Band c/s


110
100
90
80
70
60
50
40
SPL
dB
31·5
63
125
250
500
1K
2K
4K
8K
16K
31·5 K
Centre Frequency of Octave Band c/s
FACTORY F
Department
Number
1 (c)
1 (b)
1 (a)



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Department
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SPL
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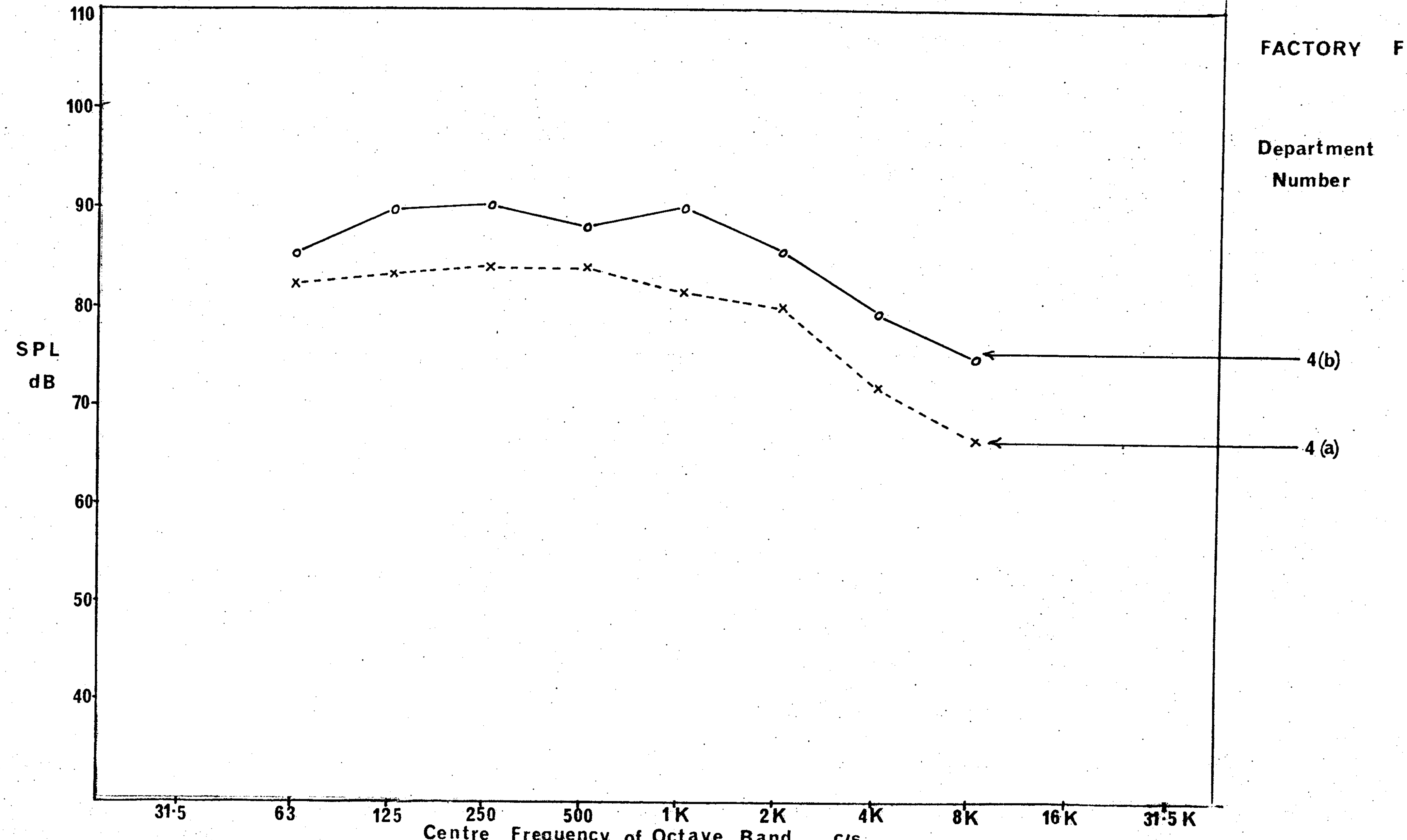
Centre Frequency of Octave Band c/s



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Centre Frequency of Octave Band c/s
4(b)
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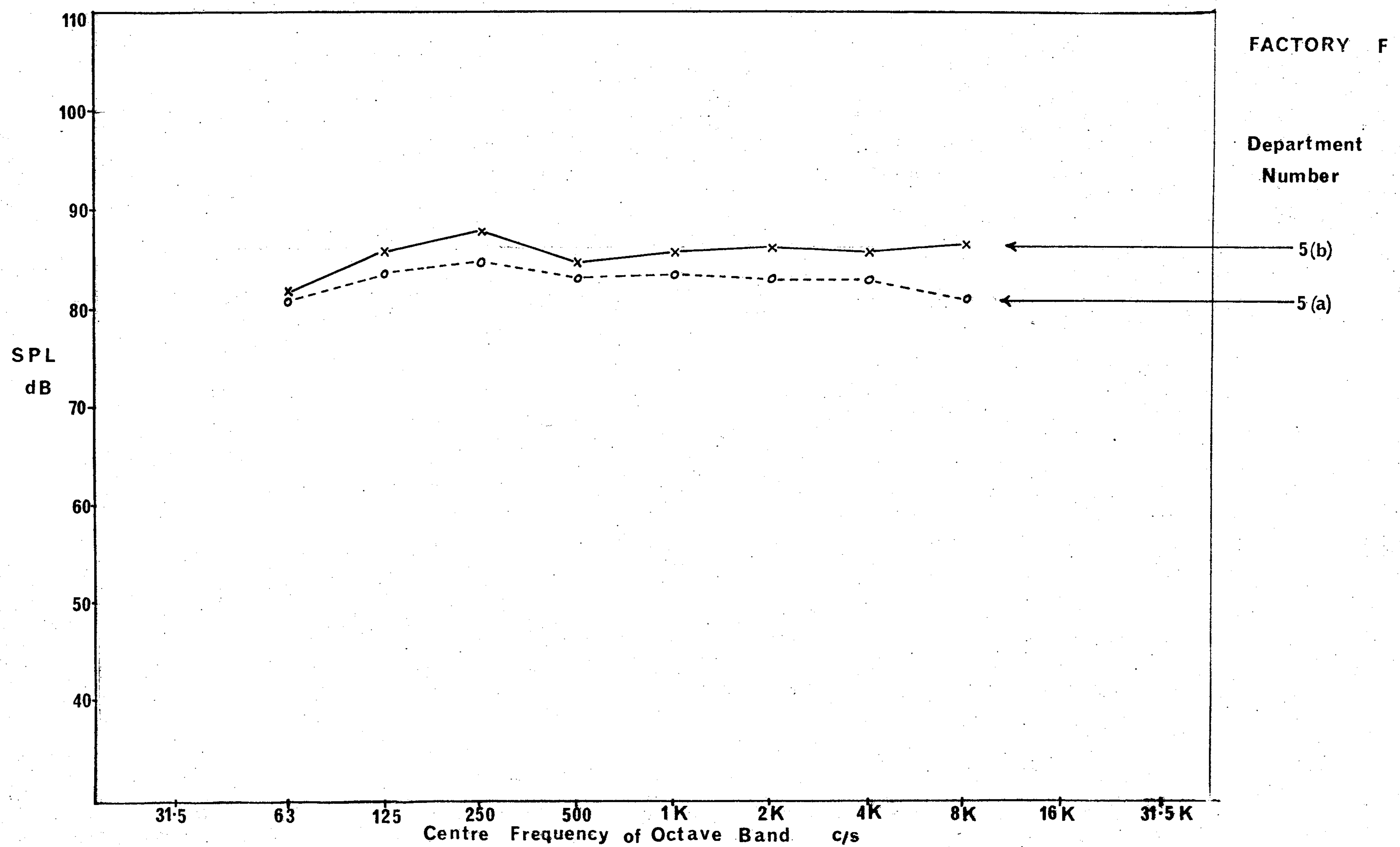

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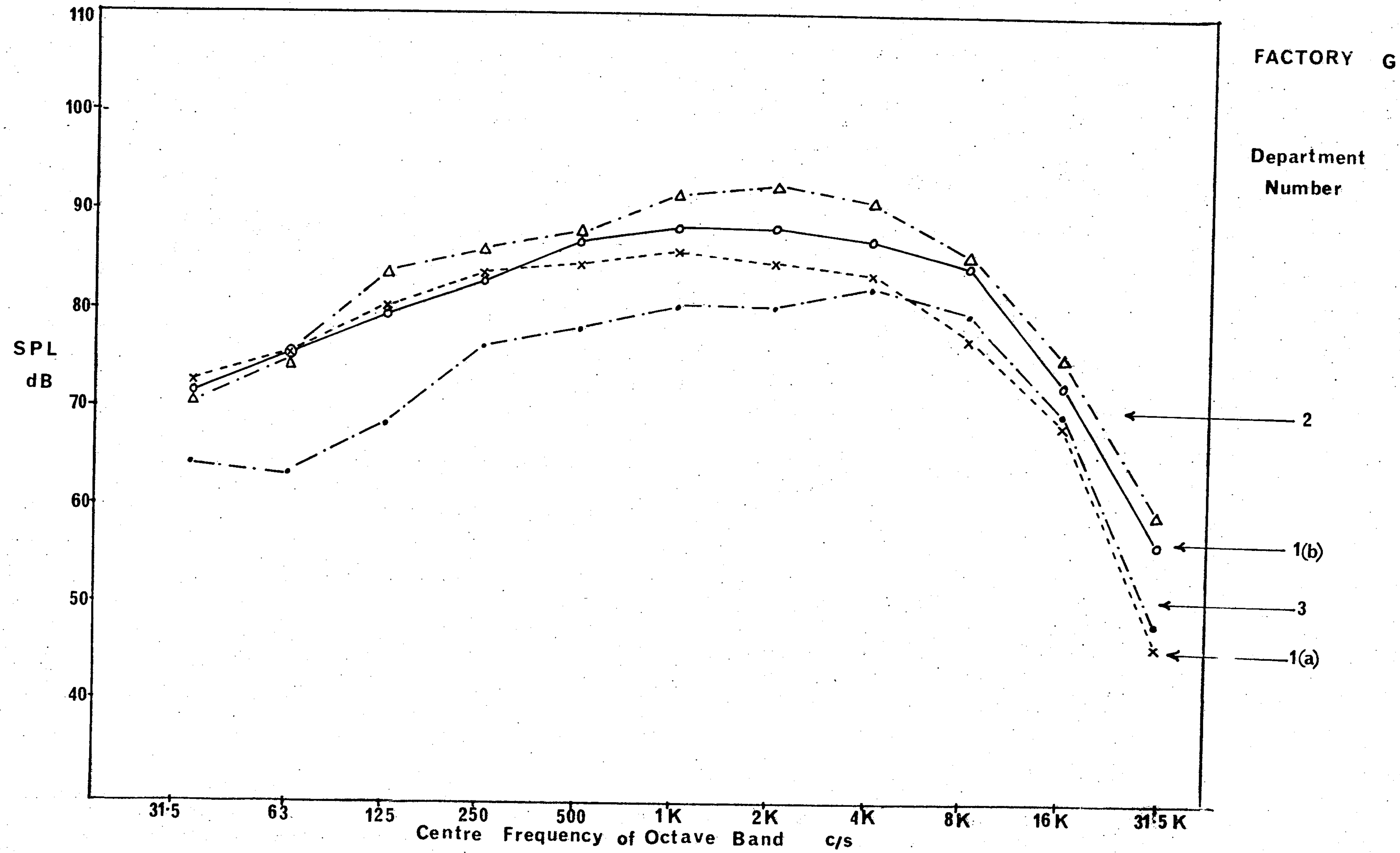
Centre Frequency of Octave Band c/s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SPL dB
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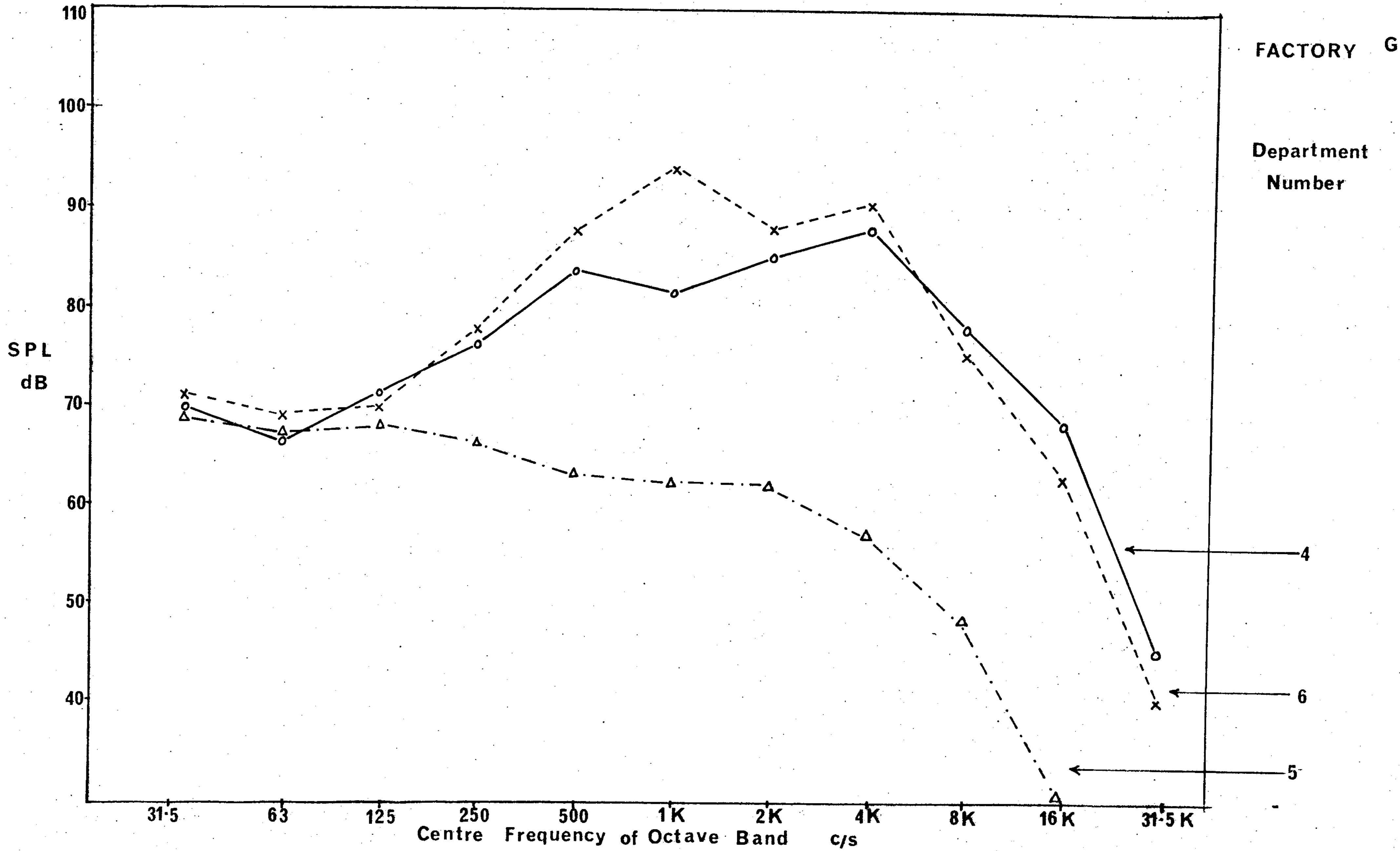
Centre Frequency of Octave Band c/s



FACTORY G
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Centre Frequency of Octave Band c/s
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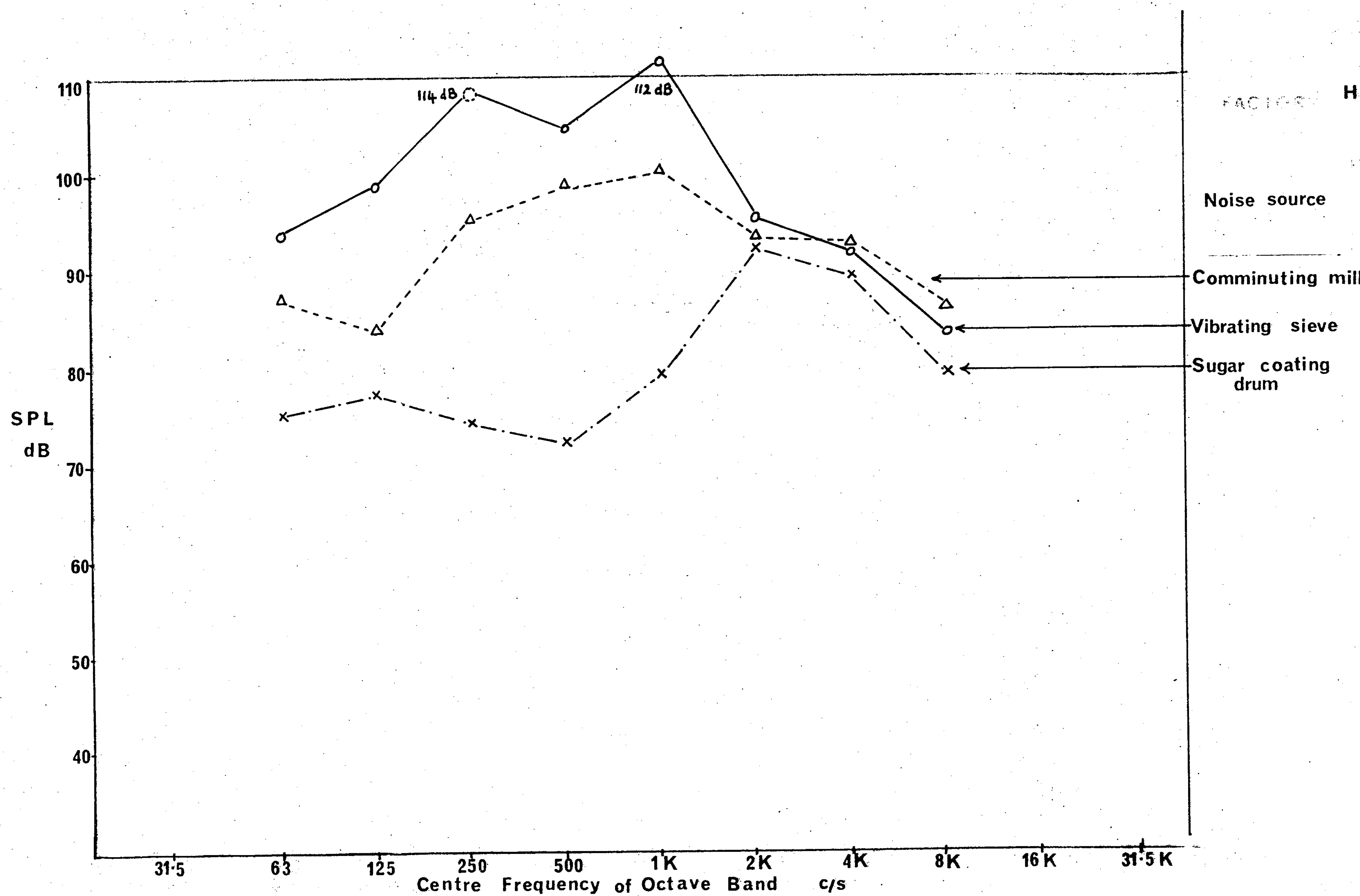

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Noise source
Comminuting mill
Vibrating sieve
Sugar coating drum
SPL dB
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16 K
31·5 K
Centre Frequency of Octave Band c/s

APPENDIX 2

PROPOSALS FOR FURTHER RESEARCH ARISING FROM THEORETICAL DISCUSSIONS IN THE TEXT.

SUBJECT MATTER OF PROJECT	POSSIBLE APPLICATION OF RESULTS	RELEVANT PAGE NUMBER IN THESIS
I. The effect on hearing of the pattern of distribution of energy in a noise spectrum. Measurements Temporary threshold shift. Loudness function. Stimuli Pure tones. Narrow band noise. Wide band noise. Factory noise.	Noise control	39-40
II. Investigation into the cause of the slective damage to the cochlea which results from exposure to occupational noise. Measurements Temporary threshold shift. Loudness function. Stimuli Broad-band noise. Broad-band noise with selected band-stop filters.	Noise control	59-60 62 63-64 78
III. The effects of noise on peripheral vision. Measurements 1. Peripheral vision plots of noise-exposed and unexposed populations. 2. Audiograms of subjects used for vision tests.	Diagnosis of occupational deafness.	7-8

APPENDIX 2 (Continued)

SUBJECT MATTER OF PROJECT	POSSIBLE APPLICATION OF RESULTS	RELEVANT PAGE NUMBERS IN THESIS
IV. The effects of the combined stimuli of heat and noise. Measurements Capillary dilation. Stimuli Heat alone Noise alone Heat & noise	Reduction of stress in a hot and noisy environment.	7

APPENDIX 3

Glossary of Acoustic Terms

Critical Band — The critical bandwidth is the width of a band of noise which is equal in energy to a pure tone whose frequency is that of the centre of the masking noise band, when the pure tone is at its masked threshold. The critical band hypothesis makes two assumptions -

(a) When broad-spectrum masking noise is present, only the frequencies within the critical bandwidth contribute to the masking effect.

(b) When a signal is at its masked threshold, the energy of the critical band (the effective masking band) is equal to the energy of the signal.

Frequency — Frequency is a physical attribute of sound and is the number of cycles occurring in unit time. The unit is the cycle per second (c/s).

Hearing-loss — A subject's hearing loss, for a given frequency, is the number of decibels by which his threshold is raised above the normal threshold, for that frequency.

Intensity — Intensity is a physical quantity and is a measure of the magnitude of the stimulus, usually measured in terms of pressure.

Intensity-level — The intensity-level of a sound is given by the number of decibels by which the sound exceeds the reference intensity. The unit is the decibel.

Loudness — Loudness is a subjective quantity and is a measure of the magnitude of one attribute of the sensation evoked by a sound stimulus. The unit is the sone.

Loudness-Level — The loudness-level of a sound is the intensity-level of a 1 Kc/s tone which gives rise to an equal sensation of loudness as the sound in question. The sound is equated for loudness with the 1 Kc/s reference tone and the intensity level of the reference tone which is required for loudness balance is the loudness-level, in phons, of the sound in question.

Masking — A signal is said to be masked when it is rendered inaudible by the presence of a second sound. The masking effect of a sound is the number of decibels by which signal threshold is elevated by the presence of the masking sound.

Mel — The mel is a unit of pitch, derived from the sensation of pitch produced by a reference tone of 1Kc/s, 40 dB above threshold. The sensation evoked by such a frequency and intensity is defined as having a pitch of 1000 mels. The pitch of all other frequencies and intensities is related to this reference tone.

Pitch — Pitch is a subjective attribute of sound and is largely a function of frequency. Pitch is also dependent upon intensity, since, with increasing intensity there is spread of excitation along the basilar membrane to involve neighbouring pitch receptors.

Phon — The phon is the unit of loudness-level. The number of phons loudness-level of a tone is given by the number of decibels by which the 1Kc/s reference tone must be raised above threshold to evoke an equal sensation of loudness as that tone.

Sensation-Level — The sensation-level of a sound is the number of decibels by which the sound is in excess of its threshold of audibility. Thus, for a given intensity-level, the sensation-level of a sound will vary, depending upon the audibility threshold of the individual subject.

Sone — The sone is the unit of loudness. It is derived from the loudness sensation evoked by a 1Kc/s reference tone, 40 dB above threshold, which is designated a loudness of 1 sone. It is a closer approximation of a 'subjective' unit than is the phon, since the remainder of the sone scale has been derived from direct assessments of loudness, either by fractionation or by multiplication of the reference point. The phon scale merely relates the loudness of a given tone to the intensity-level of an equally loud 1Kc/s tone.

Threshold of Audibility — The threshold of audibility of a sound is the minimum intensity-level of that sound

APPENDIX 3

Glossary of Acoustic Terms (continued)

which just evokes the sensation of hearing in 50% of a large number of measurements. In practical audiometry, the threshold is taken as the lowest reading of the hearing-loss attenuator which gives rise to a reliable response.

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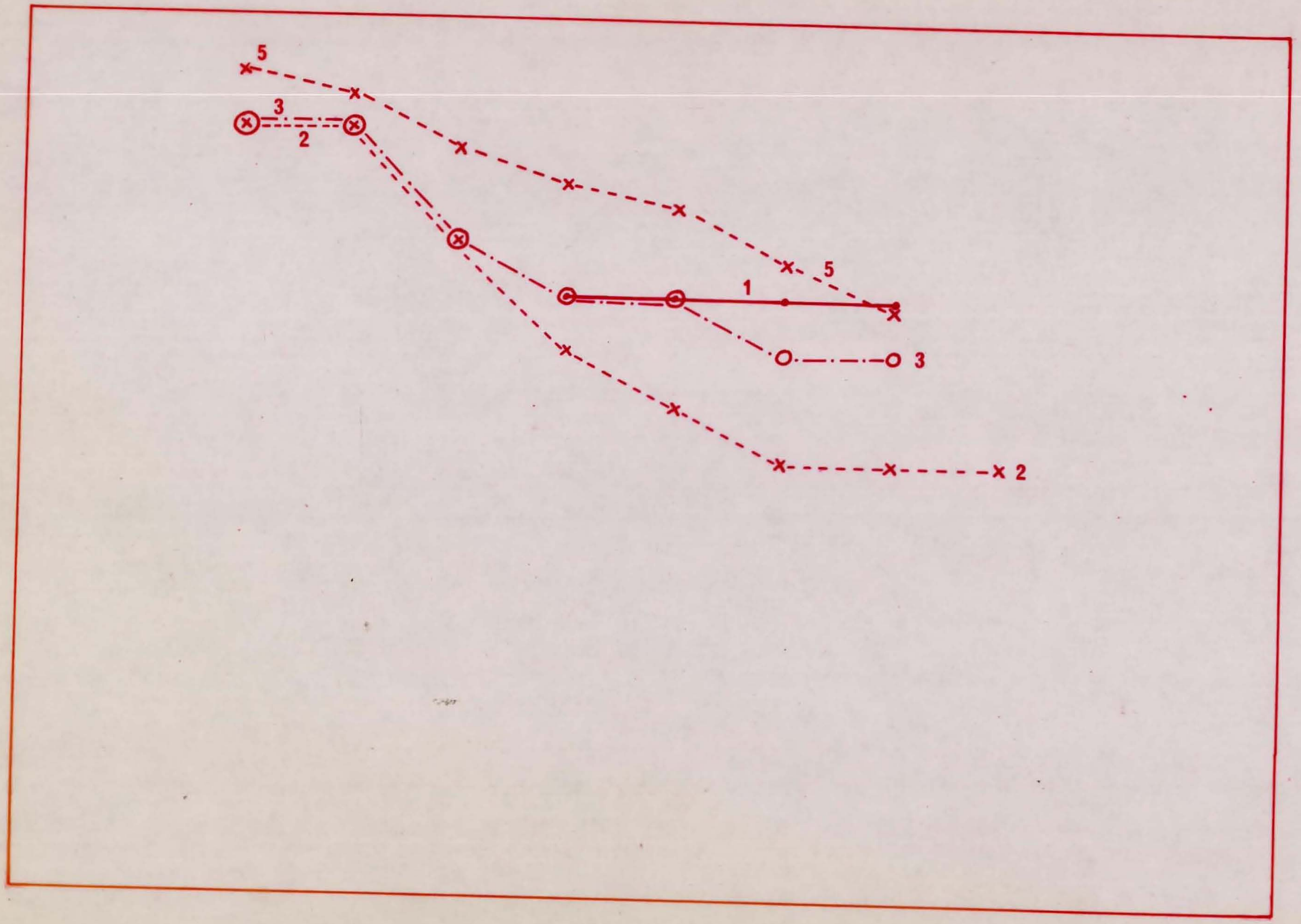

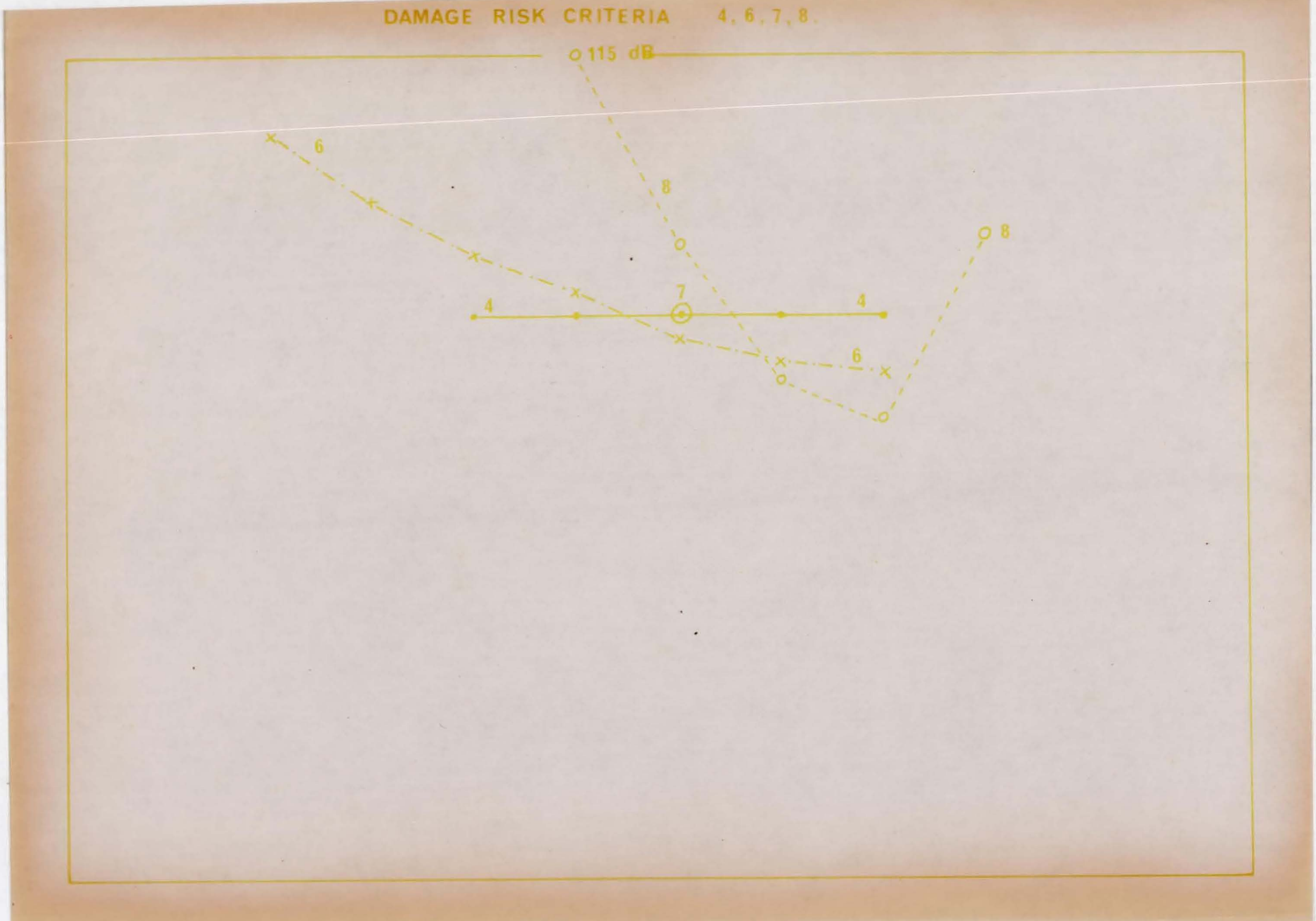
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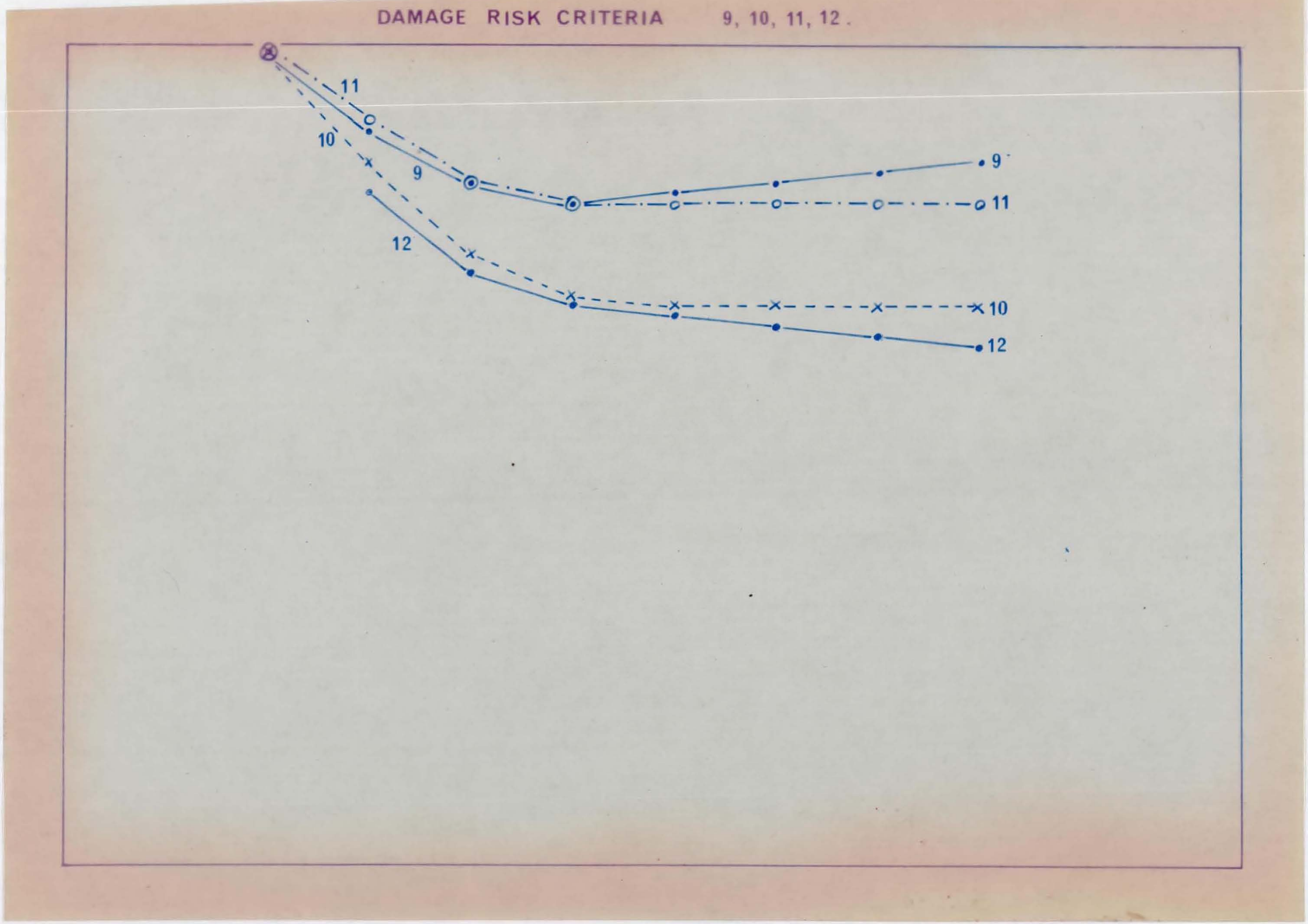
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