A Proof that Health and Productivity Benefits Can be Attained through Noise Attenuation in Factories: A Paper Written to Celebrate the Visit of a Cultural Delegation from the Darling Downs Institute of Advanced Education to the People's Republic of China, April l986.

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Abstract

The literature of permissible noise exposure limits is briefly surveyed. Prescriptions for the prevention of noise induced hearing loss, common to all of the surveyed exposure limits, are summarised. A nomogram, invented for the purpose of highlighting health and productivity benefits inherent in preventive action against noise induced hearing loss, and which incorporates the common prescriptions summarised from the survey of exposure limits, is described. The nomogram is applied in an industrial setting to reveal health and productivity benefits so substantial that they may not easily be ignored.

Introduction

Noise and its health and productivity costs have been studied for some years now. In spite of this, industrial deafness still persists, causing a loss in the quality of life of the injured and costs to industry and society in general. Noise can be attenuated at its source, along its path, or at the point of perception and, although the last method is considered the least appropriate, in reality, it may be the strategy which is affordable and which is also most likely to succeed.

The statement in the last sentence is based on two simple observed facts. First, source and path attenuation is often cost prohibitive in small to medium firms. Second, some jobs, by their very nature, are noisy. These jobs, press operation, equipment operation, jack hammer operation, for example, are unable, easily, to be quieted at source or path and are jobs which are essential to the development of society. However noise from such tasks can be attenuated at the point of perception.

Point of perception attenuation usually involves placing the worker in a confined space to protect them, or having the worker wear protective devices. As a result, there is often worker resistance, both conscious and unconscious, and for these reasons the strategy can fail. Since industrial deafness is not immediate, workers and management, even though they are aware of the risks, might consciously choose to ignore them. It is thus very important that governments bring forward occupational health legislation which makes preventative activity mandatory for both workers and management.

Unfortunately it has been found in the West that legislation per se is not enough. There are sometimes too many factories for authorities to inspect, and inspection is costly. Legislation must be backed up by an education programme which makes management and labour <u>want</u> to prevent industrial deafness. Cognitive dissonance must be overcome and management and labour must be made so continuously aware of the risks and costs of industrial deafness that they themselves initiate preventive action as a matter of routine in their day to day activities.

This paper seeks to make workers and management more fully aware of the risk of noise induced hearing loss by demonstrating the extent to which workers and industry can both be made better off through attention to noise attenuation. It proves large benefits at relatively little cost as an enticement to the initiation of preventative point of perception attenuation strategies.

The paper is structured in three sections. Section A presents a brief survey of the literature of permissible noise exposure levels. Section B presents a noise nomogram developed by the author and a colleague (N. J. Eddington) some year ago. This nomogram serves to prove that industrial deafness can be eradicated. Section C contains an application of the nomogram in an industrial setting. Section C quantifies the extent of benefits available to workers and industry through point of perception attenuation.

A: A Brief Survey of the Literature of Permissible Noise Exposure Limits

A perusal of the literature of the physics and physiology of sound reveals a body of received theory concerning the effects of noise[1] on the health and productivity of workers. Valcic[2] has discussed these effects and a summary of his work is contained in Table 1.

Table 1 suggests that the "extra-auditive" health effects of noise are more clearly understood than the "extra-auditive" productivity effects. The table does suggest, however, a relationship between noise and productivity; occupational deafness alone can reduce productivity through increased communication time, compensation payments, and the retraining costs of replaced staff. In addition, the feelings of ill-being associated with disturbed digestion, balance, psychomotor coordination, blood pressure and sight might well claim a legitimate share of the millions of days of sickness lost annually.

In order to ameliorate the effect of such disorders on health and productivity, a number of strategies have been put forward. These strategies range from those attempting to reduce noise exposure through (a) curtailment of its source; (b) curtailment at and through its path, or (c) curtailment at the point of its perception.[3] This survey will briefly discuss

[1] Noise to be thought of as unwanted sound.
[2] Valcic, I. The Medical Aspects of the Prevention of Noise and Vibration in "Noise and Vibration in the Working Environment", Geneva, ILO, 1976, pp. 57-97.
[3] ILO, Protection of Workers against Noise and Vibration in the Working Environment, ILO, Geneva, 1977, passim.

strategies of the third kind, specifically those seeking to construct indices with which to measure noise risk levels and/or exposure time limits. Such indices operate in the nature

Table 1: Effects of Noise on Health and Productivity of Workers

General Classification	Sub-Classification	Description
Auditive effects	(a) Occupational deafness	A progressive modification of the physio-pathological process which takes place in the inner ear. The disease is a degenerative impairment of the neuro-sensorial cell of the corti organ. In its final stage, almost complete atrophy results in the neuro-sensorial cells.
	(b) Behavioural induced effects of occupational deafness	A mental state thought to underlie observable moodiness and withdrawal from social contact.
Extra-Auditive effects of noise (these effects are more or less reversible)	(a) Effect on the central nervous system	Changes of the following kind are induced in the central nervous system: (a) Modification of cerebral bio-electric currents; (b) Vascular tone in the cerebral micro circulation, special blood vessels tend to spasm and the peripheral ones have a tendency to dilate; (c) A disturbance of psycho-motor reactions resulting in insufficiently precise gestures; (d) Psychological area: disturbed behaviour, apathy, moodiness, fear, insomnia.
	(b) Effects on the balance organ	(a) Intense noise may cause giddiness, loss of balance, a hesitant gait, nausea.
	(c) Effects on the endocrinous glands	(a) Under the effect of noise there occurs a temporary increase in the activity of the adrenal cortex and the medulla. There is also an increase in the growth hormones of the hypophysis.
	(d) Effects on sight organs	The following responses have been observed to occur: (a) Weakening of coloured vision; (b) Receptivity of visual impression is slowed; (c) Adaptation to darkness is slowed.
	(e) Effects on the cardio-vascular system	(a) The heart registers accelerated pulsation in the alarm stage (get the hell out of it quick stage); (b) 1. Increased blood pressure at the beginning of stress only followed by a possible (but often not) slight increase in diastolic blood pressure 2. Spasms in peripheral blood vessels such that intensity and duration depend upon the intensity and duration of the noise.
	(f) Effects on the digestive system	(a) Gastric pains may appear.
	(g) Effects on the electrolytes	(a) A certain retention of sodium and a certain loss of potassium result.
	(h) Direct effect of noise on quality of work and on productivity	(a) Disturbances in the psychomotor area lead to mistakes in delicate work. Total productivity in heavy work has *not* been seen to decrease.

Source: Valcic, I. *The Medical Aspects of the Prevention of Noise and Vibration* in "Noise and Vibration in the Working Environment", Geneva, ILO, 1976, passim.

of preventive devices. Cognitive dissonance excepted, they may serve in noise curtailment.

Table 2: Nomenclature for Noise

Characteristics ➔ / ➘ classification	Containing frequencies covering a major portion of the sound spectrum	Containing one wave length or a small group of wavelengths
Steady	White or broad based	Coloured
Intermittent	White or broad based	Coloured

Indices of Noise Risk Levels

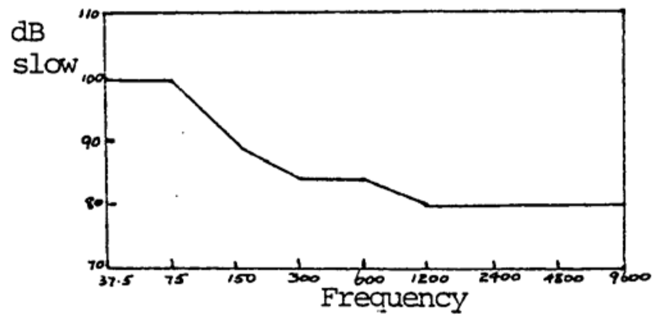
In 1957 the American Academy of Ophthalmology and Otolaryngology[4] accepted an 85dB level as a damage-risk level cut-off point for white sound in the 300 – 1200 c/s range. Previous studies had specified a damage risk level of 110dB for the 375 – 75 c/s range, reducing to approximately 95dB in the 300 – 600 c/s range.[5]

Litter[6], using American Standards Association data, specified a 70dB cut off point for the 1200 – 1600 c/s range. However, in 1960 Litter modified his work when he specified a damage risk curve based upon an eight hour day, five day week for a working life time. This measuring approach is known as the Burns-Litter damage risk curve and noise environments below the curve are preferred environments.

The Burns-Litter approach is unsatisfactory in that it is less flexible concerning age and ageing, individual susceptibility, exposure time and noise type, i.e., differing combinations of these factors are not easily incorporated in it.

[4] The American Academy of Ophthalmology and Otolaryngology, "Guide for Conservation of Hearing in Noise", Los Angeles, 1957, passim.
[5] Murrell, KFH, "Ergonomics: Man in His Working Environment", London, Chapman & Hall, 1975, p786.
[6] Litter, TS, "Noise Measurement, Analysis and Evaluation of Harmful Effects", Annals of Occupational Hygienists Association, Vol 1, 1958, p286.

Figure 1: The Burns-Litter Damage Risk Criterion

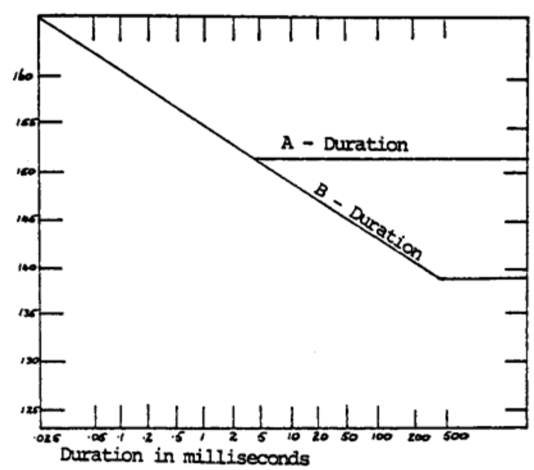


Source: Murrell, KFH, "Ergonomics: Man in His Working Environment", London, Chapman & Hall, 1975, p285.

These factors have been increasingly acknowledged in risk criteria developed subsequent to the Burns and Litter publications.

In 1966, the Committee on Hearing, Bioacoustics and Biomechanics of the US National Research Council established a criterion (the CHABA criterion- Figure 2) based on the octave band analysis of sound.

Figure 2: CHABA Criterion for Impulsive Noise



Peak sound pressure level is expressed as a function of A or B duration in the range 25ms to 1s.
Source: ILO, *Noise and Vibration in the Working Environment*, Geneva, ILO, 1976, p67.

This was followed by the ACGIH criterion (Table 3) in 1969 when the American Conference of Governmental Industrial Hygienists expressed risk levels in dB(A). They used a total noise level concept.

In the same year the Japanese Industrial Hygiene Association[7] set down a criterion. Like the CHABA criterion, it is an octave band analysis approach and is said to roughly correspond to a 90dB(A) fence.

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[7] ILO, "Noise and Vibration in the Working Environment", Geneva, ILO, 1976, p66.

In 1971, the International Standards Organisation[8] published an octave band analysis criterion based upon a 50 week working year over a 45 year working life. In this criterion a relationship is established between the noise to which an occupation is exposed and the % of workers whose hearing threshold has been raised by 25dB(A) or more when audiometric testes are made at 500, 1000 and 2000 Hz. The ISO criterion incorporates impulsive noise by adding 10dB(A) to the measured level.

[8] "International Standards Association", ISO – R/1999, passim.

Table 3: The ACGIH Criterion

Brief survey of the ACGIH criterion	
Noise intensity in dB(A)	Length of authorised presence during one working day
90 95 100	4 – 8 h 2 – 4 h 1 – 2 h

Source: ILO, *Noise and Vibration in the Working Environment*, Geneva, ILO, 1976, p66

Also in 1971, the British Occupational Hygiene Society published a criterion (BOHS criterion based upon dB(A) maximums over an eight hour day, five day week for a 30 year working life. It is briefly surveyed in Table 4.

Table 4: The BOHS Criterion

Brief survey of the BOHS criterion	
Duration of exposure in hours per day	Maximum noise level in dB(A)
8 6 5 3 2 1 0.5	90 91 92 94 96 99 100

Source: ILO, *Noise and Vibration in the Working Environment*, Geneva, ILO, 1976, p66.

It is difficult to compare these criteria to select the most appropriate one because they differ in the units in which comparison could be made. They can all be shown to correspond to a criterion which has a 90dB(A) fence as its upper total noise risk level[9].

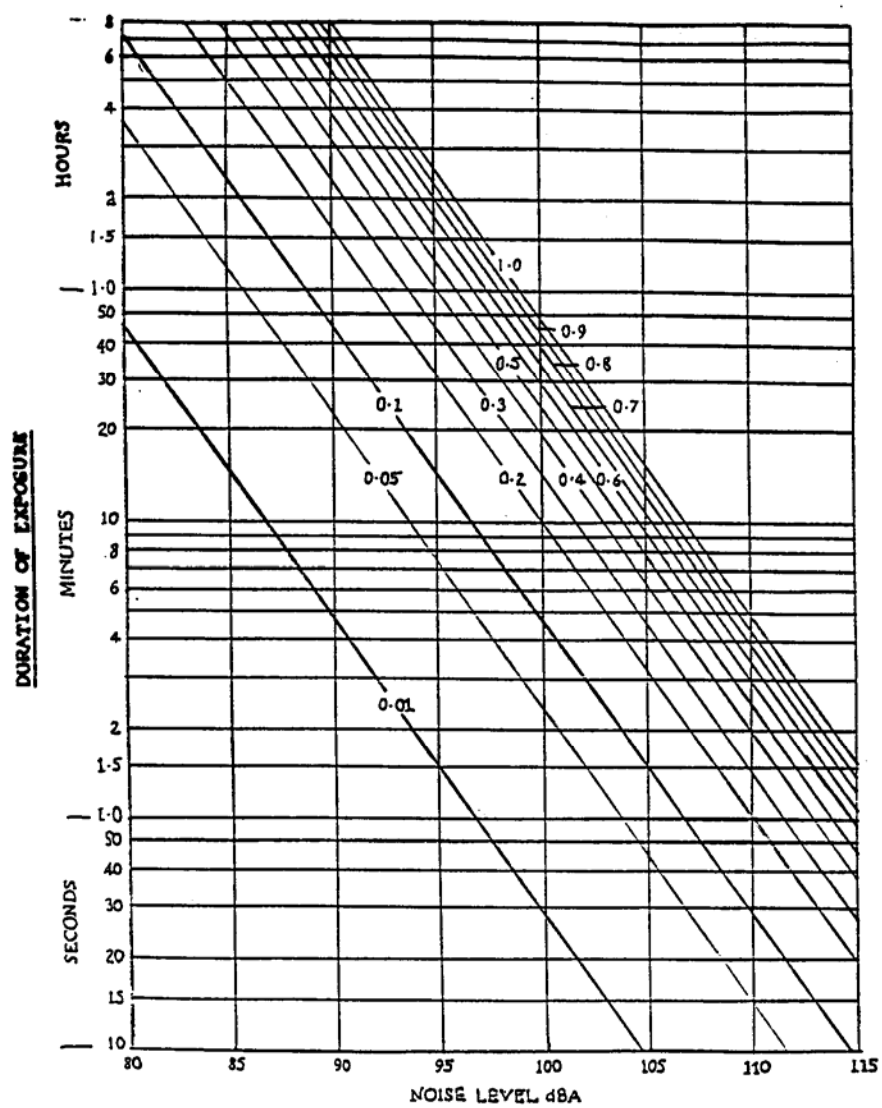
Subsequently and more recently, individual countries have begun to set codes which are based very closely in prescription upon the ones surveyed above. In Australia, regulations have been drafted to incorporate a 90dB(A) maximum permissible level with a reduction to 85dB(A) within five years. No worker is to be exposed to noise levels in excess of 115dB(A). The regulations also address the medical examination of workers at risk, hearing tests, and the provision of protective strategies and equipment. Rule 11 of the Factories and Shops Act, 1960-1970, Queensland, is an example of the state of the art in Australia.

It is interesting to note that the nomogram incorporated in Rule 11 (Figure 3) is also the one used by the National Health and Medical Research Council in its 1976 publication. This body also espouses the idea of a 90dB(A) come 85dB(A) fence, but Rule 11 makes no mention of this figure using a more general statement of upper limits around

[9] ILO, "Noise and Vibration in the Working Environment", ILO, Geneva, 1976, p67 et seq.

115dB(A) and 150dB(A) figures. The nomogram in Figure 3 applies in cases of eight hour exposure to steady noise or to varying exposures equivalent to eight hours exposure. The National Health and Medical Research Council specifies 0.33 as the factor to determine maximum dosage. Rule 11 specifies 0.1 as the figure.

Figure 3: Daily Noise Dose Calculation – Queensland Factories and Shops Act 1960



DAILY NOISE DOSE CALCULATION CHART

Source: Queensland Government, *Queensland Factories and Shops Act 1960*, Brisbane, Government Printer, 1960, Rule 11.

To Sum Up

This section of the paper has dealt with indices of noise measurement. The major indices surveyed generally accommodate both steady and intermittent noise and have been shown to use differing standard units. However, all major criteria translate approximately to a 90dB(A) noise fence. That is, 90 dB(A) for eight hours or its equivalent is considered a maximum noise dose. Further, each index is based on the premise of finding a correlation between noise level and possible injury to hearing.

This paper accepts Figure 3 as a statement of the preferred industrial environment concerning noise and applies to it 0.33 as the determining factor for noise dose. It will use the Burns-Litter Criterion to specify a ceiling across the octave band. Noise levels of the order contained in the indices above will be used in subsequent sections as a basis for the analysis of health and productivity benefits inherent in industrial noise attenuation.

B: The Noise Productivity Nomogram

In Queensland, as many as 25,954 days are lost annually as a result of some 1202 occurrences of industrial disease. Diseases of the ear, including industrial deafness, account for some 5.4 to 8.7% of all industrial disease. It is clear from these figures that noise induced hearing loss, together with industrial deafness, constitutes a significant proportion of industrial disease. It is also clear that industrial deafness contributes towards reduced productivity through days lost. Thus, reduction in the risk of noise induced hearing loss might contribute towards higher productivity.

A theoretical basis exists for the construction of a nomogram that, in terms of the argument above, can be used to investigate the productivity effects of noise. Such a nomogram would acknowledge that, apart from specific diseases of the ear, hearing loss occurs through time as a result of age (presbycusis) and because of noise exposure. In addition, it would recognise that, as well as being additive, both components of such hearing loss are randomly distributed amongst the working population.

Under these circumstances, the nomogram might best operate on the basis of general risk analysis. It would be a device which, in essence, specified the risk of a certain noise induced hearing loss (or losses) occurring as a result of exposure to differing sound energy levels for differing periods of time.

Figure 4 sets out the design of such a nomogram. Part B of the nomogram consists of curves of equal risk. Each curve depicts the % risk that, at 500, 1000 and 2000 Hz, a 25dB(A) average hearing loss will result. Each curve specifies the various combinations of dB(A) sound levels and exposure years that may be associated with certain differing risk levels that a 25dB(A) noise induced average hearing loss will occur at 500, 1000 and 2000 Hz. The equal risk curves were calculated from Intersociety Committee, International Organisation for Standardisation, and NIOSH data[10] and the observation made by the American Conference of Governmental Industrial Hygienists that for each halving of exposure time the noise limit might be increased by 5dB(A)[11].

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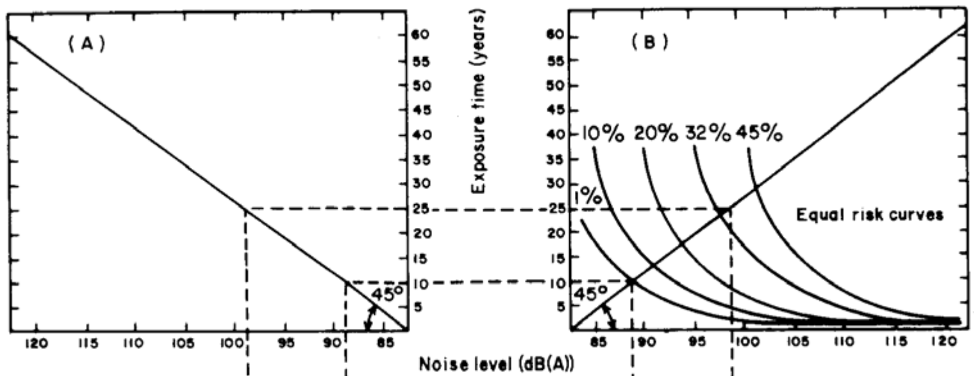
[10] Jones, HH, Environmental Monitoring and Technical Prevention of Excessive Noise Exposure in the Protection of Workers against Noise and Vibration in the Working Environment, Geneva, ILO, 1976, p28.
[11] Other authorities claim the increase is 3dB(A) (the Swedes), while others claim the appropriate figure is 6dB(A). Fortunately the figures are a question of degree rather than kind. The overall shape of the curves remains unaltered and hence the direction of the nomogram remains valid.

Figure 4: The Noise Productivity Nomogram



(C)

Reduction in % risk for specified period of equal time exposure to lower noise levels resulting from attenuation

dB(A)

120	115	110	105	100	95	90	85	5yr
·	·	·	·	·	·	·	·	85
·	·	·	·	·	·	·	·	90
·	44	31	19	9	0	·	·	95
·	35	22	10	0	9	·	·	100
·	25	12	0	10	19	·	·	105
·	13	0	12	22	31	·	·	110
·	0	13	25	35	44	·	·	115
·	·	·	·	·	·	·	·	120

120	115	110	105	100	95	90	85	10yr
·	·	·	·	·	·	·	·	85
·	·	44	31	19	9	0	·	90
·	·	35	22	10	0	9	·	95
·	·	25	12	0	10	19	·	100
·	·	13	0	12	22	31	·	105
·	·	0	13	25	35	44	·	110
·	·	·	·	·	·	·	·	115
·	·	·	·	·	·	·	·	120

120	115	110	105	100	95	90	85	15yr
·	·	·	·	·	·	·	·	85
·	·	44	31	19	9	0	·	90
·	·	35	22	10	0	9	·	95
·	·	25	12	0	10	19	·	100
·	·	13	0	12	22	31	·	105
·	·	0	13	25	35	44	·	110
·	·	·	·	·	·	·	·	115
·	·	·	·	·	·	·	·	120

120	115	110	105	100	95	90	85	20yr
·	·	·	44	31	19	9	0	85
·	·	·	35	22	10	0	9	90
·	·	·	25	12	0	10	19	95
·	·	·	13	0	12	22	31	100
·	·	·	0	13	25	35	44	105
·	·	·	·	·	·	·	·	110
·	·	·	·	·	·	·	·	115
·	·	·	·	·	·	·	·	120

120	115	110	105	100	95	90	85	25yr
·	·	·	45	32	20	10	0	85
·	·	·	35	22	10	0	10	90
·	·	·	25	12	0	10	19	95
·	·	·	13	0	12	22	32	100
·	·	·	0	13	25	35	45	105
·	·	·	·	·	·	·	·	110
·	·	·	·	·	·	·	·	115
·	·	·	·	·	·	·	·	120

(D)

Gain in equal risk years at specified % risk levels for differing levels of noise attenuation

dB(A) dB(A)

1%	85	90	95	100	105	110	115	120
85	0	10	15	17·5	18·75	19·37	19·69	19·84
90	10	0	5	7·5	8·75	9·37	9·69	9·84
95	15	5	0	2·5	3·75	4·37	4·69	4·84
100	17·5	7·5	2·5	0	1·25	1·87	2·19	2·34
105	18·75	8·75	3·75	2·5	0	0·63	0·94	1·09
110	19·37	9·37	4·37	1·87	0·63	0	0·32	0·47
115	19·69	9·69	4·69	2·19	0·94	0·32	0	0·15
120	19·84	9·84	4·84	2·34	1·09	0·47	0·15	0

10%	85	90	95	100	105	110	115	120
85	0	20	30	35	37·5	38·75	39·37	39·69
90	20	0	10	15	17·5	18·75	19·37	19·69
95	30	10	0	5	7·5	8·75	9·37	9·69
100	35	15	5	0	2·5	3·75	4·37	4·69
105	37·5	17·5	7·5	2·5	0	1·25	1·87	2·19
110	38·75	18·75	8·75	3·75	1·25	0	0·62	0·94
115	39·37	19·37	9·37	4·37	1·87	0·62	0	0·32
120	39·69	19·69	9·69	4·69	2·19	0·94	0·32	0

20%	85	90	95	100	105	110	115	120
85	·	·	·	·	·	·	·	·
90	·	0	20	30	35	37·5	38·75	39·37
95	·	20	0	10	15	17·5	18·75	19·37
100	·	30	10	0	5	7·5	8·75	9·37
105	·	35	15	5	0	2·5	3·75	4·37
110	·	37·5	17·5	7·5	2·5	0	1·25	1·87
115	·	38·75	18·75	8·75	3·75	1·25	0	0·62
120	·	39·37	19·37	9·37	4·37	1·87	0·62	0

32%	85	90	95	100	105	110	115	120
85	·	·	·	·	·	·	·	·
90	·	·	·	·	·	·	·	·
95	·	·	0	20	30	35	37·5	38·75
100	·	·	20	0	10	15	17·5	18·75
105	·	·	30	10	0	5	7·5	8·75
110	·	·	35	15	5	0	2·5	3·75
115	·	·	37·5	17·5	7·5	2·5	0	1·25
120	·	·	38·75	18·75	8·75	3·75	1·25	0

45%	85	90	95	100	105	110	115	120
85	·	·	·	·	·	·	·	·
90	·	·	·	·	·	·	·	·
95	·	·	·	·	·	·	·	·
100	·	·	·	0	20	30	35	37·5
105	·	·	·	20	0	10	15	17·5
110	·	·	·	30	10	0	5	7·5
115	·	·	·	35	15	5	0	2·5
120	·	·	·	37·5	17·5	7·5	2·5	0

The data which underwrite the risk curves also underwrite the preferred noise environment specified in Section A. Also, the 25dB(A) average hearing loss at 500, 1000 and 2000 Hz is defined by the medical profession as the beginning of slight impairment for the understanding of spoken English. The nomogram is thus shown to incorporate, as a basis for productivity study, the preferred industrial noise environment discussed in Part A.

Part A of the nomogram is simply a geometric device, which, together with the 45^{o} line in Part B allows direct attenuation readings from Part C to be transformed into their safe time increment equivalents.

Part C shows reductions in risk that would result from noise attenuation when exposure time is held constant. Part D shows the gain in years of equal risk exposure that would result from the same noise attenuation. Part C thus demonstrates the extent to which risk of noise induced hearing loss is reduced over a given period of exposure time while Part D demonstrates the extent to which the same risk of noise induced hearing loss may be spread over a longer period of exposure time. Both of these situations are consistent with fewer days lost. Both are consistent with reduced hearing loss through noise attenuation. Thus the nomogram allows the calculation of productivity gains specifically in terms of increased exposure at constant risk (or the same exposure at reduced risk) and generally in terms of a reduced lost days through time.

There are three steps involved in the use of nomogram. Step 1 – measure the actual noise levels of the work situation in dB(A). Step 2 – measure (or calculate) the attenuation resulting from the proposed environmental change. Step 3 – for the measured levels of Steps 1 and 2 read directly from parts (C) and (D), the risk reduction or equal risk years gain the attenuation provides (the 45^{o} lines in the nomogram simply project the noise level differential to the risk tables (C) and (D)). For example, a worker likely to be exposed to 100dB(A) for ten years would face a 20% (approximately) risk of hearing impairment in the manner defined. An attenuation of 10dB(A) brought about by a simple change in the environment would result in a 30 years equal risk gain or alternatively a 19% reduction in the risk of hearing impairment over the 10 years of exposure.

It is now possible to proceed to Part C of the paper where the nomogram is applied in an industrial setting to provide the extent of health and productivity benefits available.

C: Using the Nomogram in Industry to Prove the Extent of Health and Productivity Benefits Available

How will the nomogram be applied? It is unrealistic to expect firms to relocate engines, build walls, or fit additional silencers just to suit the measurement needs of this paper. For this reason, the main change to the environment to be investigated will be the provision of protective ear devices. If approximate data are available for other environment changes (eg, relocation) these will be analysed as a first approximations.

The overall attenuation provided by ear protectors can be calculated from the formulae

$$R = L_A \log S - 10.0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

or	R	=	$-10 \log S^1 - 3$ ……………………………(2)
where	S	=	$\sum_1^7 \text{antilog}\,(0.1 \times (L_1 - Q_1))$
	S^1	=	$\sum_1^7 \text{antilog}\,(-0.1 \times Q_1)$
where	Q_1	=	attenuation at 125 Hz + 16.2dB
	Q_2	=	attenuation at 250 Hz + 8.7dB
	Q_3	=	attenuation at 500 Hz + 3.3dB
	Q_4	=	attenuation at 1000 Hz
	Q_5	=	attenuation at 2000 Hz – 1.2dB
	Q_6	=	attenuation at 3000 and 4000 Hz – 1.0dB
	Q_7	=	attenuation at 6000 and 8000 Hz – 1.1dB

and L_1 - L_7 denote the octave band levels in dB at 125, 250, 500, 1000, 2000, 4000 and 8000Hz respectively, and L_A = dB(A) level of the noise.

Thus octave band analyses will be conducted for continuous noises likely to be present for the eight hour day. Attenuation levels will be calculated. The calculated levels will then be applied to the nomogram to determine productivity benefits. Attenuation levels approximating from other manipulations of the environment will also be applied to the nomogram if such approximate attenuation levels are indeed thought calculable.

Figure 5: Factory Layout and Materials Flow

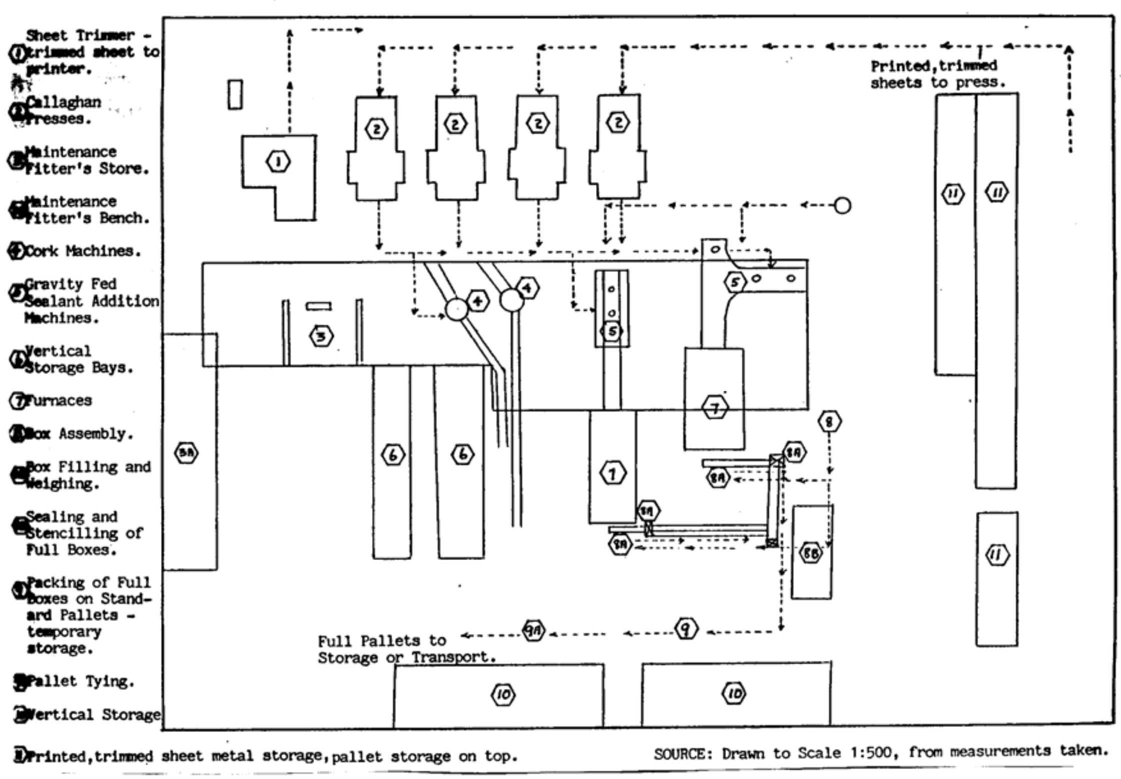
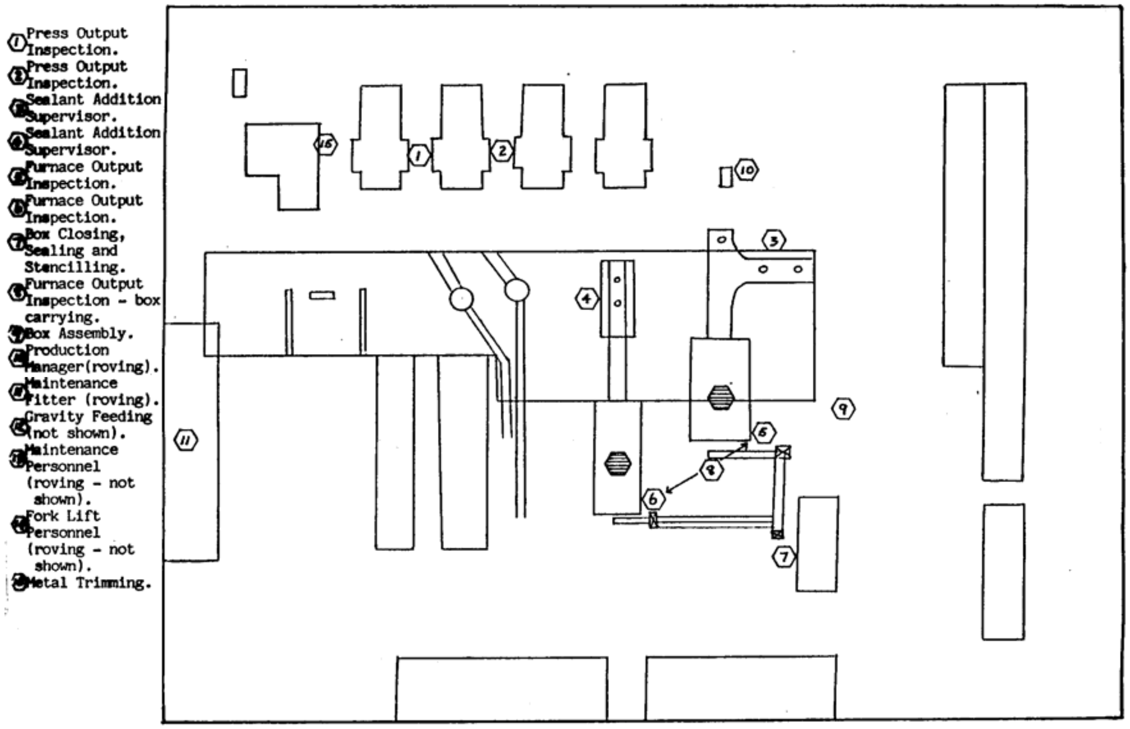
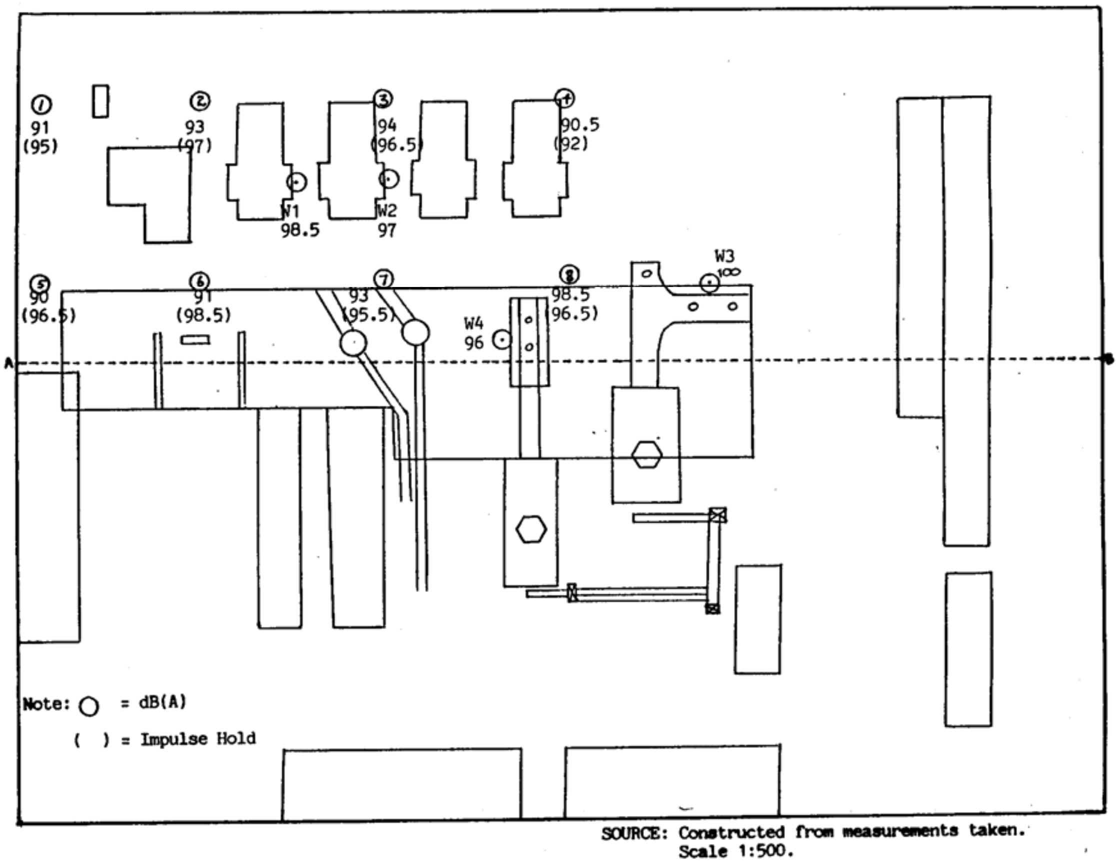


Figure 6: Operator Positions



SOURCE: Drawn to Scale 1:500 from measurements taken.

Figure 7: Grid Positions



<u>The Factory Environment</u>

The major impulsive noise sources in the plan were the Callaghan presses and the sealant adding machines. Other noise was caused by gravity feeding, vibration of filled boxes, air blasting, conveyor belt movement, electric motors, electric fork lift vehicles, maintenance fitting and sheet trimming. Figures 5 and 6 describe the factory environment and the worker positions within that environment.

Figure 8: Noise Contours dB(A) Slow – Two Presses and General Plant in Operation

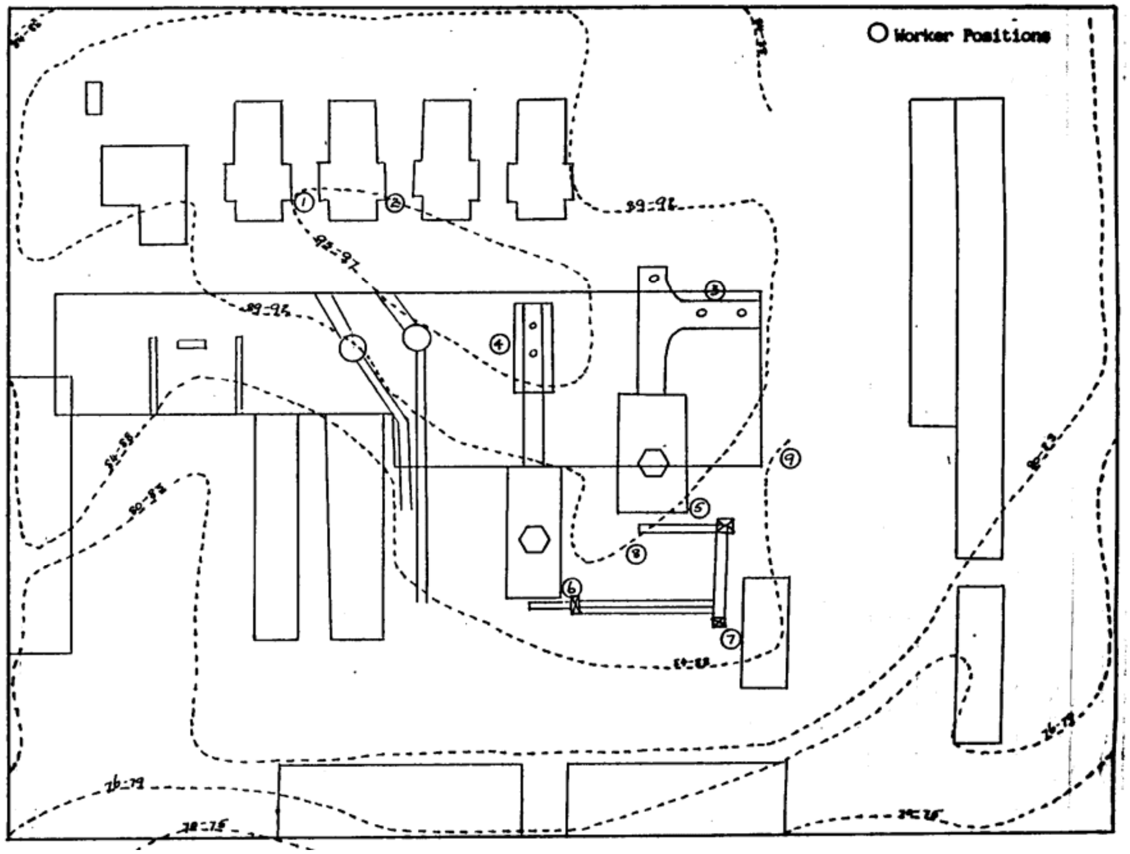


Figure 8 shows noise contours constructed on the basis of dB(A) slow measurements taken. The contours are thus general and conservative in the area of the presses. They reveal that workers 1, 2, 3, 4, 5, 6, 7 and 8 are exposed to steady noise above 85dB(A) for eight hours per day and thus allow further investigation along the lines outlined in Section A. Frequency band analyses were made for each worker position and Figure 9 (I through XI) top lines relate the data obtained to the Burns-Litter damage risk criterion.

Table 5: DB(A) Slow and Various Impulse Sound Level Pressure Readings for Specified Plant Locations

Grid Position	dB(A) slow	Impulsive (subjective)	Impulsive (hold)	Impulse Peak
1	91	93	95	107
2	93	93.5	97	108
3	94	95.5	96.5	109
4	90.5	91	92	106.5
5	90	94	96.5	105
6	91	96	98.5	109
7	93	94.5	95.5	107.5
8	98.5	94.5	96	117.5
Worker 1	98.5	102.5	104	105.5
Worker 2	97	102	102.5	116
Worker 3[1]	100	103.1	104.6	112
Worker 4[1]	96	98.9	99.2	113

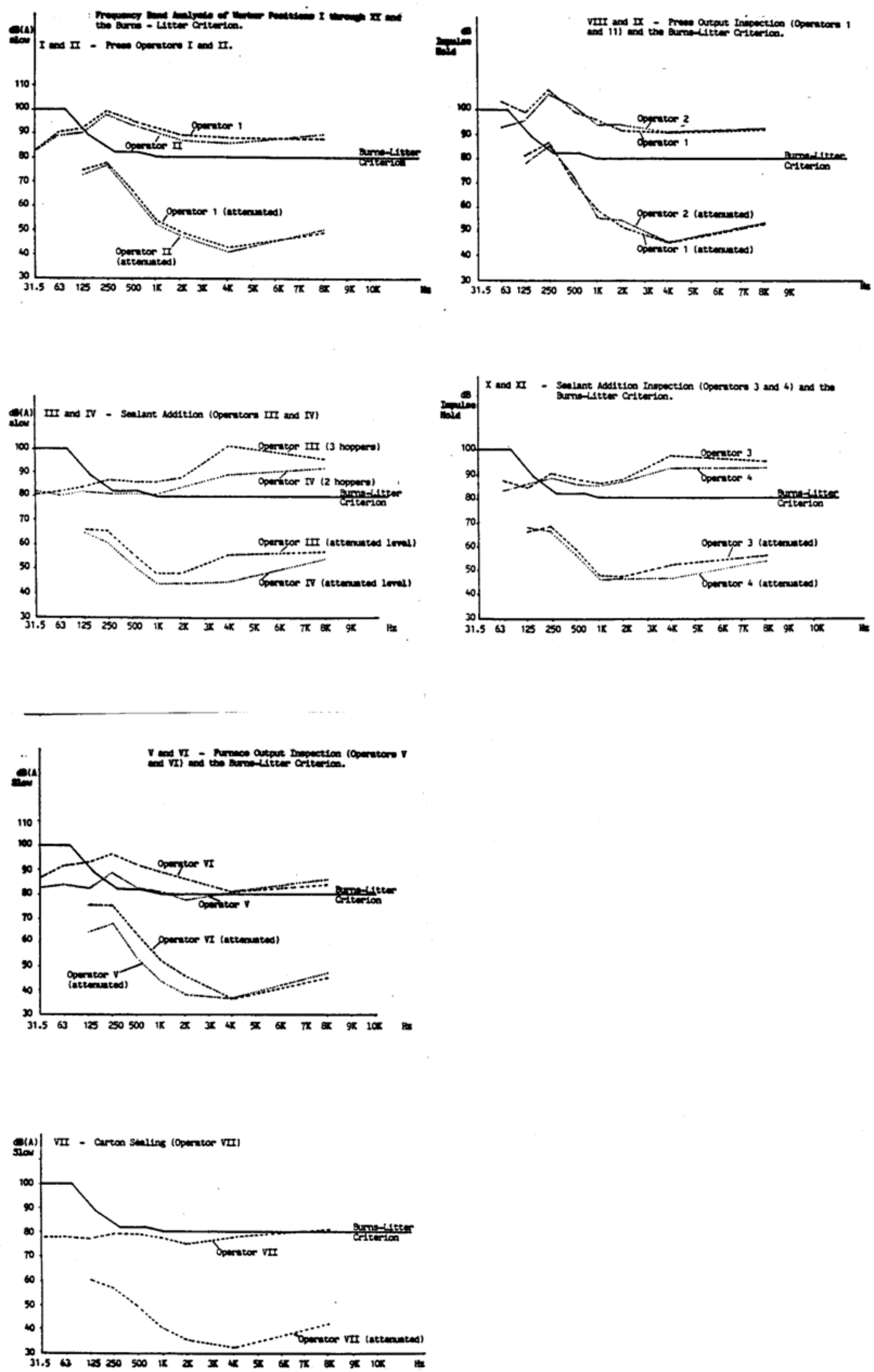
Note 1: These two positions were not included in the calculation of averages used in the text.

Because of shielding and absorption, the noise tended to be of a steady nature at distances removed from the presses. For this reason, dB(A) readings only were taken below the line AB on Figure 7. Even above this line, noise at points removed from the presses and sealant machines tended to be perceived as steady rather than impulsive noise and for this reason, both dB(A) and impulse readings are marked on the noise grid, points 1 to 8 and at worker positions 1, 2, 3 and 4. Table 5 gives detailed readings for these twelve points.

From Table 5 data allows it can be demonstrated that impulse hold levels are on average 3.8dB above dB(A) readings, and that impulse peaks are on average 15.6dB above dB(A) readings and 10.85dB on average above impulse hold levels. Such data accord with International Noise Risk findings[12] concerning differences in dB(A) and impulse levels. It was thus decided that readings with the meter set at impulse hold would be used when discussing work positions 1, 2, 3 and 4 while dB(A) slow levels would be used for work positions 5, 6 and 7.

[12] (a) ILO, "Protection of Workers against Noise and Vibration in the Working Environment", Geneva, ILO, 1977, passim.
(b) ILO, "Noise and Vibration in the Working Environment", Geneva, ILO, 1976, passim.

Figure 9: Frequency Bank Analysis of Worker Positions I through IX and the Burns-Litter Criterion



It is not technically possible to separate worker from machine by allowing inspection at the end of an extended conveyor belt because machine operators continually listen to machine noise to pick up malfunction and snarlups. To hear these they need to be close to the machine. Placing hoods around the workers is a possible solution. Workers questioned did not prefer this suggestion because of sensations of claustrophobia. The most simple change[13] to the environment in the present situation is the only option available ie, the provision of personal protective devices.

It is thus now appropriate to calculate the overall attenuation levels inherent in an environmental change of the kind proposed in Sections A and B, ie, the provision of personal protective devices.

The operative formula as explained earlier in Section B is

$R = L_A \log S - 100$

where $S = \sum^7_1 \text{antilog}\,(0.1 \times (L_1 - Q_1))$

$L_{1\text{-}7}$ = octave band levels in dB

L_2 = dB(A) noise level

Q_{17} = given adjusted attenuation parameters for apparatus at octave band levels $L_{1\text{-}7}$

An alternative formula is also available where approximations only are required.

$R = -10 \log S - 3.0$

where $S = \sum^7_1 \text{antilog}\,(-0.1 \times Q_1)$

R = overall attenuation

Table 6 sets out the overall attenuation afforded by a number of ear muffs of well known brand name. Corrected attenuation levels across the sound spectrum are given together with the overall attenuation in dB(A).

It can be seen from Table 6 that on average a reduction of 23dB(A) can be expected in the overall noise level if protective devices are worn. When the 23dB(A) attenuation figure is applied to the existing levels for worker positions 1 – 7 these workers are transposed below[14] a value of 0.33 on the damage risk criterion (85 dB(A)) for an eight hour day. (Table 7)

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[13] The change per se is a simple matter. Getting workers to wear the devices may not be such a simple undertaking.

[14] With the exception of Workers 1 and 2 for one reading.

Table 6: Corrected Attenuation across the Frequency Band (Q's) and Overall Attenuation in dB(A) Various Personal Protective Devices

Attenuation → / Hz ↓	Corrected Attenuation Across Frequency Spectrum					
	Gardwell 1100	Norton 4530	Norton Ear Plugs	Noise Free	R dB(A)	Average
125	33.2	33.4	33.0	33.0		
250	35.7	29.7	34.3	29.7		
500	38.3	35.0	29.9	34.3		
1000	36.0	42.3	27.5	45.0		
2000	43.8	42.3	34.7	40.8		
4000	45.0	49.2	39.8	44.0		
8000	42.1	38.1	41.9	36.1		
				→	23.0	A = 23
			→		21.7	
		→			24.0	
	→				23.0	

Source: Manufacturers specifications and calculations made.

In addition, the frequency band spectrum for these workers is shifted substantially downward with respect to the Burns-Litter criterion. This finding can be seen by inspection of Figure 9 (I through XI), bottom lines. In Figure 9, the attenuated bands were achieved by applying average frequency band attenuations of the various personal protective devices across the actual measured bands.

Table 7: Present and Attenuated Noise Levels – Workers 1 through 7

Worker	Present Level dB(A)	Attenuated Level dB(A)
1	98.5	75.5
2	97	74
3	100	77
4	95	72
5	89	66
6	95	72
7	84	61
	Present Level (Impulse Hold)	Attenuated Level (Impulse Hold)
1	101	78
2	101.5	78.5
3	100	77
4	96	73

Source: Constructed from measurements taken and calculations made

When the overall attenuation level is applied to the noise productivity nomogram, substantial savings are found. These are summarised in Table 8 for workers 1 to 7.

To Sum Up

The factory noise environment is shown to be one potentially capable of noise induced hearing impairment. In the factory under discussion, the technology/costs requirements make attenuation at the point of perception the more likely strategy. Source and path attenuation are virtually excluded on economic grounds.

When levels of attenuation are calculated and applied to a noise productivity nomogram, substantial savings are found inherent in the proposed change to the existing environment.

Table 8: Savings Calculated When Noise Attenuation Levels are Applied to the Noise Productivity Nomogram

Worker	Reduction in dB(A) Noise Level	Gain in Equal Risk Years	Reduction in % Risk for Same Exposure
	(a) dB(A) Slow Levels		
1	99 to 75	Not < 35	Not < 9
2	97 to 74	Not < 35	Not < 9
3	100 to 77	Not < 35	Not < 9
4	95 to 73	Not < 30	-
5	89 to 66	Not < 20	-
6	95 to 72	Not < 15	-
7	84 to 61		
	(b) dB(A) Impulse Hold Levels		
1	101 to 79	Not < 35	Not < 9
2	101.5 to 78.5	Not < 35	Not < 9
3	100 to 77	Not < 35	Not < 9
4	96 to 73	Not < 30	-

Note 1: Calculated on five years exposure
Source: Read from invented nomogram

Conclusion

This paper has presented a brief summary of the literature of permissible noise exposure limits. It has shown that although these limits are enshrined in Statute Legislation, industrial deafness remains a health and productivity cost to society. In the end, it is the workers and management themselves who must take responsibility for the preventative strategies and these groups are more likely to take the problem seriously if they are continually aware of its existence and if they believe in the inherent benefits to be won.

Devices which focus the attention of labour and management on the problem by demonstrating the extent of attainable benefits and thereby reinforcing a belief in the capture of those benefits, are themselves preventive devices. Such a device is described in this paper and its application in an industrial setting provides evidence of benefits so substantial that they are difficult to ignore.