

Change in Hearing Conservation and Legislation and Prevention of Permanent Threshold Shift

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Abstract

Change in Hearing Conservation and Legislation and Prevention of Permanent Threshold Shift

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Background:

Between 1985 and 2006 there were improvements in hearing conservation at Nyrstar Hobart Smelter, including engineering controls and the introduction of mandatory hearing protection in noisy areas.

In 1996 there was a change to Tasmanian legislation regarding compensation for hearing loss, so that compensation was based on audiometric criteria.

Objectives:

To examine the effect of changes to hearing conservation programmes and legislation on the rate of hearing deterioration in employees of Nyrstar Hobart Smelter.

Methodology:

1. The audiograms of 224 Employees of the Nyrstar Zinc Smelter were compared between two 10-year time periods (1986-1996 and 1996-2006) to determine if there is a difference in the incidence of NIHL diagnoses.

Null hypothesis 1: That there is no difference in the incidence of NIHL diagnoses between the first and second 10 year periods

2. The audiograms were further analysed to determine the incidence of NIHL diagnoses at different plants (Roast/Acid/Wharf, Leach/Purification, Electrolysis, Casting) within the site. Null hypothesis 2 – That there is no difference in the incidence of NIHL diagnoses between the areas of the site

Results:

Overall 22.6% of smelter workers met the criteria for NIHL in the 10 year period before 1996. 28.5% of workers met the criteria NIHL in the 10 year period post 1996. Therefore there was no significant difference in the rate of NIHL between the two time periods ($p=0.4864$).

The proportion of employees in the Roast and Leach plants meeting the criteria for NIHL actually was higher in the latter time period, but the difference was not statistically significant ($p= 0.494$, $p=0.0983$). The proportion of employees diagnosed with NIHL showed a mild improvement in the Casting and Electrolysis plants and other miscellaneous staff, but again was not statistically significant ($p=0.89$, $p=0.09$, $p=0.99$).

No part of the plant showed a significant difference in the proportion of employees diagnosed with NIHL compared with the population as a whole.

Discussion:

Noise Induced Hearing Loss is a major cause of occupational morbidity. This study found no significant difference in the frequency of diagnosis of NIHL between two subsequent decades. This suggests no significant impact of two known significant changes over the period - a combination of improved hearing conservation programmes at the worksite and changes to legislation on noise-induced hearing loss.

Preface

The experimental part of this thesis consists of a retrospective observational study of 214 individuals at a Zinc Smelter, analysing the incidence of diagnoses of Noise Induced Hearing Loss in two 10-year periods, 1986-1996 and 1996-2006. A comparison of the two time periods is carried out, to attempt to analyse the effects of a legislation change in the middle of the two periods and progressive improvements in hearing conservation programmes and engineering changes across the plant.

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1. Introduction

Noise induced hearing loss (NIHL) is a major compensable industrial disease in Australia. Apart from the cost in compensation, NIHL also has indirect costs in absenteeism, contribution to accidents and poor work performance¹. This paper details the theoretical and practical background to NIHL, the current situation with regards to legislation and compensation in Tasmania, and provides an analysis of the effectiveness of hearing protection at the site of a major industry.

2. Background

2.1 Pathophysiology of Noise Induced Hearing Loss

2.1.1 Physics of Sound

Sound is produced by vibrations that result in the alternating compression and rarefaction of the surrounding air. This may be due to the movement of loudspeakers or vocal cords for example. This disturbance of the air radiates outwards from the source of the noise as a pressure wave with alternating peaks and troughs of pressure.

The frequency (number of cycles of pressure change per second) determines the pitch (high or lowness) of the sound. Frequency is measured in Hertz (Hz) which is cycles per second. The human ear can hear frequencies of 20 to 20,000Hz.

The amplitude of the wave (i.e. the maximum change of air pressure) determines the loudness of the sound. Loudness is measured in decibels, which is a ratio defined as:

$$20 \log P_t / P_r$$

where P_t is the test pressure; and

P_r is the reference pressure of $20\mu\text{N}/\text{m}^2$, which is the sound pressure required to make a sound between 1000 and 3000 Hz just audible to the normal human ear.

This logarithmic equation means that a sound with pressure 10 times greater than reference would equate to 20dB of loudness, and a sound with pressure 100 times greater would equate to 40dBⁱⁱ.

2.1.2 Anatomy and Physiology of the Human Ear

The human ear consists of the external ear (the pinna and ear canal and the tympanic membrane), the middle ear (containing the ossicles – malleus, incus and stapes), and the inner ear (composed of the cochlea and vestibular apparatus). The pressure wave of sound hits the tympanic membrane, which vibrates. The sound is then transmitted through the middle ear by

the small bones – the ossicles and is transmitted to the inner ear via the footplate of the stapes bone on the oval window.

The cochlea is the organ of hearing. It consists of a bony canal that contains three fluid-containing compartments and contains the sensory transduction apparatus, the organ of corti. The stapes bone lies on the oval window, and the motion of the tympanic membrane is transmitted through the ossicles, and through the footplate of the stapes bone, the motion is transmitted as a pressure wave in the fluid of the cochlea.

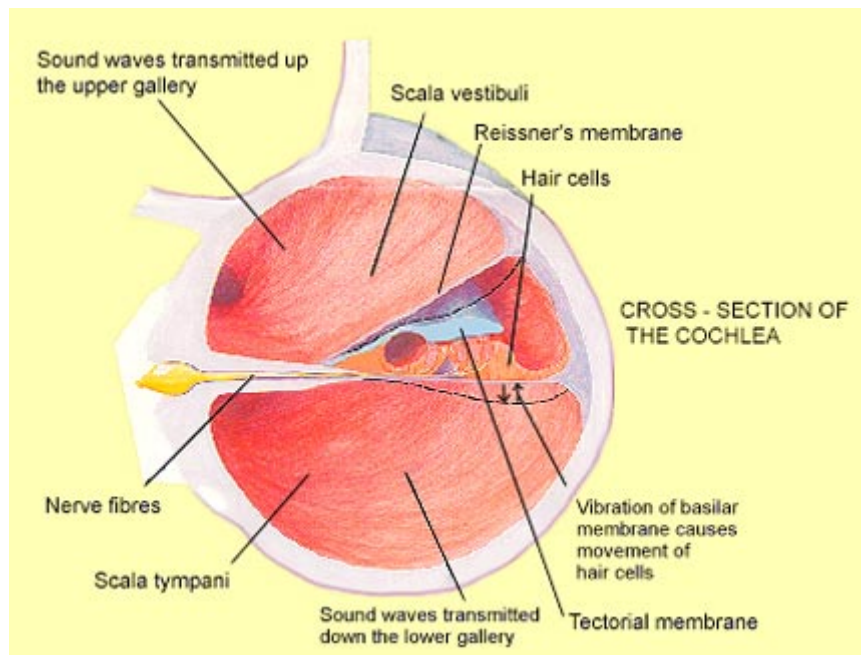


Figure 1. The Cochlea
(from www.safetyline.wa.gov.au)

The organ of corti lies on the basilar membrane, and this movement of fluid, within which it lies, stimulates the movement of the basilar membrane, and hence, the organ of corti.

The organ of corti itself consists of the sensory cells of the ear, the “hair cells”. The movement of fluid caused by a particular frequency of sound causes movement of a particular section of the basilar membrane, and hence a particular set of hair cells.

On the top of each hair cell are stereocilia, which give the cells their hairy appearance. The tips of the stereocilia are embedded in the overlying tectorial membrane. When the basilar membrane moves in response to the transmission of sound, the hair cells are bent, because

they are fixed to the tectorial membrane. The back-and-forth movement of the hair cells in response to the oscillating fluid causes biochemical changes in the cell such that the hair cell sends a signal to the underlying nerve cells.

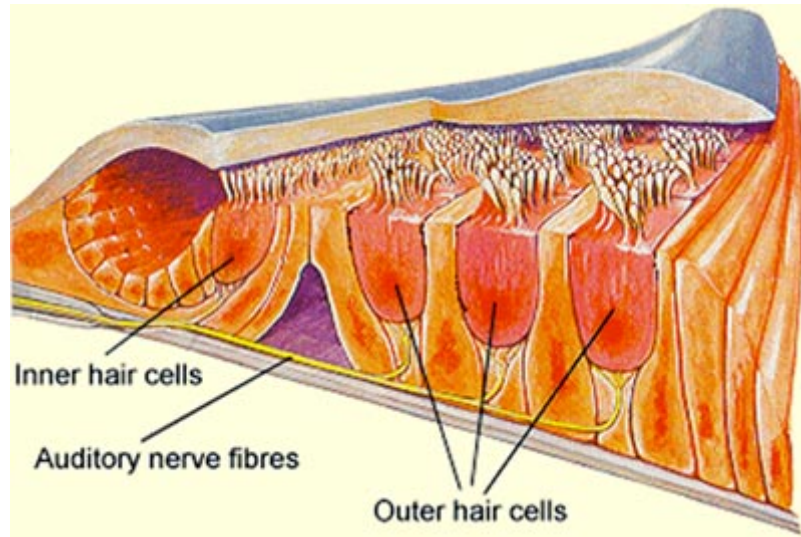


Figure 2. The organ of Corti
(from www.safetyline.wa.gov.au)

The end result is that oscillatory changes in the air due to sound in the external ear are transmitted as oscillatory movements of the tympanic membrane and bones of the middle ear, and thence as oscillatory movements of the fluid and basilar membrane of the inner ear, thence as oscillatory movements of the stereocilia of the hair cells, and subsequently as oscillatory release of signals by the hair cells to the nerve cells, and ultimately as oscillatory signals in the auditory nerve to the brain.

Different frequencies (i.e. pitch) of sound cause different shape of the wave of movement along the basilar membrane, so that each different frequency stimulates a different part of the basilar membrane. This is how the ear differentiates between different frequencies.

2.1.3 Pathology of Hearing Loss

Hearing loss may, of course, be a result of causes other than that of occupational noise. Hearing loss caused by exposure to non-occupational noise is called sociocusis, and includes recreational and environmental noise.

Combined exposures to noise and certain physical and chemical agents such as vibration, organic solvents, carbon monoxide, ototoxic drugs and certain metals, have synergistic effects on hearing loss.

Some sensorineural hearing loss occurs naturally because of aging – this is termed presbycusis. Other causes of sensorineural hearing loss include smokingⁱⁱⁱ, other chemical damage (such as some drugs such as aminoglycosides), and environmental agents.

Conductive hearing losses are usually due to diseases of the outer and middle ear and generally affect the lower spectrum of frequencies.

2.1.4 Pathology of Noise Induced Hearing Loss

Prolonged exposure to noise can damage the hair cells, the blood vessels in the cochlea, the stria vascularis (the part of the cochlea which produces fluid) and nerve endings in the cochlea.

The initial damage is to the hair cells, particularly those along the basal turn of the cochlea – this being the area associated with perception of high frequency sound. The hair cells have been shown to swell with loud noise and ultimately the cells are destroyed. The hair cells do not have the ability to regenerate and hence damage by noise is irreparable^{iv}.

Similar cellular changes have been demonstrated in the nerves supplying the cochlea, although it appears this occurs later.

NIHL can occur without hair cell death however. It has been shown that in areas of the cochlea, particularly in the area responding to low frequency sound, evidence of NIHL can be demonstrated with preservation of hair cells. Ultrastructural changes may be evident, however, including damaged stereocilia (responsible for the cochlear mechano-electrical transduction), changed F-actin level (a main component of hair cell membrane skeleton), and reduced cellular energy metabolism^v.

Studies have also shown that high noise levels disrupt the vascular supply to the basilar membrane. This reduces the oxygen supply to the cochlea.

There is also suggestion that there are mechanical and metabolic factors that may contribute to noise induced hearing loss.

2.1.5 Symptoms of Noise Induced Hearing Loss

Noise induced hearing loss tends to affect the higher frequencies of hearing initially. Loss at these frequencies is characterised by the disruption in the ability of the person to distinguish softer sounds such as high-pitched voices. For example, the person may have difficulty distinguishing between some high-pitched consonants such as *fish* and *fist*^{vi}. Early on, however, there is often no noticeable change in hearing and a hearing deficit is only revealed on formal testing.

Since most noise exposures are symmetric, the hearing loss is typically bilateral, however if the noise exposure has been related to a particular position such as a rifle during shooting or for example in a pilot seated at one side of a cockpit in a twin-engined aircraft, there may be a loss favouring the ear that is on the side of the noise exposure.

2.2 Evaluation of Hearing Impairment

2.2.1 Audiometry

Hearing loss may be diagnosed by a number of mechanisms, the commonest being a combination of clinical history and evaluation by audiometry.

Audiometry measures the hearing threshold at different frequencies (i.e. the softest sound that can be heard at each pitch). Typically tone levels are increased in volume until the person recognises the sound. This is typically recorded at frequencies of 500, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz. The end result is a graph called an audiogram, which depicts hearing loss across the different frequencies. Hearing levels of 20 dB or below reflects normal hearing. Hearing threshold greater than 20 dB reflects hearing loss.

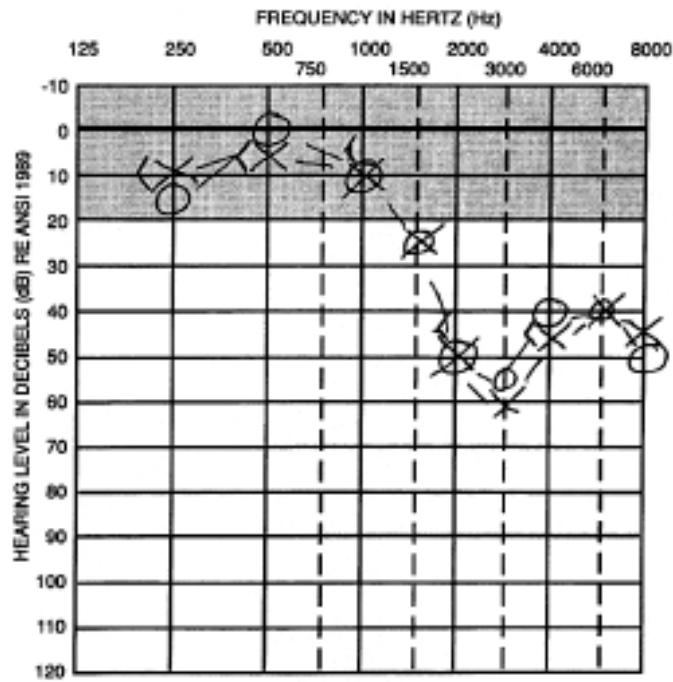


Figure 3. Audiogram showing Noise Induced Hearing Loss
 (From www.dizziness-and-balance.com)

Hearing deficits due to Noise Induced Hearing Loss are early on typically shown as a loss at 4000 Hz^{vii} with preservation at higher frequencies. As the hearing loss becomes worse the ‘notch’ at 4000 Hz becomes deeper and begins to include hearing loss at surrounding frequencies. The exact location of the notch depends on multiple factors including the frequency of the damaging noise and the length of the ear canal. The 4 kHz notch, whilst generally held to be pathognomic of NIHL^{viii}, is not always present in audiograms, or if it is, it is not always obvious. There is also great inter-rater variability when assessing whether a notch is or is not present.

Noise exposure alone usually does not produce a loss greater than 75 decibels (dB) in high frequencies, and 40 dB in lower frequencies. However, individuals with superimposed age-related losses may have hearing threshold levels in excess of these values.

The rate of hearing loss due to chronic noise exposure is greatest during the first 10-15 years of exposure, and decreases as the hearing threshold increases. This is in contrast to age-related loss, which accelerates over time

There are other means by which NIHL can be tested such as speech discrimination tests and auditory brain stem response. These tests are outside the scope of this project and as such will not be detailed.

2.2.2 Permanent and Temporary Threshold Shift

The increase in dB required to elicit a response from baseline in an audiogram is termed a “Threshold Shift”. For example, a baseline audiogram may record the threshold in the left ear at 4 kHz as 20dB. An audiogram some time in the future may then measure the threshold in the left ear at 4kHz as 40dB. It would be said then that there was a 20dB threshold shift between the baseline and subsequent audiogram.

There may be a temporary threshold shift which occurs immediately after exposure to noise, which resolves within hours of being removed from the source of noise – the hearing threshold returning to its normal value.

A threshold shift may become permanent with repeated exposure to noise over time – and this threshold shift does not return to normal hearing threshold on removal from the source of noise. This is the audiological sign of permanent hearing damage.

2.3 Interrelationship between Noise Induced Hearing Loss (NIHL) and Age Related Hearing Loss (AHL)

One of the difficulties in the diagnosis of noise induced hearing loss is differentiating hearing loss due to noise from that due to ageing – a condition termed ‘presbycusis’. In presbycusis, however, the pattern is that the loss tends to be more around 8000 Hz and there is no notch at 4000 Hz.

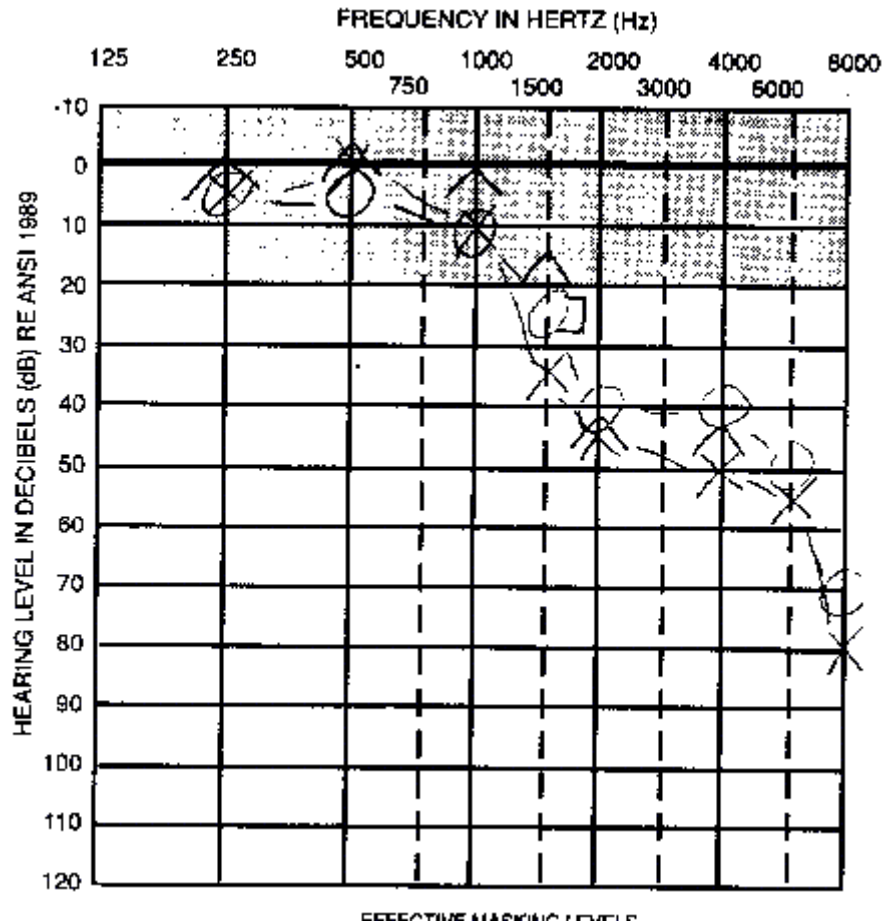


Figure 4 – Hearing Loss Due to Presbycusis
 (From www.dizziness-and-balance.com)

In a recent review of longitudinal hearing loss data from a large cohort of men in the Framingham Heart Study, Gates et al. (2000) observed that, in ears with presumed cochlear damage from previous noise exposure, subsequent hearing loss progression with age was exacerbated at frequencies outside the original NIHL. This observation suggests that ears with noise damage age differently from those without^{ix}.

Lee et al (2005)^x in a longitudinal study of pure tone thresholds in elderly people, found, however that whilst a positive noise history was associated with higher initial threshold levels, it did not have a significant effect on rate of threshold change in subsequent years. This finding suggests that pre-existing cochlear damage due to noise does not appear to potentiate any future hearing loss due to presbycusis. Interestingly, they found that whilst higher initial thresholds at high frequencies were associated with an increased rate of threshold change at lower frequencies, subjects with higher initial thresholds at mid to high frequencies actually had a slower rate of decline at these frequencies. This they concluded was due to a ‘ceiling

effect' at the higher thresholds. For example, damage at 6-8kHz was likely to be associated with an increased rate of threshold change at frequencies of 0.25-2.0kHz, but a slower rate of change at 8kHz.

One of the main differences in the two studies seems to be a more prominent 4-6kHz notch in the Gates study compared with the Lee study.

NIOSH notes that on an individual basis, although many people experience a decrease in hearing sensitivity with age, many others do not. In addition it notes that most data studying presbycusis has been sourced from population data. NIOSH therefore recommends against age correction on individual audiograms, as doing so may overestimate the expected hearing loss in some, and underestimate it in others.

In particular, NIOSH^{xi} notes that “Although many people experience some decrease in hearing sensitivity with age, some do not. It is not possible to know who will and who will not have an age-related hearing loss. Thus applying age corrections to a person’s hearing thresholds for calculation of significant threshold shift will overestimate the expected hearing loss for some and underestimate it for others, because the median hearing loss attributable to presbycusis for a given age group will not be generalisable to that experienced by an individual in that age group. The data on age-related hearing losses describe only the statistical distributions in populations..... However common, ‘age correcting’ is and regardless to the extent to which it is applied, is technically inappropriate to apply population statistics to an individual. Each age correction number is nothing more than a median value from a population distribution. In age-correcting an audiogram, the underlying assumption is that the individual value is given the 50th percentile, when in fact the 10th or 90th percentile may be the correct value. Thus age-correction formulas cannot be applied to determine with certainty how much of an individual’s hearing loss is due to age and how much is due to noise exposure”.

2.4 Other causes of hearing loss

Conductive hearing loss

Conductive hearing loss occurs due to either congenital or acquired conditions typically of the external or middle ear such as otosclerosis, glue ear, or perforation of the tympanic membrane.

The pattern of the audiogram differs significantly from that of the sensorineural loss of NIHL or presbycusis, as the frequencies involved are the lower frequencies of the audiometric spectrum and is thus quite easily distinguished from sensorineural loss unless there is a mixed picture.

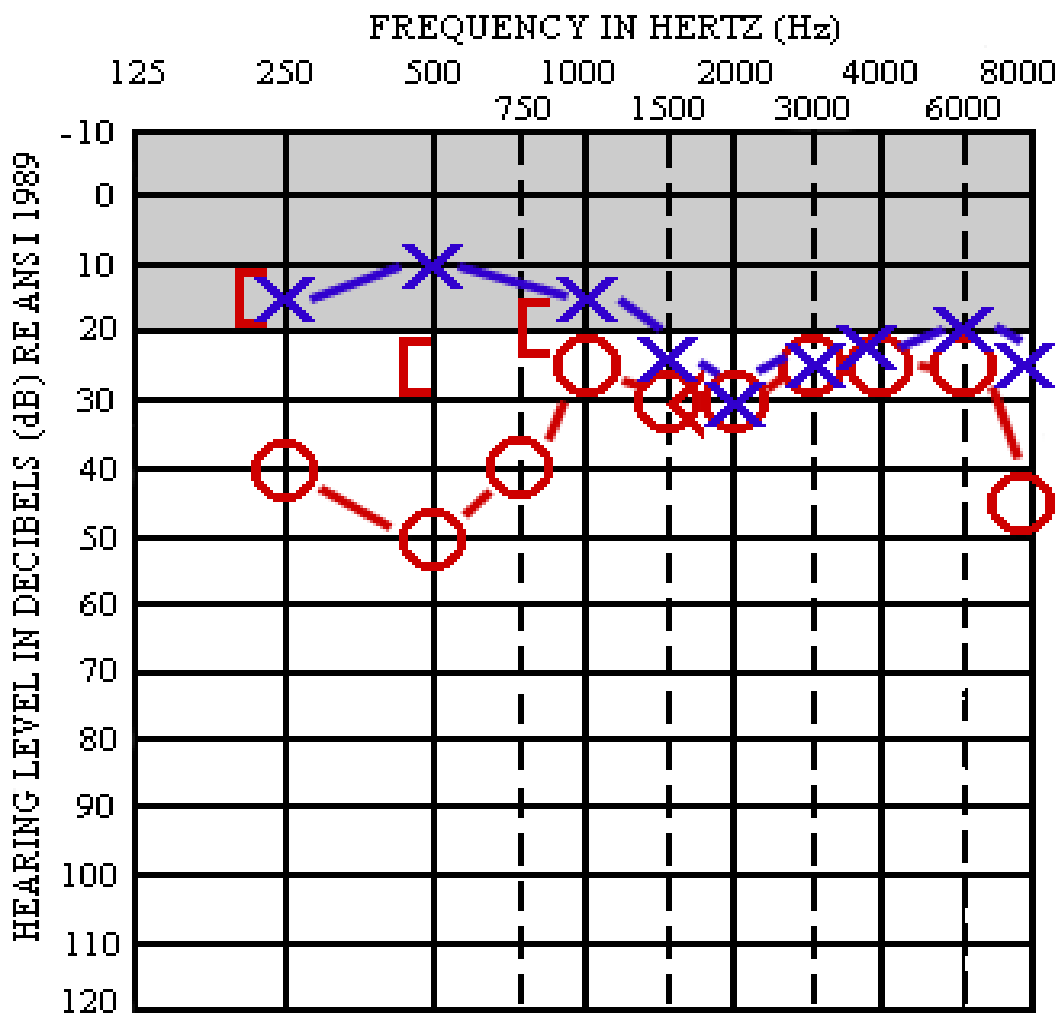


Figure 5 – Audiogram of Conductive Hearing loss

From www.dizziness-and-balance.com

2.5 Audiometrically defining NIHL

2.5.1 NIOSH Criteria

The US National Institute for Occupational Safety and Health (NIOSH) published in June 1998 Revised Criteria for a Recommended Standard for Occupational Noise Exposure. The common protection goal is the preservation of hearing for speech discrimination. In this, a number of different criterion for significant threshold shift were discussed, the recommended criterion being:

An increase of 15dB in the hearing threshold level (HTL) at 500, 1000, 2000, 3000, 4000 or 6000 Hz in either ear, as determined by two consecutive audiometric tests.

This criterion was noted to have the advantages of a high identification rate and a low false-positive rate.

A previous criterion considered a worker to have a material hearing loss only when his or her average HTLs for *both* ears exceeded 25dB at the 1000, 2000 and 3000Hz. The use of lower frequencies only was considered to provide a poorer prediction of hearing disability in terms of specificity, sensitivity and overall accuracy, when compared with inclusion of 4000Hz. The 4000Hz frequency is recognised as being both the frequency most sensitive to noise and important for hearing in noisy conditions.

Inclusion of hearing loss at the 6000Hz frequency has also been debated and studied. 6000Hz is also sensitive to early changes in hearing loss from noise. Exclusion of this frequency reduces the number of 'flags' (i.e. initial tests reaching the criteria for a diagnosis of NIHL) but does not reliably influence the number of true positive tests, thus NIOSH recommend its inclusion in screening.

NIOSH recommends that if a drop of 15dB at any of the frequencies from 500 to 6000Hz is noted, an immediate retest be conducted and if the drop persists, the test be considered as having met the criterion for a significant threshold shift and the worker be rescheduled for a further repeat test in 30 days, with the 30 day confirmatory audiogram be conducted after a 12 hour noise free period.

In addition, as has already been described above, the standard recommended against age correction on individual audiograms, saying the practice is not scientifically valid.

2.5.2 ASCC (NOHSC) Criteria

The Australian ASCC (previously NOHSC), in NOHSC:2009(2000) recommend further evaluation of audiograms when the deterioration in hearing threshold level between the initial reference audiogram and any subsequent audiogram equals, or exceeds, 15 dB at 3,000 Hz, 4,000 Hz or 6,000 Hz.

2.5.3 Study Definition

For the purposes of this study, the definition of NIHL was defined as:

An increase of 15dB in the hearing threshold level (HTL) at 500, 1000, 2000, 3000, 4000 or 6000 Hz in either ear, above 20dB.

This criteria was adopted to reflect the NIOSH criteria, with the exception that the requirement for a change in two consecutive tests was not fully adopted. The reasoning for this was that firstly, the Australian ASCC guidelines did not require this, and the study wanted to reflect as closely as possible the criteria relevant for the country in which the study was carried out. Secondly, there were a number of individuals, particularly those hired towards the latter part of the second cohort, who had only had an initial and one further biennial audiogram conducted. These individuals would have been excluded from the study should two consecutive threshold changes have been required.

2.6 Audiometric monitoring as part of a Hearing Loss Prevention Programme (HLPP)

Audiometric monitoring is a crucial component of a HLPP, as it biologically measures whether NIHL is being prevented. NIOSH recommend that audiometry be conducted at the end of the working day in order to detect temporary threshold shift (TTS) – taking the view that this is a precursor to permanent threshold shift (PTS), and thus detecting TTS should be a stimulus for action to reduce noise exposure, and that audiometry measured at the beginning of the working day may fail to identify workers who are not adequately protected from noise – as the TTS would likely have resolved.

2.7 Claims and cost of Occupationally Induced NIHL

Access economics in 2006 produced a report looking at the financial cost of NIHL in Australia. Sourcing the National Data Set for Compensation Based Statistics via an OASCC special data request, it noted the number of paid workers compensation claims by year 1998-2003:

| Year | Hearing Compensation Claims |
|-------------|------------------------------------|
| 1998 | 6,156 |
| 1999 | 4,305 |
| 2000 | 4,213 |
| 2001 | 3,973 |
| 2002 | 3,811 |
| 2003 | 3,041 |

Figure 6 – Paid Workers Compensation Claims for OHL 1998-2003^{xii}

Access noted that official rates for workers compensation claims for NIHL have been falling in recent years, and they postulate that this is due to the introduction of the minimum threshold (or ‘low fence’) for eligibility for compensation being introduced during the 1990s by many governments in response to rising workers compensation claims, reducing thus the number of people able to submit a claim for NIHL.

They also note correctly that NIHL is a slow onset condition and behaves more like a chronic disease rather than an injury. They thus suggest that as exposed workers over the age of 45 will already have some degree of hearing loss, NIHL prevention acts to reduce the severity of loss for those already affected and will prevent the onset of the condition in the next generation of workers.

Access estimated that in 2005, the real financial cost of hearing loss was \$11.75 billion or 1.4% of GDP. They estimate the largest financial cost component is productivity loss, which accounts for well over half (57%) of all financial costs (\$6.7 billion).

The ASCC^{xiii} estimated that the average cost of workers compensation claims for deafness in 2001/2 was calculated to be \$6711. Therefore, for Australia, the direct cost of deafness claims for 2001/2 was calculated to be \$6711 x 4510 claims i.e. just over \$30 million.

3. Legislation and NIHL

3.1 Effectiveness of Legislation Change in Affecting Injury and Illness Prevention in OHS

Very little has been published in the literature about the effect of changes of legislation or standard on OHS performance, and most of the studies that have been published have looked more at the rates of compliance with regulations rather than the health effects. Other studies have focused more on the effect of legislation or standard change on injury and fatality prevention, rather than employee health measures.

This is most likely because legislation change is only one element of the multifactorial effects on health outcomes with many confounding variables out of which it is very difficult, if not impossible to separate the effect of legislation change from.

Bulzacchelli et al^{xiv} Looked at the effect of the introduction in 1989, by the US federal Occupational Safety and Health Administration (OSHA) of The Control of Hazardous Energy (Lockout/Tagout) Standard, which was aimed to reduce the rates of machinery-related fatal occupational injury. The standard requires employers to establish an energy control program and sets minimum criteria for energy control procedures, training, inspections and hardware. On evaluating the average annual crude rate of machinery-related fatalities in manufacturing from 1980 to 1989 and comparing this period with that from 1990 to 2001, they found that when controlling for demographic and economic factors, there was a small non-significant increase of deaths. They concluded that there was no evidence that the lockout/tagout standard decreased fatality rates relative to other trends in occupational safety over the study period. There was therefore, no obvious intervention effect of the introduction of the standard.

The authors did suggest that a lack of decline in fatalities could have been due to a low level of compliance with the standard, or that the introduced standard in 1990 may have been voluntarily complied with by employers in the years prior to the standard becoming mandatory – such guidelines having been in existence since the 1970s. They raised the issue of the necessity of finding means of enforcing compliance with a new standard, should standards be introduced.

Daniell et al^{xv} evaluated the current extent of occupational noise exposure and hearing loss prevention efforts in a broad sample of companies in one region of the United States, in order to characterise the risk for OHL 20 years after implementation of the US hearing conservation Regulations. They were, as such, evaluating programme completeness rather than programme effectiveness. In the cross sectional study, they found that despite hearing conservation regulations that required such, nearly all of the companies in their study with high rates of occupational hearing loss compensation claims had employee exposures that required a hearing conservation programme and more than half had exposures that required the employer to consider possible noise controls. They found that most companies had potentially important shortcomings in their hearing conservation programmes and each industry included companies where policies and practices were substantially incomplete. They also found that personal hearing protection was commonly under-used. They also noted a need for increased regulatory enforcement to make regulatory strategies more effective.

In other realms, however, there is some evidence for the effectiveness of changes in legislation. Ayers et al^{xvi} examined changes in the health of bar workers after smoke-free legislation was introduced in Scotland, and found that bar workers reported significantly fewer respiratory and sensory symptoms 1 year after their working environment became smoke free.

Similar outcomes have been seen throughout the world on injury prevention with the introduction of mandatory seat belt laws and the use of infant safety seats.

3.2 Tasmanian Workers Compensation Legislation

3.2.1 Legislation existing prior to 1996

In the workers compensation legislation prior to 1996, the criteria in the Tables defining the number of units of compensation that could be awarded, only listed in section 71 of the act as:

item 23 : “Total loss of hearing” being the criteria for compensation, that being equivalent to 113 percentage units; or

item 24 : “Total loss of the hearing of one ear” being the criteria for compensation, that being equivalent to 51 percentage units.

Section 73 of the Act went on to rule:

(1) Where compensation is payable to a worker under section 71 in respect of industrial deafness, the compensation payable under that section in respect of industrial deafness shall be an amount equivalent to –

- (a) if both ears are affected, such percentage of the amount payable under item 23 in the table set out in section 71 (1); or
- (b) if only one ear is affected, such percentage of the amount payable under item 24 in that table,

as is equal to the prescribed percentage.

(2) For the purposes of subsection (1), the “prescribed percentage” means the percentage of the diminution of the normal hearing of the worker concerned, reduced, where applicable, by the percentage of that diminution as is shown –

- (a) to have arisen otherwise than from industrial deafness;
- (b) subject to section 27, to have been contracted outside this State; or
- (c) to be a condition in respect of which compensation has been awarded or paid under this Act or under a law of another State or of the Commonwealth or a Territory of the Commonwealth (being a law relating to workers’ compensation).

Thus the situation as existed in the late part of the 1980s was that to obtain compensation for “industrial deafness”, a worker would have to prove complete deafness in one or both ears, and even if this was the case, compensation would be paid only for the part of the deafness that arose from industrial deafness. This realistically made it quite difficult to obtain compensation for occupationally induced NIHL under the period during which this legislation was in force.

3.2.2 Current legislation

The *Workers Rehabilitation and Compensation Reform Act 1995* came into place in 1996 and made changes to hearing loss compensation as defined in the subsequent Act detailed in Appendix 2.

The current legislation as stands was introduced in 1996 and made an act of law in 1998. The legislation holds that :

- a) the cut-off for entitlement for compensation in respect of industrial deafness is 5% binaural hearing impairment;
- b) the percentage of binaural hearing impairment is to be calculated in accordance with the Improved Procedure for Determining Percentage Loss of Hearing, NAL Report No. 118 Commonwealth of Australia, 1988 (NAL Tables)

The effect of this legislation change was that above the now promulgated 5% cut-off, compensation was now available to workers before they became totally deaf in one or both ears. This meant that theoretically, compensation for industrial hearing loss became much more freely obtainable, and at lower levels of hearing impairment. It also meant that any further NIHL could result in further compensation claims – the so called “second bite of the cherry”, if further audiometric deterioration could be proven in future.

The hypothetical effect of this change on employers would be that the employer would be potentially liable for more compensation claims under the new legislation. Theoretically therefore, there would be a stronger obligation on employers financially to minimise their exposure to claims by providing effective steps to minimise exposure to noise.

4 The Workplace

4.1 History of the Site

Commercial production of Zinc at the worksite began in 1921. The particular smelter dates back to November 1916 when a small pilot plant was built. Thereafter, it expanded rapidly and by the early 1920s, it was the world's largest zinc smelter. Today it is one of the largest zinc operations in the world and produced more than 250,000 tonnes of zinc metal during 2003 as well as other associated metals and by-products. Since the early days the site capacity has been increased and the plant sections modernised.

4.2 Plant Structure and Process

The main structure and process of the site can be divided up as follows:

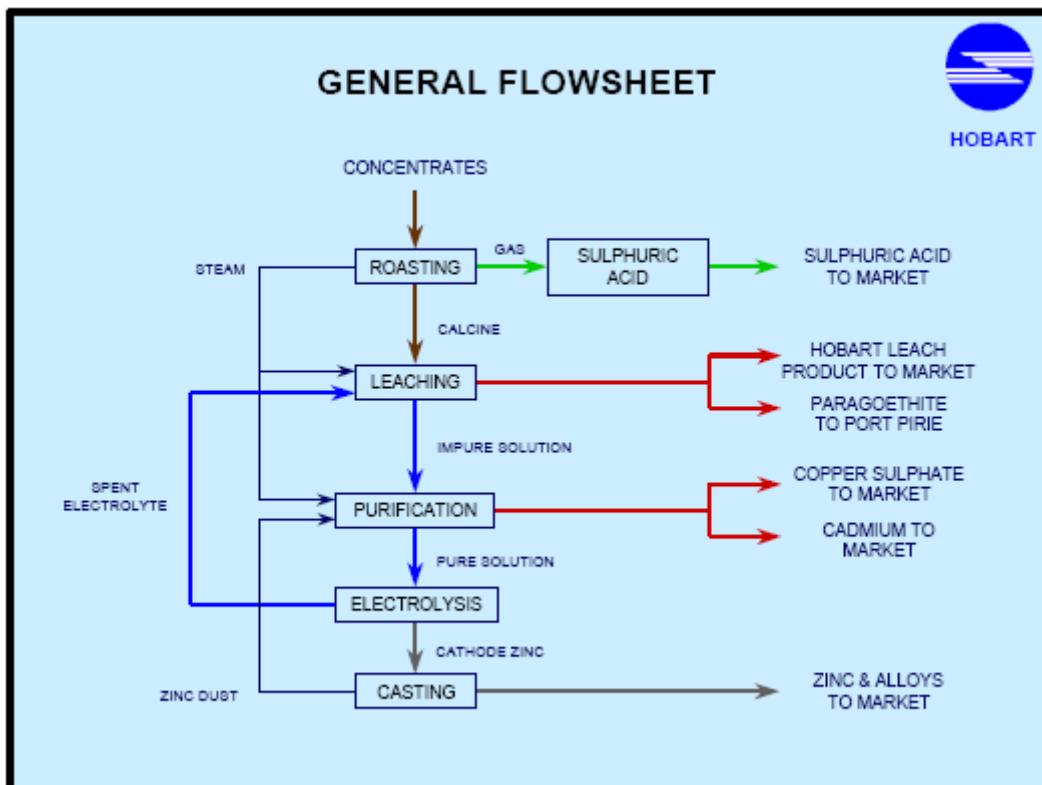


Figure 7 – Process Flow

Roasting is the process whereby raw zinc concentrate is delivered to slinger feeders via conveyor belt to fluidised bed roasters (essentially large furnaces). The aim is to convert the raw concentrate to calcine (zinc oxide), making it more readily soluble for further purification. The furnaces are large refractory brick-lined vessels, the bed of calcine being supported on a refractory grate fitted with alloy nozzles. The passage of air from a high speed blower upward through the nozzles keeps the bed in a fluidised state. The temperature in the bed ranges from 900 to 930 degrees celcius. Sulphur dioxide gas is liberated as a by-product and is delivered to the Sulphuric Acid Plant.



Figure 8 – Slinger Feeder feeding the Roaster

Leaching/Purification. The purpose of the leaching step is to dissolve as much zinc as possible from the calcine and to commence the process of purifying the zinc sulphate solution for electrolysis. At each stage, a number of reaction tanks produce a slurry, which is separated into solid and liquid. In the purification process, impurity metals are displaced from impure solution by adding metallic zinc dust.



Figure 9 – Reaction tanks and piping in the Leach/Purification Plant

Electrolysis. Metallic zinc is recovered from the pure zinc sulphate solution by electrolysis in 936 individual cells, arranged in 6 units. The spent electrolyte is recycled to the leaching stage. The electric current plates the zinc onto the aluminium cathodes. At the lead anode, oxygen is liberated and manganese dioxide forms a black scale, which falls to the bottom of the cells. Zinc deposits are stripped from the cathodes mechanically using two stripping machines.



Figure 10 – Worker moving a rack of cathodes into one of the electrolytic cells.

Casting Zinc from electrolysis is fed to three induction furnaces. Zinc dust is produced for use in the purification stage. Molten zinc is air atomised and collected via an air cyclone and baghouse. Finished products are cast by pumping molten zinc to a portable launder system for delivery either to alloying ladles, casting machines or block moulds. There are four casting machines, two are fitted with 25kg slab moulds and two with 10kg slab moulds. Large blocks from 0.9 to 1.1 tonnes are cast in two block lines.



Figure 11 – Casting worker manually stacking zinc slabs

The site runs on a continuous 24 hour basis. The shift pattern is arranged so that there are four rotating 12-hour shifts that run from 7am to 7pm and 7pm to 7am. Workers typically work two days shifts followed by two night shifts and then have four days off before returning to the next shift rotation. The particular shift pattern is, however, dependent upon job – with some positions being full time day work (Monday to Friday 8am to 5pm) – particularly in those with management, safety, engineering, laboratory or clerical positions.

4.3 Site Relevant Workplace Noise Standards and NIHL

The Tasmanian *Workplace Health and Safety Regulations 1998* (outlined as Appendix 1) adopt the Worksafe Australia Occupational Noise National Standard for exposure to noise in

the occupational environment, which is an eight-hour equivalent continuous of (L_{Aeq8h}) 85dB(A). For peak noise the standard is a peak noise level (L_{peak}) of 140dB(lin).

It has been shown that exposure to noise above 85dB(A) for extended periods can cause noise induced hearing loss. Therefore, there is an obligation by employers to reduce employee exposure to noise to below 85dB(A) L_{Aeq8h} as far as practicable

The block chart below (Figure 12) graphically shows how the 85dB(A) limit determines the permitted exposure time for different noise levels.

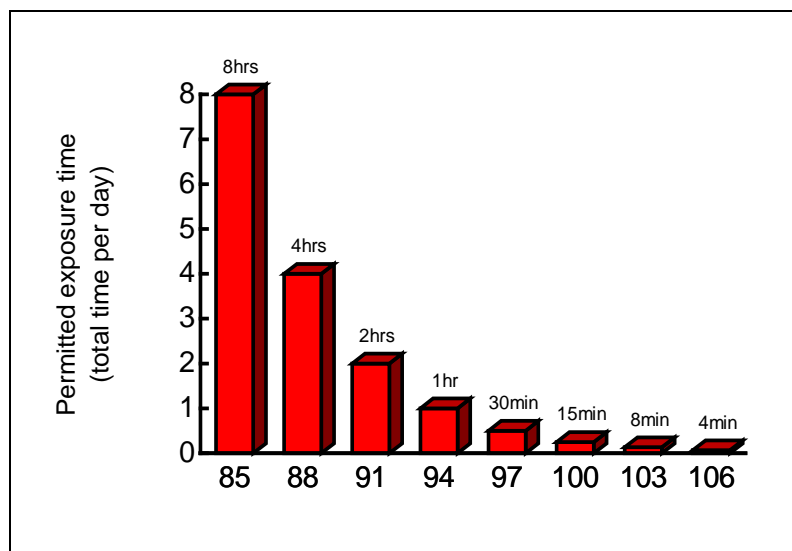


Figure 12 – Relationship between permissible noise exposure time (hrs) with noise intensity (dB)

Notably, as the noise level in the workplace increases, the exposure time, which is presumed safe, decreases accordingly. For example, a 3dB shift from an average noise level of 85dB to 88dB halves the permitted exposure time from the standard 8 hour working day to 4 hours maximum.

It is also worth noting that noise exposure standards are expressed assuming an 8 hour working day. Where longer work arrangements are observed the noise exposure level needs to be normalised to eight hours and adjusted accordingly as per Table 1.

| Shift Length, h | Adjustment to $L_{Aeq,8h}$, dB |
|------------------|---------------------------------|
| < 10 | +0 |
| ≥ 10 to <14 | +1 |
| ≥ 14 to <20 | +2 |
| ≥ 20 to 24 | +3 |

Table 1: Adjustments to Normalised Noise Exposure Level for Extended Work shifts

The permitted exposure level for the employees of the smelter, where workers are on 12-hour shifts is therefore 84dB.

The required hearing protection for exposure to increasing noise levels as adopted by Standards Australia, is outlined in table 2. The Sound Level Conversion (SLC_{80}) rating is defined as the difference between the sound level of the environment in which the Hearing Protection Device (HPD) is worn and the sound level reaching the wearer's ears. The SLC value includes a mean minus one standard deviation correction to ensure that the stated degree of noise reduction is obtained on 80% of occasions. For this reason it is called SLC_{80} , the 80 indicating the percentage protection rate. Notably as eight-hour continuous noise exposure increases, so must the degree of noise protection.

| Class | $L_{Aeq,8h}$ dB(A) | SLC_{80} Range |
|-------|----------------------|------------------|
| 1 | Less than 90 | 10 to 13 |
| 2 | 90 to less than 95 | 14 to 17 |
| 3 | 95 to less than 100 | 18 to 21 |
| 4 | 100 to less than 105 | 22 to 25 |
| 5 | 105 to less than 110 | 26 or greater |

Table 2: Hearing Protection Classification ^{xvii}

The method for selection of hearing protection when noise values exceed 85dB(A) is shown, as pertains to exposure to non-impact, continuous noise exposure.

In addition, when L_{peak} values exceed 140dB) the following selection rules apply;

-Hearing protectors of class five should be used where impulse noise is from impacts or small-calibre weapons and tools.

-Well fitted earplugs of at least class 3 in combination with earmuffs of any classification should be worn where impulse noise is from large-calibre weapons or blasting

4.4 Site noise monitoring

A contracted Occupational Hygienist conducts regular personal noise monitoring and area noise monitoring/mapping at the smelter. Areas in each of the plants are therefore identified as meeting or exceeding the 85dB continuous and 140dB impact noise standards and recommendations with respect to hearing protection are made. In addition, personal noise monitoring allows identification of particular roles that are associated with higher noise levels. Recommendations are made by the hygienist with respect to engineering controls and the use of personal protective equipment to minimise the exposure to excessive noise.

In particular, monitoring conducted throughout 2004/5 revealed:

- Monitoring of the Casting plant indicated that daily noise exposures for all employees under the conditions monitored exceed the recommended 8-hour daily average 85dB exposure standard in all production areas
- Monitoring of the Roast plant indicates that noise exposures were in most cases above the 85dB standard and a number of employees were exposed to impulse noise that exceeds the standard of 140dB.
- It was observed that employees do not comply with mandatory hearing protection signage at all times.
- In some cases, worker understanding of the risks of noise induced hearing loss was poor – when questioned some employees were observed to be without hearing protection and stated that the level of noise was not a problem “once you get used to it”.
- The personal noise exposures of the Leach plant employees were in most cases measured as below the 85dB standard with the exception of a few tasks.
- Noise monitoring in the Electrolysis plant reveal that daily noise exposures of all positions monitored exceed the 85dB daily standard . In particular positions they are subject to exposure to significant impulse noise due to frequent cell explosions.
- In general, the provided hearing personal protective equipment (PPE) of either class five ear plugs or earmuffs is sufficient to provide adequate protection, provided they are worn properly.

- Some positions or tasks were identified where due to impact noise, a combination of plugs plus earmuffs was recommended for adequate protection due to the presence of significant impact noise.

These findings support the fact that, apart from perhaps the Leach plant, working on site has significant noise exposure, and that protection against hearing damage by engineering controls or protective equipment is vital.

4.5 Site Audiometric Data Recording

As part of the ongoing biennial occupational health assessments at the site, audiometry is carried out regularly, at approximately two-year intervals. The standard practice is that the employee is interviewed briefly about their recent exposure to noise and their perception of their hearing, and then they are placed in a soundproof audiometric booth. The operator, usually the occupational health nurse, operating an audiometer, testes and records the hearing thresholds in both right and left ears at 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 6.0 and 8.0 kHz.

The data is recorded on audiometric data cards, which note the name and date of birth of the employee, their initial work area, the date of the test, and the threshold of hearing in each ear at each individual frequency in dB. The thresholds are recorded as numerals. Apart from when reviewed by an audiologist, the test results are not recorded in graphical form.

The attending occupational health medical officer reviews the audiograms during the biennial medical assessment. If there has been significant change in hearing thresholds from the previous audiogram, the common practice is to either have the audiogram repeated in the clinic at a later date after 12-16 hours of quiet, or have an assessment by an external audiologist under the same criteria of quiet.

As far as can be ascertained, there were a couple of changes of audiometers throughout the period. There were few formal records identified of maintenance of either the audiometers or the booth, however it is understood the audiometers were calibrated by a professional technician at approximately 24 month intervals.

4.6 Changes to Workplace Exposure Management

Whilst not as definitively defined in time as changes to Tasmanian legislation, there have been changes to workplace exposure management in the late 1990s as a result of which, it would be expected that would improve worker's exposure to noise and therefore susceptibility to NIHL.

In particular, hearing protection was made mandatory in operating areas during the 1990s. Previously, using earplugs or earmuffs was a recommended practice, and anecdotally it appears that PPE of this type was certainly made available at least during the 1980s. However, it appears that it was during the 1990s that hearing protection was made mandatory for all employees entering plant areas where the exposure was likely to be >85dB.

In addition, over time the plant has been modernised with new technologies being made available. In particular, during the study period, in the Electrolysis department, automatic stripping machines were introduced, which significantly minimised the requirement for operators to manually separate the plated zinc from the cathodes. The introduction of this engineering control would be expected to have lessened the overall noise exposure in the plant, and in particular the impact noise associated with the 'barring off' of the zinc.

4.7 Effectiveness of Personal Protective Equipment in preventing NIHL

For hearing protection devices (HPD) such as muffs or plugs to work effectively, they have to be worn correctly and fitted properly. As has been outlined in figure 12, even a short-lived exposure to high intensity noise can expose the employee to their maximum 'dose' of noise in a short period. This is even more so where impact noise is prevalent.

Studies have shown that if workers do not wear hearing protection for 100% of the time its effectiveness will quickly diminish. For example, wearing hearing protection for only 90% of the time will decrease effectiveness to less than one third^{xviii}. As such, there is an inverse relationship that exists between the period of time that a HPD is worn and the degree to which the HPD protects the worker from exposure.

A number of reasons exist for a worker to not wear HPD effectively, including:

- Poor fit
- Attenuation of conversational noise and difficulty with communication
- Discomfort

- Poor understanding of the risks and nature of noise exposure

Whilst in a perfect world, it is assumed that HPDs when provided will be worn 100% of the time during which exposure to noise occurs, in reality it is much less. This was born out by the observations of the occupational hygienists who were conducting noise mapping in the site, with comments in their reports such as:

“During the monitored, compliance with mandatory hearing protection signs was observed to be high. However on one occasion employees were observed to be without hearing protection, when questioned employees stated that the level of noise was not a problem “once you get used to it”. This indicates a poor level of understanding of the risks of noise induced hearing loss”^{xi}, indicating this issue is of importance.

4.8 Contribution of Non-Occupational Exposure to the amount of NIHL

One possible significant confounder in assigning NIHL to occupational causes is exposure to noise experienced in the home or during recreational activities. In some compensation schemes, some weighting may be applied for this type of exposure. Of particular significance is that whereas in the workplace, PPE may be mandatory, in the home or in recreational activities, it is not mandatory and may not be utilised – often because the significance of recreational noise exposure in contributing to NIHL is not fully appreciated.

Such exposures are controversial in their relative contribution to NIHL, however. Neitzel et al^{xx} following 266 construction workers and analysing their noise exposure levels over a year found that When compared with the high levels of occupational noise found in construction, non-occupational noise exposures generally present little additional exposure for most workers. However, they may contribute significantly to overall exposure in the subset of workers who frequently participate in selected noisy activities

4.9 The Company as a self-insurer

Tasmanian Workers Compensation Legislation^{xxi} requires employers to hold workers compensation insurance by purchasing a policy with a licensed insurer (such as QBE or Allianz) but, on special application to the workers compensation board, allows companies to

be self-insurers, dependent upon requirements such as the financial situation of the company and its commitment to workplace health and safety. This is the case for Nyrstar.

As a self-insurer, therefore, the company meets all costs associated with workers rehabilitation and compensation, including any monetary payments and ongoing medical expenses. As such, it would be expected that any change in legislation that lowered the threshold for workers becoming eligible for compensation would have a direct negative financial impact on the company directly. A similar financial effect would occur if the company was insured by an independent insurer or government insurance scheme by increase in yearly premiums and possibly excess charges, however the direct financial impact would likely be less.

5. Method

5.0 Ethics Approval

Ethics approval for the project was sought and received from the Tasmania Health and Medical Research Ethics Committee (EC00337) via the National Ethics Application Form promulgated by the National Health and Medical Research Council (www.neaf.com.au)

5.1 Data Collection

Audiometric record cards and reports from external audiometric assessments were obtained from all available medical records of employees currently and formerly employed at the plant. 575 individuals were identified. The data from the audiometric record cards and audiometric assessments were manually entered into a MS Excel spreadsheet, in the following format:

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|----|----------|-----------|----------|-----|------------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1 | ID | Date | Test Date | DOB | Sex | Date Birth | pR0500 | pR1000 | pR1500 | pR2000 | pR3000 | pR4000 | pR6000 | pR8000 |
| 2 | 1 | 24/12/87 | 12/21/87 | 30/12/63 | M | | 10 | 5 | 5 | 5 | 5 | 10 | 5 | 40 |
| 3 | 1 | 20/12/90 | | 30/12/63 | | | 10 | 10 | 5 | 5 | 5 | 5 | 20 | 45 |
| 4 | 1 | 25/7/94 | | | | | 10 | 10 | 5 | 0 | 5 | 0 | 15 | 30 |
| 5 | 1 | 07/03/95 | | | | | 5 | 5 | 5 | 0 | 0 | 0 | 15 | 30 |
| 6 | 1 | 26/10/99 | | | | | 10 | 5 | 5 | 0 | 10 | 0 | 20 | 50 |
| 7 | 1 | 21/12/99 | | | | | 5 | 5 | 0 | 5 | 5 | 0 | 15 | 35 |
| 8 | 1 | 28/11/01 | | | | | 15 | 10 | 0 | 5 | 5 | 5 | 20 | 10 |
| 9 | 1 | 17/3/04 | | | | | 10 | 10 | 5 | 5 | 10 | 10 | 25 | 45 |

Figure 13 – Excel data for study subject 1 – right ear

(left ear data not displayed for formatting purposes but is continuous to the right of this data)

5.2 Subject selection and exclusion

Of the 575 individuals identified, individuals were excluded if:

a) there was only one audiometric screening conducted.

As the study is looking at changes to threshold shift from one year to the next, only one record does not allow such an assessment to be made. This was the case if a study subject had a pre-employment medical and audiological assessment but did not end up in employment, and for some employees who were hired very close to the end of the study periods who by the end of the study period did not have a second biennial audiogram; or

b) if there was evidence of pre-existing hearing loss – defined as any increase in hearing threshold above 20dB in any of the measured frequencies.

These individuals were excluded because i) the study design looked at the incidence of new diagnoses of hearing loss, thus needing a cohort of hearing-normals at the start of the study and ii) any pre-existing hearing loss influences the subsequent rate of change in permanent threshold shift when exposed to a given 'quanta' of noise, thus influencing adversely the NIHL diagnosis rate in any individuals who already had hearing loss; or

c) If there was an obvious non-sensorineural deafness pattern to the audiogram in conjunction with a history such as middle ear disease or other ear assault not related to noise (although no such subjects were identified).

A total of 216 subjects were thus identified as eligible to enter the study, and categorised into area of work and time period as follows:

5.3 Subject Grouping

An individual was classed as working in Roast, Leach, Casting or Electrolysis if their role was determined as being limited to that area of work as determined by the medical records.

As noted above, an analysis of the company human resources data with respect to employee movements was planned, but has been unable at this time to be completed. A discussion regarding the effect on the study of being unable to perform this analysis is provided in the discussion section.

Individuals considered as being included in one of the main plants by job were operators and maintenance workers. Other workers who were not based in the Roast, Leach, Casting or Electrolysis departments, were itinerant workers, or who were not required routinely to enter operational areas, were put in the category of miscellaneous workers. These individuals included clerical and administrative staff from the main office building, and superintendent and managerial staff who, whilst attached to one of the four operational plants, had offices physically remote from the operational floor.

The study subjects were then classified into a pre or post 1996 10 year cohort, the cut-off being Jan 1st 1996. Subjects who were working at the plant from Jan 1st 1986 to Jan 1st 1996 who had initially normal audiograms were therefore categorised in the pre-1996 cohort.

Subjects who were hired after Jan 1st 1996 who had normal initial audiograms were therefore categorised in the post-1996 cohort.

5.4 Subject diagnostic classification

For the purposes of this study, the definition of NIHL was defined as:

An increase of 15dB in the hearing threshold level (HTL) at 500, 1000, 2000, 3000, 4000 or 6000 Hz in either ear, above 20dB.

The audiograms of the 216 in the study were thoroughly examined. A subject was classified as obtaining a diagnosis of NIHL if at any time over the 10 year period in which they were part of the study, their audiogram exhibited an increase of 15dB in the hearing threshold level (HTL) at 500, 1000, 2000, 3000, 4000 or 6000 Hz in either ear, above 20dB, and if further audiometric screening had been conducted, that this was sustained.

For individuals who did not show a 15dB change in HTL, they were classified as having no NIHL.

There were also individuals who had an initial 15dB increase in HTL, but subsequently their audiograms returned to, and stayed normal. It was assumed that the initial change in HTL was likely a result of temporary threshold shift or measurement error, and these individuals were considered as not having NIHL.

There were a number of individuals, joining the cohort late in their respective 10-year period, who had only two audiometric screenings conducted, and whom showed a 15dB increase in HTL in the second audiogram. By definition, these were classified as having NIHL, however their inclusion in the study is a possible source of error and the effect of these individuals will be discussed in the discussion section.

The individuals were thus classified into those with or without a diagnosis of NIHL during the relevant 10-year time period.

The proportion, or percentage of subjects in each plant being diagnosed with NIHL was therefore calculated for each cohort by plant and by the site as a whole.

5.5 Data and statistical analysis

The cohorts were analysed to determine if there was any statistically significant change in the incidence of NIHL diagnoses using the Z-test for proportions. This statistical test compares the proportions from two independent groups. The statistical testing was carried out between the two site 10-year cohorts and also between the two cohorts within each individual plant.

The audiograms of 216 Employees of the Zinc Smelter were therefore compared between two 10-year time periods (1986-1996 and 1996-2006) to determine if there is a difference in the incidence of NIHL diagnoses between the earlier and later cohorts.

- Null hypothesis: *That there is no difference in the incidence of NIHL diagnoses between the first and second 10 year periods*

The audiograms were also analysed to determine the incidence of NIHL diagnoses at different plants (Roast, Leach/Purification, Electrolysis, Casting) within the site.

- - Null hypothesis – *That there is no difference in the incidence of NIHL diagnoses between the areas of the site.*

6.0 Results

6.1 Exclusions

Of 575 individuals for whom audiometric records could be located, a resultant 216 individuals met the criteria for inclusion in the study. The exclusion rates for the different parts of the plant are outlined in Table 3:

| | Roast | Leach | Casting | Electrolysis |
|------------|-------|-------|---------|--------------|
| Total | 72 | 94 | 105 | 163 |
| Normals | 25 | 48 | 36 | 61 |
| % excluded | 66% | 49% | 66% | 63% |

Table 3: Study Exclusions

6.2 Subject Grouping

The numbers of individuals classified in each group is displayed in Table 4:

| | Roast | Leach | Casting | Electrolysis | Misc |
|-----------|-------|-------|---------|--------------|------|
| Total | 25 | 48 | 36 | 61 | 46 |
| Pre-1996 | 12 | 41 | 24 | 43 | 30 |
| Post-1996 | 13 | 7 | 12 | 18 | 16 |

Table 4: Subject Grouping

The numbers of individuals in the pre-1996 group exceeded the number in the post-1996 group, partly because a number of members of the previous cohort continued their employment into the second time period. These subjects were only considered as belonging to the first cohort – so that they were not double counted and so the average age of the second cohort was not adversely increased (thus necessitating some adjustment for presbycusis – see discussion). In addition, the plant has been streamlined over time and the number of new hires in the latter time period has been less than in earlier days of the plant.

6.3 Age distribution

The age distribution of the resultant 216 subjects is depicted in Figure 14 as the average age at entry to the study (the age at entry to the study being the age corresponding with the date of the initial audiogram).

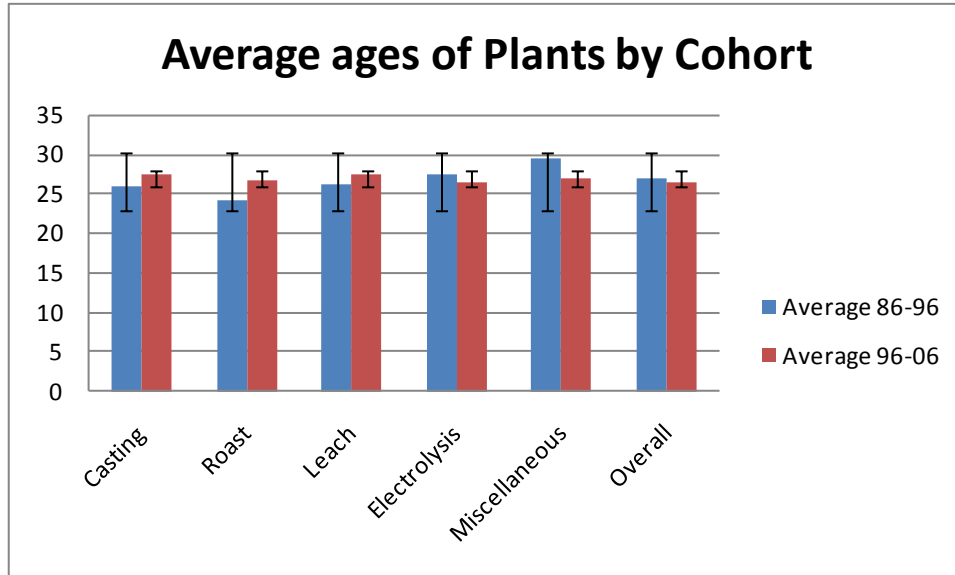


Figure 14 – Age distribution at entry to study

It can be seen that the average age on entry to the study fell within a reasonably narrow range.

6.4 Subject diagnostic classification

The individuals were thus classified into those with or without a diagnosis of NIHL during the relevant 10 year time period:

| | | Roast | Leach | Casting | Electrolysis | Misc | | Total |
|-----------|---------|-------|-------|---------|--------------|------|--|-------|
| Total | | 25 | 48 | 36 | 61 | 46 | | 216 |
| Pre 1996 | Total | 12 | 41 | 24 | 43 | 30 | | 150 |
| | NIHL | 3 | 8 | 7 | 9 | 7 | | 34 |
| | No NIHL | 9 | 33 | 17 | 34 | 23 | | 116 |
| Post 1996 | Total | 13 | 7 | 12 | 18 | 16 | | 66 |
| | NIHL | 6 | 4 | 3 | 0 | 3 | | 16 |
| | No NIHL | 7 | 3 | 9 | 18 | 13 | | 50 |

Table 5: Study subjects per plant, cohort and hearing status

There were a number of individuals whose audiograms remained normal at the end of the first time period and thus could have been included as initial normals at the start of the second

cohort and thus included in both cohorts. The advantage of including these individuals in the second cohort would be that the numbers in the second cohort would have been larger, thus increasing the power of the study. This was not done, however, as the issue of presbycusis would have become more prevalent with the first cohort's advanced age and longer history of noise exposure, thus adversely affecting the results of the second cohort.

The proportion, or percentage of subjects in each plant being diagnosed with NIHL was therefore calculated for each cohort by plant and by the site as a whole.

| | Roast | Leach | Casting | Electrolysis | Misc | Site |
|-------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Pre-1996 | 25.0% | 19.5% | 29.0% | 20.9% | 23.3% | 22.6% |
| Post -1996 | 46.0% | 57.0% | 25.0% | 0.0% | 18.8% | 24.2% |

Table 6: Percentage of Workers diagnosed with NIHL by cohort and plant

6.5 Employees by cohort and hearing status

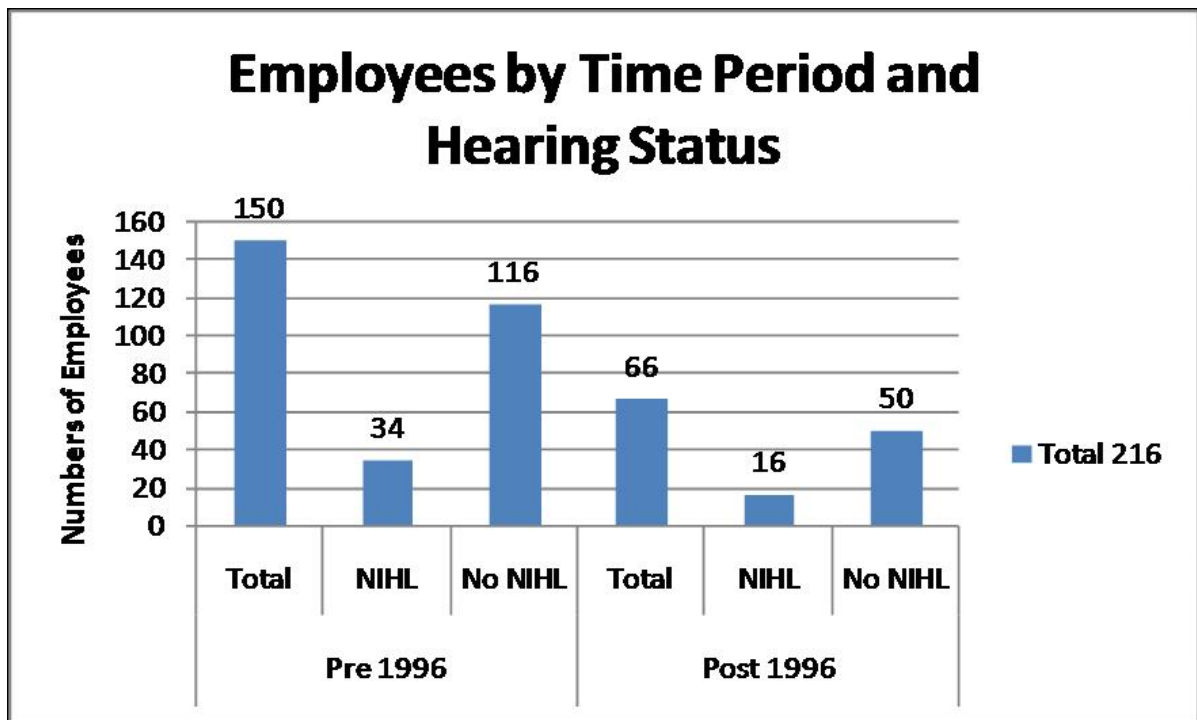


Figure 15 – Hearing status of employees by time period

In the pre-1996 cohort, there were a total of 150 subjects, of whom 34 (or 22.6%) met the criteria for a diagnosis of NIHL and 116 who remained hearing normal. In the post-1996

cohort, there were a total of 66 individuals in the cohort, 16 (or 24.2%) of whom met the criteria for a diagnosis of NIHL, and 50 subjects who remained hearing normal.

| | Total | %NIHL |
|-----------------|-------|--------|
| | 216 | |
| Total 1986-1996 | 150 | 22.60% |
| NIHL | 34 | |
| No NIHL | 116 | |
| Total 1996-2006 | 66 | 24.20% |
| NIHL | 16 | |
| No NIHL | 50 | |

**Table 7 – Statistical Assessment of Difference of incidence of NIHL in the two cohorts
(z=0.077 p=0.4693)**

As is evident from Table 7, the difference between the proportion of individuals who developed NIHL in each cohort was not statistically significant, $Z=0.077$, $p=0.4693$.

No statistically significant difference in the incidence of diagnoses of NIHL is apparent between the two time periods.

There is therefore no evidence that the change in legislation or improvements in hearing protection made any significant impact on the prevention of permanent threshold shift.

If anything, the data tends towards hearing conservation performance being slightly (although not statistically significantly) worse in the second 10 year period.

6.4 Hearing Status by individual plant

The same analysis was applied to the individual plants within the site.

The numbers of individuals in each plant in the pre-1996 cohort is displayed in figure x:

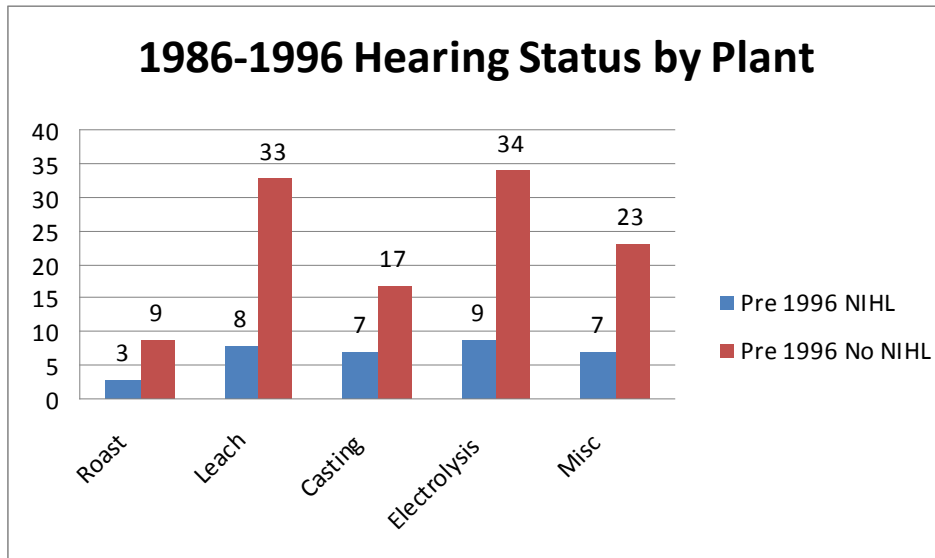


Figure 16 : Hearing status by plant – pre-1996 cohort

As is consistent with the data for the overall site, the majority of individuals did not meet the criteria for a diagnosis of NIHL in any of the plants.

The numbers of individuals in each plant in the post-1996 cohort is displayed in figure 17:

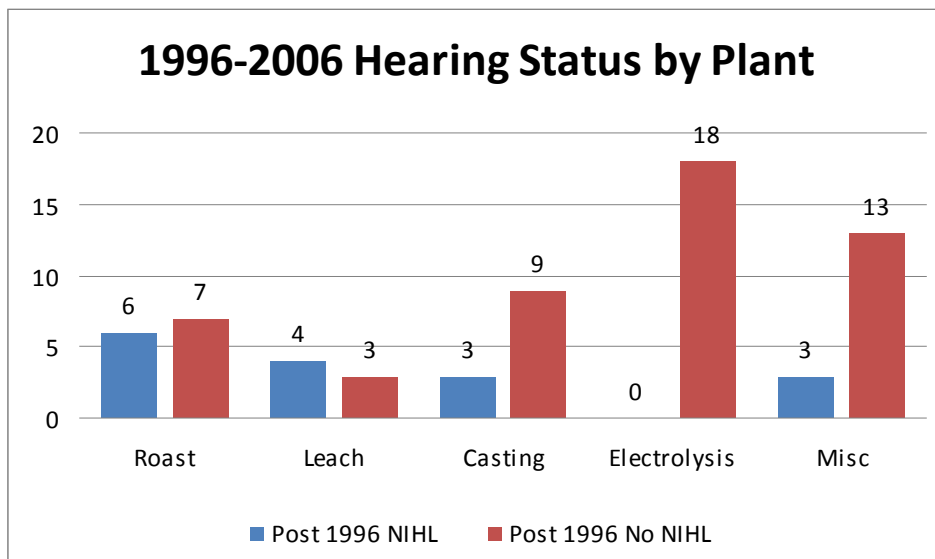


Figure 17 : Hearing status by plant – post-1996 cohort

Again, as per the site data, the majority of individuals overall did not meet the criteria for a diagnosis of NIHL. In the leach department, it is noted that more individuals met the criteria for NIHL than those who did not, however the numbers are small and little can be reliably inferred.

The proportions of employees developing NIHL in each plant were therefore determined and each plant's incidence rate in each 10-year cohort was compared (Figure 18, Table 8).

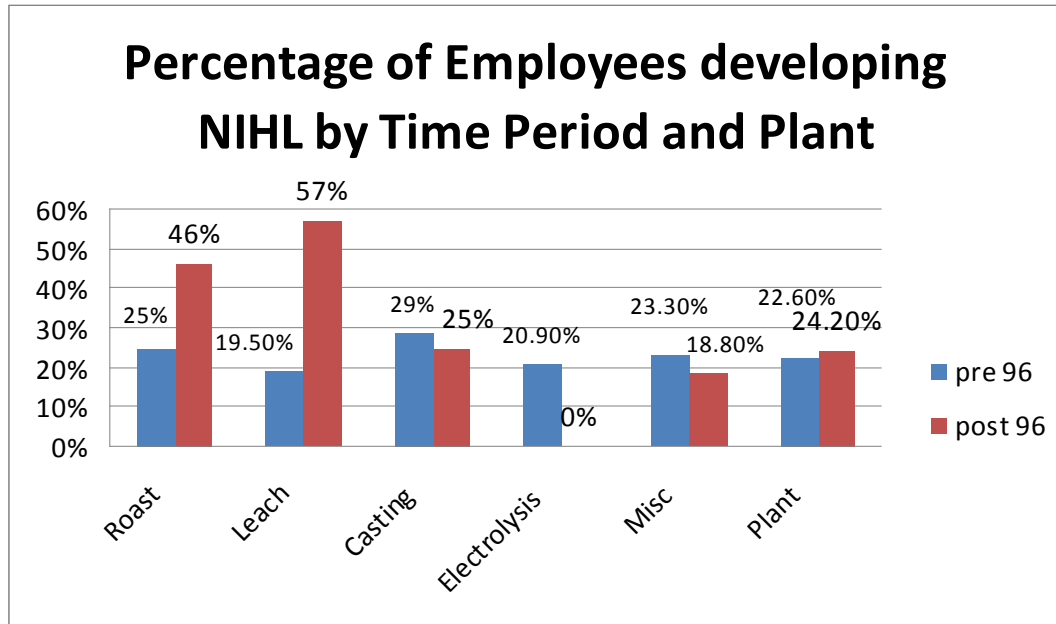


Figure 18 – Proportion of employees developing NIHL in each plant in each cohort

| | Roast | Leach | Casting | Electrolysis | Misc | Plant |
|---------|-------|--------|---------|--------------|--------|--------|
| Z value | 0.684 | 1.653 | -0.131 | 1.706 | -0.017 | 0.077 |
| P value | 0.494 | 0.0983 | 0.8958 | 0.088 | 0.9864 | 0.4693 |

Table 8 – P values for differences between incidences of NIHL comparing cohorts

As is evident from figure 18, the Roast and Leach departments appeared to perform worse in terms of hearing conservation in the second 10-year period, although this was not statistically significant (Roast $P=0.494$, Leach $P=0.0983$). The Electrolysis department was not associated with any NIHL diagnoses in the second 10 years, although this still did not reach a statistically significant difference when comparing proportions ($P=0.088$). The Casting department and the Miscellaneous category of workers made a slight improvement in hearing conservation in the second 10 year period, however again this was not statistically significant.

The Roast, Leach, Casting and Electrolysis departments were compared against the incidence of NIHL in the Miscellaneous workers. The results were not statistically significant, as outlined in table 9:

| Column1 | Roast | Leach | Casting | Electrolysis | Misc |
|----------------|--------------|--------------|----------------|---------------------|-------------|
| NIHL | 9 | 12 | 10 | 9 | 10 |
| no NIHL | 16 | 36 | 26 | 52 | 36 |
| Total | 25 | 48 | 36 | 61 | 46 |
| Z | 1.016 | 0.13 | 0.373 | 0.681 | |
| P | 0.3096 | 0.8966 | 0.7091 | 0.4959 | |

Table 9 – Comparison of Departments against Miscellaneous Workers 1986-2006

7.0 DISCUSSION

This study was designed to evaluate the effect of legislation change and improvements in hearing conservation practices in the prevention of permanent threshold shift in a particular workplace.

The results suggest there was overall no significant improvement in hearing conservation in the second 10 year period. This suggests that there was no significant effect on the change in legislation in promoting improved hearing conservation and that the improvements in exposure management also had no significant impact.

The discussion will focus on the two areas the study was designed to test – the legislation change and improvements to hearing conservation over the site, and at some of the other factors leading to bias or confounding and bias, and will end with consideration of areas for further study.

7.1 Definition of NIHL

Another factor that has a major influence on the outcome of the study is the definition of NIHL. In particular, the magnitude of the threshold shift that was accepted as diagnostic of NIHL has an influence on the results. If too little a shift is considered diagnostic, NIHL is over-diagnosed, and if too great a shift is required to assign a diagnosis – the condition will be under-diagnosed.

The criterion adopted by the study was done so as it was a generally accepted and recognised criterion.

There were other possible criteria that could have been adopted:

- i) A criterion could have been adopted that specified simply that any threshold shift of any magnitude above the level of 20dB (considered as the upper limit of human hearing) be consistent with a diagnosis of NIHL. Whilst theoretically valid, such a criteria would tend to over-diagnose, and not allow for day to day fluctuations in hearing.
- ii) A criterion could have been adopted that required the shape of the audiometric graph to have a prominent 4 kHz notch. However, as the presence of this notch is quite

variable, adopting such a criteria would have had the likely effect of under-estimating the incidence of NIHL within the cohorts.

It is important to adopt a criteria that is previously accepted as being valid rather than being arbitrary, even if modified, and it was to this extent that the modified NIOSH criteria was adopted.

In addition, it was decided not to adopt fully the criteria that NIOSH adopt, in that the shift must be sustained over two consecutive audiograms. This was done firstly for practical purposes, as it would have excluded the use in the study of individuals who had only two biennial audiograms. (Note however that including these individuals in the study may have resulted in over-diagnosis of NIHL, as a shift in the second biennial audiogram diagnostic of NIHL was not followed up in a third to confirm the persistence of the loss). The second reason for not adopting this element of the NIOSH criteria was that the Australian ASCC criteria did not require it.

7.2 Temporary vs Permanent Threshold Shift

One presumption made with respect to the study is that the increase in threshold shift in the audiograms being recorded was a permanent threshold shift.

Temporary threshold shift (TTS) is the increase in hearing threshold experienced immediately after significant noise exposure. The shift normalises some hours after noise exposure provided there is no further noise exposure. Repeated instances of TTS may lead to the development of permanent threshold shift.

Permanent threshold shift (PTS) is the permanent, irreversible increase in hearing threshold shift which occurs gradually over time in those exposed to noise.

In this study, a possible source of error is the time of the audiometric assessment. Anecdotally, in the 1980s and early 1990s, all audiograms were recorded first thing in the morning, before the employees began work, after a period of at least 12 hours away from shift – most often on the morning of the first day shift. In the latter years however, for logistical reasons, the audiograms were conducted in conjunction with the biennial medical assessments

– which occurred throughout the day, with the employees coming off shift, having already been exposed to some noise.

As the employees may have been exposed to noise up until shortly before audiometry, there is the possibility that the increase in hearing threshold measured, if any, could be attributed to a TTS related to their noise exposure earlier in the shift. The practice tended to be that if a significant shift occurred, the employee would either return to the occupational health clinic for a repeat audiogram after a period off shift, or be referred to an independent audiologist in the city for repeat audiometry, and, if necessary, more complex analysis.

To attempt to control for this as best as possible, if a subject's audiogram in one year met the criteria for assigning a diagnosis of NIHL, the diagnosis was not ascribed to that subject if a further audiogram, either soon afterwards, or in the following biennial audiogram, revealed that the threshold shift had returned back below the 15dB threshold for diagnosis.

There were a number of individuals, joining the cohort late in their respective 10 year period, who had only two audiometric screenings conducted, and whom showed a 15dB increase in HTL in the second audiogram. These individuals were counted as having a NIHL diagnosis – and as such could have introduced error in terms of over-counting if the cause of the shift was due to TTS.

7.3 Non-occupational noise exposure

Recreational noise exposure was a possible confounder not controlled for in this study. Records of recreational exposure to noise such as shooting or the use of power tools and other machinery outside the workforce was recorded fairly sparsely in the audiometric data cards, and was not of sufficient quality or quantity that such data could be reliably used to control for recreational hearing loss. What data existed certainly did not quantify in detail noise levels or precise frequency and duration of exposure.

One option that was considered was to undertake a workplace survey of those in the study, using a retrospective questionnaire about past recreational exposure to noise. Realistically, however, the utility and validity of such methods are questionable. In particular, the validity and accuracy of retrospective questionnaires about recreational activities that may have been up to 20 years prior would be unacceptably low. There would also be a degree of selection

bias caused by a likely inability or difficulty at least in locating some of the workers who have left employment at the site.

In addition, the contribution of recreational noise exposure in some studies appears to contribute minimally to total noise exposures, except for a subset of workers who participate frequently in noisy activities.

Recreational noise exposure does however remain a significant confounder and may at least partially explain why, despite improvements in noise conservation, there was no discernable improvement in the proportion of workers developing NIHL in the second 10 year cohort.

Recreational noise exposure may have lead to additional error in the potential for temporary threshold shift. There is the possibility that, if a worker had their audiogram early in the day and had been exposed to recreational noise before they came on shift, that the shift measured may have been related to the temporary effects of the recreational noise exposure. The likelihood of this being a source of error would have been proportional to the

7.4 Other causes of hearing loss

There are other possible causes of hearing loss that may have caused or contributed to an increase in permanent threshold shift.

Conductive hearing loss from middle ear disease such as otitis media or sclerosis of the ossicles is a possible cause, however this produces a pattern different to that of NIHL and if present, would have been identified and the subject selected out of the study.

Congenital hearing loss is a cause, however individuals with such loss would be expected to have abnormal hearing from birth or early childhood, and thus would not have been able to enter the study (as a requirement of the study was normal hearing on entry)

Other causes of sensorineural hearing loss that may be confounding factors include smoking, other chemical damage (such as some drugs such as aminoglycosides), environmental agents and presbycusis.

Smoking history was reasonably but not reliably recorded in the medical records, but the studies of the effect of smoking on sensorineural hearing loss are inconclusive as to the degree, and how to allow for smoking history in the analysis is unclear. If the study size was more substantial, it would be possible to compare smokers and non-smokers for change in permanent threshold shift, however the power of the study was weak as it is. This may be an area for further analysis.

It is possible that the proportion of employees who smoked may have been different between the two 10 year cohorts, in line with changes in smoking in the population generally. However, the impact on the outcome of the study is likely to be low given the above.

Presbycusis – sensorineural loss due to age – is another known confounder. In medicolegal assessment it is common to subtract a weighting to % hearing loss for age, however NIOSH, as noted earlier, recommends that this is not done as it is not valid for application to individuals, only on a population basis. As such, the analysis made no weighting for age. It is however possible that the presence of presbycusis may have lead to ‘false positives’ – i.e. attribution of NIHL where in fact the increase in permanent threshold shift was due to ageing, particularly in older members of the cohorts. Against this proposition is the fact that as noted, presbycusis is by no means inevitable or predictable – it is known that some people will get hearing loss and some people won’t. Also against this proposition is the spread of the age data. As can be seen in figure X, the average age of entry into the study was quite similar across the site and across both cohorts. It would be expected then, that the rate of decline of hearing due to presbycusis should have been fairly similar between individuals, and any differential age between cohorts should have impacted minimally on the incidence of hearing loss due to age.

7.5 Methodologic assumptions

A number of assumptions had to be made about the nature and quality of data presented due to factors related to data quality and availability

7.5.1 Employee movements

The study had to make the assumption that individuals in the study remained in the area of work for the entire period of their existence in their appropriate cohort based upon the medical records at the time of entry into the study. This was mainly because of the difficulty involved

in tracking study subject's movements over time due to the HR data records being only easily accessible by computer after 1999. Before 1999, the records of dates of transfer of employees between sites was contained in individual employee records in paper files within the HR department. To extract this pre-1999 data would be a long, laborious and difficult task which has yet been unable to be carried out due to lack of resources. It is however, at least anecdotally known, that employees in different plants tend to be quite stable in terms of their work area. Once specialising in a particular area, it is rare for individuals to be posted elsewhere. Thus the study has not made allowances for contribution of different plants to individual study subjects threshold shift.

7.5.2 Non-occupational noise exposure

The study also had to make the assumption that all permanent threshold shift was a result of noise at work. Unfortunately, the quality of data contained in the medical records about recreational noise exposure was sparse and haphazardly recorded such that it made any reliable control for it unrealistic.

7.5.3 All permanent threshold shift was due to noise

As discussed in an earlier section, a potential confounder in this study is presbycusis. However, on review of the evidence, it appeared that control for presbycusis was a) not recommended by authorities such as NIOSH and b) cumbersome.

7.6 Legislation change

One reason for the introduction of revised criteria for compensation for hearing loss in 1996 was that the ability for workers in Tasmania to successfully obtain compensation for occupationally induced NIHL was particularly difficult.

The change in the workers compensation legislation at the time meant that from 1996 onwards, the ability of employees to become successful in meeting the criteria for receiving compensation for hearing loss increased substantially.

The hypotheses rely on an assumption that the change in legislation acted as a deterrent for industry from damaging the hearing of workers, as the company would seek to minimise the injury to employees to minimise financial cost in workers compensation payouts. The results

suggest that legislation change that improves the prospect for compensation does not have at least an immediate effect on rates of employee disability.

This is particularly relevant with regards to the particular situation in Tasmania, and at this particular smelter. Unlike other countries, the workers compensation system is not funded by the government via levies or taxes.

However, it could be postulated that in terms of overall expenditure in production, the financial cost to a company of additional workers compensation payouts may not be a sufficient stimulus to make such legislation change lead to such a increase in financial risk that the cost in terms of major improvement in noise conservation measures would offset the risk of increased workers compensation payouts, particularly in a large company with workers compensation expenditure of around \$800,000 per year, with the average claim for hearing loss being only around \$6700. This is even more so with the relatively low numbers of cases of compensation being for hearing loss per year.

As outlined, it has not been very well demonstrated in the literature that there is a good correlation between the introduction of legislation or standards and improved occupational health and safety performance. One reason postulated for the lack of a clear relationship is the multifactorial nature of health outcomes in the workplace. Some disease will occur even with good workplace controls. Some of these factors have been outlined already and below and include non-occupational exposure and other factors such as smoking and age.

There is also the link between the introduction of regulation, and the enforcement of regulation that some authors have found lacking .

There is evidence that the worksite being studied certainly has taken means to comply with legislation – with personal and area noise monitoring being carried out, engineering changes being made where able, the requirement for use of protective equipment being mandatory in areas of significant noise exposure, and the ongoing biological monitoring programme in the biennial audiometric screening. What is perhaps not as evident is the efforts taken by the Workplace Health and Safety Authority in monitoring compliance with the legislation.

7.7 Improvements in Exposure Management

The main change in exposure management over the period of the study was the introduction of mandatory hearing PPE in at risk areas of the site. Other improvements were made in various parts of the site with respect to engineering changes, particularly in the electrolysis and casting areas where some processes that were once manual became automated.

Interestingly, the two areas in which the least change in the process took place were the leach and roast departments and these two departments showed the worst performance of the whole site – both noting a non-statistically significant increase in NIHL diagnoses in the latter cohorts working in those sites. It could be postulated perhaps that this may reflect that engineering controls and isolation of workers from noisy processes may be a better means of reducing audiological injury than PPE, which is consistent with the hierarchy of controls for occupational exposure.

There are a number of reasons as to why the move to mandatory PPE may not have had as significant an impact as was hoped. One reason may be the poor compliance with proper fitting and wearing. As noted previously, the protection afforded by PPE decreases dramatically in proportion to the length of time not worn whilst in a noisy environment. It was noted in the noise monitoring by the occupational hygienist that wearing of PPE was at times inadequate and that some employees showed poor understanding of the risk of noise in the workplace. If these factors were inherent across the site, it would lead to a decreased effectiveness of engineering controls and PPE, and an increase in permanent threshold shift across the site. If these factors were plant specific, it would lead to a poorer performance in the particular plant in hearing protection, compared with the site as a whole and compared also with the other plants.

An interesting observation was the poor performance of the Leach plant, with 19.5% and 57% of employees developing NIHL in the two 10-year cohorts, despite, at least from the 2004/5 noise surveys carried out, the Leach department having the least noisy profile of the plant. Again this may have been due to a degree of complacency on the part of the Leach subjects. Working in a relatively quieter environment, but still exposed to impact noise, the employees may have been less diligent about wearing PPE whilst working, even though hearing protection was mandatory throughout the plant.

Study Design Related Factors

7.8 Low numbers – poor power of study

Power in an observational study is a measure of the size of the sample required to reliably detect small to moderate but clinically significant differences between groups, as the size of a study influences the magnitude of the P value. The larger the sample size, the more readily a study can detect small differences between groups. Ideally, the sample size of the two time-based cohorts in this study would be much larger, however, the number of subjects was limited by the number of employees who had discoverable audiometric records, and also by the number of employees who had normal hearing at the start of each period of observation.

As the study currently exists, due to the low numbers, the development of even one or two cases of NIHL in an area made a significant impact on the proportion of employees with the diagnosis. This is particularly so, for example, in the Leach department in the post-96 cohort, where there were only 7 individuals in that group, 3 of whom remained hearing normal, and 4 of whom were diagnosed with NIHL. The proportion with NIHL was thus 57%. This was not statistically significant. If only 2 more individuals had been diagnosed with NIHL, the proportion would have been 85%. If the number of individuals in the Leach cohort had been 70, with 40 having NIHL, the corresponding Z value would have been 3.664 and the p value would have been 0.0002, a statistically significant result.

Thus the low numbers of subjects in the study contributed significantly to the lack of any statistical significance in the results.

7.9 Lack of control for movement of employees

The lack of control for employee movement raises the possibility of error due to inaccurately attributing NIHL to the correct plant.

The way in which the human resources records were kept created issues with the ability to control for the effects of movement of employees from plant to plant within the site over time. After 1999, records of employment were computerised and relatively easily accessible, however prior to 1999, employee records were kept in paper files. Tracking employee movement over the study was therefore going to be a very labour intensive and time consuming task – time and resources which neither the study author or others were able to spend.

Anecdotally, it is known that it is uncommon for employees to shift plants. Once employed by the company, the employees become operators in a particular plant, become specialised in that area, and rarely change plants. The most common occurrence that would necessitate a change in plant would be for rehabilitation purposes – for example where an employee becomes injured and is required to be re-deployed to another area where the physical tasks are less onerous.

The medical records did in themselves usually, although not always, record the employee's job and work area, although relying on the medical records would be inaccurate as audiometric screening is only conducted once every 2 years. Thus, for example, someone could have had a medical in November 1988, where they had been working in the Leach department, and a medical in November 1990, with the records indicating at the time they were working in Roast. There would be no indication, however, of the exact date of transfer – which could have been any time during that two year period. Utilising the medical records for this purpose would have raised the possibility of inaccurately weighting a particular plant with NIHL.

Going forward, it is intended to eventually track the movements of the employees, and apply the data to the study to more accurately weight the contribution of different departments to NIHL.

7.10 Sources of Bias

Selection Bias

The population from which the study intended to study – that being the whole workforce at the smelter – ended up being different to the actual population studied due to the necessity of excluding over half the site employees due to pre-existing hearing loss or other factors. There remains, therefore, another 359 individuals who were also being exposed to noise during the period of the study, and who may or may not have had increases in their hearing threshold whom the study has not considered. This affects the internal and external validity of the study, in that strictly speaking, the study only applies to 'hearing normals', whereas it is not uncommon for employees to start work at a company having already some level of PTS.

Selection bias arises from the way participants are selected for the study.

One possible cause of selection bias in this study can be termed “differential availability”. It is possible that there were individuals who were working at the site during the study period who were not included in the study because their audiometric cards and/or medical records were not available. This may be because the medical records may have been lost or misplaced. It is more likely that this would occur to records of employees who have left the workforce than those who are currently active, as the currently active employee records are in active storage in the occupational health clinic. There is anecdotal evidence that some medical records of past employees that were transferred to storage were accidentally destroyed some time in the early 2000s.

Healthy Worker effect

It is theoretically possible that those employees not in the active workforce, may be more likely to have NIHL as they may have a) left the workforce at retirement age and thus have had a longer exposure time or b) have left the workforce due to medical reasons – of which NIHL is an unlikely but possible reason. If so, there would be a negative inherent bias – that being the observed incidence of NIHL being actually lower than the true incidence of NIHL.

It would likely be recorded in HR data the names of employees who were working at the site in each particular year of the study – and thus possible to identify those for whom records were unavailable. However, as the records would still be unavailable, such an analysis would not provide any further useful information.

Loss to follow-up

Another type of selection bias present to a degree is loss to follow-up – in particular in those for whom only two audiometric assessments were carried out lead to a possible over-diagnosis of NIHL due to temporary threshold shift. In these individuals, if TTS was the cause of the initial audiometric deterioration, the result of a subsequent biennial audiogram, if normal, would make the certainty of the diagnosis of PTS based on the initial deterioration questionable. A number of individuals were also excluded from the study due to only having one audiometric screening.

Age

Another source of selection bias generally is age. There was no matching for age in each cohort. Due to the small numbers available, all employees who were hearing normal were entered into the study regardless of age. A broad consideration of the average age on entry to the study and the standard deviation, however, suggests that the effect of age should have been minimal – although the introduction of presbycusis as a possible confounder is acknowledged.

Observation Bias

In terms of classification by exposure, in effect all individuals in the study were exposed to noise in some quantity. One issue inherent in this study and partly related to the inability to control for employee movement – is that only in a very broad sense did the study control for degree of noise exposure.

It is known that some areas of the site are inherently noisier than others. Legislation and occupational hygiene principles dictate that noise mapping and exposure assessment is carried out at intervals – and such evaluation has been done from time to time. However exposure and biological effect are two related but different entities.

As noted, the employees were classified broadly into their plant as noted by job. However practically, this was the limit of their classification by exposure. There was no more specific classification by individual – and not all employees have individual noise monitoring carried out.

In addition, classification was not able to be carried out for wearing of hearing protection. In this sense, outcome is also related to the effectiveness of controls. It is interesting to postulate, for example, why the miscellaneous category of workers did not appear to fare significantly differently to the other plant workers when their exposure would be expected to be less. It is possible that whilst they may not enter noisy areas as frequently as the operators and maintenance crew, inasmuch, they may not be as used to or as diligent in wearing hearing protection. As it is known that the utility of earplugs or muffs decreases significantly with time not worn – it may go some way to explain the loss in the miscellaneous group.

Measurement error

In terms of measurement error, inaccuracies may have occurred in a number of processes in the audiometric testing process. This type of error may have potentially lead to either an over-classification or under-classification of individuals as having NIHL.

The audiometric testing may have been done haphazardly, or without due care. The subjects may not have been paying attention. The audiometric booth may have inadequately attenuated outside noise.

There were a number of 'data collectors' conducting the audiometric testing throughout the 20 years of the study. There were at least four occupational health nurses who came and went during the period, and there may have been some instances in which the occupational physician may have conducted some testing. It is not recorded whether or not any training was done either initially or recurrently, and it is possible that the testing could have been conducted in a different manner by each individual.

The audiometric data cards may have been misclassified in terms of meeting the criteria for NIHL or there may have been transcription errors in transferring the data from the audiometric cards into the excel database. One particular source of this type of error was that there was only one researcher who did all transcription and classification. This source of error could have been reduced if more than one observer was used.

Recall Bias

Recall bias is another type of bias, however in this study it is not relevant, as it is presumed that all the audiometric tests were recorded simultaneously with the testing, thus there should be no errors due to memory items.

7.11 Other Confounders

Confounders are extraneous factors that independently affect the recorded outcome. Confounding is distortion of the estimate of effect due to the effect of an extraneous factor such that there is a mixing of the effect of the study exposure with the effects of other risk factors.

Of potential confounders, other causes of increase in permanent threshold shift including presbycusis, recreational noise exposure, temporary threshold shift and smoking have already been discussed.

Of the methods for control for confounding, randomisation was not able to be done in this study – there was no control over what area or time period the study subjects found themselves in.

Confounding for the effect of pre-existing hearing loss was effectively controlled for by excluding those in the site who already had PTS above 20dB at the time of entry into the study.

Matching for age was not a practical means of controlling for confounding for a study with such small numbers, and the purpose of the study was not to compare with population incidence of hearing loss.

7.12 Areas for Further Study

The results of the study and the difficulties faced in the analysis give rise to some further areas for study and raise some other possible mechanisms for analysis.

The study as it eventuated was essentially a counting exercise in terms of analysing the differences in incidence of NIHL diagnoses between two time periods, using a defined criteria for assigning study subjects a diagnosis. This was different to the original intention. The original intention was to analyse the rate of deterioration of the employee audiograms over time. Unfortunately, whilst this may be a more reliable and more statistically accurate means of assessing the changes over time, with the resources and expertise available, this was not a practical means of analysis at this time. Issues with this method include the validity of the method, the criteria to be used for deterioration, and the use of the logarithmic basis of the dB scale. It is hoped, however, that this may be an area of future study – to look at the same question but using a perhaps more mathematically based method.

The question of the power of the study has been raised. One way to increase the power of the study, as mentioned, would be to re-assess the data, including in the second cohort of

individuals those who also were part of the initial 1986-1996 cohort, and remained hearing-normal at the end of that cohort and who continued their employment into the 1996-2006 cohort. As mentioned, a mechanism to account and control for the resulting increased age of the second cohort would have to be applied.

Collation of the HR employee movement data is ongoing, and it is hoped in the future to produce a more accurate classification of employees by job area and description than was able to be done using the medical and audiological records. Once this is done, a re-evaluation of the incidence data can be carried out with appropriate weighting for area of work.

7.13 Summary

In summary, based on the data in this study, there appears to be no statistically significant effect of more restrictive legislation and improvement in hearing conservation practices on the incidence of NIHL at this site.

The results however may not be an accurate reflection of the true relationship. The study has been limited by the small study size and other possible confounders such as temporary threshold shift and lack of the ability to accurately control for employee movements.

Further study using accurate employee movement data, designing a more intricate method to determine rate of hearing deterioration rather than a simple diagnostic classification and collation of further audiometric data into the future may refine the study design and produce a more accurate assessment of the true relationship.

Appendix 1

Workplace Health and Safety Regulations 1998 (S.R. 1998, No. 152)

Division 4 - Noise

107. Exposure standard for noise

(1) For the purposes of this Division, the exposure standard for noise is –

- (a) an eight-hour equivalent continuous A-weighted sound pressure level ($L_{Aeq,8h}$) of 85dB(A) referenced to 20 micropascals; or
- (b) a C weighted peak sound pressure level ($L_{C,peak}$) of 140 dB(C).

(2) The noise to which a person is exposed is the noise measured at the person's ear position –

- (a) in accordance with AS 1269; and
- (b) without taking into account any protection that may be provided by a personal hearing protection device.

(3) The value of $L_{C,peak}$ is to be determined by using sound-measuring equipment with a peak detector-indicator that complies with AS 1259.

108. Noise identification

An accountable person must comply with the requirements of regulation 17 in relation to noise in a workplace.

Penalty:

Level 3.

109. Noise assessment

(1) A noise assessment is to be carried out by a competent person.

(2) If a noise assessment is required by the Act or these regulations and is carried out, the accountable person must arrange for another noise assessment to be carried out no more than 5 years later.

Penalty:

Level 2.

(3) An accountable person must revise a noise assessment, or arrange for a new noise assessment to be carried out, to take account of any change in the practices or the administration of the workplace, or the installation of new plant, that may cause a significant increase in the noise to which a person is exposed.

Penalty:

Level 2.

(4) If an assessment shows that the noise in any part of the workplace is likely to cause a person's exposure to noise to exceed the exposure standard, the accountable person, within 6 months of the completion of the assessment, must develop, in consultation with any relevant person or employee affected or a person representing such an employee, a written plan of action for control of the noise.

Penalty:

Level 2.

(5) Until the written plan is implemented, the accountable person must ensure that appropriate interim measures are taken to ensure that a person in the workplace is not exposed to noise at a level that may adversely affect the health or safety of that person.

Penalty:

Level 2.

(6) The accountable person must –

(a) keep records of assessments for 5 years; and

(b) make the records available during that time to any relevant person.

Penalty:

Level 2.

110. Risk control

An accountable person at a workplace where the noise to which a person is exposed exceeds, or is likely to exceed, the exposure standard must –

(a) implement engineering noise controls, as far as reasonably practicable, to reduce the noise to which the person is exposed; and

(b) if those engineering noise controls do not reduce the noise to which the person is exposed to a level that does not exceed the exposure standard, implement administrative noise controls, as far as reasonably practicable, to reduce the noise to which the person is exposed; and

(c) if those engineering noise controls or administrative noise controls do not reduce the noise to which the person is exposed to a level that does not exceed the exposure standard, and in any case while such controls are being developed and implemented, provide to the person an appropriate personal hearing protector that –

(i) meets the requirements of AS 1270; and

(ii) has been selected according to the procedures specified in AS 1269.

Penalty:

Level 3.

111. Audiometric testing

(1) An accountable person must ensure audiometric testing of any employee, if the employee is required to use personal hearing protectors.

Penalty:

Level 1.

(2) An accountable person must ensure audiometric testing is carried out by a person who –

(a) has successfully completed a course of training listed on the register of courses maintained by the Director; or

(b) meets any other criterion specified by the Director.

(3) A person must not carry out audiometric testing unless the person satisfies the requirements set out in subregulation (2).

Penalty:

Level 2.

(4) Persons conducting audiometric testing must ensure that the procedures and equipment used are in accordance with AS 1269.

Penalty:

Level 2.

(5) The accountable person must ensure that audiometric testing required under subregulation (1) is provided –

(a) as soon as reasonably practicable after the commencement day, but in no case longer than 3 months after the employee commences employment; and

(b) at any time when reasonably requested by the safety committee or a relevant employees' safety representative or employee; and

(c) at least every 2 years or when directed by an inspector.

Penalty:

Level 2.

(6) The accountable person is to ensure that –

(a) any records of audiometric testing are kept for 20 years from the date of the last testing; and

(b) those records are made available on demand to an employee or person authorised by an employee or an inspector.

(7) The accountable person, if requested to do so by an employee, must provide the employee with copies of all audiometric testing relevant to the employee on the employee ceasing employment.

Penalty:

Level 2.

Appendix 2

Workers Rehabilitation and Compensation Act 1988

72A. Industrial deafness

(1) A worker who has industrial deafness is a person who has suffered an injury within the meaning of this Act, notwithstanding that the worker has not become totally or partially incapacitated.

(2) A worker is entitled to compensation under this Act in respect of industrial deafness which occurred after the commencement of the *Workers Rehabilitation and Compensation Reform Act 1995*.

(3) A worker is entitled to compensation for permanent impairment under this Act in respect of industrial deafness which exceeds 5% binaural hearing impairment.

(4) For the purposes of subsection (3) –

(a) the binaural hearing impairment is to be calculated by reference to the worker's hearing ability at the commencement of the *Workers Rehabilitation and Compensation Reform Act 1995*; and

(b) a worker's hearing loss is taken to have been sustained at a constant rate over the course of the worker's exposure to workplace noise in employment of a nature likely to have caused industrial deafness unless a hearing test that has been conducted since 16 August 1995, in accordance with the regulations, establishes otherwise.

(5) The amount of compensation payable under this Part to a worker who suffers permanent impairment in respect of industrial deafness is to be calculated in accordance with section 71(1).

73. Computation of industrial deafness

(1) The degree of a worker's industrial deafness is to be measured according to the worker's binaural hearing impairment.

(2) The degree of a worker's industrial deafness is not to include the percentage of deafness as is shown –

(a) to have arisen otherwise than from industrial deafness; or

(b) subject to section 27, to have been contracted outside this State; or

(c) to be a condition in respect of which compensation has been awarded or paid under this Act or under a law of another State or of the Commonwealth or a Territory of the Commonwealth.

(3) A worker's binaural hearing impairment is to be determined by the prescribed class of persons in accordance with the Improved Procedure for Determining Percentage Loss of Hearing, NAL Report No. 118 Commonwealth of Australia, 1988 (NAL Tables), as amended, or any similar report or other document as may be prescribed.

(4) The percentage of binaural hearing impairment is to be converted to a percentage of whole person impairment using the prescribed table.

(5) The regulations may prescribe the manner in which any determination or assessment under this section is required to be made and the persons or class of persons able to make such a determination or assessment.

73A. Date of industrial deafness

Notwithstanding section 3(5), in respect of a claim for compensation for industrial deafness the date of injury is –

(a) the last day of the worker's employment out of which, or in the course of which, the deafness arose; or

(b) if the worker is still in that employment, the date the claim is made.

73B. Determination for payment of compensation

(1) A determination for the payment of compensation for a claim for permanent impairment or industrial deafness is to include a statement of the percentage of the whole person impairment of the worker at the date of the determination.

(2) A person who makes a payment of compensation for a claim for permanent impairment or industrial deafness is to advise the Board of –

(a) the date of the determination; and

(b) in the case of a payment for industrial deafness, the degree of industrial deafness of the worker in respect of whom the payment is made; and

(c) the percentage of the whole person impairment of the worker at the date of the determination.

(3) The Board is to keep a register of all determinations for the payment of compensation for permanent impairment or industrial deafness.

References

- ⁱ NOHSC; *National Standard for Occupational Noise* [NOHSC:(1007:2000)] 2nd Edition 2000.
- ⁱⁱ Kandel and Schwartz; *Principles of Neural Science* Chap 32 p 482; Appleton and Lange 1991.
- ⁱⁱⁱ Nomura K, Nakao M, Morimoto T; Effect of smoking on hearing loss: quality assessment and meta-analysis; *Preventive Medicine*, (2005) 40:138-144.
- ^{iv} Garipay – in *Hamilton and Hardy's Industrial Toxicology* fifth edition 1998; pg 536.
- ^v Chen GD, Fechter LD.; The relationship between noise-induced hearing loss and hair cell loss in rats; *Hear Res.* 2003 Mar;177(1-2):81-90.
- ^{vi} McCunney and Meyer; *Environmental and Occupational Medicine* ed William N Rom; Chapter 101 p1349.
- ^{vii} McBride D, Williams S; Characteristics of the audiometric notch as a clinical sign of noise exposure; *Scand Audiol* 2001;30:106– 111
- ^{viii} McBride DI, Williams S; Audiometric notch as a sign of noise induced hearing loss; *Occupational and Environmental Medicine*; Jan 2001; 58, 1; pg. 46-51
- ^{ix} Gates GA et al; Longitudinal threshold changes in older men with audiometric notches ; *Hearing Research*; 141 (2000) 220-228
- ^x Lee F et al; Longitudinal Study of Pure-Tone Thresholds in Older Persons; *Ear & Hearing* 2005;26;1–11.
- ^{xi} NIOSH; *Revised Criteria for a Recommended Standard for Occupational Noise Exposure*; June 1998.

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- ^{xii} Access Economics Pty Ltd; *Listen hear! The Economic impact and cost of hearing loss in Australia*; Access Economics Pty Ltd, Victoria, Australia. 2006; pp 91
- ^{xiii} Australian Safety and Compensation Council; *Work Related Noise Induced Hearing Loss in Australia*; April 2006
- ^{xiv} Bulzacchelli, Vernick, Webster, et al; Effects of the Occupational Safety and Health Administration's control of hazardous energy (lockout/tagout) standard on rates of machinery-related fatal occupational injury; *Inj. Prev.* 2007;13;334-338
- ^{xv} W E Daniell, S S Swan, M M McDaniel, J E Camp, M A Cohen, J G Stebbins; Noise exposure and hearing loss prevention programmes after 20 years of regulations in the United States; *Occup Environ Med* 2006;63:343–351
- ^{xvi} J G Ayres, S Semple, L MacCalman, S Dempsey, S Hilton, J F Hurley, B G Miller, A Naji and M Petticrew; Bar workers' health and environmental tobacco smoke exposure (BHETSE): symptomatic improvement in bar staff following smoke-free legislation in Scotland; *Occup Environ Med* 2009;66:339–346
- ^{xvii} AS/NZS 1269.3; '*Occupational Noise Management Part 3: Hearing protector program*'; 1998
- ^{xviii} Arezes PM, Miguel AS. Hearing protectors acceptability in noisy environments; *Annals of Occupational Hygiene*; 2002;46(6):531–6.
- ^{xix} Willams A; *Noise Monitoring Report – Electrolysis Department October 2004*; Injury Prevention and Management
- ^{xx} Neitzel R, Seixas N, Goldman B, Daniell W (2004); Contributions of non-occupational activities to total noise exposure of construction workers; *Annals of Occupational Hygiene*, 48(5):463-473
- ^{xxi} Section 104 of the Workers Rehabilitation and Compensation Act 1988.