Identification, elimination and reduction of barriers to the effective use of respiratory personal protective equipment

Author:
Wallaart, Johannes Christiaan

Publication Date:
2008

DOI:
https://doi.org/10.26190/unsworks/18159

License:
https://creativecommons.org/licenses/by-nc-nd/3.0/au/
Link to license to see what you are allowed to do with this resource.

Downloaded from http://hdl.handle.net/1959.4/43293 in https://unsworks.unsw.edu.au on 2024-05-03

THE UNIVERSITY OF
NEW SOUTH WALES

Identification, Elimination and Reduction of Barriers to the Effective Use of Respiratory Personal Protective Equipment

by

Johannes Christiaan Wallaart
Student number: 2215634

A thesis submitted for completion
of the degree of Doctor of Philosophy
School of Risk and Safety Sciences
University of New South Wales

2008

0.1 Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment is made in the text. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

Johannes Christiaan Wallaart

April 2008

0.2 *Acknowledgements*

I wish to acknowledge a number of key people for their assistance and support throughout the course of this thesis - this work would not have been possible without the support of key people:

- Practical work was carried out largely in the field and at the laboratories of Safety Equipment Australia (SEA) Pty Ltd in Sydney.
- Support from SEA Pty Ltd has enabled many of the projects to be developed and without their assistance in many areas, this work would not have proceeded. In particular, the guidance, help and motivation of the Managing Director (USA) and General Manager (Australia) of SEA Pty Ltd, Goran Berntsson, was invaluable.
- The support and advice of Prof Chris Winder of the School of Risk and Safety Sciences, UNSW is similarly acknowledged. This Thesis was completed externally and extramurally from New Zealand and communication difficulties were a significant challenge.

Thanks again.

Johannes Christiaan Wallaart

October 2008

0.3 Abstract

While some workplace associated respiratory diseases such as pneumonoconioses are in decline, others, such as occupational asthma are increasing in most parts of the World including New Zealand and Australia. Personal protective equipment (PPE) is used worldwide as a means of protecting people from workplace injury and disease when other preferable methods of control such as elimination or isolation are not possible. PPE that provides protection against inhalational hazards is called respiratory protective equipment (RPE).

This thesis is concerned with the identification, elimination and reduction of some of the barriers in the use of respiratory protective equipment for protection against inhalational hazards, particularly in industry.

There are enormous practical, physiological and psychological difficulties in the wearing RPE by the worker in the workplace. The practical difficulties faced by the worker in wearing the equipment, particularly for extended periods of time, often remain unrecognised by PPE manufacturers, physicians, occupational hygienists and other professionals.

Much of the commercial RPE available fails to take into account more recent scientific information available. Because of the increasing diagnosed incidence of diseases such as some types of respiratory disease in the workplace, scientific insights into RPE protection for the workplace are becoming increasingly urgent. To do so, requires practical insights into the respirator design and manufacturing industry, workplace health and safety programs and an understanding of clinical diagnosis of occupational diseases such as occupational asthma in industry.

The programme for this thesis was initiated by work conducted in a New Zealand aluminium smelter in the 1990s after a mandatory respirator program was introduced. Working conditions were harsh, and included contaminated environments, high radiant heat, and heavy physical work. These conditions were not conducive to good respirator compliance, and

studies began on looking at identifying and removing barriers to compliance.

Initially, studies of respiratory parameters in workers in the smelter suggested that at certain times of heavy work, the respirators could not handle the physiological demand that workers required even though such respirators complied with the technical requirements specified in relevant respirator standards (most notably, AS/NZS 1716:2003). The results of this work is described in this thesis.

This work lead to laboratory-based studies looking at respirator design and function, in particular, the requirements of two different types of airflow, Peak Inspiratory Air Flows (PIAF) including communication (an essential safety requirement in many applications) and Minute Volumes (MV). A wide variation in Minute Volumes were found in a typical workplace group which was not represented by values currently used by respirator certifying bodies. In addition, very large values of PIAF values were found, particularly when subjects were communicating as in a workplace. At present, the certifying bodies do not require a value for PIAF to be considered in spite of this being quoted as being more important than Minute Volumes. This is now being reconsidered following this work and subsequently that of others. In addition, an alternative method of determining the total inward leakage has been suggested which is directly related to the needs of the individual in the workplace rather than adopting standards methodology and values derived from a previously selected test group.

A final survey was conducted in the agricultural industry, looking at knowledge and use of respirators. This industry has a different outlook on working conditions, tempered by a belief in self-reliance and the agrarian myth, and attitudes towards respiratory hazards and respiratory disease as being of minor consequence. However, survey results indicate that this attitude has little basis in reality, especially with regard to the complexity of respiratory hazards (most notably in confined space entry), and that the prevalence of some occupational diseases (most notably asthma) is not well understood. This agricultural group represents 10% of New Zealand's total workforce.

This research identified a number of barriers to the design and use of respirators and implementation of respiratory programs. These include the likelihood of most commercial types of respirators being unable to meet the high airflow requirements of users, particularly peak flows, inappropriate values for airflows used in Australian Standards (AS/NZS 1715:1994) in RPE and the apparent lack of appropriate training, education and awareness of a typical and key employer group in New Zealand in spite of numerous efforts historically by key Government and other organisations.

Barriers to improving respiratory protection in workers in New Zealand to reduce the future workplace burden will require concerted action by governments, standard setting bodies, industry associations, unions (where relevant) and health and safety practitioners.

0.4 Table of Contents

0.4.1 List of Figures

0.4.2 List of Tables

Part 1: Introduction

1. INTRODUCTION

1.1 Overview

Workplace injuries and deaths receive a great deal of public attention because the events that produce them tend to be severe, traumatic and sudden. They shock society and Governments into acknowledging the social and real costs of workplace injury, including social, moral and indirect financial costs. The reported figures are usually underestimates and contrast unfavourably with other causes of death. For example, even in 1999, the Chief of the International Labor Organisation's (ILO) Health and Safety Program, drew attention to the workplace hecatomb, and showed that workplace fatalities from occupational disease and injury was about 1,100,000 compared with HIV/AIDS at 312,000.[1]

However, the incidence of workplace disease as well as the associated social and economic costs are known to be much greater than those from sudden traumatic events. They receive much less public attention at the present time, albeit it is rapidly changing in New Zealand. The actual figures vary between Government agencies in one country and between countries depending on a range of factors including the methodology used to record the events. The ILO in April 1999 reported that the annual workplace death rate of 1.1 million of which about 25% result from exposure to hazardous substances which cause such disabling illnesses as cancer and cardiovascular, respiratory and nervous system disorders[2]. This is rapidly changing as society becomes aware of the much higher likely future costs associated with longer-term occupational disease and associated compensation costs.[1] This is particularly valid for organisations such as the New Zealand Accident Compensation Corporation who will invitably administer the associated future compensation costs.

---

[1] For example, at the present time (2008), ACC in New Zealand is embarking on a major media and awareness campaign to both health providers and the public about the potential relationship between workplace contaminants and occupational disease.

An historical example is the compensation claims in Britain (1999 and later) on behalf of hundreds of British Miners who worked predominantly in coal mines after 1954 and Scotland after 1949 and associated claims for respiratory illness-likely to cost the nation billions of pounds[3]. Yet much of this cost, both in terms of human suffering and financial, could have been prevented by closer control of the workplace exposure. Currently, both in New Zealand and Australia, there are asbestos exposure claims arising from working with this previously common material, i.e., widely used throughout all types of industries worldwide. While there is much legal debate surrounding exposure and claims, some have claimed that about 12,000 New Zealanders could die from occupational exposure to this substance.[4] Much of this could likely have been prevented. Evidence from other settings has shown that respiratory protection will reduce the incidence of occupational respiratory disease,[5,6] including occupational asthma.[7,8]

The ILO warned in 1999, that the incidence of work related disease was expected to double by the year 2020 if improvements in the control of exposures were not implemented.[9] Presently, in the USA, 137 people die daily as a result of work related disease, in addition to the 16 from traumatic injuries on the job-giving a concept of the relative numbers of workers affected by injury versus disease[10].

The cost of workplace related injury to people is underestimated. For comparison, if the value of industries in Australia such as health and community services is $24M, transport and storage $23M, mining $18M, the cost of injury to people by comparison at the same time is $20M.[11] The relationship and incidence of occupational disease is even further underestimated because of the difficulties in correlation between exposure and disease.[12] Typical difficulties include the time period between exposure and diagnosis which can be decades[13]. In addition, there are many other complications such as the ability of health providers to recognise the disease as being work related as well as workers compensation schemes which tend to be associated with employer responsibility[14].

The WHO (World Health Organisation) is concerned with the under-estimation of the global burden of occupational diseases and injury, because of the difficulty in diagnosis and reporting systems. The WHO estimates, for example, in Latin America, that only between 1-4% of occupational diseases are reported.[15] The ILO (International Labour Office) estimates 21% of all mortality is due to chronic respiratory failure, 34% due to cancers and 21% due to acute workplace injury. The WHO is concerned at the increasing rate of workplace disease as is the ILO.[16] In New Zealand, it has been estimated that between 700 and 1000 people die each year from occupational diseases such as cancer, respiratory disease and ischaemic heart disease. It is estimated that the fatality rate from occupational disease kills is seven times the rate from occupational injury, 17,000 to 20,000 new cases of occupational diseases are recorded each year-while 80% of work related deaths are not reported.[17]

In April 1999, the ILO also reported that the worldwide estimated annual workplace death rate of 1.1 million exceeded the average deaths from road accidents, war deaths and HIV/AIDS[18]. Approximately one-quarter of these deaths result from exposure to hazardous substances which cause such disabling illnesses as cancer and cardiovascular, respiratory and nervous system disorders. NIOSH reported that while workplace injuries and deaths are recorded in the workplace, disease will result in the death of nine times that number of people.[53] The “Clean Air Month” has been established in the USA to highlight the growing concerns and importance of lung health with 3 May being World Asthma Day every year declared by the WHO.

1.1.1 The Respiratory Systems as a Route of Exposure of Airborne Contaminants into the Body

The respiratory tract is the most commonly affected organ system for occupational disease as it represents the port of entry for irritating and intoxicating agents.[5,19] The respiratory system is the organ involved in supplying oxygen (O_2) to the body and removing the waste product carbon dioxide (CO_2). To do this, the lungs have evolved into a system which bring the atmosphere from the external environment into the body, humidifies this air, brings it to body temperature, and delivers it to the gas exchange area in the deep portions of the lungs. It has been estimated that the total area of the gas exchange surface within the lungs is 140 to 150 m^2. While this gas exchange area is very thin (in most cases from 0.4 to 2.5 μm thick), this surface area is about seventy times the surface of the skin.

There are a number of issues in relation to respiratory systems and airborne contaminants:

- the human lung comes into contact with about 10-12 cubic metres of air every day, with its accompanying chemical, particulate and microbial load;
- there are no membrane barriers between the external environment and the physiological surfaces of the respiratory system, and therefore the only obstacles that inhaled gases, vapours and small particles have before they can be absorbed into the body are based on physical properties, such as particle size and solubility. By necessity, the mammalian lung has developed an elaborate defence system to preserve its structure and function;
- from an evolutional perspective, the respiratory system has evolved to deal with the kinds of airborne materials found in the natural environment. The respiratory system is poorly equipped to deal with the range of pollutants and contaminants of the modern environment, particularly those found in workplaces. For this reason, sometimes the conventional responses of the respiratory system are not adequate enough to cope with such exposures;
- there is wide variability in individual responses to inhaled materials. This variability may be observed as a genetic predisposition to particular contaminants (atopy), or as an acquired trait from previous exposures (for example, impairment in lung function induced by cigarette smoking);

- the likelihood of respiratory problems from inhalation of airborne contaminants depends on a range of factors, including how much is inhaled, how much is retained, how much is cleared out of the lungs, how much is biotransformed, whether critical doses are reached in target tissues, and the pathological sequence of molecular, biochemical, and cellular events, as well as tissue effects and defence responses that can lead to clinical disease.

All cardiac output travels through the respiratory system with each cardiac cycle through the body. This makes the lung particularly suited for the uptake of gases and volatile compounds, and an efficient organ for the uptake of non-volatile materials and soluble, adsorbed particulates, as well. Materials that can inflict direct injury to lung tissue can lead to respiratory malfunction. This can cause a spectrum of pathological changes up to and including death. The importance of inhalation as a route of exposure at the workplace cannot be overemphasised.

1.1.2 Occupational Respiratory Diseases

Occupational lung diseases are among the earliest occupational diseases reported. Coal miners pneumoconiosis, cereal handler's lung diseases, silicosis and asbestosis are examples of occupational respiratory diseases that have well established histories.

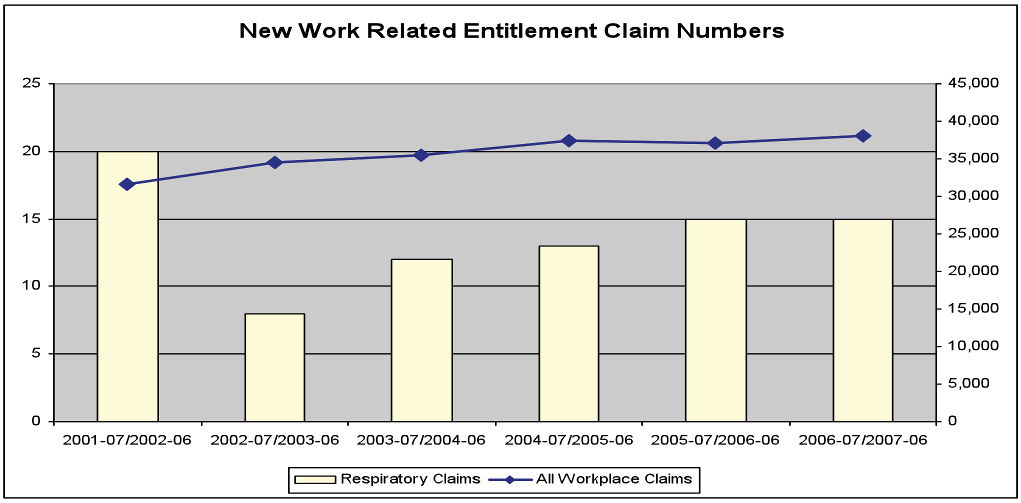
Notifications to the NZ Occupational Health and Safety Service noted:

- in 1993-1996, 73 cases of asthma, of which 35 were accepted as being from occupational causes.[20]
- in 1996-1999, 54 cases of asthma, of which 21 were accepted as being from occupational causes.[21]

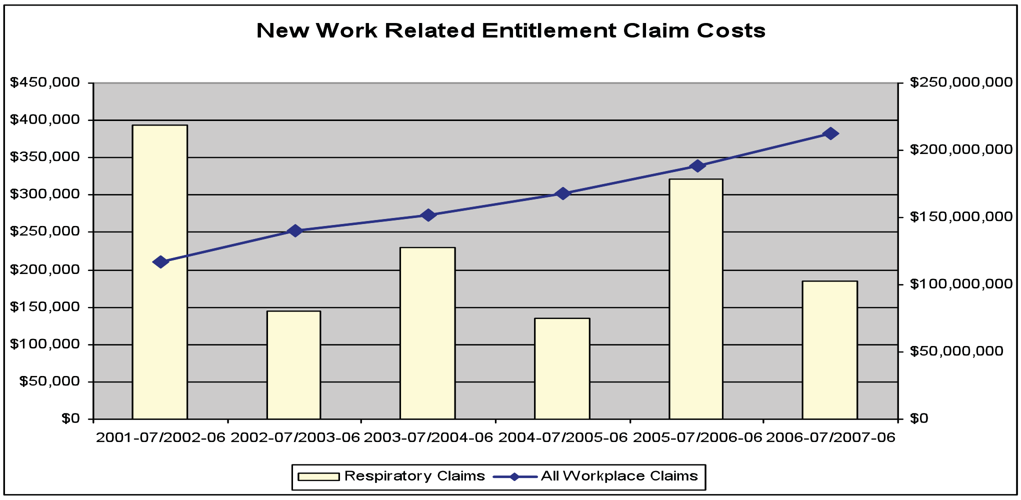
(Later information from the same source is not reliable due to the non-reporting by health professionals of this voluntary reporting system).

Claims to the Accident Compensation Corporation (ACC) in New Zealand from occupational disease are few, reflecting the likely lack of awareness of occupational disease as being work related by the general public.[22] The graph below indicates the slowly changing pattern of claims to the ACC compared with total claims primarily from traumatic injury. The claim compensation costs show a different pattern. The current claim numbers are low, which does not reflect the true cases of inhalation disease known to be present.[23]

Figure 1.1: Respiratory inhalation diseases-compensation claims and associated costs last 6 years[24].



<u>Graph showing the number of serious total and respiratory disease claims to ACC over the last 6 years.</u>



<u>Graph showing the compensation costs associated with total workplace and respiratory disease claims over the last 6 years.</u>

Currently, the New Zealand Government personal accident insurance body, the New Zealand Accident Compensation Corporation (ACC), is educating and raising awareness among health workers and the public in New Zealand about the importance of relating workplace exposure to disease so that the claims are expected to rise dramatically in this country.[2]

The range of most diagnosed and reported diseases from the workplace is increasing including those in the Western World. The occupational asthma incidence appears to be increasing both in New Zealand and internationally. The disease is now the top ten topics of NORA (National Occupational Research Agenda) focus of further research as it is currently the most frequent occupational respiratory diagnosis[25].

1.1.2.1 Pneumoconiosis

The word pneumoconiosis literally means dust in the lungs.[26] Since not all dusts deposited in the lungs cause disease, the more widely accepted definition is that of the ILO which is that *pneumoconiosis is the accumulation of dust in the lungs and the tissue reaction to its presence*. The term normally means fibrosis of the lung due to accumulation of dust (mostly inorganic dusts).[27]

Some dusts are non-toxic following inhalation. The term *benign* or *nonfibrotic pneumoconiosis* has been used to describe this situation, and a range of inorganic materials have been shown not to damage alveolar architecture or give rise to collagenous fibrosis when they are inhaled and retained in the lungs.[28] Materials such as iron ore (siderosis), tin ore (stannosis), barium compounds (baritosis), antimony ore, zirconium compounds and titanium dioxide are classified as inert dusts (provided they are free of other toxic impurities and contain less than 1% quartz).

[2] Currently, the New Zealand Government is about to approve the “Schedule 2” amendment to the IPRC Act 2002, which allows the automatic compensation under the New Zealand ACC scheme for occupational disease such as occupational asthma.

The most common of these is siderosis, occurring in welders, iron ore workers, and foundry workers.

Inhalation of other inorganic dusts will stimulate responses that eventually lead to structural alterations in lung tissue and irreversible fibrosis. These are called the collagenous pneumoconiosis. There are a range of materials that cause this condition, including silica (silicosis), quartz, cristobalite, tridymite, diatomaceous earth, beryllium, asbestos (asbestosis), coal dust (coal workers pneumoconiosis), graphite (graphite lung), carbon black, mica, aluminium and talc (talcosis). Of these, the most important are silica, asbestos and coal dust.[29] The fatality rate varies according to the type of exposures, for example, coal workers' pneumoconiosis deaths have decreased in recent decades and deaths from asbestosis have increased in the last three decades[30].

1.1.2.2 Hypersensitivity Pneumonitis

Dust diseases from inorganic dusts (the pneumoconiosis) are pathologically different from diseases caused by organic dusts, which tend to be of a hypersensitivity pneumonitis type (also called extrinsic allergic alveolitis).[31,32] Many of the organic dusts have biological activity, or are contaminated by bacteria or fungi, which cause inflammation in the lung tissues. The range of materials that can precipitate such reactions is quite large, and includes chemicals, dusts from cereals, mouldy hay, cotton, bird droppings, cork, bagasse (sugar cane fibres), coconuts, paprika and compost and some medical treatments.

In the workplace, exposure to respirable particles (that is, particles with an aerodynamic diameter below about 5 μm) produces an immunologically mediated inflammation pulmonary response located in the alveoli.[33] Common occupational hypersensitivity pneumonitis includes farmers lung,[34] byssinosis,[35] bagassosis[36] and mushroom workers lung.[37]

There are acute, subacute, and chronic features.[38] In about two-thirds of sufferers, the typical acute disease presents as an attack of chills, fever, cough and shortness of breath occurring four to eight hours after exposure. This can be measured by a reduction in FEV_1 and FVC. This is also associated with malaise, gradual resolution of fever (perhaps to 41°C), a harsh cough, headache, myalgia (muscle pain), and persisting dyspnoea. Acute symptoms usually subside within hours but may persist for days.

The subacute syndrome is characterised by gradually progressive dyspnoea and productive cough often associated with repeated low grade exposures. The acute symptoms appear to abate, but the dyspnoea is progressive and associated with anorexia and weight loss. X-rays may show interstitial reticulonodular opacities up to several millimetres in diameter scattered diffusely. These tend to clear up gradually over a period of weeks to months. Individuals with multiple exposures may have fibrotic densities that will clear slowly, or not at all. X-rays of advanced hypersensitivity pneumonitis show honeycombing similar to that of other end stage lung diseases.

A smaller percentage of patients have chronic disease that has an insidious onset. This is characterised by progressive dyspnoea, with features of interstitial fibrosis and/or airways obstruction. This occurs most commonly after multiple episodes of symptomatic exposure in the subacute and chronic individual. However, chronic hypersensitivity pneumonitis is indistinguishable from other types of combined obstructive airways disease and diffuse interstitial fibrosis.

Death can occur at any stage and the overall mortality rate has been estimated at between 9 and 17%.

The mechanism of hypersensitivity pneumonitis is not completely understood, but is essentially immunological.[39] The hypersensitivity is classified as a type III or immune complex mediated reaction. The alveolar macrophage, T-lymphocyte, NK cells and cytokines are not considered key. Further, as symptoms appear at higher incidence in exposed relatives, genetic mechanisms are likely. Early diagnosis and effective remediation of probable causes are critical to better health outcomes, whereas diagnosis in advanced stages leads to disability and/or shortened life span.[40] In the USA, generally the number of fatalities from diagnosed hypersensitivity pneumonitis has increased since 1979[41].

1.1.2.3 Rhinitis

The nose and nasal cavity is the entry point for air into the body by the inhalational route. Inhaled air is humidified, warmed and filtered as it moves through the passages of the upper airway. Occasionally, airborne contaminants that are inhaled may affect the surfaces of the upper airways with which they make contact. Rhinitis is an inflammation of the nasal passages causing stuffiness and runny nose, often accompanied by watery and red eyes.

Inhalation exposures can produce asthma and rhinitis by several mechanisms.[42] Allergic mechanisms occur through sensitisation with the production of immunoglobulin proteins (mainly IgE) specific for a substance can lead to symptoms of inflammation on re-exposure. Irritant mechanisms occur from exposure to respiratory irritants, and can lead to asthma and rhinitis through interaction with chemical irritant receptors in the airway, leading to inflammation. The reactive airways dysfunction syndrome is a chronic asthma-like syndrome resulting from a single acute exposure to a respiratory irritant, while the reactive upper-airways dysfunction syndrome is chronic rhinitis stemming from an irritant exposure.[43] Physical signs are reliable indicator of occupational damage to the nasal mucosa.[44]

Therefore, the main mechanisms of these effects are irritancy or allergy (it can be argued that rhinitis from respiratory infections is of an irritant type). For this reason, rhinitis is usually classified simply as being of allergic or nonallergic types, although this may be an oversimplification.

Allergic rhinitis is a very common cause of rhinitis. However, since approximately 50% of patients with rhinitis do not have allergic rhinitis, other potential causes must also be ruled out.[45] Though all types of rhinitis do fall into these two categories, there are a number of variations of the nonallergic form. There are a number of different forms of rhinitis, such as allergic, nonallergic rhinitis with eosinophilia syndrome, occupational rhinitis, hormonal rhinitis (for example, in pregnancy or hypothyroidism), drug-induced rhinitis and rhinitis from food ingestion.[46]

Individuals with rhinitis are bothered both by the nasal symptoms themselves and by associated symptoms such as headache and fatigue. The combination can produce quite severe impairment of day-to-day physical, emotional, occupational, and social functioning and can cause emotional distress. This breadth of impairment of health-related quality of life in patients with rhinitis is often not recognised and is sometimes trivialised by some health care professionals.[47] The condition is common in New Zealand with about 20% of the population affected by allergic rhinitis and the diagnosed incidence appears to be increasing[48].

1.1.2.4 Asthma

Asthma is a widespread lung condition which affects 5-15% of the general population. It is a condition characterised by variable air flow limitation and/or airway hyper-responsiveness. Asthma can be triggered by a variety of environmental agents such as gases, particulates and allergens. However other exposures, such as cold air or exercise, can precipitate asthmatic reactions.

In the first instance, the symptoms of chest tightness, wheezing, shortness of breath, dry cough and so on, constitutes asthma.

Occupational asthma refers to asthma, caused by factors in the workplace.[49] The symptomology is due to causes and conditions attributable to a particular occupational environment and not to stimuli encountered outside the workplace. Well over 200 chemicals have been identified as causing asthma at work and these are found in a wide variety of occupations.[50]

The airways that are afflicted by asthma are generally part of the tracheobronchial compartment. However, these are a continuation of the airways starting in the nasopharyngeal area. It is therefore not surprising that many asthma cases also have rhinitis, (sometimes preceding the asthma). Rhinitis literally means inflammation of the nose. Its symptoms are commonly those which the lay person associates with "hay fever" - an itchy, blocked or runny nose, often red and accompanied by sneezes. There may also be eye symptoms (itchy, glazed or runny).

Asthma consists of attacks of wheezing and breathlessness due to bronchospasm and secretions of thick mucus. There are a number of variables which can affect the rate of asthma including:

- pre-morbid health state;
- nature of occupationally encountered substances;
- concentration and duration of exposure;
- availability and use of ventilation and/or protective devices in the workplace;
- the presence of co-existent asthmogenic factors or agents.

Asthma can be defined as a disorder characterised by an increased response by the airways to irritants or more properly, sensitising irritants.[51] Simply put, the effects of asthma are bronchospasm, mucus production in the airways, and cough. With occupational asthma, the natural functional responses of the lung are exaggerated in response to irritants. Occupational asthma is defined characterised by variable airflow limitation and/or airway hyper-responsiveness die to causes and conditions attributable to a particular occupational environment and not to stimuli encountered[52].

A variety of protective responses occurs in the lung after inhalation of an irritant. By diminishing the diameter of the airways, bronchospasm limits airway diameter and reduces the amount of irritant entry into the lungs. Mucus secretion and cough assist in the removal of air from the lungs. Everyone has these responses, but individuals who possess exaggerated responses are diagnosed as having asthma.

Asthma can be diagnosed historically (episodes of wheezing/shortness of breath, cough and mucus production), physically (by ausculating wheezes) or physiologically. Occupational asthma is defined by a disorder where there is generalised obstruction of the airways, usually reversible and caused by the inhalation of substances or material which the worker uses or which are incidentally present in the workplace.

Asthma can be initiated or provoked by workplace exposures. The asthmatic response can be activated by either intrinsic (exaggerated response) or extrinsic (exaggerated stimulus) factors.

The number of general asthmatics in the community has jumped by 60% since the early 1980's[53] and occupational asthma can be expected to have increased correspondingly. There is general agreement that occupational asthma has become the most prevalent occupational lung disease in developed countries, although estimates of actual prevalence and incidence are quite variable.[54] A Canadian study reported in the American Journal of Respiratory and Clinical Care Medicine that in 19,000 people randomly selected in the age group of 20-44, 2% were found to have asthma. A third of these had their first attack as an adult and many were thought to be due to workplace exposures.[55] Work related illness can be hard to detect-many physicians are not trained to ask patients about their work and the association may well be overlooked.[56] Many substances that people work with commonly are identified with carcinogens, such as wood dust and many common substances also contribute to an increased incidence of occupational asthma.[57]

Occupationally related asthma is estimated to cost New Zealand well in excess of $25m a year in direct medical costs and $140m in indirect costs due to working days lost.[58,59]

Approximately 7.7% of all adults have active asthma with up to 30% reported as being related to work contaminants.[60] Internationally, the incidence has been reported from 3.4% to as high as 54% in some industries[61]. In Britain, it is estimated 2000 people develop occupational asthma each year at present[62]. Internationally, occupational asthma is the most common form of occupational disease in the developed world.[63]

It is the leading work-related lung disease in the USA. The UK HSE has set a target to reduce new occupational asthma cases by 30% by 2010.[64]

1.1.2.5 *Reactive Airways Dysfunction Syndrome*

Reactive airways dysfunction syndrome (RADS) is a term first described in 1985 as an asthma like condition following a toxic or irritating exposure:[65]

- preceding absence of respiratory complaints (if possible, documented);
- onset of symptoms after a single or short period of exposure;
- other types of respiratory disease have been ruled out;
- the exposure was to a gas, vapour, smoke or fume present in high concentrations and with irritant qualities in its nature (it has become established that these exposures are gaseous, rather than particulate);
- onset of symptoms occurrs within 24 hours after the exposure and persisted for at least three months;
- symptoms simulated asthma with cough, wheezing and dyspnoea predominating;
- pulmonary tests show airflow obstruction;
- challenge testing with methacholine is positive.

This is a definition of one type of asthma that is different from for example, airways obstruction.[66] Obviously, RADS is important from the occupational perspective.[67]

The narrative below lists some of the better known agents that are known to contribute to asthma. These can be divided into three main types:

- high molecular weight compounds;
- low molecular weight compounds; and
- high levels of irritants (which can be considered the agents that produce RADS).

High molecular weight irritants are frequently biological proteins and their responses are mediated by immunological mechanisms (including production of the immunoglobulin IgE antibodies). Patients with this form of occupational asthma are commonly atopic and their sensitisation can be diagnosed using skin (patch) tests.

By contrast, low molecular weight antigens, are usually inorganic compounds with a molecular weight of less than 1000, are not usually allergically mediated, and are less frequently a cause of occupational asthma than the high molecular weight compounds. There are exceptions to these rules.

Bronchitis attributed to the workplace is at the other end of the spectrum. It is a disorder characterised by dyspnoea, cough and mucus production occurring in the workplace because of high concentrations of irritants, often particulate in nature. It usually occurs over long periods of time with repeated exposure and is usually not permanent.

Asthma is typically diagnosed by history, physical examination, and by pulmonary function testing. Obtaining information on timing or asthmatic symptoms is crucial. The objective tests for occupational asthma are either of pulmonary function type or alternative tests designed to demonstrate hypersensitivity (such as immunological tests).

The treatment of asthma is quite simple:

- standard medical treatment for asthma; and
- avoidance of further exposure.

The latter of these is essential. The majority of individuals with occupational asthma will have chronic persistent symptoms, and these will diminish with time (but in most cases, will not resolve). If continued work is to occur, then the options are transfer to a different area, or the use of ventilation or respiratory protection (air supplied respirators should be used, as filter-type respirators increase the effort required for breathing). However, these measures will not guarantee protection. Even discontinuation of exposure can not be assumed to remove the risk if the agent is encountered in the environment.

1.1.2.6 *Chronic Obstructive Lung (or Pulmonary) Disease*

Chronic obstructive lung (or pulmonary) disease (COLD or COPD) has many factors working in combination for its development (smoking, air pollution, genetic factors, pre-existing respiratory disease). In some ways, it is a condition that develops but does not progress to other conditions (hypersensitivity, fibrosis and so on).[68] The main mechanisms that may contribute to airflow limitation in COLD are fixed narrowing of small airways, emphysema and luminal obstruction with mucus secretions. COLD is characterised by a chronic inflammatory process in the pulmonary tissue, with a pattern different from bronchial asthma, associated with extrapulmonary effects and is considered now a complex, systemic disease.[69] Workers working in dusty occupations, such as those employed in foundries, mining and milling, brick and tile manufacture, textile manufacturing and so forth are more likely to suffer from COLD.[70] The diagnosed incidence appears to be generally increasing[71].

1.1.2.7 *Respiratory Infections*

At the cellular level, the respiratory tract has a variety of defence mechanisms to prevent bacterial infection, and the respiratory epithelium plays a very active role in this process.[72] While many respiratory diseases can be considered non-occupational, there is little doubt that workers with respiratory infections, such as influenza, pneumonia or rhinitis will impact on worker health. Other diseases, such as tuberculosis will also affect worker morbidity. Further, concomitant exposure to airborne toxicants (for example, tobacco smoke or asbestos) may impair the ability of the body to fight infection.

1.1.2.8 *Lung Cancer*

Lung cancer is a major cancer in the community to non-occupationally exposed individuals (mainly from smoking). However, there are many occupationally-induced cancers of the respiratory system in workers.[73] Several controversial factors, such as the degree of risk relative to exposure dose, the synergistic effect of cocarcinogens, and the question of existence of a threshold dose, complicate the understanding of the magnitude of the risk for exposed workers.[74] As with other occupationally induced respiratory diseases, the site of the cancer is often related to the carcinogenic agent.

Cancers can occur in the upper respiratory tract, such as cancers from formaldehyde, some wood dusts, leather work and isopropyl alcohol, which cause cancer of the nasal cavity and turbinates. Further, asbestos is implicated in producing cancer of the larynx.[75]

Several cancers of the lungs have also been reported:

- asbestos;
- chromium and its salts;
- tars, pitches and bitumen;
- ionising radiation;
- nickel and its salts and nickel carbonyl;
- bis-chloromethyl ether and chloromethyl ether;
- arsenic (possible lung carcinogen);
- diesel exhaust particulates.
- At the present time, the total diagnosed incidence appears to be decreasing in Australia, although the rate differs between the genders with males decreasing and females increasing over the last decade[76].

1.1.3 *Control of Hazards in the Workplace*

Workplace injury and disease continues to be one of the most important practical issues facing employees and employers worldwide.[16,77] Chronic obstructive pulmonary disease (COPD), for example is an increasing health problem and a leading cause of morbidity and mortality.[78] In New Zealand, Occupational asthma, COPD and occupational cancers have recently (2008) been accepted as automatic workplace personal accident cover for insurance under the Accident Compensation Corporation (ACC) scheme.

In Australia, a close geographic neighbour to New Zealand with similar workplace practices, the exposure to workplace hazardous substances is estimated to contribute to 2300 deaths per annum, seventy-eight percent male.[79] The study indicated that cancer was the prime cause of death, followed by renal, cardiovascular, neurological and chronic respiratory disease.[80] Costs due to hospital costs and loss of productivity were estimated at $160 million although the exact details are difficult to determine. The difficulties arise because in determining the nature of cause of disease attributable to a particular industry, length of time of the causative event, workers compensation systems which may readily recognise an occupational injury but not disease, difficulties in recording by various agencies and other factors.[81] Society awareness and concerns related to workplace disease is steadily increasing and will affect future compensation schemes much more dramatically. This commenced in 2003 in New Zealand[82] with the New Zealand Injury Prevention Strategy,[83] the subsequent Implementation Plans,[84] changes to the ACC IPRC (Injury Prevention, Rehabilitation and Compensation) Act 2002, the technical reports on the burden of occupational disease and injury in New Zealand.[85,86]

Controlling exposure to hazards at work is an employer obligation imposed in NZ labour legislation[87]. The process of hazard management, as outlined in this legislation, requires the employer to identify and control workplace hazards. The range of possible controls to be used ranges from workplace safe, to systems safe, to worker safe policies and practices,[88] as is more commonly known as the hierarchy of controls. Control of workplace hazards is generally made by workplace safe practices such as isolation or engineering controls (for example, process enclosure and ventilation), or safe systems practices (for example, job rotation and safety operating instructions). While PPE is an option at the end of the hierarchy of controls, inevitably, where residual hazards remain uncontrolled to acceptable levels, safe worker practices, the use of personal protective equipment (PPE) will be needed.

1.1.3.1 Control of Inhalation Hazards in the Workplace

Controlling exposure to hazardous inhalation contaminants also is under the employer obligation imposed in NZ health and safety legislation. Employers should be notified of any occupational health problems so that steps can be taken to identify and control hazards, and establish medical and compensation action. However, not all employees inform their employers about workplace related health problems because of discrimination, lack of career advancement or job dismissal. For example, in 1990, a review of 93 cases of asthma in an Auckland Hospital noted that 77% had not informed their employer, and 32% had problems getting time off to attend clinic. A further 8.3% noted that having asthma was a material contributor to losing their job.[89]

As above, the full range of options in the hierarchy of controls is available to control such hazards.

For inhalational hazards, the last option in the hierachy of controls for airborne substances is Respiratory Protective Equipment (RPE) such as "masks" or respirators. These form the subject of this thesis, and are discussed below.

1.1.3.2 Control of Inhalational Hazards by RPE

At the user level, there are significant technical and practical wearer complications with regard to respiratory protection in industry and other areas which currently hinder the resulting protection available from ambient contaminants.

Respiratory protection is the last line of defence after other options are no longer possible, e.g., elimination of the contaminant or removal of the person from the contaminated environment. Protection worldwide for workers against airborne hazards are varied such as industrial contaminants or tuberculosis protection of health care workers in hospitals or biological warfare protection (CBRN-chemical, biological, radiological and nuclear) for military personnel.

Typical industries, workplace contaminants and associated possible respiratory disease[90] are illustrated in table 1.1 below.

The characteristic of most workplace inhalation diseases is that they are generally preventable and this makes these important from the perspective of intervention opportunities. While most are not always recognised as work related[91] in New Zealand by physicians, this is likely to change with the rapid development and an increasing focus on occupational disease[92 93].

New Zealand's national priorities, in terms of the Workplace Health and Safety Strategy[94] has, as one of the key priorities a focus on airborne substances[3]. The inhalation route is the most important route of entry of workplace contaminants into the human body and is therefore the most significant field of intervention. Many countries are asking assistance from employers to reduce the high costs of occupational lung disease (estimated to be $8.5 billion in the USA in 2002)[95]. USA figures indicate that about 400,000 people have developed disease caused by their jobs over which more than half are due to lung diseases[96].

Asthma and chronic obstructive pulmonary disease (COPD) is in the top 8 topics of concern and a key subject of research by most development nations[97].

Identification of lung disease may be difficult because of the latency period[98], but in other cases can be identified readily as work related.

Workplace awareness of the causes and impact of occupational disease in New Zealand is low except in some specific workplaces[4]. Even when

---

3 An occupational hygienist is specifically trained in this field, but their numbering New Zealand is very small. The science of occupational hygiene is the identification, measurement and control of industrial hazards. These contaminants can be physical, chemical or biological.

4 Part of the thesis focuses on the agricultural sector of New Zealand. It will be shown that farmer awareness of respiratory hazards and appropriate protection is

the risks are well identified, action to prevent disease from the workplace is often lacking[99].

The table below show some typical industries and associated potential inhalation disease as a consequence of exposure. The physical states of the contaminants can be varied such as mineral or organic. It can exist in the form of dusts (e.g., wood, cotton, coal, asbestos, silica and talc), fumes (e.g., from metals that are heated and cooled quickly), smoke (from burning organic materials and can contain a variety of dusts, gases and vapours), vapours (a form of gas given off by all liquids such as solvents), mists or sprays (from paints, lacquers, hair sprays, pesticides, cleaning products , acids, oils and solvents).[100]

The table below lists some typical examples of industries, the types of tasks, contaminants likely to be present and the associated occupational disease possible from exposure.

Table 1.1: Typical examples of industry contaminants and potential for occupational disease.

Industry	Tasks	Contaminants	Occupational inhalation disease	Comments
Aluminium smelting.	Potroom and carbon products operations.	Fluorides, sulphur dioxide, polycyclic aromatic hydrocarbons and particulates.	Occupational asthma.	Incidence varies, but new diagnosed cases typically can be from 0.1 to 0.3% p.a.
Metal manufacturing.	Various tasks in different metal industries.	These are varied, but include SO2 and metal fume.	Occupational asthma.	In the metal manufacturing industries in New Zealand this is the most common

low. However, in the multinational plants of aluminium smelting of New Zealand, awareness of occupational asthma is very high and very high levels of interventions are applied in practice.

Industry	Tasks	Contaminants	Occupational inhalation disease	Comments
	Metalworking fluids.	Metalworking fluid	Metalworkers fluid lung disease.	compensation disease.
Animal workers (e.g., in laboratory settings).	Various tasks associated in the pharmaceutical industry, university laboratories, research units and animal breeding facilities.	Animal dander, hair, urine, saliva, tissues and sera.	Occupational asthma and allergies.	One survey of 5641 workers reported 33% affected with asthma.
Agricultural industry sectors.	Various farm operations, including hay making and working with animals.	These range from particulates such as grain dust, organic materials, bacteria, agrichemicals, flour and fungi[101].	Occupational asthma.	Incidence is higher in New Zealand in certain types of agricultural operations, e.g., working with horses or in poultry sheds.
Food processing industries.	Working with or around fine particulate contaminants.	Plants, grain dusts, tobacco, tea, hops. Enzymes: Bacillius subtilis, pancreatic extracts, papain, trypsin, fungal arnylase.	Occupational asthma.	Typically affects bakers, manufacturing, tobacco and food processing. Typically affects bakers and workers in the detergent, pharmaceutical and plastic industries.

Industry	Tasks	Contaminants	Occupational inhalation disease	Comments
Pharmaceutical industry	Manufacture of various drugs and exposure to particulates.	For example, penicillin, methyldopa, tetracyclines, cephalosporins, psyllium[102].	Occupational asthma.	
Cotton processing industry.	Handling cotton based raw materials.	Cotton dust, flax or hemp.	Byssinosis	
Sugar mill workers	Working in cane sugar processing facilities.	Inhalation of fine dust from bagasse or cane waste.	Bagassosis	
Coal mining.	Coal handling such as extraction, generating significant amounts of dust.	Coal dust.	Coal workers pneumoconiosis.	Coal mining operators and mining machine operators has pneumoconiosis as the industry's most significant recorded disease on the death certificate in the USA[103]. The disease affects all parts of the lung.
Plastics, metals and varnish industries.	Variety of tasks with potential exposure to particulates and vapours.	Low molecular weight compounds. Di-isocyanates: Toluene diisocyante (TDI), methylene-	Occupational asthma.	

Industry	Tasks	Contaminants	Occupational inhalation disease	Comments
		diphenyldiisocyante (MDI). Anhydrides: Phthallic and trimellitic anhydride.		
Metal industries.	Smelting or activities generating particulates. Soldering.	Particulates of, e.g., platinum, nickel, chromium, cobalt, vanadium, tungsten carbide. Fluxes and metals.	Occupational asthma. Occupational asthma.	Typical workers affected are platinum and nickel reefing workers and hard metal workers.
Wood processing[104].	Tasks in many different timber operations such as pulp and paper, sawmills, veneer and plywood plants, woodchip operations and joineries.	Typically oak, mahogonany, California redwood, Western red cedar[105]. Generally dust exposures albeit some New Zealand operations also involve urea-formaldehyde exposure (MDF plants), biohazards from exposure to micro-organisms that grow on wood and some	Occupational asthma.	Typically affects carpenters, sawmill workers and furniture makers.

Industry	Tasks	Contaminants	Occupational inhalation disease	Comments
		preservatives that are used to treat timber.		
Fish processing.	Opening shells such as in mussels, crab or prawn operations.		Occupational asthma.	
Berrylium metals	Processing	Fine metal particulate	Acute berrylium disease (a rapid onset pneumonia – like condition involving swelling of the lungs.[106]	
Sand blasting.	Silica dust exposure.	Silica particles.	Silicosis.	Latency period may be 15 years. It is well recognised in most of the developed world[107].
Asbestos and user industries.	Various involving asbestos in different industries in New Zealand[108].	Asbestos fibres, particularly with “blue asbestos” (crocidolite), and “brown asbestos” (amosite) while less commonly “white asbestos” (chrysotile).	Asbestosis.	Deaths from asbestos related lung disease are likely to be grossly underestimated [109110]. Alternative materials are usually available[111].

Industry	Tasks	Contaminants	Occupational inhalation disease	Comments
Printing and gum manufacturing operations.	Processing.	Gum acacia, gum tragacanth.	Occupational asthma.	
Various industries.	Welding operations involving different metals and fluxes.	Metal (e.g., chromium and nickel), flux fumes and products of combustion (e.g., nitrogen dioxide)..	Respiratory symptoms and bronchitis	One study in New Zealand in 1991 reported 67% of welders were reported with respiratory disease of which 37% met the criteria for chronic bronchitis[112].
Various industries	Variety of operations inherent in the industry.		Lung cancers. Contaminating agents include arsenic, asbestos, chromates, nickel. polycyclic aromatic hydrocarbons (PAH) and asbestos.	
Various industries with exposure to organic chemicals.	Variety of operations leading to potential exposures of particulates or gases.	Typically urea formaldehyde, dyes, formalin, azodicarbonamide, hexachlorophene, ethylene diamine, dimethyl ethanolamine, polyvinyl chloride	Occupational asthma.	

Industry	Tasks	Contaminants	Occupational inhalation disease	Comments
		pyrolysates[113].		
Military or emergency personnel required to deal with biological warfare contaminants	Dealing with infected people in a variety of settings.	For example, anthrax and SARS.	Respiratory disease	
Health care workers, for example, dealing with patients infected by tuberculosis bacteria.	Health care professionals working with patients.	Tb bacteria.	Tuberculosis	
Health care workers or first responders such as police.	Dealing with people affected by the avian flu virus or its mutation products.	Body fluids such as saliva with virus adsorbed onto the fluid.	"Avian Flu"	

Table 1.1: Typical industry contaminants and potential for occupational disease.

1.1.3.3 Respiratory equipment

There are many different types of respiratory protective equipment. These range from disposable types to half-face rubber or silicone type respirators, Power Assisted Air Purifying Respirators (PAPR) to air-line respiratory equipment. Similarly, filters range from low efficiency filters to HEPA (High Efficiency Particulate Air filters) to gas, acid and alkaline absorption filters. The type of respirator and cartridges depend on a range of factors including the toxicology of the contaminant substances, the concentration, whether a mixture or single type substance as well as other factors and the degree of protection sought. In general, respiratory protective equipment rely on filtering contaminants from the air or independently supplied breathable air.

There are a wide variety of publications produced by the New Zealand Department of Labour and commercial organisations giving advice as to the type of respirator and cartridge most suitable for different applications-including specialised tasks such as isocyanate painting in aircraft painting works or agrichemical spraying in agriculture.

Respirators are assigned a “protector factor” (the ratio of the concentration of contaminants outside versus inside a respirator) which attempts to ensure that the wearer is not subjected to excessive levels of the contaminant in the workplace. The actual definition of protection factor varies and also varies in values between nations. There is no consensus opinion and there is debate about the exact meaning of the terminology. Further, there appears to be considerable variability in respiratory protection practices and the assigned protection factor[114].

Relatively little is really known as to the true protection available by protective equipment in the practical working environment, particularly respiratory protective equipment albeit there have been many workplace studies carried out by respirator manufacturers. It is assumed that PPE and RPE (Respiratory Protective Equipment) protects the user from the hazard, however, this is rarely verified by field trails in the workplace. The author has carried out a number of investigations over the last ten years in aluminium smelting industry in New Zealand, in an attempt to determine the real protection offered by respirator. Included in the trials by the author was the use of real time video imaging while electronically determining the concentration of contaminant inside and outside the respirator. While the technique appeared feasible and has been applied in other industries[115 116], difficulties were encountered due to the strong electromagnetic fields in a smelter in New Zealand and experiments were not continued further. Other techniques are also possible, but there remain some complications due to excessive moisture (from exhaled breaths) and the manner in which the sampling is carried out (e.g., close to the mouth or further away).

In Australia and New Zealand, the Standards that relate to respiratory protection are AS/NZS 1715:1994 (selection, use and maintenance of respiratory protective devices) and AS/NZS 1716:2003 (respiratory protective devices). Further development of these standards are on hold, depending on the outcome of the current ISO (international Standards Organisation) work, particularly those of the physiological working and other specialised groups. AS/NZS 1716:2003 noted that there two major points of concern still being expressed at the time of issue[117]:

- The inadequacy of total inward leakage testing to accurately and reproducibly measure the quality and protection provided by a respirator in the workplace, and,
- The lack of testing of all types of respirators at the very high breathing rates that have been found on experimental subjects doing sustained work.

Identification of some of the limitations of commercial respiratory equipment such as the inability of most respiratory equipment to meet the practical needs of users in the workplace, international standards and industry practices, have recently been made possible by new technology developed in Australia and NZ and will be described later in this thesis.

Typical limitations of RPE are many and are dependent upon the type of equipment but include the need for an adequate face-seal on negative pressure equipment and the need for powered equipment to be able to meet the airflows of the user.

Many of the scientific recommendations made as far back as 1943 by Silverman et al,[118] have received little attention over the past decades in spite of criticisms by physiologists about the use of data assumed to be correct by respirator manufacturers and standard organisations, but now suspected to be in error.[119]

As a further example, “disposable” respirators are widely used in applications such as as industry and hospitals in New Zealand, yet are permitted for certification purposes to leak contaminants to the wearer well in excess of 20% (and in practice is probably much higher than this because of training and face fit issues) according to AS/NZS 1716:2003.[120] In addition, there is the need for wearers to be able to both physiologically and psychologically deal with wearing the RPE. In many industry sectors, this is becoming a significant issue with many industries in New Zealand now working an extended 12 hours per day. In some industries, wearers are expected to wear the RPE for very long periods of time during these shifts. Typically with negative pressure respirators for example, sweating inside the unit with subsequent condensation of the moisture creates significant barriers for the user. In addition, in many applications other types of RPE may be excluded because of other practical considerations such as the need for the wearer to move freely around the plant and machinery.

A number of papers on this issue were presented by the author at the International Society of Respiratory Protection (ISRP) conference in Amsterdam in December 1997,[121,122,123] and a paper was presented at the July 2000 International Occupational Hygiene Association conference in Cairns, Australia[124]. Numerous presentations have also been made at technical meetings[125] and industry groups in New Zealand.[126]

Silverman et al, in 1943 pointed out that “for protective equipment, the mean inspiratory flow is of more significance than the minute volume” and warned that it is possible that the flow rates now used as standard in the testing of protective equipment in terms of peak air flows were too low to ensure complete protection”. This remains a significant drawback in respirator design and use.[127]

All respirators will expose the user to some levels of contamination and this is well recognised by the manufacturing industry and manufacturing standard organisations such as AS/NZ Standards. The percentage of contaminant penetration currently allowed will range from a maximum of 20% to 0.05% for other than SCBA (Self-Contained Breathing Apparatus) or Air-Line Respirators.[128] In the USA, other criteria are set such as the designation “N95”, that is, a filter efficiency level of 95% against solid or non-oil based particles (0.1 to 0.3 µm).[129,130]

1.1.3.4 *Design and Manufacture of RPE*

From a manufacturer perspective, there are significant commercial interests at stake. Most manufacturers of respiratory equipment focus production quality on meeting relevant Australian and New Zealand Standards, or other standards such as those of the USA, European or those produced by ISO (International Standards Organisation). Such standards tend to be developed in consultation with interested and knowledgeable individuals who meet to discuss (in this case) respirator design and use. Unfortunately, users are generally not widely represented on the various Standards organisation expert committees, with the exception of specific interest groups such as the firefighter community but they tend to consist primarily of manufacturers with their specific focussed interests. Recently, the efforts of both the ISRP (International Society of Respiratory Protection) and the ISO have attempted to increasingly focus on meeting the respiratory and physiological user needs of the wearer.

There are fundamental concerns arising in the community concerned with respiratory protection which has had an increasing imputes because of the terrorist attack on the World Trade Centre in September 2001, the resulting exposure of contaminants to rescue workers and the increasing threat of biological warfare[131].

There is now a body of evidence[132] to suggest that the laboratory testing of RPE (Respiratory Protective Equipment), contrasts significantly with the work-place testing of RPE. In addition, the approach to create international standards of RPE under the auspices of ISO supported by the work of the ISRP (International Society of Respiratory Protection) seems to differ fundamentally from the European approach under the auspices of the Comite Europeen de Normalisation (CEN). The former group seems to be keen to predominantly establish standards that equate to what the human needs to do to perform (an important part of the research outlined in this thesis). The older body seeks principally to establish performance against standard norms.[133] This difference in approach is critical to the development of improved respiratory protective equipment and forms the impetus of much of this work.

The ISRP is an independent professional organisation that regularly publishes technical advances and conducts technical conferences in the field of respiratory protection. This younger body is keener to establish standards that relate to the needs of the human body to do work and develop respirators that are able to meet that need. A typical example is the need to develop air flows, particularly peak flows, that can be met by commercial equipment in the market place by workers carrying out heavy work (i.e., when high demands are placed on the RPE). On the other hand, the ISRP is a voluntary and international body, not necessarily driven by historical precedents that may, at least in part, drive the standard committees concerned with commercial needs. An example of their concern is the current debate in the literature about the importance of peak inspiratory air flows in equipment such as PAPR (Power assisted Air Purifying Respirators)[134] or the minimum values of air to be used for standards testing of filters used with respirators[135 136].

Currently, new standards are being considered by ISO[137] and other Standard or certifying organisations partly as a result of new technical information coming to hand, but also partly as a result of the changing modern views of “acceptable risk” in the workplace. It is at least recognised that much of the RPE does not work as well in the workplace as it does in the laboratory or even theoretically and this is giving rise to means to better advise the user about the limitations of RPE in different situations.

It does seem that the work of the ISRP and others have now had a significant impact on the current work of standard committees who are setting new standards for respiratory protection. It is likely that this trend will continue.

1.1.4 What are the current issues with respiratory protection in the workplace?

1.1.4.1 Introduction

There are a range of issues with respiratory protection for users which prevent or provide barriers to wearing the protective equipment in the workplace. Many are well recognised by users of the equipment, particularly half-face rubber or silicone respirators. Examples are shown in Table 1.2.

Table 1.2: Examples of barriers for wearers to respiratory protective equipment (RPE), particularly half-face negative pressure respirators

Examples of barriers to wearing of RPE identified.	Issues associated with these barriers.
Breathing resistance.	Most of the available evidence would suggest that at sub-maximal levels of work there is little impact on the wearer, albeit this changes at higher levels of work. Generally employees can cope by altering their output to compensate for the additional work-load.[138] In some situations, however, this may not be possible (for example, where the work itself requires the employee to work at a pre-determined level of output such as removing burnt-out anodes from an electrolytic cell. Generally a deepening of the breathing and a decrease in the rate of breathing has been observed as a result of increase in breathing resistance.[139]
Heat "build-up" inside the respirator.	The air exhaled while working gradually increases the temperature inside the respirator cavity with no available ventilation to the outside air. In addition, the exhaled air contains a high concentration of moisture which condenses on the inside of the respirator. This water sloshes inside the equipment which becomes uncomfortable.
Discomfort.	The face inside of the respirator can become "itchy" and as a result, people will remove the respirator out of necessity often while in the exposed environment.
Psychological and physiological.	There are employees who find it difficult to wear a respirator (for example, anxiety) and there are practical difficulties such as communication issues.
High ambient heat applications.	In main industrial applications such as aluminium smelters, the only practical type of respirators that can be worn need to be light and self-contained. This generally restricts the type to a half-face or PAPR type equipment. In aluminium smelters, operators have to

Examples of barriers to wearing of RPE identified.	Issues associated with these barriers.
	work in high ambient heat environments. The cells are at 1000°C and the rising air heats the RPE in contact with the face. After a period of time, the equipment becomes intolerable.
Coupled with other PPE.	Respirators generally have to be worn with other equipment such as safety glasses or spectacles or other PPE. These often are difficult to wear with RPE and operators often complain of "glasses fogging up"-a sure sign that the respirator is leaking air through the nosepiece.

Table 1.2. Typical examples of barriers for wearers of RPE, particularly half-face negative pressure respirators.

These frequently results in an intolerable situation for the wearer and the respirator is often discarded even while the wearer is in the exposed environment. It was noted as long ago as during the Second World War, the path of soldiers could be observed simply by following the trail of discarded respirators in the battlefield[140].

The removal and minimisation of these and other barriers are important. The number of people to which these considerations apply are significant. Respirators are worn in New Zealand in many work and non-work situations. There are an estimated 17,030 daily wearers at any time in 4430 workplaces in New Zealand (this is derived from proportional numbers in the USA, with a population of 293.6 million, 5 million wearers in 1.3 million workplaces.

Examples of typical respirator use are shown in Table 1.3.

Table 1.3: Examples of the usage of respiratory protection in industry, HCW (Health Care Worker) settings and elsewhere

Examples of typical respirator use	Typical issues (see below)
Occupational asthma in industries	This disease is prevalent in many industries such as aluminium smelting and certain types of agriculture, particularly those where animals are housed in confined spaces. Total costs currently are about $25m in direct costs and $140m in indirect costs. About 1 in 5 people with asthma have their condition as potentially attributable to the workplace.
Respiratory disease from workplace contaminants	The range of workplaces issuing respirators is huge and ranges from paint workshops to farm contaminants.

Examples of typical respirator use	Typical issues (see below)
Chemical and biological warfare	Worldwide the concern is increasing as a result of the bombing of the Twin Towers in New York and unstable Governments. As a result of recognised limitations of respiratory equipment, there are now new Standards being developed to react to these types of situations, that is, CBRN-Chemical, Biological Radiological, Nuclear threats.
Health care settings	There are many examples such as the protection of HCW (health Care Workers) from patients infected with tuberculosis.
Protection of the general public	This has recently been highlighted further with such events as Anthrax and SARS (Severe Acute Respiratory Syndrome) where there is potential for large sectors of the population to be affected,

Table 1.3: Examples of where respirators are used in industry, warfare, health care and the general public.

Uses of respirators are widespread such as in the prevention of occupational respiratory disease from contaminants in industry, prevention of biological or chemical warfare agents by the military or emergency services or other applications such as in hospital settings to prevent the spread of tuberculosis viruses.

So long as this type of equipment is uncomfortable-if not intolerable-for the user and the only practicable remaining option is respiratory protection, these barriers have to be urgently addressed by researchers, manufacturers, Government agencies, Standard organisations, employers, workers and others. There are significant barriers for users at the present time with regard to respiratory protection that are often unrecognised such as those listed in Table 1.2.

The cost of occupational respiratory diseases are known to be high and the number of diagnosed cases are increasing-probably in part owing to the greater awareness of the relation between the workplace exposure and occupational respiratory disease[5].

[5] This is based on ACC claim data. However, there are legislative changes occurring to the IPRC (Injury Prevention, Rehabilitation and Compensation) Act 2002 that are increasingly enabling occupational diseases (e.g., asthma) to be compensated directly via the diagnosis of a health provider (without an extensive onus of proof). In addition, the New Zealand ACC is active in raising awareness of the

From a compensation perspective such as that with the New Zealand ACC, there are often difficulties in attributing the causative agent of the disease to the workplace and it may not be recognised by the treating physician as work related.[60,141] In addition, the personal effect of a range of respiratory diseases significantly raises the human and financial costs well above the direct compensation figures in New Zealand.

There are many other inhalation risks arising from the workplace environment generally. More than 17,000 lung cancer deaths per year are attributable to inhalation hazards in the workplace in the USA,[142] while the total costs related to lung disease is estimated at $8.5 billion US. Proportionally this would represent an estimated 232 deaths in New Zealand due to workplace inhalation hazards (this is similar to the estimated deaths in New Zealand due to respiratory disease in the 2004 report). [86]

The total fatality rate from occupational disease has been estimated at 700-1000 deaths per annum in New Zealand.[143] This recent report from the independent advisor to the New Zealand Government has raised the awareness of occupational disease in New Zealand.

While workplace injuries receive considerable public attention in New Zealand by the Department of Labour and ACC occupational respiratory diseases are emerging as a much greater problem with diagnosed cases increasing in New Zealand.[61,144] Respiratory disease receives little public attention at present, albeit there are significant efforts being made by many Government agencies to change this perspective at the present time[6].

Workplace diseases such as occupational asthma are largely preventable. This makes the subject of particular importance to Government agencies and businesses in New Zealand and elsewhere.

---

association between work and disease at the present time (2008) with both the general public and health providers.

[6] The focus of the New Zealand Department of Labour intervention programmes is on “airborne substances”, i.e., the prevention of disease from workplace contaminants.

While the barriers to workplace inhalation protection are discussed in each Chapter of this Thesis in more detail, the topics and applications for the workplace considered particularly relevant at the present time are outlined in the discussion below.

1.1.4.2 Discussion

Some of the major issues of current respiratory protection in the workplace include the face seal of the equipment to the face. In practical applications in industry, this critical issue in protection is often ignored in almost all published studies. It is also ignored in studies reporting on the filter capacity of respirators as tests are carried out on simulated face shapes with a breathing machine or with a group of carefully test panel under close scrutiny-as currently occurs in the Australian and New Zealand standards. This type of testing bears little practical reality to the workplace.

Limitations in the RPE that allow leakage also has increasingly important implications in fields such as biological exposure in warfare as there are no work exposure limits that can be set (initial low levels of organisms can grow inside both the respiratory equipment and the body of the user).[145,146]

The respiratory manufacturing industry is primarily motivated to produce respiratory protective equipment to the standards set by organisations such as the Australian and New Zealand Standard 1715:1994 and 1716:2003.[147] Many of the current standard test method as AS/NZS 1715:1994 and 1716:2003 need to be reviewed, as field usage bears little relation to laboratory evaluation of the equipment as currently required.[148]

Disposable type respirators, widely available and used, present a particular concern In New Zealand. Most of their original use occurred with the use in low risk situations, but they are now used extensively in a variety of settings such as hospitals, industry, agriculture and by emergency services workers. They are popular because of their apparent ease of use and low cost, and they do not need maintenance, being thrown away at the end of the task. Today, these types of respirators dominate the respirator market in New Zealand. Under AS/NZS 1716:2003, both disposable and half-face rubber type respirators are classified with a protection factor of ten and there is little apparent difference to the user. In manufacturer training sessions held throughout New Zealand in 2003 by a major respirator manufacturer, industry was advised that there was no difference between the half-face rubber or silicone respirators and the more common disposable respirators. Clearly this is doubtful in practice. At least, with rubber or silicone type half-face respirators a quantitative face fit test is possible as a face seal can be achieved-a factor much more difficult to achieve with disposable type equipment where a close fit is not possible. There are also additional considerations that relate to comfort and hence removal of the rubber or silicone equipment while the worker is in the contaminated environment as compared against the disposable type.

There has been concern expressed in meetings of the ISO Standards group as well as recommendations made to NIOSH to have the protection factor for disposable respirators reduced to half that of the close fitting rubber type, that is, five instead of ten. There is scientific evidence for this judgement,[149] which is mainly focussed on the difficulty of achieving a good face seal by the equipment. There are increasing warnings against the use of these types of respirators in both the USA and Britain. The UK HSE is recommending “nuisance dust masks” (a type of disposable respirator) be removed from the marketplace.[64] However, these respirators continue to be used in all types of workplaces including, oddly, by health care workers (HCW) in health care settings. Surgical masks, another type of respirator used in the health industry, provide even less respiratory protection to either the HCW or the patients but continue to be used.

Some industries where respiratory protection is used present challenges which are not easily resolved by the application of standard respiratory equipment commercially available. For example, in an aluminium smelter, there are efforts internationally to reduce the incidence of potroom asthma (an occupational asthma of aluminium smelter workers). Efforts have recently focussed on improving respiratory protection in this industry. While engineering changes are in progress, in the immediate term respiratory protection is frequently necessary. Workers have to wear respiratory protective equipment in conditions of high radiant heat from the molten aluminium metal in a strong electromagnetic field. Employees have to move in a variety of locations with overhead and local obstacles that prevent restrictive protective equipment being worn such as SCBA or air-line respirators.

Industry sectors such as agriculture present challenges in terms of reducing occupational respiratory disease. Agriculture is the leading export earner (over 75% of the value of New Zealand exports) for New Zealand and employs well over 100,000 people directly with many more indirectly (about 10% of the workforce). Various reports have shown increases in asthma incidence in this sector,[150,151] although in New Zealand this has recently been disputed for the overall agricultural population although some agricultural sectors have significantly higher incidences of occupationally related asthma rather than others.[152] Variations in agricultural practices can have an impact on comparison between different sources in varying countries. In New Zealand, significant increases in inhalation disease in the agricultural population has been seen in the equine, poultry, pigs and the horticultural sectors.[59]

Specific applications of respiratory protection in different industries such as with welding applications also challenge manufacturers and users of RPE. A recent study in New Zealand has reinforced the need for correct respiratory practices among welders due to exposure of welding fumes,[153] yet five years later from the date of the first study 23% of the welders in the original group were still not using any respiratory protection despite their closeness to the welding plume.[144] Difficulties with PPE compatibility and difficulty in wearing the equipment while welding (for example, the use of a welding hood and respirator) probably accounts for part of the problem. This is a good example of the practical barriers for users of respiratory equipment in which users appear to choose the risk of contracting a future occupational respiratory disease rather than suffer the current limitations of available respiratory equipment. It may also be due to the lack of knowledge due to inadequate training and education. This is a requirement under AS/NZS 1715:1994.

Specifications for breakthrough testing of gas cartridges (the time taken to detect a determined concentration of test gas) are set at 30 litres/minute (l/m) continuous flow in Australian/New Zealand Standards, while in European Standards these are set at 95 l/m. It is unclear as to the scientific basis for either value. Practical evaluation tests have shown that the low values are exceeded at even moderate levels of work and would not represent the conditions of the workplace.[154,155] Neither is breathing perfectly sinusoidal or continuous, particularly when communicating.[156,157] These considerations may be important in the design and application of respiratory equipment. Peak air flows have to date been ignored in publications by manufacturers, This may be due to the reluctance of manufacturers to illustrate an inability of their equipment specifications to meet this need or the belief that the high values exist only for very short periods of time and are not significant in terms of the total protection afforded by the RPE. Minute volumes (the air used by the user per minute) are normally the values quoted by manufacturers. To date, manufacturers do not quote peak flows and usually quote minute ventilation values only. Many manufactures appear to be unaware of the importance of peak air flows.

Further evaluation of the actual protection afforded by RPE include monitoring of contaminant inside and outside the respirator in real time coupled with video imaging of the task being undertaken, as attempted by the author in the aluminium industry will provide the most suitable analysis of contaminant reaching the wearer.[158,159,160] The technique is able to graphically present the concentration of contaminant, in real time, both inside and outside the respirator being worn. However, instrumental analysis technology that can readily determine many gaseous contaminants are not yet commercially available which restricts the applicability of this technique in some industrial applications such as in aluminium smelting. This work is outside the immediate scope of this thesis but will have important practical applications in the future.

Confusion may exist by manufacturers and Standard organisations in some of the requirements in AS/NZS 1716:2003. For example, for mechanically generated particulates the required protection factor (concentration outside the respirator versus that inside) is given as 10 with a P1 filter. However, the latter is allowed a penetration at a maximum of 20% against particulates of 0.3 μm (aerodynamic particle size).[128,161] Standard requirements to determine Total Inward Leakage only on selected, carefully chosen subjects may mislead users as to the suitability of PPE in the workplace. Training, education, supervision and maintenance of equipment as well as individual facial fit testing of users who are required to wear respiratory protection is critical to achieving protection, but is often ignored in industrial practice. Wearers may assume that by donning a respirator, protection is achieved but this is not the case.

Facial fit and a range of other factors affect the protection as well as the equipment itself. Even when the fit is measured in the laboratory and subsequently in the workplace, no relationship is seen and the latter is invariably considerably less.[162] Incorrect advice may also be provided by various New Zealand agencies who may lack appropriate expertise (for example, the New Zealand Health Department and ACC) in the case of potential SARS, Bird Flu or anthrax exposures albeit more recent information is available from a variety of international sources.[163,164,165]

In many countries, there are recommendations to initiate and maintain a workplace policy on occupational respiratory diseases, for example, occupational asthma and respiratory protection.[62] In practice, those people affected by occupational asthma are removed from the trigger source immediately to prevent possible further damage,[166] and the use of respiratory protection may be possible at a future point in time to allow the individual to continue working.[167,168,169] However, this requires close medical supervision and the type of equipment chosen becomes critical.

There have been positive results seen in some workplaces such as in agriculture and aluminium smelting, where employees were able to continue to work in their chosen field by wearing a respirator. However, just providing a filter respirator to an asthmatic without training or medical monitoring is not generally recommended by respiratory specialists[7].

Biological and chemical warfare are a significant and increasing threat worldwide and respiratory protection is essential for both the military and emergency response teams. Recent acts of terrorism have created an urgent awareness of domestic security and preparedness issues.[170] The range of possible biological threats (such as, anthrax, ebola and the plague) or chemical threats (sarin, phosgene) is large, can be based on choking agents, blister agents, nerve agents, blood agents and incapacitating agents,[171] and can be more difficult to protect people from than most industrial contaminants.[172] Specific respiratory standards from this new threat are only now being considered and developed.[173,174,175,176]

1.1.4.3 Conclusion

Most of the technical information related to RPE sold in New Zealand is generated by commercial organisations providing respiratory equipment to industry, where the main concern may be more likely the commercial drivers of sales rather than a reduction of occupational disease. Under NZ legislation, there is a requirement to provide “equipment suitable for purpose” and the suitability of much of the equipment sold could be argued. The driver on sales influences the type and manner of research by RPE manufacturers that is undertaken and evaluated. Examples include the lack of real-time monitoring research and the determination of true exposure in the workplace by monitoring under real-life use rather than carefully structured workplace evaluations (workplace studies) that resemble the methods, controls and overview of laboratory conditions.

---

[7] In the experience of the author in the aluminium smelting industry in New Zealand, occupational physicians generally recommended that workers affected by asthma could continue to work in the smelter, but under close medical supervision with carefully fit tested RPE.

In spite of many of the problems for users being well documented, very little progress has been made in the last five decades to improve respiratory equipment such as increasing airflows, whether these are in industry, hospital or other settings. Manufacturers have made significant advances in the type of material that respirators are made from, for examples, silicone materials instead of rubber and have made the equipment available in different sizes to fit different face shapes and sizes, but fundamental changes in respiratory design (such as to increase airflows) has not occurred. The work presented in this thesis, in part, suggests that this is now necessary.

There are practical considerations for the end-user in obtaining advice in health and safety. In smaller organisations these are often the suppliers of safety equipment (who are often ill-equipped to provide this advice) and in larger organisations,[177] purchase decisions are often made by purchasing departments removed from the issue of attempting to reduce the incidence of respiratory disease in the workplace. Even in Government regulatory or advisory groups, there can be very limited knowledge in the prevention of respiratory disease or respiratory protection as illustrated by the examples above. However, the significance is not only in preventing respiratory disease - there are reports of people diagnosed with occupational asthma who are able to continue working by the correct application of different types of protective equipment in the milling industry,[169] in the agricultural industry [167,168] and in the aluminium smelting industry in New Zealand. In the aluminium smelting industry, employees diagnosed with occupational asthma were often successfully returned to the working environment by wearing carefully fitted and worn respiratory protective equipment and under close medical supervision.

Many safety professionals are aware that some of the available RPE for some airborne hazards in industry are not suitable to protect the health of all workers. This, combined with unsatisfactory practices and policies on workplace contaminant control, make the use of RPE problematic. The primary preventive approach is to eliminate or control exposure. Where some exposure may still arise, a secondary priority is to eliminate or reduce the incidence and intensity of occupational injuries and diseases.

Further, many health sector specialists, as well as safety professionals in industry, are becoming increasingly concerned about the respiratory protection that is able to be offered to some groups of workers, for example, health care workers, particularly with the advent of modern resistant stains of tuberculosis, public threats such as SARS (Severe Acute Respiratory Syndrome), Anthrax or the more recent threats of biological and chemical warfare.

The incidence of respiratory disease appears to be increasing worldwide, including those in an occupational setting. Part of the increase may be due to the increased awareness and reporting of the condition by physicians and plant management. The increased incidence is recognised by such bodies as the CDC[178], the ILO,[179] the UK HSE[180] and elsewhere such as Australia by the Australian Safety and Compensation Council. There is also an increasing awareness of the disease following traumatic events in which airborne dusts breathed in by emergency workers are a major factor.[181]

Current commercial equipment available present significant barriers to the reduction of occupational respiratory disease such as limitations in airflows, practical heat and moisture issues, communication difficulties, facial fit difficulties and many others. Until these are mitigated or removed, little significant advances in improvements for users can be expected. It is critical to identify and overcome the barriers for users of respiratory equipment and educate and inform Government agencies such as ACC, Ministry of Health and OSH in New Zealand as to the need to emphasise insights, research, understanding and improve on the current efforts to reduce occupational disease. Asthma as a disease is currently a cost to the nation of $825 million a year in direct medical costs. A significant proportion is known to be work related (estimates range from 3 to 30%, but recent information would suggest that it is more likely at the top of this range).[58] Unfortunately, reporting at the present time to authorities is poor indicating an under-recognition of this problem and others as work related.[59] A large percentage of future occupationally related respiratory diseases will be able to be prevented by improved design and user acceptance of new developments in RPE are now urgently needed.

Overseas authorities are also recognising the need for increased research and preventive applications, particularly in certain industries,[182] such as industry[183] and agriculture.[184]

Intervention to prevent inhalation respiratory disease in industry in New Zealand is critical. It is important to focus on current knowledge and by seeking new knowledge to reduce human suffering as well as reduce impending future high compensation costs. Increasingly, legislation will see more imposition for compensation as the incidence of respiratory diseases from the workplace become recognised, and New Zealand will be forced to follow the current example set by the developed nations such as the UK and USA. Organisations such as ACC focus on reducing high costs of injuries rather than long-term disease where the relation between occupational exposure and incidence may be difficult to establish. This is tending to change with current high media profiles of occupational exposures to asbestos, dioxins, PAH (polycyclic aromatic hydrocarbons) and PCB compounds from industries such as the timber processing sectors.

This thesis focuses providing data to reduce some of the key barriers in the last of the control options in the workplace to reduce respiratory disease in the workplace with a focus on occupational asthma as this is one of the primary, potentially preventable inhalation diseases to the aluminium and other industries, reduce human suffering and reduce the very large burden of potentially large future compensation costs in New Zealand.

1.1.5 *The incidence and prevalence of the occupational asthma problem*

1.1.5.1 Background

Occupational asthma is generally regarded as one of the most common form of occupational work related respiratory disease in the developed world at the present time and is either stable or increasing in incidence according to the latest summaries.[85,59] Prevention of new cases is regarded as the best approach to reducing asthma attributable to occupational exposures.[63]

Asthma in general is a serious public health concern. It is rated as the number one cause of "years lost to disability" in males and is the third highest ranking cause in females.[59] The costs are estimated at about $125M in direct medical costs and about $700M in indirect medical costs including days off work, premature disability and death from asthma.[59]

By comparion current intervention efforts of organisations such as the ACC are focussed on traumatic injuries in the agricultural sector with a total compensation cost of approximately $50M/year in 2007-08 or the total NIHL (noise-induced hearing loss) compensation costs in the same year at $50M/year for all industry sectors.

The incidence of occupationally related asthma varies in New Zealand according to occupation and also to the methodology and definition chosen for the recording of the disease incidence. In agriculture the self-reported incidence has been noted as high as 17.4% (that is, almost one in five) in poultry farmers, 18.2% in pig farmers, 16.5% in the equine industry, 12.5% with fruit growers to a relative low of 10.6% in deer farming operations[185]. Recent research results have indicated that while the total incidence of occupational asthma is low overall in agriculture in some specific agricultural sectors it is high. This may reflect the type of operation such as dairy farming which in New Zealand is in the open environment, while pig or poultry farming are generally in enclosed buildings with subsequent much higher potential exposures.

Other occupations affected in New Zealand are almost every industry sector, but typically include laboratory workers, food processors, plastics and rubber workers and chemical processors, woodworking industries and aluminium smelting. Notification through the NODS (Occupational Safety Service and Health Service Notifiable Occupational Disease System) is known to be poor, indicating an under-recognition of the problem at present[186]. It is likely that estimates of incidence from Government sources underestimate the real problem and that other methodologies that involve occupational hygiene monitoring and questionnaires are more useful.

The prevalence of asthma may be considerably higher in low income urban populations, possibly due to higher exposures of contaminants in the breathing environment and other factors[187]. In a review of 22 selected studies of workplaces with exposures to specific substances, prevalences range from 3 to 54%. Similarly, studies comparing low socio-economic areas with highest areas, showed a 2-3 fold increase in fatality rates. [54]

The ILO reported in February 2001 that in Britain, about one-third of all British workers could be breathing harmful fumes and dusts on a daily basis at work particularly in agriculture, construction and the metal industries.[188]

In Western Europe the numbers of reported asthma cases has doubled in the last 10 years[189]. The CDC (US Centre for Communicable Diseases) has reported that the number of people diagnosed with asthma has increased by about 75%[190]. In New Zealand, the total cost to the taxpayer of asthma is estimated at $3.75 per year for every person and a total of 990,000 work days are estimated to be lost each year[191].

While up to 30% of asthma is believed to be occupationally related by NORA in the USA,[182] another source quotes 1.2% to 15.4% of all asthmatics attributing their condition to the workplace. Many will not recognise that their condition is in fact due to the workplace. More recent studies in the USA have shown the prevalance to be up to 25.8% if respondents had previously smoked.[192] Exact incidence figures vary depending on the diagnosis criteria used to determine asthma incidence.

Occupational asthma is now the most frequent occupational respiratory disease diagnosis,[182] in the USA alone affecting over 6 million people and causing 92,000 reported deaths in 1987. Studies indicate that asthma and allergic conditions are most prevalent in the UK, Australia and New Zealand.[193] It is now the fourth leading cause of mortality.[190] In Australia, occupational asthma is the most common occupational respiratory condition reported.[194] In New South Wales, an estimated 9.5% of all asthma is believed to be occupationally related.[195] The numbers are increasing as are the associated problems for the workplace. For example, latex protective gloves worn particularly in the health field have resulted 2.5% of these workers suffering from latex developed asthma.

There are many compounds known or suspected to contribute occupational asthma. This list is in addition to Table 1.1 above to demonstrate the range of different compounds which may be present in more than one type of industry.

- aluminium smelter contaminants (e.g., fluorides);[196,197,198]
- boat building solvents and particulates;[199]
- range of general chemicals present in industries;[200]
- diesel exhaust from machinery;[201,202,203]
- contaminants from agricultural operations;[151]
- glutaraldehyde;[204,205]
- grain such as in stores;[206,207]
- range of compounds used by hairdressers;[208,209,210]
- isocyanates;[211,212,213]
- metal particulates;[214,215,216]
- metalworking fluids;[217,218,219]
- particulates generated from mussel opening;[220]

- range of paint solvents;[221,222,223]
- range of pesticides;[224,225]
- wide variety of petroleum products;[226]
- particulates generated from wood processing;[227228,229,230,231,232]
- range of synthetic fibers;[233,234]
- particulates generated from textile plants;[235,236,237]
- welding fume particulates and vapours;[153,238,239,240]

This list is not meant to be definitive, there are many other examples.

The incidence of occupational disease can be extremely high, such as with Organic Dust Toxic Syndrome (ODTS) in agriculture. The exposure to organic dust contaminated with micro-organisms will result in an estimated 30% to 40% of workers exposed to develop respiratory disease, albeit they may initially be unaware.[244] Similarly with people exposed to animals. It is estimated that about 33% of animal handlers have allergic symptoms and approximately 10% have symptoms of animal induced asthma.[245]

Not all chemicals are equally contributive and nor is the evidence for occupational asthma equally robust. Allergic sensitisation often occurs during a latency period of one to three years, whereas irritant induced asthma (also known as RADS-Reactive Airways Dysfunction Syndrome) asthma symptoms and cough begin within 24 hours after a single high-level exposure to a respiratory irritant.[246] Variations of exposure and reaction to these are possible.[247] RADS tends to be associated with gaseous rather than particulate exposure.[248] RADS was a phrase coined to refer to persistent asthma after high level irritant exposure (see above).[249,250]

Many cases are induced by particulate organic antigens but also other compounds such as soluble antigens and low molecular weight reactive chemicals such as isocyanates and trimellitic anhydride[251] or particulates such as the proteins responsible for latex allergies that fasten on the powder used in latex gloves. These can become airborne and induce latex induced asthma.[252,253] In many practical cases in industry, the identification of the causative agent is difficult.

Common to all is the recommendation to wear respiratory protection as the preventive strategy,[244,254] even after the person has been diagnosed as suffering from occupational asthma[255]. This is important for many individuals where the lifestyle and the working history of the patient would suggest that their choices may be limited in another form of employment, for example, farmers. The suggestion to seek an alternative type of employment is often not practicable. It has been shown that by wearing the correct type of respiratory equipment many may be able to continue working (for example, in poultry sheds or piggeries) or in other industries such as potroom workers in the aluminium smelting industry as already described.

The choice of respiratory equipment becomes a critical issue for workers sensitised to a chemical or range of chemicals in the workplace. While in the hierarchy of controls, that is, elimination, substitution, isolation engineering controls, minimisation, administrative controls and then only PPE (Personal Protective Equipment), should preferably exclude exposure of the individual worker, in practice options below minimization are the only practicable short term option. The technical development of PPE which recognises the barriers to the use of PPE is one of the most critical industry and agency issue by those concerned with reducing the burden of occupational disease both in New Zealand and internationally. While many of the developed nations have recognized this need and it is one of the top research topics (for example, NORA in the USA), New Zealand agencies concerned with workplace health have yet to recognize this critical issue.

1.1.5.2 Occupational asthma and prevention

Occupational asthma is a particularly valid field of detailed study as the responsible agent may often be identified, complete avoidance may be possible and exposure can be measured or estimated.[256] In practice, this is more complicated, because the exact chemical agent may be part of many agents, different people react differently and the published workplace exposure limits may not be applicable. Some compounds act as sensitisers producing antibodies to the compound or the protein conjugate and others induce asthma by acting as irritants and produce bronchoconstriction probably by inducing acute airway inflammation, that is, Reactive Airways Dysfunction Syndrome (RADS).[257]

Practically, most respirators recommended in the industry focus on removing most acid and organic compounds (with a boiling point above 65°C) and particulates greater than 0.3 μm aerodynamic size.

Diagnosis of occupational asthma is complicated. Timing characteristics (that is, when the reaction to the contaminant takes place which can vary from immediate to eight hours after exposure), medical testing (falls into two main categories, that is, pulmonary function testing and alternative tests designed to demonstrate hypersensitivity), the reliability of the history of exposure (because of legal issues and timing) and the effects of time, that is, patients remaining symptomatic years after exposure.[248] Sometimes symptoms can be delayed as long as 25 years.[258] Specific diagnosis can be complicated as well.[259] These factors and others complicate the identification of specific contaminants.

Attention has usually been focused on specific aluminum smelting industry contaminants (for example, hydrogen fluoride). The aluminium industry is almost unique in Australasia in that the Australasian industry actively seeks to identify the responsible chemical agents as well as to identify, treat and monitor employees that are affected.

In agriculture, farmers may have repeated diagnosis of "bronchitis" before the recurrent nature of the condition suggests asthma. Farmers may have been exposed their whole life (that is, many years) before becoming sensitised.[255] A recent study in New Zealand showed that 10% of the farmer group were exposed to workplace particulate exposures above 5 mg/m^3. Almost 19% of the same group of farmers said that their breathing had become uncomfortable after handling grain or hay.[151] Recording systems invariably under-report the incidence of occupational asthma for a variety of reasons which will be described later in the Thesis. In the Australasian aluminium smelting industry, affected employees are removed from the industry site into a remote workshop 20 km removed from the smelter, where they were able to continue contributing to the industry activities. While this had a number of specific advantages in isolating most of the contaminants from the workforce, most of the employees were so sensitised to specific agents that any material arising from the industry site such as contamination on out-going parcels was sufficient to initiate an asthma attack.

NORA (National Occupational Research Agenda in the USA) has identified the need to develop effective and practical means to prevent work-related airway diseases in at-risk workers. In their view, occupationally related asthma morbidity is preventable.[182]

This preventability makes the subject of respiratory protection and the protection from industry contaminants an important subject for study as well as future research. Because the WES-TWA (Workplace Exposure Standards-Time Weighted Average), may not apply in case of occupational asthma, that is, it is not known if the workplace exposure limits are applicable.[260,261] It is more likely that any exposure, including those below the limit, may trigger an attack. This has significant implications in the recommendations made to those suffering from occupational asthma. Published limits for workplace ambient exposure may not be applicable in the prevention of occupational asthma. Individuals may be sensitised at much lower concentrations and these will vary according to the individuals past exposures and a range of other complex considerations. While it may be argued that the definition of WES-TWA includes the term that they apply to “nearly all workers”, and that the sensitised workers falls into this definition (that is, one of the workers outside the scope of nearly all workers), this is not helpful.

For this reason, respiratory equipment design is critically important as there is evidence that much current equipment will allow some penetration of the workplace contaminants through the filters and may therefore provide little or no benefit. NIOSH in the USA have formally recognised this when describing RPE, “as the inhalation process, under the best of circumstances, will allow some contaminated air to leak into the facepiece.[262] However, reducing the exposure as low as practically possible may not protect all workers.

Lung diseases to farmers, coal workers, grain and cotton workers in the workplace are well documented, but very little is published about preventive measures such as those related to respiratory protection. Even exposure to the general environment, where the levels tend to be lower, suggest that COPD (chronic obstructive pulmonary disease) may be a very important cause of preventable disease and death in the general community.

1.1.5.3 Difficulties in determining the true incidence of occupational asthma

As mentioned, in Australia exposure to workplace hazardous substances is estimated to cause 2300 deaths per annum, seventy-eight percent male.[79] The study indicated that cancer was the prime cause of death, followed by renal, cardiovascular, neurological and chronic respiratory disease.[80] Costs due to hospital costs and loss of productivity were estimated at $160 million although the exact details are difficult to determine. The difficulties arise because in determining the nature of cause of disease attributable to a particular industry, length of time of the causative event, workers compensation systems which may readily recognise an occupational injury but not disease, difficulties in recording by various agencies and other factors.[81]

As an example of distortion in this type of reporting was the data collected to an air accident in New Zealand. An aircraft was forced to ditch in the sea, with the resultant loss of five lives. The fatality of the pilot was not recorded in NZ Department of Labor statistics (he was included in aviation specific records), whereas a builder who also died in the accident was deemed to travelling from work, and therefore his death was recorded as a work related accident.

Costs to workers compensation insurance can be much higher than injury, but owing to current under-reporting, the true incidence is underestimated. While various agencies publish injury and disease data worldwide, the true incidence is always difficult to determine. This primarily happens because the various agencies collect data for different reasons. In addition, political, legal or other factors may result in a fatality or injury being classified differently. Further, the perception of workplace hazards has not been matched to the injury or illness patterns.[263,264] Notwithsatnding the utility and application of the hieararchy of controls, the incidence of injury and disease could be reduced in many workplace environments by the use of existing PPE or development of appropriate PPE.[265]

A "Clean Air Month" has been established in the USA to highlight the growing concerns and importance of lung health with 3 May being declared by the WHO as World Asthma Day. The respiratory tract is the most commonly affected organ system for occupational disease as it represents the port of entry to the body for irritating and intoxicating agents.[19]

Most workplace organisations are very small, including those in the developed world. In New Zealand, about 85% of organisations employ less than five people. This has enormous implications in terms of distributing knowledge and encouraging preventive measures for occupational disease and injury, as well as contributing to under-reporting of true incidence. Typical in the group of self-employed are farmers and agricultural workers who are unlikely to cease working as this significantly reduces the income. This group also tends to be independent, suspicious of interference and tends to regard occupational injury and disease prevention as a luxury.[266]

A taxonomy of workplace injury and disease will assist in identifying the true incidence of occupational disease and injury.[267,268,269,270]

Most industrial injuries and disease reporting is subject to legislation which is unlikely to be fully followed by that group of workers known as the self-employed. In addition, organisations typically report LTI (lost-time injury) which can be altered for a variety of reasons[271], but may seriously develop a culture in organisations or people (a culture of denial[272]) which mislead people in a false sense of awareness leading to poor workplace safety or in exceptional situations, catastrophic failure.[273]

These implications are critical in the effort to reduce occupationally related disease and injury. In the USA alone, in a working population of 125 million, in each day 137 individuals die from work-related disease and a further sixteen die from injuries.[182] The ratio of occupational disease fatality to injury fatality is of interest as workplace organisations can usually identify readily with workplace injury but not so rapidly disease. Similar statistics are likely for other developed nations. In Australia, the figure is about 5% of GDP, that is, 5% of the country's total production of goods and services.[274] In the workplace, about 30% of this is borne by employers, the rest by the employee, the employee's family and the country.[2]

1.1.6 The basis for primary, secondary and tertiary prevention of occupational asthma

In the view of a 1993 expert committee (Report of the Subcommittee of the Epidemiologic Assessment of Occupational Asthma, Occupational Lung Disease Committee) asked to set guidelines for the epidemiological assessment of occupational asthma, the potential of environmental measurements for evaluating the workplace exposures and practices as well as environmental controls has not yet been realised.[275]

An example of this is observed in the aluminium smelting industry. In this industry, extensive monitoring of the environment was carried out as well as personal monitoring (using personal dosimeters to determine, for example, sulphur dioxide or fluoride) and exposure of biological monitoring of individual exposure (for example, urinary fluoride). The physicochemical nature of airborne contaminants in the aluminium smelting industry are often complex, for example, there may be irritants adsorbed onto particulates, and the long-term effects on personnel are in many cases not known. Some chemical compounds only existed in the heated state directly above the cell and changed their chemical structure when cooled. It was thought that some of these temporary compounds had an effect on occupational disease. In addition, the individual worker's susceptibility to the range of occupational contaminants has significant implications. While a great deal of research was, and is currently carried out, much of the impact on the health effects remain topics of research. Typical of this work is Priest and O'Donnell in New Zealand who were active in efforts to reduce the incidence of occupational asthma in the industry.[276] Apart from occupational asthma, cancers from exposure to PAH (polycyclic aromatic hydrocarbons) and potentially from electromagnetic fields are topics of concern to this industry. The aluminium industry actively seeks to identify cases of occupational asthma and seeks interventions to prevent further cases. However, this is unusual. Most industries in Australasia do not actively seek to identify cases of respiratory diseases such as occupational asthma and as reporting is also inadequate and incomplete. Much information about disease related to the work environment remains unknown.

Prevention of asthma today involves practitioners in such fields as in medicine, nursing and hygiene, management as well as others directly affected by the respiratory disease from exposure to industrial contaminants. The problem requires expertise from a number of different scientific and medical disciplines.

Some papers suggest that it may be useful to assess the chemical structure of a substance that may present a risk in terms of occupational asthma.[277] However, the range of known compounds is expanding rapidly and many compounds that currently are a known factor are well recognised. Compounds apparently as innocuous as flour can cause asthma, especially in conditions of high exposure. It is not only the presence of the contaminant that is important, but also intensity and duration of exposures. Additional complicating factors are the type of exposure (TWA-Time Weighted Average or Peak Exposures) or just random, infrequent exposures. In addition, the onset of symptoms of the disease can occur many years after exposure. All of these topics are discussed in more detail with tables in other sections of this Chapter as well as in other Chapters of this thesis.

In terms of this thesis, primary prevention refers to the identification, monitoring and control of the exposures, that is, eliminating, isolating and reducing the airborne contaminants to which people potentially could be exposed to generally referred to as the hierarchy of controls. Secondary prevention refers to the identification of people who could potentially suffer occupationally related asthmas in the workplace such as people with a history of asthma. Tertiary prevention refers to the medical and occupational hygiene management of people affected by occupational asthma.

A brief outline is given here while more information is given in the remainder of the thesis - in particular, as it affects the barriers to the wearing of RPE (Respiratory Protective Equipment) and highlighting the need for improved respiratory protective equipment in the workplace.

1.1.6.1 Primary prevention of occupational asthma

Organisations such as the UK Health and Safety Executive, NIOSH and the New Zealand Department of Labour (Occupational Safety and Health Service) recommend the following:[278]

- Identify the risk of exposure;
- Take measurements of personal exposure sufficient to gain an estimate of the mean of the range of concentrations;
- Take additional samples at relevant background locations and of lower exposure and of lower exposure tasks.

While this is good occupational hygiene practice, the difficulty remains that the information is difficult to relate directly to the prevention of occupational asthma. However, it useful in indicating potential areas of plants or tasks where the likelihood of the disease could be higher due to airborne contaminants.

In work areas where there is potential for exposures to contaminants above Workplace Exposure Standards (and often lower) control measures should be implemented. These are elimination (is the substance necessary in the first place), substitution (can another substance or process be used), isolation and minimisation (that is, local exhaust ventilation and personal protection). However, the complex nature of many occupational disease exposures result in minimisation tactics that are difficult to apply rigorously. In practice, WES (Workplace Exposure Standards) are normally used as a guide to exposure limitations, but it is not known what the exposure limit is for many chemical compounds and generally updated revisions of the former WES show lower limits. In addition, there are a range of complicating factors, such as sensitisation of many individuals to specific chemicals possibly due to previous exposures or the unknown effects of lengthy exposure times to low concentrations (as opposed to short periods of high exposures) as well as individual tolerances to specific chemicals.

Like many industries, the process of aluminium smelting releases a variety of contaminants to the atmosphere, some of which exist for only a short time due to cooling. These vary according to the type of operation, the section and specific tasks been carried out, and the temperature (aluminium smelting is carried out at about 1000°C).

Personal protection is often the only practicable option in industry, health care and other settings when elimination and isolation of the person from the contaminated atmosphere is not possible. In many large industrial plants, it is often difficult to rapidly change the technology of the process rapidly (for example, aluminium smelting by the electrolytic process) without the scrapping of large infrastructures and recapitalisation of new technology.

The recommendation to wear respiratory equipment is the last resort to protect people from the working and contaminated atmosphere. Often, the ideal RPE is not practicable in the working environment, for example, air line respiratory protective equipment can not be used due to the air lines from the blower or compressor unit not being able to be used around complex and protruding plant and molten metal at over 1000°C.

This may limit the type of RPE that can be worn to a PAPR (or more recently, the FPBR) or negative pressure respirator.

Most PPE, including RPE, is uncomfortable to wear, particularly for extended periods of time[279]. In addition, the need to wear the equipment for extended working periods up to twelve hours per day,[†] results in real practical constraints for the employee who is required to wear the equipment. The difficulty often is unrecognised by the employer or the medical personnel making this recommendation. The result in practice is that the RPE is often removed from the face by workers whenever supervisory management is away from the workplace[8]. This, off course, negates the use of the equipment as only short periods of non-wear time can result in little effective protection over the shift period of twelve hours. For example, removing the respirator from the face for five minutes in an eight hour shift while in the exposed environment, reduces the protection factor available significantly.

The negative pressure respirator (in which air has to be drawn through a particulate and gaseous filter) has serious practical disadvantages in that significant work is done by the wearer to filter the incoming air even to any plant work being done, but are inexpensive to manufacture compared against alternatives. The PAPR type equipment commercially available has a number of advantages in this situation, but has been shown in this thesis to provide limited air rates below that required by the wearer. This led to the further research described in this Thesis on the development of Minute Air Flows and Peak Inspiratory Air Flows and the subsequent development of the FPBR (Fan supplied Positive pressure Breath responsive Respirator-a type of respirator incorporating the information derived from this work and others).

[†] Especially noting that workplace exposure standards are generally established for eight hour/shift exposures that may not apply to longer shifts.

[8] This observation is from the author's practical experience in the aluminium smelting and pulp and paper industries in New Zealand.

1.1.6.2 *Secondary prevention of occupational asthma*

Secondary prevention and health surveillance may be useful but are often difficult to apply in practice. For example, there is evidence that smoking and atopy (a genetic predisposition to allergy to common allergens such as dust mites and grass pollen) may increase the chance of sensitisation[280]. To exclude these people from the working population would suggest that the work cannot be completed by a large part (perhaps as much as two-thirds) of the population. This would probably be in controvention of much legislation in many countries. For example, the aluminium smelting is where people with a history of asthma (including occupational asthma) are excluded from the work environment though a process of active pre-employment health screening. This did not prevent the development of occupational asthma in about 0.3% a year of the remaining smelter population annually in spite of known issues such as the “healthy worker effect”, “survivor populations” and close medical screening of all staff by a team of medical and health professionals.

In practice, it was known that some potential employees were not detected as having asthma because they took dilators prior to the medical required as part of the induction process of new employees. In locations where availability of work, particularly in higher paying roles, is limited, this type of practice could negate the desire by the employing organisation to limit the entrance of only “non-asthma” affected employees. Pre-employment medical examinations are therefore helpful but do not always exclude potential employees that may be affected by atmospheric contamination from the smelting and other processes. Further, some exposures induce asthma in the non-atopic individual, for which no amount of health screening will be useful.

1.1.6.3 *Tertiary prevention of occupational asthma*

Tertiary prevention and case management become important for those who become affected. A number of articles and experience would indicate in many cases an unsatisfactory outcome in terms of health, financial situation and social well-being in those who become afflicted with occupational asthma[9] [281]. Normally, patients are advised to seek alternative employment or at least be redirected towards work without exposure to causative sensitisers. Unfortunately, this often leads to a reduction in income, loss of benefits and even loss of job. In the NZ situation, however, because of the ACC system, people are not financially disadvantaged, but may be disadvantaged socially or by peer pressure. There is some evidence that respiratory protection may be possible to allow these individuals to remain in their work, albeit the choice of protection becomes critical as does the consistency of wearing the RPE.[10]

Treatment and prevention involves both medical and occupational hygiene interventions. Medical management alone is rarely adequate and additionally, cessation of exposure is an integral part of the treatment. The difficulty remains that almost all practicable personal protection currently commercially available is limited in the ability to exclude harmful substances from the breathing environment. It was recognised in the aluminium industry, particularly as experience was gained with half-face respiratory protection, that new developments in PPE was essential and that current paradigms were inadequate to cope with the current situation and the increasing respiratory disease problem.

There is some evidence from the aluminium industry and from the agricultural industry (particularly in poultry sheds) that people affected by occupational asthma and sensitised to their industry contaminants may be able to continue working provided suitable respiratory protection is worn before any chemical exposure induces asthma-like symptoms such as wheeze. The difficulty of recommending correct protection as well as

---

[9] The author established a rehabilitation centre for employees of an aluminium smelter in New Zealand diagnosed with occupational asthma. This centre is staffed with health providers and rehabilitation experts.

[10] This is from the author's personal experience as a health and safety professional in an aluminium smelter in New Zealand. He was part of a team of physicians, occupational specialists and other health care professionals who favoured a return to work under closely managed conditions.

the limitations of protective equipment in practice may not be recognised by the treating physician.

If improvements in this type of situation are to be improved, then the barriers to current respiratory protection and the limitations have to be more widely known and applied research taken in identified areas. This and other factors led to this program of work at conducted in this thesis.

1.1.7 What are the practical options for lowering the exposures that contribute to occupational asthma in workplaces such as an aluminium smelter

1.1.7.1 Introduction

It is generally agreed that respiratory protection offers a last line of defence against workplace airborne hazards following elimination, substitution, prior engineering controls, isolation from the contaminant and administrative controls. In many industrial situations, immediate changes to engineering alternatives are not always practicable. Examples such as reducing the emission from hundreds of operating cells ("pots") in an aluminium smelter or isolation of the people from the contaminant at all times is often difficult, and leave few available immediate practical options to respiratory protection. The need to provide protection of employees from smelter-type airborne contaminants remains.

Apart from the practical issues related to RPE in this type of environment mentioned earlier, there are other known problems such as the need to communicate in the workplace, which can be sometimes essential for safety reasons. For example, employees have expressed concerns to the author about the effect of inhalation resistance (because work is required to draw air through the filter) as well as the need to increase airflows over that provided by currently commercially available respiratory equipment, that is, employees felt they were "over-breathing" the equipment. Inhalation resistance has been thought to be significant at higher rates of work. Some of the issues are examined in more detail below.

In industry practice, many of these limitations are not apparently present with disposable type half-face respirators. These tend to be viewed as comfortable to the wearer. This type of equipment cannot seal against the face as it required by all other negative pressure respiratory equipment. Unfortunately, large amounts of inward leakage invariably results but will usually remain unrecognised by employees. Disposable type respirators remain the preferred equipment of choice in the aluminium industry and other industries. Many of the technical issues related to ineffective protection remain unrecognised by many employees. There are increasingly calls for this type of equipment to be given a much lower protection factor than other types of half-face respiratory equipment. Currently under standards such as AS/NZS (Joint Australian and New Zealand Standards) 1715:1994 and 1716:2003, the protection factor for loose fitting disposable respirators and tight fitting half-face respiratory protection is the same. The scientific reasoning for this basis remains unclear.

Therefore, there are significant practical problems for the users of respiratory equipment that appears undocumented. In aluminium smelters the radiant heat from uncovered electrolytic cells quickly heats the protective equipment itself to well over 60°C - around the temperature at which the equipment cannot be tolerated against the skin and will be removed by the wearer. Similarly, in industrial paper mills, there is relatively high heat from the process of the rolling mills at about 100°C but in addition, the water vapour concentration is very high (paper is produced by rolling a suspension of wood fibre in water through high pressure rollers at high temperatures). Any surface will quickly have water condensing on and inside the equipment. This not only has a huge effect of the capacities of the activated carbon filters (because the adsorbing capacity is limited) but as the water condenses inside the equipment, it becomes intolerable to the wearer (water sloshes inside the face piece and causes discomfort and severe itching). As a result, the equipment is invariably removed by the wearer while in the exposed environment

In order to ensure that the equipment can be worn for extended periods of time these and other barriers to the usage of the equipment need to be overcome. The reduction of occupational respiratory disease by the use of RPE is unlikely to be substantially affected unless these barriers are reduced or removed. The barriers and others that were identified by the author in these industries were largely not able to be overcome by currently commercially available equipment. These include the need for physiological work to be reduced, temperature exposures to be reduced, filtered air delivered to the wearer to be drawn away from the front of the worker, and boh the air rate and volume to be excesss of that needed particularly during high physiological loads (e.g., changing anodes in an aluminium smelter.

Respirators of the PAPR (Power Assisted Air Purifying Respirators) type are popular with employees in industry as filtered air is supplied to the wearer without the need to overcome inhalation resistance. However, it is easy to “over-breathe” the equipment (that is, the wearer requires air at a greater rate than can be supplied), particularly at high rates of work (in an aluminium smelter this typically occurs during recognised tasks such as “anode changing”). This type of respiratory equipment is often confused with positive pressure equipment (which deliver air to the wearer at all times under higher than ambient pressure).

With this background a series of applied research projects were designed and conducted to determine the practical needs of employees in this type of working environment. Examples included air flows and air flow rates, how these altered during speech or communication, identification of some of the barriers in another industry (agriculture) and how they could be overcome.

1.1.7.2 *Effect on inhalation resistance of negative pressure respirators at high metabolic work levels*

The effect of inhalation resistance on employees required to wear respiratory protection is likely to be underestimated by industry practitioners. Respirators in many industries such as metal smelters and to a lesser extent in paper mills (among others) are likely to be needed most during times of high exposure to airborne contaminants but also at high heat and high personal work loads (that is, high metabolic rates).

There is increasing scientific evidence expressing concern over the need to carry out significant work itself to filter air through the respirator cartridge, that is, the work required to be done in drawing air through the respirator filter without any external work being done. It has been suggested that half-face respiratory protection may present an injury risk in heavy industry owing to the increased effort required to filter air through a negative pressure half-face or full-face respirator). However, under carefully controlled physician care this was an option in the New Zealand aluminium smelting industry (as previously described). The effect may become critical at high work loadings as hypoventilation can be induced with lower oxygen consumption.[282] Managers may need to be aware of these factors to compensate for performance decrements by assigning more help to the tasks. Little is known about these limitations in practice and managers may be asking employees to perform tasks outside their normal physiological capability.

It is only relatively recently that subjective effects of respirator use have been studied in detail. Perceived Difficulty Breathing (PDB-a seven point psychophysical scale) showed significant ($P < 0.05$) increases in a measurement of strain in one study at submaximal levels of external load. Wearing respiratory protection does impose a feeling of respiratory distress in individuals exercising at moderate workloads and manifests itself in a perception of difficulty breathing.[283] Early work has shown that perceived exertion is an important measure of an individual's strain.[283]

In a number of studies, subjects walking on a treadmill in endurance exercises to exhaustion resulted in significant increase in physiological effort of breathing to overcome the added resistance, particularly at higher rates of work. The perception of exertion by subjects increased progressively with each level of work and more significantly when the respirator was worn. No significant effects of the respirator was measured at low levels of external work.[283] Most subjects in studies have indicated discomfort while wearing a respirator and have mentioned that breathing requires more effort.[†] This is logical to wearers of respiratory equipment and is well known.

It appears workers wearing masks (respirators) cannot work as long or as hard as they can without wearing masks, and this affects worker productivity. Masks have been shown to increase the oxygen cost of exercise probably due to increased weight, constriction of normal breathing patterns and the increased cost of respiratory work.[284] However, another study has shown that at least for young men of military age, there seem to be few if any, performance and psychophysiological effects of respirator wear for a variety of cognitive, psychomotor and physical tasks, but it is not clear whether this study explored specifically hard work as would be experienced by workers in industrial settings of a wide range of age and other personal factors.[285] There are also major problems in extrapolating the results of surveys conducted in fit, young men to the higher aged workforce, genders or indeed, the general population.

A linear decrease in performance times have been shown with increase in resistance level without any apparent threshold level. It appears that for workers required to work at rates approaching 80-85% of maximum, there are significant effects on work performance[282.] There may also be cases where the employee may in fact be unable to carry out the physiological work at all while wearing respiratory protection. This has significant, practical and limiting implications for many industries such as mining, metals refining and smelting, heavy manufacturing, agriculture, fire fighting and so on, where employees are required to work for short periods at maximal loading at high radiant heat. This issue is unlikely to be recognised by organisational managers insisting on the wearing of respiratory protection in the workplace in the experience of the author. It is not surprising that disposable type, loose-fitting respirators are preferred by employees in industry. While workers are unlikely to be receiving adequate respiratory protection (due to face seal leakage with this type of equipment), the wearing of this equipment at least satisfies management requirements that RPE must be worn - and the wearing can be observed.

This imposed additional load on the employee has been the subject of concern, particularly in situations where the person may not be able to adjust the workload (the normal compensating mechanism) as in the removal of burnt-out anodes from the cells in an aluminium smelter where employees have to work hard physiologically while subjected to significant radiant heat.

For these reasons and others, development and of positive pressure respiratory equipment in these types of industrial environments has occurred, i.e., development of a FPBR (Fan supplied Positive pressure Breath responsive Respirator). There are significant limitations in currently available commercial equipment such as PAPRs including that none could supply air at all work rates to maintain positive pressure.

This resulted in applied research being initiated at a facility in Sydney to assist in the development of respiratory protective equipment that would allow the removal of some of the identified barriers to the wearing of respiratory protection in industry (for example, overcoming the inhalation resistance issues, the condensed vapour issues inside the respirator, difficulties with communication) and allow employees to continue to wear RPE for extended periods under positive pressure as industry work patterns or tasks changed.

1.1.7.3 Minute Volume Flows (MV) and Peak Inspiratory Air Flow (PIAF)

Many authors have quoted the values of minute volume flows as part of the equipment needs for employees while wearing respiratory protection.[286 287] The initial work in this area appears to have been carried out by Silverman and others over fifty years ago,[288 289] but has been repeated at regular intervals since then.[290] The more significant values of inspiratory air flow rates appear to have been ignored over the years by organisations such as standard organisations, government agencies working in this area as well as manufacturers. Even when minute volume flows (MV) and peak inspiratory air flows (PIAF) are mentioned they are quoted incorrectly[291] or interchangeably. In recent times, this has began to change with the work of the author, ISO, the ISRP and others who have all highlighted the importance of peak air flows.

PAPR equipment is often quoted as being positive pressure - which is incorrect. Information in relation to these critical aspects of respiratory protection forms parts of this thesis and details are given further in each of the chapters. Research described in this thesis has subsequently been complemented by other researchers working in different parts of the world and is now also a significant component of the working parties on the current ISO Standards on respiratory protection.

It appears that none of the respiratory equipment commercially PAPR[292] available today can meet the PIAF airflow requirements which may be the reason for the non-inclusion of the real values in the commercial literature. These factors may also contribute to the practical problems being experienced by users such as: “not enough air when it is needed most”.

The difference between PAPR and a positive pressure respirator is now being recognised in USA Standards and different definitions are now given.[294] Contrary to popular opinion, no PAPR can currently claim to be positive during moderate to hard work. Particularly when people are required to communicate while working, the wearing of PAPR will result in significant negative pressure inside the respirator with subsequent potential entry of contaminants particularly with loose fitting facepieces.

Current work by ISO (International Standards Organisation) work is focusing user requirements into the physiological needs of respirators rather than manufacturers meeting the minimal requirements of manufacturing standards as is currently the case with standards such as the present Australian and New Zealand Standards AS/NZS 1715 and AS/NZS 1716.

The recognition of the limitations of currently available commercial RPE for the aluminium smelting industry led to the subsequent development of the FPBR (Fan supplied, Positive pressure, Breath responsive Respirator) in Australia. While this is an independent commercial venture, the applied research work done in it's development, identified and confirmed many of the limitations and barriers to RPE.

1.1.8 Background to respiratory protection in the aluminium smelting industry

Half-face rubber respiratory protective equipment was introduced to the Australasian aluminium industry in 1985 following increasing concerns related to occupational asthma by both the general surrounding community and a recognition by management of the smelters that using the higher level options in the hierarchy of controls was not practicable.

These types of respirators depend on a face seal at the respirator-face contact (one of the main concerns with disposable respirators and reason they are unlikely to be effective) as well as the filter and cartridge materials. Increasing concerns were expressed by the work force over the next few years related to communication difficulties, inhalation resistance (particularly at high physiological work rates), condensed sweat inside the respirator and so on. Respirator manufacturers were contacted expressing this industry concern, but it was not seriously considered except by a single Australasian supplier of respiratory equipment. This subsequently resulted in a number of joint projects while the author was an employee of the smelter and continued after leaving it. Recognising that the problem with respiratory protection was a key one and affected all workers world-wide, the research in this thesis increasingly showed that many of the current paradigms accepted by industry, manufacturers and suppliers were, on closer examination, incorrect.

Occupational asthma, albeit described in more detail in other parts of this Chapter is one of the major concerns of the aluminium smelting industry. Asthma is a disease in which the resistance to the flow of air in the lungs in the airways changes markedly over time.[295] Occupational asthma has been defined as asthma, contributed by compounds in the working atmosphere. Many other definitions have emerged over the last three decades which reflect the complexity and in which the disease can be demonstrated to an association to the workplace. Brooks (1985) defined it as "a disorder where there is generalised obstruction of the airways, usually reversible, and caused by the inhalation of substances or materials which the worker-manufacturer used directly or is incidentally present at the worksite".[249] A variation in responses can occur in the lung after the inhalation of an irritant. By diminishing the diameter of the airways, bronchospasm limits air and hence also limits irritant entry into the lungs. Mucous production and cough serve to maximise irritant removal from the lungs.[248]

It is believed by Comalco [296] occupational respiratory physicians that the incidence of occupational asthma could be reduced by the wearing of effective respiratory protection which significantly reduced exposure to the particulate and most gaseous contaminants from the industry environment.[297]

1.1.8.1 Treatment for workplace respiratory disease and respirator advice

The medical treatment for occupational asthma in the aluminium smelting industry took basically two forms, treatment and avoidance of further exposure. Three ways of avoiding exposure in the industrial were recognised. Transfer to a different area was an option, the use of ventilation and the use of respirators.[248] Unfortunately, this is where the limitations of current commercially available equipment and their practical performance in the working environment arose. One research group [305] studied a group of workers who remained on the job after having been diagnosed with occupational asthma and who continued to be exposed to the asthmogenic agent. There were no recoveries. Although the employees were given respirators, an airstream helmet did not prevent deterioration although a twin-cartridge respirator was of more value.

It is perhaps intuitive that an airstream type helmet (a type of PAPR-Power Assisted Air Purifying Respirator) would not improve the patient's condition as the air supply is generally too low for practical requirements, particularly when the workload increases,[306] and this can allow contaminants to enter the facepiece. A half-face respirator could be of value, but there are significant issues in requiring a worker identified with asthma to wear a negative pressure respirator, particularly in a working environment. Practical difficulties in wearing a tight fitting respirator for an extended period of time is very difficult and at high work loads, there is significant work required to draw air through a filter. This can result in contaminated air entering the facepiece as people lift the respirator off the face. As previously mentioned, under close medical supervision some people were able to return to the workforce.

Current commercial respiratory equipment used in the practical industrial environment allows contaminated air to enter the breathing zone (this is recognized by all manufacturers), albeit in a reduced concentration compared against the ambient environment.

Currently available protective PPE such as respirators, traditionally used in the workplace as a last option to combat occupational disease, has huge practical limitations making much of PPE unsuitable, and may even be hazardous in the practical working environment. An additional complication is from the "wear-time" (the time the respirator is worn in the exposed environment versus the time it is not worn) of a respirator. The non-wearing time of a respirator is due to many factors including heat and moisture build-up (thermal burden[307]) inside the respirator resulting in significant discomfort for the wearer, inability to be heard when shouting or speaking, loss of visual acuity and depth perception,[307,308] irritation of the facial skin particularly after recent shaving and inspiratory resistance particularly at maximal work loadings.[309],[310],[311]

Advice from distributors is often incorrect, albeit that industry is heavily dependant on RPE suppliers and manufacturers.[312] RPE training is often unsatisfactory, biased and breakthrough times and conditions are often unknown and estimated. There are some manufacturers who are active in conducting seminars related to RPE throughout New Zealand, but will generally focus the issue on the specific sales related to their products rather than industry specific topics.

Respirators are used increasingly in a variety of applications in an attempt to prevent or reduce the increasing need to protect people in the workplace and elsewhere from disease such as those orginating in agriculture, for example grain dust exposure (asthma), cancers and livestock (ammonia).[313]

Additional complications in the workplace is the management perspective as the investment made may not be evident for some time. Accounting practices focussing on the financial burden of occupational disease typically concentrate on the short-term outlook (for example, one year), and this is in conflict with many injury and disease initiatives which may take much longer than this.

In spite of this, respiratory equipment continues to be a standard recommendation from physicians and health organisations to reduce or prevent occupational asthma, even when the limitation of current commercially available equipment is recognised and exposure is known to continue, albeit at a reduced concentration (this advice was also given by Respiratory Specialist Physicians to plant management of Comalco about 1995 in both Australia and New Zealand).

1.1.8.2 Practical difficulties with advice on respiratory protection in the workplace

Fit testing of respirators (where the fit of a respirator to an individuals face is validated by a number of possible means either qualitatively or quantitatively), is a requirement in various Standards and by regulatory authorities and is also a good opportunity to educate personnel about respiratory protection and its limitations. Both qualitative (exposure to substances with a strong odour or unpleasant smell) and quantitative methods (for example, Portacount instrumentation which measures particulate concentration in the atmosphere) have been prominently used over the last decade by industry. Unfortunately it has been repeatedly demonstrated that results have no or little relationship to the protection afforded in the workplace.[314]

Workplace evaluation of respirators used in the workplace has been used but has also been strongly critiqued because the methodology chosen often bears little relationship to what normally happens in the workplace. Subjects and equipment in research trials are often very carefully monitored and controlled. Almost all the trials reported have been conducted by respirator manufacturers and are carefully designed to exclude parameters that have a negative impact on the results, for example, ceasing monitoring when the respirator is removed from the face while in the exposed environment - a practice often necessitated by the uncomfortable nature of the equipment in the practical working environment or because of an urgent need to communicate.

In addition, much of the equipment designed over the years has used outdated information about air flow rates and volumes. PAPR (Powered Air Purifying Respirators) are often assumed to be “Positive Air Pressure Respirators” by industry, when they are clearly not in the latter category. The flow rates and volumes required are substantially more than this equipment can meet at the present time.[124,315] Again, this has crucial importance in workplace protection.

Yet further difficulties arise from the protection factors assigned to respirators by such organisations as NIOSH (US National Institute of Occupational Health and Safety). For example, in the 1987 Respirator Decision Logic,[316] a recommendation was made a reduction of protection factors of hood and helmet style respirators from 2000 to 25 (a very large reduction) and yet in 1999, consideration was given to increasing this back to 1000 as a result of pressure from commercial manufacturers.[317]

The implications for advice for workplace protection is very significant. To complicate the topic, particularly for the user, is that there are at least nine different meanings of ‘protection factor” in frequent use (listed later in this thesis). Further, there are many reports of workplace studies where the results are difficult to understand, for example, the same protection being quoted for loose fitting disposable respirators as opposed to tight fitting respirators.[318] There is also confusion in terminology, such as the term “positive pressure” respirator. This implies a positive pressure inside a respirator during the time worn, but this is not the reality, certainly not under conditions of high workload.[319]

The time worn and the manner in which equipment such as respirators are worn all have a significant influence on the final protection afforded. While people may be expected to wear the equipment correctly by management and health professionals in the exposed environment, this is not often what really happens. In addition, the equipment may be expected to be worn for a full shift, which increasingly is for twelve hours. This has implications in a number of ways which relate to the applicability of WES (Workplace Exposure Standards)[320,321] and for the wearer.[322,323,324,325,326] Almost all the equipment is extremely uncomfortable, if not impossible, to wear for this period of time and for this reason as well as other reasons (for example, the need to communicate) it is removed and protection is lost. The total amount of protection is dramatically reduced by non-wear time in the exposed environment. For example, a respirator with a protection factor of 10,000 (the ratio of contaminant outside to inside the respirator), if not worn for ten minutes in an eight hour working day, will reduce the factor to 50[327] (similar arguments can be presented for hearing protection equipment).

For these reasons and others, protective equipment rarely functions as intended. This issue is becoming increasingly important, not only in industry, but in other fields such as civilian and military personnel protection in case of war[328] or terrorism, for example, the well publicised nerve gas attack on the Tokyo subway system.[329] In hospitals around the world as, multi-drug resistant TB cases have been reported in 40 States in the USA[330] and hospital staff are being ordered to wear respiratory protection.[331] Increasingly, concerns are being expressed for the health of staff as well as patients, particularly during certain types of surgical procedures when people may be exposed to aerosolised particles rather than only spattered blood and bone particles,[332] that is, particles whose mean aerodynamic size is much smaller. Studies in other occupations, for example, exposure to dusts in the paper and wood industry, show that much of the exposure (up to 75%) to particles of size less than 2 μm in diameter.[333] Most of the respirators recommended by commercial organisations for this industry, and the types commonly worn, are known not to be able to filter out these small particle sizes in practice (e.g., “N 95” or P2 respirators).

Physicians, managers, employers and others prescribe protective equipment to be worn in the exposed environment in industry, but tend to be unaware of the practical difficulties to do so and have a lack of knowledge of the type of equipment most suitable. An incorrect diagnosis of the type of protective equipment can be extremely hazardous to the wearer.

Those affected by workplace respiratory disease such as a machinist working with cutting oils or the agricultural worker may have to relinquish their skilled professions. Even when removed from the exposed environment, the quality of life is often significantly reduced. An example of this, employees working in the New Zealand aluminium smelting industry about 1985 who were diagnosed with occupational asthma were removed from the exposure by relocating and application of different work. They were physically removed by 20 miles from the plant. This did not diminish the effects of the disease for many of those involved.

In common practice, occupational physicians may recommend that the person wear a respirator, assuming that it will reduce the ambient contaminants and be returned to work. In many other situations in Australasia, the employee may be given alternative duties. Even more serious, in many parts of the world, workplace respiratory disease may not be recognised because of possible litigation issues. Most physicians, including respiratory or occupational trained, do not have training in respiratory protection and may not recognise the implications of this lack of knowledge in the practical workplace.

After the events of the 11th September 2002 terrorist attack on the New York World Trade Centre, significant concerns were subsequently expressed by workers such as fire crews exposed to the building contaminants about the state of respiratory readiness for these sorts of catastrophic incidents.[334] In addition, worldwide concerns about potential biological and chemical warfare in the future and the ability of emergency and military respiratory readiness has raised the "profile" of the equipment ability to meet these kinds of events that were not previously anticipated.

Increasingly some of the problems with PPE, particularly respiratory protection, are starting to be challenged,[306,335] although commercial respirator manufacturers interests from respirator manufacturers still tend to dominate both the presence at Standard organisation meetings as well as in workplace publications.[293] The work of the current ISO groups working on the physiological requirements of wearers some of it based on the work outlined in this thesis and of others in the area, will likely make significant advances in the protection afforded to the wearers in the immediate future.

1.1.8.3 Immediate issues for respiratory protection in the workplace

Much of the currently commercially available respirators are required to operate particularly when people work at high metabolic work rate. Generally in workplaces such as the aluminium industry, the highest exposure also occurs when people have to work at high work rates (such as removing burnt-out anodes from an electrolytic cell). At the higher work rate, the oxygen or air uptake through respiratory protective equipment substantially increases depending on such factors as sex, age and fitness. The current values quoted in such documents as European Standards are substantially lower than recent research. [337] In addition, respirator cartridge air resistance becomes critical at higher metabolic rates,[338,339] involving factors such as higher blood lactose accumulation.[339]

True workplace respiratory protection is a critical issue. There is an enormous need for unbiased research. Most applied research to this day, is carried out by manufacturers. There is also much contradictory information and incorrect information given to industry, even by distributors of safety equipment.[†] The protection offered may vary with current equipment, depending on ambient concentrations of contaminants.[340]

Respirator comfort is often the only reason for choice. Lack of detailed knowledge is a major issue in this area. There are complications in insight which have implications for the health of the wearer. For example, some low molecular weight compounds are known to cause occupational asthma, but may not be removed by vapour cartridges.[341] Similarly, ozone produced in welding operations will not be removed by organic vapour cartridges.[342,343] HEPA (High Efficiency Particulate) filter cartridges are should be used in welding applications largely based on

---

† S. Hancock, H., personal communication, 1999. Welders risk their lungs. Respiratory specialist, BOC Safety Ltd. Safeguard. “Positive pressure is best” is quoted, instead of “powered air purifying respirator”.

their ability to remove the very fine welding particulate, yet many recommendations exist for disposable respirators as the variety of PPE equipment required to be worn can impact on the ability of the welder to carry out the tasks.

This thesis concentrates on a number of important areas in respiratory protection that have not been studied extensively in terms of the user as opposed to the manufacturers of RPE. It is hoped that the results from this work will allow a significant contribution to improving workplace safety and reducing workplace diseases. In addition, enhancement of respiratory protection in other areas such as in times of military conflicts due to chemical warfare or protection of hospital staff from diseases such as tuberculosis, are becoming increasingly urgent as previously mentioned.

To lower occupational respiratory disease, modern standards at least will need to take into consideration work related to:

- International Standards in respiratory protection and the identification of new requirements which need to be internationally agreed. Many Standards are now obsolete and do not take into account recent scientific information (such as minimum breathing requirements). The current ISO work on the physiological requirements of respirator wearers as opposed to the current descriptive requirements will be a significant move to provide better protection for workers in industry and elsewhere.
- Self-employed people dominate the employment numbers in both New Zealand and Australia, but this group appears to be least knowledgeable about occupational respiratory disease and are at need of the greatest intervention. Recent work completed in Southland, New Zealand, showed the extent of the issues in the farming community.[151] The publication of the report “The Burden of Occupational Disease in New Zealand”, published in 2004,[85] once again highlights the significant burden to the nation of occupational disease and focuses on three main areas including respiratory protection.

- The need to have internationally accepted definition of "protection factor", particularly in respiratory protection is important. There are at least nine different definitions and interpretations in common use and these frequently change over time. This confuses the issue for manufacturers, distributors, advisors and users. Oddly, it is currently one of the basis of selecting appropriate types of respiratory equipment.
- Physiological factors and psychological factors present barriers to employees and the self-employed from wearing protective equipment, particularly RPE in the workplace such as breathing resistance, insufficient air supplied, comfort and many others. Unless the barriers can be overcome, respiratory disease will likely not be prevented or reduced as the short-term concerns override the long-term effects.

Employer representatives and occupational health and safety advisers working in large organisations present different challenges in terms of respiratory protection. This is valid whether the application is in hospitals, industry or in military situations. Advice will likely come from a corporate group or an industry specialist. The knowledge, experience and insight of that individual will be paramount, and will be tempered by the employer's wish to optimise costs. As many self-employed will believe that "large organisations know best" (because they have the resources, capabilities and so forth), the "corporate drivers" of these organisations and their ability to acquire new knowledge needs to be understood.

Disposable respirators are widely used, but there are increasing concerns about their ability to function in the workplace as a tight seal on the face (on which all negative pressure respirators depend) is impossible to attain with this type of equipment.

Studies on respirator use are relatively recent. Research into both subjective and quantitative data is very limited in the literature (as shown in this literature review) and the practical requirements of users in the workplace tend to be underestimated. The number of people estimated that are required to wear respiratory protection is, however, huge. In the USA alone, there are 1.3 million worksites which require over five million workers to wear respiratory equipment in daily work.[345] It is likely that a substantial proportion of this five million workers do not comply with the full requirements of respiratory protection, and therefore they will not benefit from any protection it may confer. This is likely to be higher in other nations, particularly in the developing world.

This thesis aims to identify the main barriers for people required to wear protective equipment, particularly in respiratory protection, and encourage manufacturers to build equipment more suited to the workplace needs of people who are required to wear PPE in the work environment so as to improve workplace safety, and ultimately lower the incidence of workplace respiratory disease.

1.1.8.4 The FPBR (Fan Supplied, Positive Pressure, Breath Responsive, Respirator

A new class of respirator, the FPBR (Fan Supplied, Positive Pressure, Breath Responsive Respirator) was designed by staff at SEA Pty Ltd to overcome many of the limitations of current respiratory equipment used in the workplace. Research to determine the breathing volumes and rates is described in this Thesis. The equipment took many years to develop and became commercially available throughout the world in 1999. It is now being used by defence forces, emergency response teams and in industry. Currently, it the only commercial model in existence that meets the airflow requirements that are being suggested by ISO and various authors in recent publications.[346] [347] [348] This equipment is radically new in design and capability. It is truly positive pressure as airflows up to 400 litres per minute can be met.

Commercially available PAPR equipment has shown limitations of this type of RPE in industry. This has implications for many recommendations made as it is usually quoted as giving a higher protection than the tight fitting half-face respirator but this may not be correct.

FPBR equipment is quoted as being equivalent in protection factor to a SCBA-Self contained Breathing Apparatus in atmospheres containing filterable air with no oxygen deficiency. The equipment is advanced in terms of modern respiratory protection and automatically via a micrprocessor continually checks battery power, mask pressure, pressure drop across the filter and records many other events in real-time. This recorded data can be downloaded to a PC for subsequent examination. The equipment also has an internal microphone which aids communication. Breathing rates are continuously monitored and as additional air is required by the user it is supplied. This type of RPE offers opportunities for improved respiratory protection in industry, hospitals and military settings.

Importantly, negative pressure equipment commonly used in many workplaces requires people to inhale air through a filter which can have significant effects such as impaired work output[349] owing to the energy required to draw air through the filter (described above). There is increasing concerns being expressed in the aluminium industry and elsewhere recognising the difficulties of both hard physical work and the requirement to wear a negative pressure respirator.

The inadequacy of PAPR equipment to supply enough air for the user has now been well recognised but still debated. Papers published as far back as 1951 quoted peak inspiratory air flows well above those able to be achieved then[350] and now. It is largely the result of commercial pressure and lack of user concerns that only recently concerns and working parties are being expressed by organisations such as ISO and others.

The work of this thesis required the different types of airflows to be determined under various personal working loads by a typical Australian workforce. These values were used to subsequently design the FPBR operational requirements. The work has subsequently been confirmed by other researchers and is currently being incorporated in the new ISO respirator standards by the physiological working group parties.

1.1.8.5 *Thesis presentation*

This Thesis is presented in the following format:

Introduction

This Chapter gives an introduction and background from the perspective of improving respiratory equipment for workers. While the prevalence of occupational respiratory disease remains an important stimulus for improving working conditions in many industries, the identification, assessment and control of workplace exposures that induce such diseases remains paramount.

Many practical concerns have been expressed by employees in various industries who are required to wear RPE. Commercially available RPE has severe practical limitations. In addition to the need to reduce the incidence of occupational asthma in the industry, these considerations stimulated research to improve respiratory protection for employees. This, in turn, lead to the need to verify existing physiological requirements for wearers of respiratory equipment and to influence Standards to more appropriately meet the needs of employees.

Much of the work in this thesis focuses on the physiological and practical working needs of the wearer. Different types of practical working environments such as in the aluminium smelting or paper manufacturing industry presents challenges which present difficulties for wearers of PPE and RPE, such as:

- The need to work in areas of high ambient temperature (in excess of 1000°C);
- The need to work in areas of high humidity;
- The need for high personal physical work output (i.e., high physiological loading) during specific tasks (and as a result, considerable personal sweating, high air flow volumes and rates

through the filter and an unpleasant itchiness and discomfort within the respirator while worn);

- The presence of a strong magnetic field prohibiting the use of much RPE (the strong magnetic field attracts or repels specific metals);
- The inability to tolerate any attachments such as hosing for air-line respiratory equipment due to the complex industrial structures in which employees work.

These and other limitations often remain unrecognised by management or occupational physicians, who will recommend that some form of RPE to be worn. This often results in conflict as employees try to meet the needs of both management and their own physiological requirements. The focus in practice often shifts from the need to reduce occupationally related respiratory disease to a conflict between employees and their management.

In this thesis, the first section gives an overview of RPE particularly as it relates to industry based on the experience of the author in the aluminium smelting industry, the research aims, research questions and aims are then described followed by 4 case studies related to air flows and finally a case study related to agriculture in New Zealand.

- Chapter 1 gives an introduction to the RPE as it relates to industry particularly aluminium smelting and the practical means to lower the incidence of inhalation disease typically occupational asthma.
- Chapter 2 outlines the research questions and the resulting project aims and objectives.
- Chapter 3 describes the methodology used in the Thesis.
- Case study 1 is a determination of the minute volumes and peak inspiratory air flows during key operating tasks in an aluminium smelter.

- Case study 2 is a laboratory study of heart rates and minute volumes that could be expected from volunteers in a typical SME (Small to Medium Sized Enterprise).

- Case study 3 derives an possible alternative method of determining TIL (Total Inward Leakage) which is more representative of a typical SME with an older age group and both genders.

- Case study 4 is a laboratory study to determine the Peak Inspiratory Air Flows during work and when communicating.

- Case study 5 describes the methodology and results from a questionnaire designed to gain an insight into the current awareness of respiratory disease and RPE in the New Zealand agricultural sector.

Total Inward Leakage (TIL)

Total Inward Leakage (TIL) is currently determined in most Standards by taking ten very carefully selected subjects and quantitatively analysing the concentration of a particulate contaminant such as sodium chloride of a range of known particle sizes inside and outside the respirator while a selected subject is performing a set of pre-set exercises.[†]

This bears no resemblance to the protection afforded to the wearer in the workplace.[‡] Employees can exhibit a wide range of face shapes (for example, from different cultures, gender or as the result of injury) and often little training is given in the use of the equipment-particularly in SMEs or with the self-employed. It is difficult to get the same TIL results

---

† This is the contaminant usually used by Standard organisations because of the common nature of the chemical and the ability to obtain a reasonably select range of particulate sizes at low but consistent particle size.

‡ Manufacturers will argue that this is not the purpose of the test. Their view is that the purpose is to determine the suitability of the RPE on a set of subjects to meet standard requirements. Standards are currently prescriptive rather than the currently in development descriptive ISO standards where the basis is the physiological requirements of the user.

on different days and between laboratories, but more importantly, the results bear little results to reality or what can be expected under practical conditions. This results in purchasers of RPE having confidence in the efficacy of the equipment which is likely to be misplaced. Also, people do not normally work under such carefully monitored "working" conditions.

An alternative methodology is suggested in this Thesis and experimental results shown. The adoption of a technique such as that proposed in this thesis would improve the current methodology for TIL while meeting the physiological requirements of RPE wearers.

This part of the thesis was to demonstrate that an alternative method of determining TIL is important in ensuring that the minute volumes used approximate the values from a typical SME (e.g., an older age group and of both genders). At the present time, the TIL results obtained in testing by certifying organisations may not reflect those typically found in the New Zealand workforce.

Use of Minute Volume

One of the important physiological factors required in RPE is the minute volume, or the volume of air used per minute. This value is used in the design of PAPR type RPE as well as to determine the useful life or cartridges or filters. Particularly at high levels of work, the ability of the PAPR delivery system to deliver sufficient air and the ability of the cartridges to ad/absorb air becomes critical. In practice, the type of PAPR also has a significant influence, such as whether the PAPR equipment has a tight face fitting arrangement or not (there are many different configurations made by different manufacturers and also by each manufacturer). This has an influence in such environments as an aluminium smelter where rising hot and contaminated air from the cell can "over-ride" the downward flow of purified air through the PAPR in a loose-fitting configuration. There was a wide variation found in the values of minute volumes from this group, often well in excess of that used by Standard organisations to certify respirators or cartridges for use in industry.

Peak Inspiratory Air Flow (PIAF)

The determination of PIAF (Peak Inspiratory Air Flow) during various levels of work and while communicating in the workplace is particularly important. PIAF refers to the speed of air being delivered by the RPE and by convention, has the same units as the minute volume, that is, litres a minute. PIAF values are rarely quoted by the manufacturers of RPE. Manufacturers to date still do not quote both minute volume and PIAF values and cartridge testing is often completed at unrealistic low minute volumes by both standard testing authorities and manufacturers.

Current ISO working groups are now incorporating the different values of minute volume and PIAF values in their current standards work on meeting the physiological needs of wearers.[†] The use of PIAF values in the specifications of PAPR equipment and the determination of the practical life of cartridges significantly alter the values used by standard organisations worldwide to determine the suitability of RPE equipment. It is also a critical value in meeting one of the barriers that wearers of PAPR have frequently asserted, that is, "insufficient air at high working rates". This part of the thesis describes the values of PIAF under different physiological loads and also when communicating in the workplace. The values were found to be particularly high when communicating in the workplace. PIAF, as a result of this work and others, have become a major topic of discussion in specialist journals such as those of the ISRP as the significance is debated by manufacturers of RPE and whether current RPR such as PAPR (Power

---

[†] Various ISO working groups are involved in developing descriptive standards that incorporate the physiological needs of wearers rather than prescriptive standards that set out the minimum standards that RPE must meet. The change in focus on meeting the physiological needs of wearers is a significant and critical worldwide change in focus. Standard organisations in Europe as well as in Australia and New Zealand are postponing development until the ISO working groups have completed their work. Typical of this is AUS/NZS 1716:2003 which describes this in the foreword to the standard.

Assisted Air Purifying Respirators) deliver sufficient air volume and rate[365 366].

Respiratory Protection in the Primary Aluminium Smelting Industry

This Thesis contains a case study that investigates the relationship between minute air volume and PIAF during various tasks at an aluminium smelter in New Zealand. The work related to PIAF has been subsequently duplicated in other industries in the USA and Europe as well as in lead smelters and with fire services personnel within Australia. The work here has been the basis of investigating PIAF further in this Thesis as the high airflows experienced resulted in concern by the aluminium smelting industry as to whether the RPE provided to thousands of workers inside the industry was sufficient to meet the needs of the users particularly under high physiological loading (and at the radiant heat experienced in a typical smelter).

To reduce occupational disease, detailed insights into the concentration of contaminants reaching inside the respirator in real time during all stages of work needs to be better understood.[367] The introduction and application of the PIMEX technique may provide significant opportunities for an improved understanding of the exposure of people in the workplace in real time (most current investigations use averaged time such as TWA-time weighted average calculations) during the respiratory cycle.

Respiratory Protection in Agriculture

Respiratory protection in the agricultural industry is typical of many of the challenges faced by self-employed and SMEs in New Zealand. In addition, farmers are usually geographically isolated and the home is also the place of work. Health and safety regulations, common in the urban industrial centres, are difficult to enforce in rural areas.[†] The

---

[†] There are many examples of this. In New Zealand, a tractor is legally allowed to be driven off road by a 12 year old. This is often a very large piece of machinery,

sectors are often difficult to influence, they are used to taking risks (for example, weather variation affecting crops, international prices for commodities) and the where the Agrarian Myth dominates.

In New Zealand, well over 100,000 people are actively engaged in agricultural work (about 10% of the total workforce) in a variety of different and large agricultural sectors (for example, dairying and kiwi fruit growing). Many operations involving agrichemicals require handling involving respiratory equipment and there are also many daily operations in confined space environments such as occurs daily in over 16,000 dairy sheds spread throughout the country. In New Zealand, Government agencies are becoming increasingly concerned, and there are now new and specific chemical handling requirements under the HSNO (Hazardous Substances and New Organisms) Act.

There are currently significant barriers for the users in the wearing of RPE that have to be overcome. This research attempts to identify some of the key barriers to this group to gain a better insight into the views and understanding of respiratory protection in this industry with a view to developing interventions in the future by surveying farmers in the New Zealand FarmSafe program.

Results indicate that in spite of the numerous awareness and education campaigns conducted in New Zealand over the previous decades by numerous Government departments and non-Government agencies, there appears to have been few key concepts related to RPE and occupational disease incorporated by the agricultural community in New Zealand. It is suggested that a comprehensive and more intensive campaign is necessary if the concerns expressed by New Zealand Government agencies about the potential liability related to disease is to be addressed[11].

---

sometimes driven on steep sloping country. By comparison, in the urban centre, the use of a forklift requires a trained adult driver.

[11] At the present time in New Zealand, the key directive from the Government to the Department of Labour is a focus on “airborne substances”, their identification and

Barriers to the Use of Respirators

Respiratory equipment in the future will need to recognise some of the barriers that exist in industry, particularly with SMEs. It will be important to design equipment that recognises the limitations and overcomes recognised barriers rather than to rely on principally on education as has occurred to date, that is, implement long-term engineering solutions to RPE rather than focusing on short-term behaviour changes. There is already a strong move in organisations and working groups such as the ISO Physiological Working Groups to focus attention on the physiological needs of the user, rather than the historic emphasis by these organisations on meeting the needs of the manufacturers. There is evidence that people in SMEs generally do not read and act on information that does not directly influence the profitability of their individual businesses.

It is the national overview role of New Zealand Government organisations (for example, Department of Labour and the Accident Compensation Corporation) to set the long-term direction to reduce occupationally related disease. They need to provide incentives to stimulate further research and PPE technical development and be active on national and international technical committees, as well as encourage the correct type and use of PPE including RPE. These organisations have traditionally tended to focus on the more obvious and immediate impact of traumatic events and this is required to change if the aim is to reduce occupationally related respiratory disease. Results of parts of this thesis, particularly those sections related to minute and peak air flows are now being incorporated into the ISO Standards and including the work of other subsequent workers in this field as data is now provided in this thesis that demonstrates that airflows may not be

---

control as it relates to occupational disease. This has arisen because of reports such as those by NOHSAC (2004) (National Occupational Health and Safety Advisory Committee) in the report, "*The burden of occupational disease and injury in New Zealand*" (Driscoll, T., Mannetje, A.T., Dryson, E., Feyer, A.M., Gander, P., McCracken, S., Pearce, N., Wagstaffe, M. ISBN 0-478-28011-4.

adequate to meet the needs of users in the workplace, particularly under high physiological loads and when communicating in the workplace.

1.2 References

1 ILO. Occupational Health and Safety: Current work. *International Labor Office, Geneva*, 1999.

2 ILO. Occupational Health and Safety: Current work. *International Labor Office, Geneva*, 1999.

3 BBC news and associated comments. Retrieved http://news.bbc.co.uk/2/low/health/medical_notes/304383.stm on the 14th August 2008. See also http://news.bbc.co.uk/2/low/uk_news/304198.stm.

4 NZ Herald (2004). 5/11/04. Reporting on research published in the Medical Journal. Dr Tord Kjellstrom and Dr Smartt, *Auckland Medical School*.

5 Winder, C. Occupational respiratory diseases. Chapter 4 in: Occupational Toxicology, second edition, Winder, C., Stacey, N.H, editors. *CRC Press*, Boca Raton, pp 71-114, 2004.

6 Wallaart, J. Last line of defence. John Wallaart on respiratory issues. *Safeguard,* **92**. July/August 2005.

7 Grammer, L.C., Harris, K.E., Yarnold, P.R. Effect of respiratory protective devices on development of antibody and occupational asthma to an acid anhydride. *Chest* **4:** 1317-1322, 2002.

8 Editorial letter. Wallaart, J. Workplace Diseases on the rise. *ISRP Journal*, **19**. Spring/Summer 2002. p 3-5

9 Patchett, L. Assessing health risks. *Safeguard* January/February **1**. 2000.

10 NIOSH USA. See for example, http://www.cdc.gov/NIOSH/pdfs/2002-118.pdf retrieved 14th August 2008.

11 McDonald, G.E. Measuring safety performance. Measuring “a” while hoping for “b”. Unpublished document. *InterSafe Pty Ltd*. Brisbane, 2001.

12 Westerholm, P. Occupational disease-harmful effects-conjunction with work. AMF Insurance-National Institute for Working Life. (Scientific documentation as the basis for insurance assessments in occupational disorders (6 Injury categories). *Arbete Och Halsa-Scientific Publications Series*, 1995.

13 Lax M, Manetti F A, Klein R. (2004). *Recognising occupational disease-taking an effective occupational history.* Retrieved from the website http://www.aafp.org/afp/980915ap/lax.html 14th August 2008.

14 Driscoll T R. (1999). *Are work-related injuries more common than disease in the workplace?* Retrieved from the website http://www.worksafe.gov.au/worksafe/biblio/a/003680.htm

15 WHO. Fact Sheet no. 84. *Occupational Health*. World Health Organisation, Geneva, 1999.

16 ILO. From radiation leaks to “jet lag: Work related health threats are growing. *World of Work* No. 28, 1999.

17 NZOHSC Reports. . Wellington, 2004. I *NZ Occupational Health and Safety Advisory Council (NOHSAC)*SBN 0-478-28011-4.

18 ILO. Occupational Health and Safety: Current work. *International Labor Office, Geneva*, 1999.

19 Montanaro, A. 2000. Allergies and asthma in the workplace. *Allergy and Asthma Magazine.* At: http://www.health-line.com/articles/ac920013.htm

20 Walls, C., Crane, J., Gillies, J., Wilsher, M., Wong, C. Occupational asthma and other nonasbestos occupational respiratory diseases notified between 1993 and 1996. *New Zealand Medical Journal* **110:** 246-249, 1997.

[21] Walls, C., Crane, J., Gillies, J., Wilsher, M., Wong, C. Occupational asthma cases notified to OSH from 1996 to 1999. *New Zealand Medical Journal* **113:** 491-492, 2000.

[22] ACC. ACC Injury Statistics 1999-2000. *NZ Accident and Compensation Corporation.* Wellington, New Zealand. 2002.

[23] Driscoll, T, Mannetje, A, Dryson, E, Feyer, A-M, Gander, P, McCracken, S, Pearce, N, Wagstaffe, M. The burden of occupational disease in New Zealand.. Technical report. NOHSAC-*National Occupational Health and Safety Advisory Committee.* ISBN 0-478-28011-4.

[24] ACC statistical data retrieved from the ACC data warehouse February 2008 (the author is an employee of ACC and has ready internal access to this information, but it is also widely available through annual reports).

[25] NORA. Retrieved from website http://www.cdc.gov/NIOSH/99-108.html on the 16th March 2008.

[26] Bell, R.F., Waring, J.J. Pneumonoconioisis. *AMA Archives of Industrial Health* **11:** 159-171, 1955.

[27] Holt, P.F. Inhaled Dust and Disease. John Wiley and Sons, New York, 1988.

[28] Chong, S., Lee, K.S., Chung, M.J., Han, J., Kwon, O.J., Kim, T.S. Pneumonoconiosis: Comparison of imaging and pathologic findings. *Radiograophics* **26:** 59-77, 2006.

[29] Tsai, W., Morgan, W.K. The pneumonoconioises. *Current Opinions in Pulmonary Medicine* **2:** 116-120, 1996.

[30] NIOSH (2000). *Worker Health Chartbook. Fatal Illness.* Publication 2002-118. CDC, USA.

[31] Grammer, L.C. Occupational allergic alveolitis. *Annals of Allergy, Asthma and Immunology* **83:** 602-606, 1999.

[32] Patel, A.M., Ryu, J.H., Reed, C.E. Hypersensitivity pneumonitis: Current concepts and future questions. *Journal of Allergy and Clinical Immunology* **108:** 661-670, 2001.

[33] Wild, L.G., Lopez, M. Hypersensitivity pneumonitis, a comprehensive review. *Journal of Investigative Allergology and Clinical Immunology* **11:** 3-15, 2001.

[34] Linaker, C., Smedley, J. Respiratory illness in agricultural workers. *Occupational Medicine* **52:** 451-459, 2002.

[35] McLNiven, R., Pickering, C.A. Bysinnosis: A review. *Thorax* **51:** 632-637, 1996.

[36] Phoolchund, H.N. Aspects of occupational health in the sugar cane industry. *Journal of the Society of Occupational Medicine* **41:** 133-136, 1991.

[37] Jackson, E., Welch, K.M. Mushroom worker's lung. *Thorax* **25:** 25-30, 1970.

[38] Mohr, L.C. Hypersensitivity pneumonitis. *Current Opinions in Pulmonary Medicine* **10:** 401-411, 2004.

[39] Stankus, R.P., Salvaggio, J.E. Hypersensitivity pneumonitis. *Clinics in Chest Medicine* **4:** 55-62, 1983.

[40] Jacobs, R.L., Andrews, C.P., Coalson, J.J. Hypersensitivity pneumonitis: Beyond classic occupational disease changing concepts of diagnosis and management. *Annals of Allergy, Asthma and Immunology* **95:** 115-128, 2005.

[41] NIOSH (2000). *Worker Health Chartbook. Fatal Illness.* Publication 2002-118. CDC, USA.

[42] Turner, W.E. Chronic rhinitis/laryngitis. *New Zealand Medical Journal* **104:** 170, 1991.

[43] Meggs, W.J. RADS and RUDS: The toxic induction of asthma and rhinitis. *Journal of Toxicology and Clinical Toxicology* **32:** 487-501, 1994.

[44] Welch, A.R., Birchall, J.P., Stafford, F.W. Occupational rhinitis: Possible mechanisms of pathogenesis. *Journal of Laryngology and Otology* **109:** 104-107, 1995.

45 Mygind, N., Anggard, A., Druce, H.M. Definition, classification, and terminology [of rhinitis]. In: *Allergic and Vasomotor Rhinitis,* Mygind, N., Weeke, B., editors. Munksgaard, Copenhagen, 1985.

46 Dykewicz, M.S., Fineman, S., Skoner, D.P., Nicklas, R., Lee, R., Blessing-Moore, J., Li, J.T., Bernstein, I.L., Berger, W., Spector, S., Schuller, D. Diagnosis and management of rhinitis: complete guidelines of the Joint Task Force on Practice Parameters in Allergy, Asthma and Immunology. American Academy of Allergy, Asthma, and Immunology. *Annals of Allergy Asthma and Immunology* **81:** 478-518, 1998.

47 Juniper, E.F. Measuring health-related quality of life in rhinitis. *Journal of Allergy and Clinical Immunology* **99:** S742-749, 1997.

48 Retrieved from the website http://www.entauckland.co.nz/Allergic%20Rhinitis%20Body.htm on the 15th August 2008.

49 Bernstein, I.L., Chan-Yeung, M., Malo, J.-L., Bernstein, D.I., editors. *Asthma in the Workplace*, second edition. *Marcel Dekker*, 1999.

50 Demeter, S.L., Cordasco, E.M. Occupational asthma. Chapter 18 (pp 213-228) in: *Occupational Medicine*, third edition (Zenz, C, Dickerson OB, Horvath, E.P., editors). Mosby, St Louis, 1994.

51 Bardana, E.J., Montanaro, A., O'Hollaren, M.T., editors. *Occupational Asthma*. Hanley and Belfus, 1991,

52 Bernstein I L, Chan-Yeung M, Malo J-L, Bernstein D I (1993). Asthma in the workplace. Pp 1-4. Marcel Dekker, New York,

53 WHO. Help Our Children Breathe. First World Asthma Day Launched: Press release WHO/92*.* *World Health Organisation*, 1998, At: http://www.who.int/

54 Friedman-Jimenez, G., Petsonk, E. Occupational asthma. ILO *Encyclopedia of Occupational Health and Safety*. International Labour Office, Geneva, 1997. At: http://www.ilo.org/encyclopedia

55 *Safeguard* **170:** Work linked to I in 3 asthmas. Pp 4. 21 May 2001.

56 *Safeguard* **173:** Pp 3, 2 July 2001.

57 Schlunssen, V., Vinzents, S., Mikkelsen, A.B., Schaumburg, I. Wood dust exposure in the Danish furniture industry using conventional and passive monitors. *Annals of Occupational Hygiene*. Pp 157-164, 2000.

58 Johnston, M., Gregory, A. Asthma causes remain a mystery. *NZ Herald,* 16 May 2004.

59 Holt, S., Beasley, R. The Burden of Asthma in New Zealand: Report. Medical Research Institute of New Zealand. *Asthma and Respiratory Foundation of New Zealand*, Wellington, 2001.

60 CROET. Occupational asthma seminar summary. *Center for Research on Occupational and Environmental Toxicology, Oregon Health and Science* University, Portland, Oregon, 2001. At: http://www.ohsu.edu/croet/outreach/symposia/occasthma.html

61 Chan-Yeung, M. Occupational asthma: Global perspective; Research trends. *Allergy and Clinical Immunology International - Journal of the World Allergy Organization* **15:** 203-207, 2003.

62 Asthma: An occupational hazard. *Asthma News* 1998. At: http://www.asthma.org.uk/about/an020.php

63 Lombardo, L.J., Balmes, J.R. Occupational asthma: A review. *Environmental Health Perspectives Supplements* **108 S4**: 697-704, 2000. At: http://ehp.niehs.nih.gov/members/2000/suppl-4/697-704lombardo/lombardo-full.html

64 Smith, S. HSE warns against nuisance dust masks. *Occupational Hazards* 24 January 2003 at: http://www.occupationalhazards.com/articles/5459.

65 Brooks, S.M., Weiss, M.A., Bernstein, I.L. Reactive airways dysfunction syndrome (RADS): Persistent asthma syndrome after hight level irritant exposures. *Chest* **88:** 376-384, 1985.

66 Bardana, E.J., Jnr. Reactive airways dysfunction syndrome (RADS): fact or fantasy? *Allergy* **54 Suppl 58**: 33-35, 1999.

67 Tarlo, S.M. Workplace irritant exposures: Do they produce true occupational asthma? *Annals of Allergy, Asthma and Immunology* **90:** 19-23, 2003.

68 Mannino, D.M., Buist, A.S. Global burden of COPSD: Risk factors, prevalence, and future trends. *Lancet* **1;370:** 765-773, 2007.

69 Cazzola, M., Donner, C.F., Hanania, N.A. One hundred years of chronic obstructive pulmonary disease. *Respiratory Medicine* **101:** 1049-1065, 2007.

70 Blanc, P.D., Torén, K. Occupation in chronic obstructive pulmonary disease and chronic bronchitis: an update. *International Journal of Tuberculosis and Lung Diseases* **11:** 251-257, 2007.

71 Retrieved from website http://www.wrongdiagnosis.com/c/copd/prevalence.htm#prevalence_intro on the 15th August 2008.

72 Zeiher, B.G., Hornick, D.B. Pathogenesis of respiratory infections and host defenses. *Current Opinions in Pulmonary Medicine* **2:** 1656-173, 1996.

73 Doll, R., Occupational lung cancer: a review. *British Journal of Industrial Medicine* **16:** 181-190, 1959.

74 Whitesell, P.L., Drage, C.W. Occupational lung cancer. *Mayo Clinic Proceedings* **68:** 183-188, 1993.

75 Swift, D.L., Foster, W.M., editors. *Air Pollutants and the Respiratory Tract.* Macel Dekker, New York, 1999.

76 National Health and Medical Research Council. Clinical Practice Guidelines for the prevention, diagnosis and management of lung cancer. Retrieved from website http://www.nhmrc.gov.au/publications/synopses/_files/cp97.pdf on the 15th August 2008.

77 Patchett, L. Assessing health risks. *Safeguard*. Pages?, 2001.

78 Sturesson, M., Branholm, I.-B. Life satisfaction in subjects with chronic obstructive pulmonary disease. *Work* **14**: 2000.

79 NOHSC. National OHS Improvement Framework. *National Occupational Health and Safety Commission*, Canberra, 1999.

80 Kerr, C., Morrell, S., Salkeld, G., Corbett, S., Taylor, R., Webster, F. Best Estimate of the Magnitude of Health Effects of Exposure to Hazardous Substances. *National Institute of Occupational Health of Safety*, Sydney, 1996. At: http://www.worksafe.gov.au/worksafe/08/kerr.html

81 Driscoll, T.R. 1999. Are work-related injuries more common than disease in the workplace? http://www.worksafe.gov.au/worksafe/biblio/a/003680.htms

82 Dyson, R., Minister for ACC. Statement: New Zealand Injury Prevention Strategy. *NZ Accident and Compensation Corporation*, Wellington, 2003.

83 ACC. New Zealand Injury Prevention Strategy, *NZ Accident and Compensation Corporation*, Wellington, 2003.

84 ACC. New Zealand Injury Prevention Strategy: 2004/05 Implementation Plan. *NZ Accident and Compensation Corporation*, Wellington, 2004.

85 Driscoll, T., Mannetje, A., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., Pearce, N., Wagstaffe, M. The Burden of Occupational Disease and Injury in New Zealand: Technical Report. *NZ Occupational Health and Safety Advisory Council*, Wellington, 2004.

86 Pearce, N., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., Wagstaffe, M. The Burden of Occupational Disease and Injury in New Zealand. Report to the Associate Minister of Labour. *NZ Occupational Health and Safety Advisory Council*, Wellington, 2004.

87 New Zealand Health and Safety in Employment Act 1992. Part 2. Duties relating to the health and safety in employment.

88 Roelofs, R.R., Barbeau, E.M., Ellenbecker, M.J., Moure-Eraso, R. Prevention strategies in industrial hygiene: A critical literature review. *American Industrial Hygiene Association Journal* **64:** 62-67, 2003.

89 McClellan, V.E., Garret, J.E. Asthma and the employment experience. *New Zealand Medical Journal* **103:** 399-401, 1990.

90 For a more detailed list of occupational asthma and associated industries, see sites such as http://www.remcomp.fr/asmanet/asmapro/jobs.htm and http://www.remcomp.fr/asmanet/asmapro/e011-020.htm as well as the CDC sites http://www.cdc.gov/niosh/docs/2003-111/2003-111.html and the NYCOSH site http://www.nycosh.org/workplace_hazards/resp_hazards_protection.html

A further useful site is http://www.ccosh.ca/oshanswers/diseases/asthma.html. Retrieved 24th February 2006.

91 There is an increasing emphasis worldwide to alert general practitioners to recognising a disease as occupationally related. Typical of this is: Lax M B, Manetti F A, Klein R. (1998). Recognising occupational disease-taking an effective occupational history. *American Academy of Family Physicians*. Sept. Retrieved from the website http://ww.aafp.org/afp/980915/lax.html. on the 9th February 2006.

92 Driscoll T, Mannetje A, Dryson E, Feyer A_M, Gander P, McCracken S, Pearce N, Wagstaffe M. (2004). The burden of occupational disease and injury in New Zealand: Technical Report. Wellington: *NOHSC.* ISBN 0-478-28011-4.

93 Action Plan 2005/06. (2005). Workplace health and safety strategy. New Zealand.

94 Dyson R. (2005). *Workplace health and safety strategy*. Pp 20. New Zealand.

95 Typical of this is: Smith S. (2002). Occupational lung disease: Airing on the side of caution. Retrieved from the website http://www.setonresourcecenter.com/Alerts/jul/jul_2002a.htm on the 9th February 2006.

96 CDC. MMWR Weekly, *1983). Leading work-related diseases and injuries-Unites States. Retrieved from the website http://www.cdc.gov/mmwr/preview/mmwrhtml/00001234.htm on the 9th February 2006.

97 NIOSH. NORA Priority Research Areas. Retrieved from the website http://www2a.cdc.gov/NORA/default.html on the 9th February 2006.

98 CDC MMWR. (1983). Leading work-related diseases and injuries-United States. Obtained from the website http://www.cdc.gov/mmwr/preview/mmwrhtml/00001234.htm on the 9th February 2006. Typical of this is: Smith S. (2002). Occupational lung disease: Airing on the side of caution. Retrieved from the website http://www.setonresourcecenter.com/Alerts/jul/jul_2002a.htm on the 9th February 2006.

98 CDC. MMWR Weekly, *1983). Leading work-related diseases and injuries-Unites States. Retrieved from the website http://www.cdc.gov/mmwr/preview/mmwrhtml/00001234.htm on the 9th February 2006.

98 NIOSH. NORA Priority Research Areas. Retrieved from the website http://www2a.cdc.gov/NORA/default.html on the 9th February 2006.

98 CDC MMWR. (1983). Leading work-related diseases and injuries-United States. Obtained from the website http://www.cdc.gov/mmwr/preview/mmwrhtml/00001234.htm on the 9th February 2006.

99 Walls C B and Dryson E W. (2002). Failure after 5 years of self-regulation: A health and safety audit of New Zealand engineering companies carrying out

welding. Retrieved from the website http://www.occmed.oxfordjournals.org/cgi/content/abstract/52/6/305.

100 Family Doctor. (2005). Occupational Respiratory Disease: Your workplace and your lungs. American Academy of Family Physicians. Retrieved from the website http://familydoctor.org/134.xml on the 9th February 2006.

101 NIOSH Alert (1998). Preventing asthma in animal handlers. DHHS (NIOSH) publications No.97-116.Pp4. Retrieved from the website http://www.cdc.gov/niosh/animals.html.

102 Occupational disease: Lung. Retrieved 24th February 2002, from http://www.safesci.unsw.edu.au/gens8003/module3/lung.htm. UNSW, Sydney, Australia. Module 3. Pp3.

103 USA. Unspecified and other pneumoconiosis: Mortality. Retrieved from the website http://www.cdc.gov/niosh/docs/2003.htmll. Pp 115.

104 Worksafe Australia. Worksafe reps. Wood dust. Retrieved from the website on the 20th February 2006 http://www.worksafereps.org.nzhazards/1054849600_100004.html.

105 Occupational disease: Lung. Retrieved 24th February 2002, from http://www.safesci.unsw.edu.au/gens8003/module3/lung.htm. UNSW, Sydney, Australia. Pp 3

106 International Precious Metals Institute-Environmental and Regulatory Affairs Committee (2002). Guidance to members on beyllium management.

107 Typical of this is: Siang L H. (1997). Mineral dusts and prevention of silicosis. Eradication of the silicosis problem in Singapore. Vol. 4: No. 2.

108 There is a vast amount of information available in New Zealand, for example: Kazan-Allen L. (2004). New Zealand: Asbestos Epidemic. International Ban Asbestos Secretariat. Retrieved from the website http://www.binternet.com/~ibas/lka_new_zeal_asb_ep.htm and Kjellstrom T E. (2004). The epidemic of asbestos-related diseases in New Zealand. Int. J. Occup. Environ Health. Vol. 10. Pp 212-219.

109 Smart P. (2004). Mortality, morbidity, and asbestosis in New Zealand: the hidden legacy of asbestos exposure. Journal of the New Zealand Medical Association. Vol. 117, No. 1205.

110 Blennerhassett J, Farlow D, Glass W, Howard J K, McLea K, Martin P, Stoke J, White P and Wilkenson S. (1995). OSH report. Asbestos exposure and disease: Notes for medical practitioners.

111 NOHSC (2003). Asbestos. Department of Employment and Workplace Relations. Australian Government. Retrieved from the website http://www.nohsc.gov.au/OSHLegalObligations/HazSubstancesAndDngGoods/Chrysotile.html.

112 Dryson E W and Rogers D A. (1991). Exposure to fumes in typical New Zealand welding operations. NZ Med. J. Aug 28;104 (918). Pp 365-7.

114 Nicas, M and Neuhaus, J. Variability in respiratory protection and the assigned protection factor. *Journal of occupational and environmental hygiene* **1**. Pp 99-109.

115 Forsman, M, Sandsjo, R and Kadefors, R. Synchronised exposure and image presentation: Analysis of digital EMG and video recordings of work sequences. *International Journal of Industrial Ergonomics 24*. Pp 261-272.

116 Archibald, B.A, Solomon K.R, Stephenson, G.R. Estimation of pesticide exposure to greenhouse applicators using video imaging and other assessment techniques. *Am. Ind. Hyg. Assoc. J.* **56** Pp 226-235. 1995.

117 AS/NZS 1716:2003. Respiratory Protective Devices. Preface. Pp 2.

118 Silverman, L., Lee, R.C., Lee, G., Drinker, K.R., Carpenter, T.M. Fundamental factors in the design of protective respiratory equipment: Inspiratory air flow measurements on human subjects with and without resistance. Departments of

Physiology and Industrial Hygiene, Harvard School of Public Health and the Nutrition Laboratory of the Carnegie Institution of Washington, 1943.

119 Myhre, L.G. 1997. Physiological criteria for the valid selection of workers who must perform physical tasks while wearing respiratory and/or environment protection equipment. *Proceedings of the Australian Institute of Occupational Hygienists, Albury conference,* 1997, pp ?-?

120 NIOSH/CDC. Laboratory performance evaluation of N95 filtering facepiece respirators 1996. *Mortality and Morbidity Weekly Report* **47:** 1045-1049, 1998. At: http://www.cdc.gov/mmwr/preview/mmwrhtml/00055954.htm

121 Wallaart, J. The effects of speech on peak flow values at varied levels of work load. A paper presented at the International Society for Respiratory Protection Conference, Amsterdam, September 1997.

122 Wallaart, J. Relationship between heart rate and minute breathing volume-the implications in industry. A paper presented at the International Society for Respiratory Protection Conference, Amsterdam, September 1997.

123 Wallaart, J. A study to show the need to calibrate test subjects when determining the total inward leakage of respirators. A paper presented at the International Society for Respiratory Protection Conference, Amsterdam, September 1997.

124 Wallaart, J. Air flows required for respiratory protection. Proceedings of the Australian Institute of Occupational Hygiene conference, Cairns, 2000.

125 For example, at a meeting of the New Zealand Occupational Physician technical training session (to prepare physicians for occupational medicine examinations) in November 2007.

126 The author currently works with many different industry groups in New Zealand, including the agricultural, construction, aviation, on-hire, manufacturing and many other industry sectors as part of his role as Manager with the Corporate Office of the New Zealand ACC. The most recent presentation was to representatives of the construction sector in New Zealand at the end of March, 2008.

127 Kaufman, J.W., Hastings, S.A. Respiratory demand in individuals performing rigorous physical tasks in chemical protective ensembles. *Journal of Occupational and Environmental Hygiene* **2:** 98-110, 2005.

128 Standards Australia; Standards New Zealand. *AS/NZS 1716 Respiratory Protective Devices*. Standards New Zealand, 2003, p 21.

130 Willeke, K., Qian, Y., Grinspun, S.A., Donnelly, J., Coffey C.C. Performance of N95 respirators: filtration efficiency for airborne microbial and inert particles. *American Industrial Hygiene Association Journal* **59:** 128-132, 1998.

131 Jackson B A, Peterson D J, Bartis J T, LaTaurrette T, Brahmakulam I, Houser A and Sollinger J (2002). RAND Science and Technology Institute. *Protecting Emergency Responders. Lessons learned from the terrorist attacks.* Conference Proceedings. Available from The Director, 1200 South Hayes Street, Arlington VA 22202-5050, USA.

132 There are a huge range of studies completed on the variation between laboratory studies and workplace studies. For example; Zhuang Z, Coffee C C, Jensen P A, Campbell D L, Lawrence R B and Meyers W R. (2003), *Correlation between quantitaive fit factors and workplace protection factors measured in actual workplace environemnts at a steel foundry.* AIHA Journal, vol.64. December.

133 Gibson, S.D. Respiratory protective equipment and the management of risk: Where safety and security diverge. *Journal of the International Society for Respiratory Protection* **21:** 40, 2004.

134 Nathan J, Anderson P E, Cassidy L, Janssen D.R, Dangel. (2006). *Peak Inspiratory Flows of Adults Exercising at Light, Moderate and Heavy Work Loads.* ISRP Jounla, Spring/Summer. Vol. 23, issues 1 and 2, Pp 53-64.

135 Mackey K R M, Johnson A T, Scottt W H, Koh F C. (2005). Over-breathing a loose-fitting PAPR. ISRP journal. Spring/Summer. Vol. 22, issues 1 and 2. Pp 1-11.

136 AS/NZS 1716:2003. Standards NZ (2003). Respiratory Protective Devices. Preface. Pp 1.

137 Varius Committee draft reports ISO/TC 94/SC15. (this is the physiological working group. The author represents NZ as an observer member).

138 Harber, P., Barhart, S., Boehlecke, B.A., Beckett, W.S., Gerrity, T., McDiarmid, M.A., Nardelle, E., Repsher, L., Brousseau, L., Hodous, T.K., Utell, M.J. Respiratory Protection Guidelines: This official statement of the American Thoracic Society was adopted by the ATS Board of Directors, March 1996. *American Journal of Respiratory and Critical Care Medicine* **154:** 1153-1165, 1996.

139 Silverman, L., Billings, C.E. *Inhaled Particles and Vapours*. Pergamon Press, London, 1961.

140 Myhre, L.G. Physiological criteria for the valid selection of workers who must perform physical tasks while wearing protective equipment. U.S. Air Force Research Laboratory, Brooks Air Force Base, Texas. (Not dated)

141 Martin, L. Pitfalls in diagnosing occupational lung disease for purposes of compensation. At: http://www.mtsinai.org/pulmonary/papers/pitfalls/pitfalls 8-15.html

142 Smith, S. . Occupational lung disease: airing on the side of caution. *Seton Alerts for Safety*, July 2002. At: http://www.setonresourcecenter.com/Alerts/jul/jul_2002a.htm

143 NOHSAC (National Occupational Health and safety Advisory Committee). The burden of occupational disease and injury in New Zealand. Driscoll, T, Mannetje A.T, Dryson, E, Feyer, A-M, Gander, P, McCracken, S, Pearce, N and Wagstaffe, M. 2004. ISBN 0-478-28011-4.

144 Gregory, A. Firms slow to cut asthma risks. New Zealand Herald, 12 June 2002. At: Retrieved from http://www.massey.ac.nz/~wwwcphr/firms%20slow%20to%20cut%20asthma%20risks.pdf

145 RIG. European respiratory standards explained. Regency International Group. At: http://www.respiratorfilterfinder.com/html/european_respiratory_standards.html

146 RIG. Special considerations in the selection of respirators. Regency International Group. At: http://www.respiratorfilterfinder.com/html/special_considerations_in_the_.html

147 AS/NZS 1715:1994 (Selection, use and maintenance of respiratory protective devices) and 1716:2004 (Respiratory protective devices). Published jointly by Standards Australia and Standards New Zealand.

148 NIOSH. *Program Concept for Total Inward Leakage (TIL) Performance Requirements and Test Methods.* US National Institute for Occupaional Safety and Health, Cincinnati, 2004. At http://www.cdc.gov/niosh/npptl/standardsdev/til/

149 Revoir, H.W., Bien, C. Respiratory Protection Handbook. *Lewis Publishers*, New York, 1997.

150 Fishwick, D., Pearce, N., Souza, W.D., Lewis., S, Town, T., Armstrong, R., Kogevinas, M., Crane, J. Occupational asthma in New Zealanders: a population based study. *Occupational and Environmental Medicine* **54:** 301-306, 1997.

151 Firth, H., Herbison, P., McBride, D., Feyer, A.M. Health of farmers in Southland. *New Zealand Medical Journal* **114:** 426-428, 2001.

152 Kimbell-Dunn, M., Bradshaw, L., Slater, T., Erkinjuntti-Pekkanen, R., Fishwick, D., Pearce, N. Asthma and allergy in New Zealand farmers. *American Journal of Industrial Medicine* **35:** 51-57, 1999.

153 Erkinjuntti-Pekkanen, R., Slater, T., Cheng, S., Fishwick, D., Bradshaw. L,, Kimbell-Dunn, M., Dronfield, L. Pearce, N. Two year follow up of pulmonary function values among welders in New Zealand. *Occupational and Environmental Medicine* **56:** 328-333, 1999.

154 Berndtsson, G., Howie, R., Kjellberg, B., Simmons, P., Berdtsson, F., Berntdtsson, K. Peak Inhalation Air Flow During an Agility Test Performed by the US Marine Corps. *SEA Group*, Los Angeles, 2002. At: http://www.sea.com.au/docs/papers/gb_us_marines.pdf

155 Kranenburg, S. Wear Time and Peak Airflow Monitoring in a Lead Smelter. *Safety Equipment Australia*, Sydney, 2002. At: http://www.sea.com.au/docs/papers/skisrp2002.pdf

156 Berndtsson, G., Berdtsson, F., Jessup, S., McNamara, T. Peak Inhalation Air Flow and Minute Volume during a Controlled Test Performed on an Ergonometer. *SEA Group*, Los Angeles, 2003. At: http://www.cdc.gov/niosh/npptl/standardsdev/other/papr/meetings/041003/pdfs/presentation_papr_1_paper.pdf

157 Holmer, I., Kuklane, K., Gao, C. Minute volumes and inspiratory flow rates during exhaustive treadmill walking using respirators. *Annals of Occupational Hygiene* preprint, 2007.

158 Forsman, M., Sandsjo, L., Kadefors, R. Synchronised exposure and image presentation: Analysis of digital EMG and video recordings of work sequences. *International Journal of Industrial Ergonomics* **24:** 261-272, 1999.

159 Archibald, B.A., Solomon, K.R., Stephenson, G.R. Estimation of pesticide exposure to greenhouse applicators using video imaging and other assessment techniques. *American Industrial Hygiene Association Journal* **56:** 226-235, 1995.

160 Gunnar, R. Seeing is believing. *Annals of Occupational Hygiene* **46:** 3-4, 2002.

161 Standards Australia; Standards New Zealand. *AS/NZS 1715 Selection, Use and Maintenance of Respiratory Protective Devices*. Standards New Zealand, 1994, p 21.

162 Myers, W.R., Peach, M.J., Cutright, K., Iskander, W. Workplace protection factor measurements on powered air-purifying respirators at a secondary lead smelter: Results and discussion. *American Industrial Hygiene Association Journal* **45:** 681-688, 1984.

163 Chia, S.E, Koh, D, Takahashi, K, Li, Y, Imai, T, Li, W, MMed, C.F, Ng, V and Lim, M.K. Appropriate use of ersonal protective equipment among health care workers in Singapore, China and Japan hospitals during the SARS outbreak. *ISRP Journal,* **23**. Fall/Winter 2006.

164 Siegel, J.D, Rhinehart, E, Jackson, M.J, Chiarello, L. Guidelines for isolation precautions:Preventing transmission of infectious agents in healthcare settings 2007. *CDC.* At: http://www.cdc.gov/ncidod/dhgp/pdf/isolation2007.pdf.

165 Lavoie, J, Cloutier, Y, Lara, J and Marchand, G. Chemical substances and biological agents. Studies and Research Projects. Institut de recherché Robert-Sauve en sante et en securite du travail (IRSST). Technical Guide RG-501. Montreal, Canada.

166 Kuschner, W.G., Chitkara, R.K., Sarinas, P.S. Occupational asthma: Practical points for diagnosis and management. *Western Journal of Medicine* **169:** 342-350, 1998.

167 Muller-Wening, D., Neuhauss, M. Protective effect of respiratory devices in farmers with occupational asthma. *European Respiratory Journal* **12:** 569-572, 1998.

168 Taivainen, A.I., Tukianan, H.O., Terho, E.O., Husman, K.R. Powered dust respirator helmets in the prevention of asthma among farmers. Scandinavian *Journal of Work Environment and Health* **24:** 503-507, 1998.

169 Obase, Y., Shimoda, T., Mitsuta, K., Matsuse, H., Kohno, S. Two patients with occupational asthma, who returned to work with dust respirators. *Occupational and Environmental Medicine* **57:** 62-64, 2000.

170 Federal Register. Department of Labor. March 24 Notices. *Federal Register* **69(57):** 13855, 1994.

171 Eubanks, L.M., Dickerson, T.J., Janda, K.D. Technological advancements for the detection of and protection against biological and chemical warfare agents. *Chemical Society Review* **36:** 458-470, 2007.

172 Sawicki, J. Protection from chemical and biological warfare. *Surgical Services Management* **5:** 11, 1999. At: http://www.nbcprotection.com/new/geometarticles/protfromchembiowarfare.htm

173 NIOSH. *CBRN Respirator Standards Development: Full Facepiece Air-Purifying Respirators.* US National Institute of Occupational Safety and Health, Cincinnati, 2002. At: http://www.cdc.gov/niosh/npptl/standardsdev/cbrn/apr/

174 NIOSH. Concept for CBRN Escape Respirator Standard*. US National Institute of Occupational Safety and Health*, Cincinnati, 2003. At: http://www.cdc.gov/niosh/ npptl/standardsdev/cbrn/escape/concepts/apercon-063003.html

175 NIOSH. *Concept for CBRN Air-Purifying Respirator (PAPR) Standard.* US National Institute of Occupational Safety and Health, Cincinnati, 2005. At: http://www.cdc. gov/niosh/npptl/standardsdev/cbrn/papr/concepts/paprcon-062005.html

176 Howie, R.M. Respiratory protective equipment. *Occupational and Environmental Medicine* **62:** 423-428, 2005.

177 Bradshaw, L.M., Curran, A.D., Eskin, F., Fishwick, D. Provision and perception of occupational health in small and medium-sized enterprises in Sheffield, UK. *Occupational Medicine* **51:** 39-44, 2001.

178 CDC MMWR. Notice to readers National Occupational Research Agenda. May 31.1996.

179 Wallaart, J. Editorial: Workplace diseases on the rise. Respiratory Protection: Prescription without diagnosis. *Journal of the International Society for Respiratory Protection* **20:** 3-5, 2002.

180 Retrieved from the website http://hse.gov.uk/pubns/guidance/gseries.htm in March 2008.

181 Xuguang, T, Massa, J, Ashwell, L, Davis, K, Schwab, M and Geyh, A. The world trade centre clean up and recovery worker cohort study: Respiratory health among cleanup workers approximately 20 months after initial exposure at the disaster site. *Journal of Occupational and Environmental Medicine*, **49.** Pp 1063-1072. 2007.

182 NORA. Occupational asthma and chronic obstructive pulmonary disease. National Occupational Research Agenda, *US Centers for Diseases Control*, Atlanta, 1997-2005. At: http://www.cdc.gov/niosh/nora.htlmhttp://cdc.gov/niosh/psacops.html

183 The Australian Safety and Compensation Council is concerned with a variety of major industries typically found in that part of the world, including mining. See http://www.aph.gov.au/Senate/committee/clac_ctte/toxic_dust/report/c01.htm retrieved in March 2008.

184 NIOSH. New Leads for Lung-Disease Prevention Offered in NIOSH Study that Charts Areas of High Prevalence. US National Institute of Occupational Safety and Health, Cincinnati, 2002. At: http://www.cdc.gov/niosh/updates/lungdisprev.html

185 Kimbell-Dunn, M.R, Fishwick, R.D, Bradshaw, L, Erkinjuntti-Pekkanen, R and Pearce, N. Work related respiratory symptoms in New Zealand farmers. *American Journal of Industrial Medicine* **39**. Pp 292-300. 2001.

186 Discussion with the New Zealand Department of Labour, March 2008.

[187] Holt S. (2001). *The burden of asthma in New Zealand.* Asthma and Respiratory Foundation of New Zealand (Inc). 123 Molesworth Street, Wellington, New Zealand.

[188] ILO. *World of Work* **38:** 21, Jan/Feb 2001.

[189] WHO. Help Our Children Breathe: First World Asthma Day: WHO/92 Press release. World Health Organisation, 1998. At: http://www.who.int/inf-pr-1998/en/pr98-92.html

[190] Harber, P., Barlow, J. Workplace asthma: Nothing to sneeze about. *ACOEM Newswise*. 31 August 1999. At: http://www.newswise.com/articles/view/?id=LABRDAY2.ACO

[191] Healthwise. Life's a Wheeze for One in Six New Zealanders. *Healthwise Magazine* Oct/Nov 1999.

[192] DHHS/NIOSH/CDC. Work Related Lung Disease Surveillance Report 1999: DHHS Report 2000-105. US Department of Health and Human Services, National Institute for Occupational Safety and Health, Centers for Diseases Control, Cincinnati, 1999. .

[193] Lundback, B. Epidemiology of rhinitis and asthma. *Clinical and Experimental Allergy* **28 Suppl 2:** 3-10, 1998.

[194] Elder, D., Abramson, M., Fish, D., Johnson, A., McKenzie, D., Sim, M. Surveillance of Australian workplace based respiratory events (SABRE): Notification for the first 3.5 years and validation of occupational asthma cases. *Occupational Medicine* **54:** 395-399, 2004.

[195] Johnson, A., Toelle, B.G., Yates, D., Belousova, E., Ng, K., Corbett, S., Marks, G. Occupational asthma in New South Wales: A population based study. *Occupational Medicine* **56:** 258-262, 2006.

[196] O'Donnell, T.V., Welford, B., Coleman, E.D. Potroom asthma: New Zealand experisnce and follow up. *American Journal of Industrial Medicine* **15:** 43-49, 1989.

[197] Winder, C., Yeung, P. Health problems in aluminium smelter workers: Hazards, exposures and respiratory disease. *Journal of Occupational Health and Safety - Australia and New Zealand* **5:** 391-402, 1989.

[198] Taiwo, O.A., Sircar, K.D., Slade, M.D., Cantley, L.F., Rabinowita, P.M., Fiellin, M.G., Cullen, M.R. Incidence of asthma among aluminium workers. *Journal of Occupational and Environmental Medicine* **48:** 275-282, 2006.

[199] Ruttenberg, D., Dryson, E., Walls, C., Curran, N. Hazards associated with the boat building industry in New Zealand. *New Zealand Medical Journal* **114:** 225-226, 2001.

[200] O'Donnell, T.V. Chemical poisoning and occupational asthma: Diagnosis and/or acceptance for current compensation. *New Zealand Medical Journal* **111:** 372-373, 1998.

[201] Wade, J.F., Newman, L.S. Diesel asthma: Reactive airways disease following exposure to locomotive exhaust. *Journal of Occupational Medicine* **35:** 149-154, 1993.

[202] Rudell, B., Blomberg, A., Helleday, R., Ledin, M.C., Lundback, B., Stjernberg, N., Horstedt, P., Sandstrom, T. Brochoalveolar inflammation after exposure to diesel exhaust: comparison between unfiltered and particle trap filtered exhaust. *Occupational and Environmental Medicine* **56:** 527-534, 1999.

[203] Hoppin, J.A., Spanel, P., Dabill, D., Cocker, J., Rajan, B. Diesel exhaust, solvents and other occupational exposures as risk factors for wheeze among farmers. *American Journal of Respiratory and Critical Care Medicine* **169:** 1308-1313, 2004.

[204] Waclawski, E.R. Glutaraldehyde induced asthma in endoscopy nursing staff. *Occupational and Environmental Medicine* **68:** 544-545, 2001.

205 Ong, T.H., Tan, K.J., Lee, H.S, Eng, P. A case report of occupational asthma to glutaraldehyde exposure. *Annals of the Academy of Medicine of Singapore* **33:** 275-278, 2004.

206 Fonn, S., Becklake, M.R. Documentation of ill-health of occupational exposure to grain dust through sequential, coherent, epidemiologic investigation. *Scandinavian Journal of Work Environment and Health* **20:** 13-21, 1994.

207 Baur, X., Posch, A. Characterized allergens and baker's asthma. *Allergy* **28:** 537-544, 1998.

208 Slater, T., Bradshaw, L., Fisjwick, D., Cheng, S., Kimbell-Dunn, M., Erkinjuntii-Pekkanen, R., Douwes, J., Pearce, N. Occupational respiratory symptoms in New Zealand hairdressers. *Occupational Medicine* **50:** 586-590, 2000.

209 Hollund, B.E., Moen, B.E., Egeland, G.M., Florvaag, E., Omenass, E. Prevalence of airway symptoms among hairdressers in Bergen, Norway. *Occupational and Environmental Medicine* **28:** 264-269, 2002.

210 Moscoto, G., Galdi, E. Asthma in hairdressers. *Current Opinion in Allergy and Clinical Immunology* **6:** 91-96, 2006.

211 Paggiaro, P.L., Rossi, D., Lastrucci, L., Pardi, F., Pezzini, A., Baschieri, L. TDI induced oculorhinitis and bronchial asthma. *Journal of Occupational Medicine* **27:** 51-52, 1985.

212 Musk, A.W., Peters, J.M., Wegman, D.H. Isocyanates and respiratory disease. *American Journal of Industrial Medicine* **13:** 331-349, 1988.

213 Tarlo, S.M., Liss, G.M. Diisocyanate-induced asthma: Diagnosis, prognosis, and effects of medical surveillance measures. *Applied Occupational and Environmental Hygiene* **17:** 902-908, 2002.

214 Milne, J.E. A case of platinosis. *Medical Journal of Australia* **19:** 1194-1195, 1970.

215 Musk, A.W., Tees, J.G. Asthma caused by occupational exposure to vanadium compounds. *Medical Journal of Australia* **20:** 183-184, 1982.

216 Malo, J.L. Occupational rhinitis and asthma due to metals salts. *Allergy* **60:** 138-139, 2005.

217 Robins, T., Seixas, N., Franzblau, A., Abrams, L., Minick, S., Burge, H., Schork, M.A. Acute respiratory effects on workers exposed to metalworking fluids in an automotive transmission plant. *American Journal of Industrial Medicine* **31:** 87-93, 1999.

218 Kennedy, S.M., Chan-Yeung, M., Teschke, K., Karlen, B. Change in airway responsiveness among apprentices exposed to metal working fluids. *American Journal of Respiratory and Critical Care Medicine* **159:** 1-20, 1999.

219 Bukowski, J.A. Review of respiratory morbidity from occupational exposure to oil mists. *Applied Occupational and Environmental Hygiene* **18:** 828-837, 2003.

220 Glass, W.I., Power, P., Burt, R., Fishwick, D., Bradshaw, L.M., Pearce, N.E. Work related respiratory symptoms and lung function in New Zealand mussel openers. American Journal of Industrial Medicine 34: 163-168, 1998.

221 Wieslander, G., Norback, D., Edling, C. Airway symptoms among housepainters in relation to exposure to volatile organic compounds (VOCs): A longitudinal study. *Annals of Occupational Hygiene* **41:** 155-166, 1997.

222 Kaukiainen, A., Riala, R., Martikainen, R., Reijula, K., Riihimaki, H., Tammilehto, L. Respiratory symptoms and diseases among construction painters. *International Archives of Occupational and Environmental Health* **78:** 452-458, 2005.

223 Hammond. S.K., Gold, E., Baker, R., Quinlan, P., Smith, W., Pandya, R., Balmes, J. Respiratory health effects related to occupational spray painting and welding. *Journal of Occupational Medicine* **47:** 728-739, 2005.

224 Dalvie, M.A. Long-term respiratory health effects of the herbicide, paraquat, among workers in the Western Cape. *Occupational and Environmental Medicine* **56:** 391-396, 1999.

225 Beard, J., Sladden, T., Morgan, G., Berry, G., Brooks, L, McMichael, A. Health impacts of pesticide exposure in a cohort of outdoor workers. *Environmental Health Perspectives* **111:** 724-730, 2003.

226 Rushton, L., Alderson, M.R. Epidemiological survey of oil distribution centres in Britain. *British Journal of Industrial Medicine* **40:** 330-339, 1983

227 Norrish, A.E., Beasley, R., Hodgkinson, E.J., Pearce, N. A study of New Zealand wood workers: Exposure to wood dust, respiratory symptoms, and suspected cases of occupational asthma. *New Zealand Medical Journal* **105:** 185-187, 1992.

228 Hessel, PA, Herbert, F.A., Melenka, L.S., Yoshida, K., Michaelchuk, D., Nakaza, M. Lung health in sawmill workers exposed to pine and spruce. *Chest* **108:** 642-646, 1995.

229 Mandyk, J., Alwis, K.U., Hocking, A.D. Effects of personal exposure on pulmonary function and work related symptoms among sawmill workers. *Annals of Occupational Hygiene* **44:** 281-289, 2000.

230 Douwes, J., McLean, D., Slater, T., Pearce, N. Asthma and other respiratory symptoms in New Zeland pine processing sawmill operators. *American Journal of Industrial Medicine* **39:** 608-615, 2001.

231 Bohadana, A.B, Massin, N, Wild, P, Toamain, J-P, Engel, S and Gouter, P. Symptoms, airway responsiveness, and exposure to dust in beech and oak wood workers. *Occupational and Environmental Medicine* **57:** 268-273, 2000.

232 Fransman, W., McLean, D., Douwes, J., Demers, P.A., Leung, V., Pearce, N. Respiratory symptoms in New Zealand plywood mill workers. *Annals of Occupational Hygiene* **47:** 287-295, 2003.

233 Pimentel, J.C., Avila, R., Lourenco, A.G. Respiratory disease caused by synthetic fibres: A new occupational disease. *Thorax* **30:** 204-219, 1975.

234 Pal, T.M., de Monchy, J.G., Groothoff, J.W., Post, D. Follow-up investigation of workers in synthetic fibre plants with humidifier disease and work-related asthma. *Occupational and Environmental Medicine* **56:** 403-410, 1999.

235 Zuskin, E., Mustajbegovic, J., Schacter, E.N., Kern, J. Respiratory function and immunological function in jute workers. *International Arcives of Occupational and Environmental Health* **66:** 43-48, 1994.

236 Zuskin, E., Mustajbegovic, J., Schacter, E.N., Doko-Jelnic, J. Respiratory findings in synthetic textile workers. *American Journal of Industrial Medicine* **33:** 263-273, 1998.

237 Raza, S.N, Fletcher, A.M., Pickering, C.A., Niven, C.A., Faragher, E. Ventilatory function and personal breathing zone dust concentrations in Lancashire textile workers. *Occupational and Environmental Medicine* **56:** 520-526, 1999.

238 Erkinjuntti-Pekkanen, R et al. 1999. Two year follow up of pulmonary function values among welders in New Zealand. Occup. Environ Med 1999;56:328-333.

239 Bradshaw, L.M., Fishwick, D., Slater, T., Pearce, N. Chronic bronchitis, work related respiratory symptoms, and pulmonary function in welders in New Zealand. *Occupational and Environmental Medicine* **55:** 150-154, 1998.

240 Hannu, T., Piipari, R., Tuppurainen, M., Nordman, H., Tuomi, T. Occupational asthma caused by stainless steel welding fumes: A clinical study. *European Respiratory Journal* **29:** 85-90, 2007.

244 NIOSH. *NIOSH Warns of Agricultural Hazards: Organic Dust Toxic Syndrome*. US National Institute of Occupational Safety and Health, Cincinnati, 1994. At: http://www.cdc.gov/niosh/94-121.html

245 DHHS/NIOSH. *NIOSH Alert. Preventing Asthma in Animal Handlers. Publication No. 97-116*. US Department of Health and Human Services, National Institute for

Occupational Safety and Health, Cincinnati, 1998. At: http://www.cdc.gov/niosh/animalrt.html

246 Alberts, W.M., do Pico, G.A. Reactive airways dysfunction syndrome. *Chest* **109:** 1618-1626, 1996.

247 Banks, D.E., Jalloul, A. Occupational asthma, work related asthma and reactive airways dysfunction. *Current Opinions in Pulmonary Medicine* **13:** 131-136, 2007.

248 Dementer, S.L., Cordasco, E.M. Occupational asthma. Occupational Medicine, third edition. Mosby, London, year?, p 215.

249 Brooks, S.M., Weiss, M.A., Bernstein, I.L. Reactive airways dysfunction syndrome (RADS). Persistent asthma syndrome after high level irritant exposures. *Chest* **88:** 376-384, 1985.

250 Harber, P., Schenker, M.B., Balmes, J.R. *Occupational and Environmental Respiratory Disease.* Mosby, New York, 1996, p 189.

251 DHHS/NIOSH. *Atlas of Respiratory Protection: Publication 98-157.* US Department of Health and Human Services, National Institute for Occupational Safety and Health, Cincinnati, 1998. At: http://www.cdc.gov/niosh/98-157pd.html

252 DHHS/NIOSH. 1997. Preventing Allergic Reactions to Natural Rubber Latex in the Workplace: Publication no. 97-135. US Department of Health and Human Services, *National Institute for Occupational Safety and Health*, Cincinnati, 1998. At: http://www.cdc.gov/niosh/latexalt.html

253 NIOSH. *Latex Allergy: A Prevention Guide.* US National Institute for Occupational Safety and Health, Cincinnati, 1999. At: http://www.cdc.gov/niosh/98-113.html

254 NIOSH/CDC. *Silica: It's not just Dust*. US National Institute for Occupational Safety and Health, Centers for Disease Control, Atlanta, 1998. At: http://www.cdc.gov/niosh/rock.html

255 Schenker, M.B. Farming and asthma. *Occupational and Environmental Medicine* **62:** 211-212, 2005.

256 Chan-Yeung, M. Occupational asthma. *Environmental Health Perspectives* **103 Suppl 6:** 249-252, 1995. At: http://www.ncbi.nlm.nih.gov

257 Fletcher, G., Agius, R. Occupational asthma and rhinitis. Part 1: Definitions and Incidence. *Occupational Health Review* **53:** 15, 1995.

258 CCOHS. *What is Occupational Asthma?* Canadian Centre for Occupational Health and Safety, 2000. At: http://www.ccohs.ca/oshanswers/diseases/asthma.html

259 Agius, R.M 1995. Occupational asthma and rhinitis. Part 3: Health Surveillance and secondary prevention. *Occupational Health Review* **55:** 29, 1995.

260 Roach, S.A., Rappaport, S.M. But they are not thresholds: A critical analysis of the documentation of the threshold limit values. *American Journal of Industrial Medicine* **17:** 727-753, 1990.

261 Castleman, B.I., Ziem, G.E. American Conference of Governmental Industrial Hygienists: Low threshold of credibility. *American Journal of Industrial Medicine* **26:** 133-143, 1994.

262 NIOSH. *Respirator Information*. US National Institute of Occupational Safety and Health, Cincinnati. At: http://www.cdc.gov/niosh/tb-ii.html

263 Mayhew, C., Gibson, G. Self-employed builders: factors which influence the probability of work-related injury and illness. *Journal of Occupational Health and Safety – Australia and New Zealand* **12:** 61-67, 1996.

264 Wadud, S.E., Kreuter, M.W., Clarkson, S. Risk perception, beliefs about prevention and preventive behaviours of farmers. *Journal of Agricultural Safety and Health* **4:** 15-24, 1998.

265 Parker, R.J, Gaskin, J.E, Kirk, P.M. Contribution of protective equipment in reducing injury. Proceedings of the FAO/ECE/ILO *Seminar on Clothing and Safety Equipment in Forestry*, Kuopio, Finland, 1994.

266 Mayhew, C. Barriers to Implementation of Known Occupational Health and Safety Solutions in Small Business. *National Occupational Health and Safety Commission*, Canberra, 1997.

267 McDonald, G.L. Of leadership and champions. Presented at an Occupational Health and Safety Conference, Brisbane, 1999.

268 Shepherd, G., Kahler, R. Ready-aim-fire: focussing safety effort. A presentation at the Third National Conference on Injury Prevention and Control. Brisbane, 1999.

269 Kahler, R. 1999. Damage prediction: The relevance of experience, goal and expectation. Presented at an Occupational Health and Safety Conference, Brisbane, 1999.

270 Kahler, R. How and where is damage occurring? Presented at an Occupational Health and Safety Conference, Brisbane, 1999.

271 Winder, C., Dingsdag, D., Dain, S. Development of training programs for eye safety in the NSW coal mining industry. *Journal of Occupational Health and Safety – Australia and New Zealand* **14:** 599-606, 1998.

273 Hopkins, A. Managing Major Hazards: The Lessons from the Moura Mine Disaster. *CCH*, Sydney, 1999.

274 Hopkins, A. For whom does safety pay? The case of major accidents. *Safety Science* **32:** 143-153, 1999.

275 Bernstein, L.I., Chan-Yeung, M., Malo, J.-L., Bernstein, D.I. *Asthma in the Workplace.* Marcel Dekker, New York, 1993, p 45.

276 Priest, N.D., O'Donnell, T. Managing health in the aluminium industry. Proceedings of the International Conference on Managing Health Issues in the Aluminium Industry, Montreal, Canada, 26-29 October 1997. *Middlesex University Press*, London, 1997.

277 Agius, R. *Occupational Asthma: Current Perspectives*. At: http://www/agius.com/hew/resource/ocasthma.htm. Pp 3 of 10.

278 HSE. *Preventing Asthma at Work.* UK Health and Safety Executive, HMSO, London, 1994.

279 Laird, I. S, Goldsmith, R and Vitalis, A. (2002). The effect on heart rate and facial skin temperature of wearing respiratory protection of work. Ann.Occ.Hyg., Vol.46. Pp 143-148.

280 Duffy, D. L, Mitchell, C. A, Martin, N. G. (1998). *Genetic and environmental risk factors for asthma.* Am. J. Respir.Crit. Care Med. Vol. 157, No.3. Pp 840-845.

281 American Association of cardiovascular and pulmonary rehabilitation. Third Edition. *Guidelines for pulmonary rehabilitation programs*. Available from the website http://books.google.co.nz/books?id=XNgJNIm3QsQC&pg=PA68&lpg=PA68&dq=asthma+rehabilitation+work&source=web&ots=cVgQ1pFJ-4&sig=2TNml5r2raSV5LcR9FGEPVvBZgE&hl=en&sa=X&oi=book_result&resnum=6&ct=result#PPP1,M1. Retrieved 16th August 2008.

282 Johnson, A.T, Scott, W.H, Lausted, G.C, Benjamin, M.B, Coyne, K.M, Sahota, M.S., Johnson, M.M. Effect of respirator inspiratory resistance level on constant load treadmill work performance. *American Industrial Hygiene Association Journal* **60:** 474-479, 1999.

283 Laird, I. PhD Thesis 1995, p 92. Massey University, Palmerston North, New Zealand, 1995.

† Personal Communication, Ian Laird, Massey University, 1995.

284 Johnson A.T, Dooley, C.R., Dotson, C.O. 1995. Respirator mask effects on exercise metabolic measures. *American Industrial Hygiene Association Journal* **56:** 467-473, 1995.

285 Johnson, A.T., Dooly, C.R., Caretti, D.M., Green, M., Scott, W.H., Coyne, K.M., Sahota, M.S., Benjamin B. 1997. Individual work performance during a 10 hour period of respirator wear. *American Industrial Hygiene Association Journal* **58:** 578-582, 1997.

286 Johnson, A, Mackey, K, Scott, W, Koh, F. *Overbreathing a loose-fitting PAPR.* Retrieved from website http://www.aiha.org/abs04/po120.htm. September 2005.

287 Sharkey, B, Gaskill, S. *Respiration, respirators and work capacity.* (source not identified).

288 Silverman, L, Lee, G, Plotlin, T, Sawyers L,A, Yancey, A. Air flow measurements on human subjects with and without respiratory resistance at several work rates. *Archives of Industrial Hygiene and Occupational Medicine*, **3.** 1951.

289 Silverman, L and Billings, C.E. Pattern of airflow in the respiratory tract. Inhaled particles and vapours. *Pergamon Press*. 1961.

290 For example, Kroemer, K.H.E and Grandjean, E. Fitting the task to the human. A textbook of occupational ergonomics. London: Taylor and Francis. Pp 119

291 European Standard prCR 529: Guidelines for the Use of Respirators, 1991. Appendix 5. Work Rates and Work Durations.

292 Rabin, P.R. Critique of the R.A de Roza et al Paper Titled "Powered Air-Purifying Respiratory Study Trial: Report UCRL-53757. *Racal Safety Ltd*, Wembley, 1987.

294 OSHA. *Respiratory Protection: 29CFR 1910.134.* US Occupational Safety and Health Administration, Washington, 1998. At: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716

295 Agius, R. 1999. *Airborne Environmental Pollutants and Asthma*. University of Edinburgh. http://www.med.ed.ac.uk/HEW/medical/asthma.html

296 Commonwealth Aluminium Company. It has since been purchased by Rio Tinto (U.K).

297 The author was part of an occupational health group consisting of physicians and occupational physicians as well as hygienists and others. Monitoring of the atmosphere in different part of the plant was a routine activity and results related where possible, to the prevention of potential occupational disease.

305 Cote, J, Chan-Yeung, M. Outcome of patients with cedar asthma with continuous exposure. *American Review of Respiratory Diseases* **141:** 373-376, 1990.

306 Roza, R.A, Cadena-Fix, C.A, Kramer, J.E. Powered-Air purifying study. *Journal of the International Society of Respiratory Protection* **8:** 1990.

307 Whitley, J.A., Caretti, D.M. Respirator wear and its effects on visual acuity, depth perception and field of view. *Journal of the International Society of Respiratory Protection* **14:** 9-18, 1996.

308 Caretti, D.M. Effects of full face-piece respirator design on detection of peripherally located stimuli. *Journal of the International Society of Respiratory Protection* **14:** 11, 1996.

309 Johnson, A.T., Scott, W.H., Lausted, C.G., Coyne, K.M. Comparison of treadmill exercise performance times for several types of respirators. *Journal of the International Society for Respiratory Protection* **17:** pages?, 1999.

310 Caretti, D.M. Effect of respirator inspiratory resistances on respiratory muscle performance following long-term exercise. *Journal of the International Society for Respiratory Protection* **17:** pages?, 1999.

311 Johnson, A.T., Dooley, C.R., Coyne, K.M., Sahota, M.S., Benjamin, M.B. Work performance when breathing through very high exhalation resistance. *Journal of the International Society for Respiratory Protection* **15:** pages?, 1997.

[312] Alston, S., Powell, L., Stroud, P., Brown, R.C. A workplace study of the use and maintenance of respiratory protective equipment against vapour. *Journal of the International Society for Respiratory Protection* **15:** 24-29, 1997.

[313] McDuffie, H.H., Dosman, J.A., Semchuk, Olenchock, S.A., Senthilselvan, A. *Agricultural Health and Safety. Workplace, Environment, Sustainability.* Lewis publishers , New York, 1999.

[314] Coffey, C.C, Campbell, D.L., Myers, W.R., Zhuang, Z. Comparison of six respirator fit-test methods with actual measurement of exposure in a simulated health care environment: Part 1-protocol development. *American Industrial Hygiene Association Journal* **59:** 852-861, 1998.

[315] Revoir, H.W., Bien, C. *Respiratory Protection Handbook.* Lewis Publishers, New York, 1997, p 124.

[316] U.S Department of Health and Human Services. *NIOSH Respirator Decision Logic.* NIOSH publication No. 87-108. May 1987.

[317] Parker, J., Scholar, R. 1999. At: http://www.stevenspublis…/6A0219A67FB65DA86256848005AAD03?Opendocument

[318] Nelson, T. The performance of half-mask respirators. *3M Job Health Highlights* **14:** 3-5, 1996. At: http://www.3m.com/intl/ca/english/market/traffic/ohes/pdf_health/ 14-1.html

[319] Janssen, L. What is a positive pressure respirator? *3M Job Health Highlights* **15:** 1-4, 1997. At: http://www.3m.com/intl/ca/english/market/traffic/ohes/pdf_health/15-1.pdf

[320] Eide, I. The application of 8 hour occupational exposure limits to non-standard work schedules offshore. *Annals of Occupational Hygiene* **34:** 13-17, 1990.

[321] Chamings, A., Agius, R.M. 1995. Occupational asthma and rhinitis. Part 2: A basis for primary prevention. **54:** 33, March/April, 1995.

[322] Nelson, L., Holland, P. Assessing the impact of 12-hour shifts. *Journal of Occupational Health and Safety – Australia and New Zealand* **15:** 263-265, 1999.

[323] Smith, P., Wedderburn, A. The compressed work week (CWW) and longer shifts. Presented at the ANZAOHSE Shiftwork Workshop, 1999.

[324] Tucker, P., Smith, L., MacDonald, I., Folkard, S. Distribution of rest days in 12 hour shift systems: Impacts on health, wellbeing, and on shift alertness. *Occupational and Environmental Medicine* **56:** 206-214, 1999.

[325] Williamson, A.M, Gower, C.G.I., Clarke. Changing the hours of shiftwork: a comparison of 8 and 12 hour shift rosters in a group of computer operators. *Ergonomics* **37:** 287-298, 1994.

[326] Fairhurst, S. The uncertainty factor in the setting of occupational exposure standards. *Annals of Occupational Hygiene* **39:** 375-385, 1995.

[327] Raihans, G.S., Blackwell, D.S.L. Practical Guide to Respirators in Industry. Butterworths publishers, MA, 1985.

[328] Israeli Ministry of Defence. Desert Storm: Protecting the Israeli Military. *Journal of the International Society of Respiratory Protection* **14:** 25, 1996.

[329] Ogawa, Y., Shimizu, H., Yamamura, Y., Ando, H. Symptoms of victims suffered from sarin nerve gas attack on the Tokyo Subway System. *Journal of the International Society of Respiratory Protection* **17:** 1999.

[330] NIOSH. Types or respirators for protection against TB. Case studies. Protect yourself against TB. *US National Institute of Occupational Safety and Health*, Cincinnati, 1999. At: http://www.cdc.gov/niosh/tb-case.html

[331] NIOSH. Respirators in the Health-Care Industry*:* DHHS (NIOSH) publication No. 96-102. US *National Institute of Occupational Safety and Health*, Cincinnati, 1996. At: http://www.cdc.gov/niosh/tb.html

[332] Conrad, F. Surgical and other aerosols: Protection in the operating room. *Professional Safety.* August 1994.

333 Bullock, W.H., Laird, L.T. A pilot study of the particle size distribution of dust in the paper and wood products industry. *American Industrial Hygiene Association Journal* **55:** 836-840, 1994.

334 Xuguang, T, Massa, J, Ashwell, L, Davis, K, Schwab, M, Gehn, A. The World Trade Centre clean up and recovery worker cohort study: Respiratory health amongst cleanup workers approximately 20 months after initial exposure at the disaster site. Journal of Occupational and Environmental Medicine, **49**. Pp 1063-1072. 2007.

337 European Standard prCR 529: *Guidelines for the Use of Respirators*, 1991.

338 Johnson, A.T, Scott, W.H, Lausted, C.G, Benjmin, M.B, Coyne, K.M, Sahota, M.S., Johnson, M.M . Effect of respirator inspiratory resistance level on constant load treadmill work performance: Report. Biological Resources Engineering, University of Maryland, College Park, MD 20742-5711, USA..

339 Johnson, A.T, Dooly, C.R., Dotson, CO. Respirator mask effects on exercise metabolic measures. *American Industrial Hygiene Association Journal* **56:** 467-473, 1995.

340 Hery, M., Meyer, J.P., Villa, M., Hubert, G., Gerber, J.M., Hecht, G., Franc, D., Herrault, J. Measurement of workplace protection factors of six negative pressure half-masks. *Journal of the International Society of Respiratory Protection* **11:** 15-38, 1993.

341 Agius, R.M., Elton, R.A., Sawyer, L., Taylor, P. Occupational asthma and the chemical properties of low molecular weight organic substances. *Occupational Medicine* **44:** 34-36, 1994.

342 Avol, E.L., Linn, W.S., Venet, T.G., Shamoo, D.A., Hackney, J.D. Laboratory evaluation of disposable half-face mask for protection against ozone. *Journal of the Air Pollution Control Association* **34:** 804-809, 1984.

343 Johnston, A.R., Dryud, J.F., Shih, Y.T. Ozone removal capability of a welding fume respirator containing activated charcoal. American Industrial Hygiene Association Journal **50:** 451-454, 1989.

345 OSHA. OSHA improves respiratory protection for 5 million workers in 1.3 million worksites: Press Release. US Occupational Safety and Health Administration, Washington DC, 1999. At: http://www.usfa.fema.gov/alerts/osha9804.htm

346 Berndtsson, G. and Berndtsson, F, Jessup, S, McNamara, T. *Peak inhalation air flow and minute volume during a controlled test performed on an ergometer.* The SEA Group Pty Ltd. Submitted to NIOSH April 2003.

347 Kuklane, K, Holmer, I. *Respiratory flow patterns during physical work with respirators.* Department of Ergonomics, National Institute of Working Life, Solna, Sweden.

348 Howie, R.M. Effectiveness of Safety Equipment Australia SE400AT Positive Pressure Demand Filtering Device during asbestos removal operations. Report no. RMH/01/196. *Robin Howie Associates*. 1996.

349 Johnson, A.T. Effect of respirator inspiratory level on constant load treadmill work performance. A presentation at the American Industrial Hygiene Conference and Exposition, Dallas, Texas, USA, 1997.

350 Silverman, L., Plotkin, T., Sawyers, L.A., Yancee, A.R. Air flow measurements oh human subjects with and without respiratory resistance at several work rates. *Archives of Industrial Hygiene and Occupational Medicine* 3: 461-478, 1951.

365 Nathan, J. A, Cassidy, P.E, Janssen, L,L, Dengel, D,R. (2006). *Peak inspiratory flows of adults exercising at light, moderate and heavy work loads.* ISRP Journal. Vo. 23, issues 1 and 2. Pp 53-64.

366 Mackey, K, R,M., Johnson, A.T., Scott, W, H., Koh, F,C. *Over breathing a loose-fitting PAPR.* ISRP Journal. Vol. 22, issues 1 and 2. Pp 1-11. Spring/Summer.

367 Richardson, G. A system for the remote acquisition of respirator protection factors. *Journal of the International Society for Respiratory Protection* 17**:** Sping/Summer 1999.

Part 2: Research Project Aims and Research Questions

2. RESEARCH PROJECT AIMS AND RESEARCH QUESTIONS AND OBJECTIVES

2.1 Introduction

Respiratory protection is a last line of defense of contaminants in the workplace to prevent occupational disease. Elimination and isolation methods to prevent airborne contaminants from reaching the wearer are always preferred, but may not be possible. The purpose of respiratory protection is to protect the user from airborne hazards while in the exposed environment.

Current and future respiratory protection in all workplace environments is therefore a critical health issue for many workers in every country. Improvements in both the equipment and in the ability of the wearer to wear the protective equipment are needed to reduce the likely exposure as in many practical situations, respiratory protection is the only remaining option to reduce exposure of contaminants to the wearer.

Studies in the field in the field have usually been carried out by manufacturers of respiratory equipment in a number of workplaces such as foundries but the work is usually limited in that they focus is on the respirator being worn under ideal conditions which is rarely the case. There are also at least seven definitions of “protection factor” (the ratio of contaminant outside to inside the respirator so that interpretation of the studies to the practical working environment is often difficult to interpret).

Knowledge of protection factor (there are currently different definitions) is essential information to wearers and others. However, the variation in understanding of the methodology applied is currently confusing for both professionals in the field of respiratory protection as well as users, manufacturers and distributors and is placing users at risk.[368] Widely different values are promoted for the same equipment and in different countries. It has been stated “that APF’s (Assigned Protection Factors) have been determined through rigorous test procedures implemented under 30CFR 11 by NIOSH (National Institute of Occupational

Health)".[369] NIOSH further states that "assignment of protection factor is not an arbitrary process". This belief is appears incorrect. The procedure does not include a test procedure for setting APF's. The values are based on very limited amount of information and a significant amount of professional judgement.[370] The only valid protection factor number needs to be based on actual performance in the workplace. This requires a standardised experimental methodology and interpretation. The experimental method is not simple as there are many practical problems to be overcome, such as the condensed moisture inside the sampling lines (as breath moisture condenses on the cooler surfaces) and the position of the sampling head inside the respirator.[372]

Design and use of respirators is driven by a variety of standards either in the country of manufacture or use. As such, manufacturers rather than users are generally represented on the development committees of these standards. This has implications for the design of respiratory equipment.

Respiratory manufacturing standards are set by various countries, such as the Australian and New Zealand Standard 1715:2003 and 1716:2003, in Japan, USA, Europe and others. Increasingly, the ISO (International Standards Organisation) is setting the more recent modern trend with the work of the ISRP (International Society of Respiratory Protection) in meeting the needs of the human subjects whereas previous work by many standard bodies has focused on manufacturers meeting the requirements of standard norms.[133] This is a significant difference in the relevance of certifying standards for the user in the workplace.

The needs of the users in standards may not be well represented and can be in conflict with the manufacturers (for example, the need for high airflows by users may be a difficult criteria to meet by manufacturers). Standards do not require any validation of the equipment in the workplace by users which is a controversial and technically challenging task. Testing of the equipment on users is conducted under laboratory simulated conditions, and do not represent the true workplace conditions such as an aluminium smelter with high radiant heat and high personal working loads for periods of time which can significantly have an impact on the protection available from the RPE.

There are many other apparent contradictions in current Australian and New Zealand Standards such as TIL (Total Inward Leakage) testing of respirators. It is a requirement that ten subjects are used to validate the respirator under very controlled conditions and with subjects that are carefully chosen to exclude facial characteristics. This is very different to what normally occurs in the workplace. Half-face disposable respirators present serious problems in the TIL testing and it is not normally carried out (the respirators cannot develop a tight facial seal with the wearer). Yet these respirators are the ones that are in most common use in New Zealand by almost every industry including the health care sectors. A total of an estimated 17,000 users are estimated to wear RPE in New Zealand every day.

Similarly, cartridges are tested with test gases at flows which are based at constant low minute volumes. This again bears no resemblance to the manner in which the equipment will perform in the workplace. Flows in the workplace are sinusoidal (breathing in and out) and both flow volumes and flow rates need to be taken into account. This was pointed out as far back as 1923 and again, early, in 1943 by Silverman et al. Further, albeit with the realisation that PIAF rates may be significant, these concepts appear to have been disregarded by manufacturers over the decades. In addition, the low minute volumes used in testing do not represent the typical working requirements of most individuals working in industry.

Applied research by manufacturers is generally restricted to workplace studies under laboratory or controlled conditions or which do not represent the practical use of the equipment by users, whether in industrial, health care, military or other conditions of use. Requirements are influenced by manufacturers showing the equipment to be used under ideal and closely monitored use, rather than addressing user concerns or the need to show that respiratory disease is likely to be reduced by the use of particular types of respiratory equipment.

Standards set in Australia and New Zealand tend to set the minimum requirements that have to be met. The Standards should ideally be agreed internationally by those who have not a commercial interest only, but also users of respiratory protection, industry and others. This has been the subject of debate. [375]

Nationally, it is often difficult to get agreement but internationally, such as at the ISO level on the values and impact of PIAF as is currently the case, it becomes much more challenging[376]. However, there have been recent acknowledgements that current Australian and New Zealand Standards such as the AS/NZS 1716:2003 are very much in need of revision,[377] in part following findings that breathing rates used by workers in their normal environments do not match specifications on how respirators are designed or manufactured. There has been an apparent reluctance by respirator manufacturers to enter the debate but the advent of the activities and recommendations arising out of the ISO working groups on respiratory protection are forcing the technical issues to be discussed and the technical journals such as the ISRP (International Society for Respiratory Protection) are beginning to publish in topics such as the issue of PIAF.

The technical details in standards are critical to promote effective respiratory protection. For example, the maximum airflow rates required by users in the workplace must be able to be met by the equipment to ensure that contaminants do not enter the respirator (particularly under conditions of high work load), yet few of the commercial equipment currently available likely meets this need or even mention studies to ensure that the requirements are met. Nor is it yet a requirement of the Standards such as AS/NZS 1716:2003. Work has shown that these criteria are important for user acceptability as well and ensuring that protection of the wearer is acceptable. [378,379] At the present time, there are significant concerns with the relevance of these respiratory standards for the user in the workplace.

2.2 Summary of Planned Work

This thesis is concerned with removing the barriers to the use or respiratory protective equipment, particularly for users by:

Total inward leakage

- ❍ Suggesting an improved method of determining the TIL (Total Inward leakage) which incorporates the user of the RPE (generally an older work group) rather than a carefully selected panel of younger test subjects which do not represent the typical Australasian workforce.

Minute volumes of air used

- ❍ Measurement of incremental peak inspiratory air flow (PIAF) during respiration with a wider age group and both genders. Respirator design currently uses only minute volume (MV) of air criteria to estimate peak flows for respirator effectiveness. These criteria are believed to be inadequate for purpose in the workplace, particularly under high personal workloads.

Peak inspiratory air flows (PIAF)

- ❍ Current standards do not involve PIAF when testing respirators for use. In addition, current standards use low air flows to certify respirator cartridges for use in the workplace and this work will recommend changes. Both minute volume and PIAF increase significantly as the work load increases on any individual.

PIAF when communicating

- ❍ The determination of PIAF when communicating in the workplace. Communicating is an essential in the workplace and is often a critical safety issue. Work here will show that PIAF is high during this time and may significantly affect the performance of the respirator in the workplace.

A major New Zealand application knowledge and awareness of inhalation disease and respiratory equipment

- Identifying improvement and barriers to the use of respiratory equipment in specific application, ie., in New Zealand agricultural operations.

The results of this thesis have the potential to be applicable in many parts of the world to assist to:

- Reduce the incidence of occupational lung disease by the subsequent development of improved respiratory protective equipment;
- The application of improved respiratory protection in, for example, industrial, hospital and military applications; and
- Stimulate improvements in respirator design.

2.3 Research Plan

The research is this thesis is designed:

- To draw on the authors 30 years practical experience in this area, in a number multinational industries (particularly aluminum smelting) and SMEs such as in agriculture in New Zealand.
- To initiate and expand applied research to identify critical needs of users, particularly minute volumes (MV) and peak flows (PIAF) under workplace conditions.
- Raise the awareness of the key issues that will improve respiratory protection by standard organizations such as AUS/NZ Standards or others.
- Identify and recommend improvements in respiratory protection to reduce occupational respiratory disease in the future, particularly in key industry areas and other specified applications.

Typical of the issues that need to be addressed at the present time include the correct values of minute volume, peak inspiratory air flows in industrial, health settings, military situations and an evaluation of the protection preferably real-time (for example, by the use of real time video and electronic sensor monitoring of contaminants opportunities). The applicability of this technique is outside the extent of this work, but is important for the future development of respiratory protection and the prevention of occupational respiratory disease. The technique is useful in that observations and measurement of contaminant inside and outside the respirator can be done in real time. Other techniques are being developed as well in an effort to obtain real-time workplace exposures. [381]

The future prevention of occupational respiratory disease using RPE is critically dependant on more detailed insights into minimum respiratory requirements and the requirements of users in the practical workplace. The most effective way to address these issues for the future is to influence national and international standards in respiratory equipment based on independent research and practical insights of experienced users in industry.

Practical insights and applied research to improve respiratory protection for users is becoming even more important in increasing number of applications in personal protection which have not been seriously considered in the last decades (such as biological warfare). In addition, the limitations of current respiratory equipment for users needs to be recognized and if possible, overcome.

These and similar considerations are the focus of this work.

2.4 Research Questions

- What are the typical values for Minute Volume (MV) and Peak Inspiratory Air Volume (PIAF) in an aluminium smelter in New Zealand during key tasks performed?
- Are the current methods of estimating Total Inward Leakage adequate for measuring the effectiveness of negative pressure Respiratory Protective Equipment (RPE)?

- How do Total Inward Leakage (TIL) measurements in the laboratory compare with TIL measurements in the workplace?
- What are the other options to determine the user TIL of a worker in the workplace with the RPE that is in use, using heart rates at the site as an indicator of the physiological demand of the tasks?
- What are the MV (Minute Volumes) of air used in a typical Australian workforce during various physiological demands while working so as to relate this to the current AS/NZS 1716:2003 Standard?
- What are the Peak Inspiratory Air Flows (PIAF) used by a typical Australian workforce under various physiological demands in the workplace and what is the effect on PIAF rates when communicating in the workplace?
- How is respiratory protection perceived by users in a defined occupational sector (agriculture) in New Zealand?
- What is the current knowledge of a major occupational inhalation disease in agriculture and what are the current practices of a major group of SMEs (Small to Medium sized Enterprises) in New Zealand in terms of respiratory protection?

Structure of the Thesis presentation

Introduction

Research project aims and research questions and objectives

Determination of minute volumes and peak inspiratory flows in a workplace (aluminium smelter).

(Practical study in a smelter in New Zealand.

Heart rates, minute volumes, work and TIL (Total Inward Leakage).

(A laboratory study)

Peak Inspiratory air flows (PIAF) during work and when communicating.

(A laboratory study)

Respiratory protection in agriculture

(Questionnaire survey in the New Zealand agricultural sector)

Discussion, conclusions and recommendations

Diagrammatic representation of the presentation of this Thesis.

2.5 References

[368] Howie, R.M. The FPBR and protection in the asbestos stripping industry. Presented at the International Society for Respiratory Protection conference, Cairns, 2000.

[369] NIOSH. Interpretation on Respirator Use Under the Interim Final Rule for Lead in Construction. Office of Compliance Assistance, *US Occupational Safety and Health Administration (OSHA)*, Washington, 26 February, 1996.

[370] Janssen, L. Assigned protection factors: A Perspective. *3M Job Health Highlights* **16:** 12-15, 2000. At: http://www.3m.com/intl/CA/english/market/traffic/ohes/ pdf_health/16-4.html

[375] Berndtsson, G. Tomorrow's Standards-where are we heading? The case for objective, performance based, internationally applicable standards in respiratory protection. *ISRP Journal*, **17**. Spring 1999. Pp 7-9.

[376] The meeting notes from the ISO technical committees are confidential but the level of interest is now high. See also: Johnson, A.T, Koh, F.C, Scott, W.H, Mackey K.M, Chen, K.Y.S and Rehak, T. Inhalation flow during strenuous exercise. *ISRP* Journal, **22**. Pp 79-96.

[377] Standards Australia/Standards New Zealand. *AS/NZS 1716 Respiratory Protective Devices*. Preface. Standards New Zealand, 2003, p 2.

[378] Mackey, R.M, Johnson, A.T, Scott, W.H, Koh, F.C. Over breathing a loose-fitting PAPR. *ISRP Journal*, **22**. Spring/Summer 2005.

[379] Johnson, A.T, Koh, F.C, Scott, W.H, Mackey, K.M, Chen, K.Y.S and Rehak, T. Inhalation flow rates during strenuous exercise. *ISRP Journal*, **22**. Fall/Winter 2005. Pp 79-96.

[381] Groves, W.A. Personal sampling system for measuring workplace protection factors for gases and vapors. *ISRP Journal*, **23**. Spring/Summer 2006.

Part 3: Methods

3. METHODS

3.1 Introduction

This thesis has no unifying methodology, but examines various factors affecting respiratory protection in the occupational environment taking a case study approach, covered in the following chapters. Specific methods (and results, discussion and conclusions) for those investigations will be outlined in the individual chapters for each case study.

3.2 The Case Studies

The research investigations in this thesis are:

- Chapter 4: Determination of minute volumes and peak inspiratory air flows in an aluminium smelter. This is the summary results of a small survey conducted in an aluminium smelter in 1995, which provided impetus to further work in this thesis.
- Chapter 5: Determination of minute volumes which could be used to determine total inward leakage values for respirators and for testing respirator filters and cartridges that more closely resemble workplace conditions.
- Chapter 6: Determination of minute volume flows used by respirator wearers and heart rates for a typical work group in industry at various levels of work (physiological loadings).
- Chapter 7: Determination of Peak Inspiratory Air Flows (PIAF) at various levels of work and the increased air flows that result when communicating in the workplace.
- Chapter 8: A questionnnaire to determine the beliefs and practices related to respiratory protection and inhalation disease in the New Zealand agricultural sector.

Chapter 4 is an introductory workplace project looking at physiological parameters by workers completing key tasks in an aluminium smelting operation in New Zealand.

Chapters 5-7 are laboratory based experiments investigating respiratory parameters, i.e., minute volume and peak air flows while using respirators.

Chapter 9 summarises the work with conclusions and makes recommendations for the future to improve respiratory protection in the workplace particularly for users.

In the work trials with volunteer subjects (Chapter 4-7), all were already participating in workplace trials to which the determination of minute volumes and peak inspiratory air flows were added. All were from the same company, followed company ethics and the activities were part of their work in developing new RPE particularly the FPBR. The work was part of their normal employment. All subjects were requested to undertake prior medical examinations and advised to cease during the trials if they felt uncomfortable. All volunteers were well briefed. In the trials, no subject name was recorded and identification of any individual is not possible. Only summary data has been kept and all other records have been destroyed.

The FarmSafe questionnaires (Chapter 8) were completed by course volunteers and there was no compulsion to participate or respond to the questions. No identification of any individual is possible. The questionnaires fully explained the purpose of the work and a contact name was given in case of any additional inquires. The questionnaires were deemed to be low risk. They were part of normal ACC activities in this field and part of a range of questionnaires completed as part of normal business of this large Government workplace insurer. All questionnaires were destroyed at the end of the analysis and no records other than summary data has been kept.

Owing to the case study approach of the work provided in this thesis, references will be appended at the end of each chapter, not at the end of the thesis.

Part 4: The Case Studies

4. CASE STUDY 1: DETERMINATION OF MINUTE VOLUMES AND PEAK INSPIRATORY FLOWS IN THE WORKPLACE (ALUMINIUM SMELTER)

4.1 Introduction

Occupational asthma is a major occupational disease issue for the primary aluminium smelting industry. The contributing factors are not known, but many chemical agents are suspected.[382] Further, aluminium smelter employees work intensively for relatively short periods at high radiant heat and high work rates throughout a twelve hour shift (the industry norm).

Compulsory wearing of respiratory equipment was introduced at Australasian smelters in about 1985 in an effort to reduce the incidence of occupational asthma. Half-face rubber respirators were introduced accompanied by quantitative respirator fit tests, training and education programs.

Difficulties were experienced by supervision in ensuring that the equipment was being worn while in the contaminated environment, mainly on the “potlines” where aluminium is smelted (i.e., converted electrochemically from bauxite to aluminium metal). The main contributing factors raised were the presence of irritants in workplace air, the additional load placed on the employee required to draw air through a filter at maximal work loads, condensed moisture build-up inside the respirator, increasing heat build-up inside the respirator and difficulties in communicating-some of which was for social reasons but in other cases was for warning or emergency situations.

An investigation was carried out to determine the minute flows and peak inspiratory air flows involving about fifty people from a primary aluminium smelter in New Zealand who were required to wear half-face respiratory protection while working in the potline.

These workers are required to work in very high radiant heat conditions. There are increasing concerns that the additional load placed on people (the requirement to draw air through filters when working at very high physiological loads in a high exposure environment) may increase the danger of traumatic physical injury (for example, molten metal splash) through thermal stress adding to the overall stress of the worker.

The respirator management of the company became increasingly concerned about some of these issues and the same concerns were expressed in numerous papers published at the same time and afterwards.[383,384,385,386] Efforts were directed at communicating with respirator companies who often were not involved in how the equipment was being used in the practical work situation.[387]

As a result an independent company, Safety Equipment Australia Pty Ltd became a partner in attempting to overcome the issues raised by the employees of the aluminium smelter (and the same issues are evident in many other industries). PAPR (Powered Air Purifying Respiratory) equipment[12] appeared to offer a solution to many of the problems raised.

Consideration of PAPR equipment also raised many issues of concern such as the air flows required to protect the employee,[388] the need to communicate, the need to ensure that over-breathing[13] did not occur and many other practical factors.

Method

The survey of the minute volumes and peak inspiratory volumes was conducted at a primary aluminium smelter in 1995 to estimate the range

---

[12] The PAPR is a respirator that has a motor attached that results in air being delivered to the wearer in a variety of different face pieces. The minute volume flow rate of a new respirator with new filters attached will deliver up to a maximum of 120 litres per minute. This value reduces very quicky when the batteries decrease in energy and the filters load with particulates. The peak inspiratory air values are not measured or supplied by the manufacturers.

[13] Over-breathing has been raised as now the major concern of this type of equipment following work by the author and others (Mackey, K.R.M., Johnson, A.T., Scott, W.H., Koh, F.C. (2005), *Overbreathing a loose fitting PAPR.* ISRP Journal, Vol. 22, issues 1 and 2. Srping/Summer).

in these parameters at various places around the smelter in workers carrying out various tasks.

The initial trials here were completed using equipment developed specifically for work in an aluminium smelter. As a result of this work, the equipment was further developed and is described further in this thesis. The methodology involved workers wearing RPE fitted with pressure sensitive devices that monitored and measured the minute and peak inspiratory air flows during the task being performed. These results were downloaded into a computer at the end of the day. The results of this work subsequently became the basis of further work to determine air flows in a laboratory setting and this is also further described later in this thesis.

The equipment designed and built rapidly measured changes in pressure inside and outside the respirator being worn and translated this via transducers into air flows and recorded onto a microprocessor. The equipment was calibrated with certified standards with all components. The maximum error due to equipment and calibration was calculated at 10% of the flow value reported.

This equipment, based on the results obtained here, was subsequently refined and further developed. It was finally incorporated into all production models of the FPBR (Fan supplied Positive pressure Breath responsive Respirator) sold internationally.

All participants from the smelter were fully briefed and volunteered to take part. The volunteers were fitted with the recording equipment at the start of the shift. They recorded their tasks and times during the day. At the end of the shift, the logged values of minute volume and peak inspiratory air flows were downloaded to a PC and compared againts the activities manually recorded.

All volunteers using the Sundstrom® respirator had the respirator/face fit tested[14] using Portacount® equipment. Only those that attained a fit factor of 100 (i.e., 1% leakage) participated further. This was done to ensure that leakage factors did not significantly affect results and subsequent analysis of the information.

Initial results are presented in summary form below.

4.2 Results

The Table below outlines minute volumes and peak inspiratory flows in smelter workers. These are also further illustrated with the following two Figures.

Table 4.1: Range of values for minute volume and peak inspiratory air flows used by employees in an aluminium smelter

Activity[†]	Minute volume (L/min)	Peak inspiratory air flow (L/min)
Deck plate	13.8 to 41.8	75.2 to 264.5
Pulling burn-offs	8.7 to 34.6	50 to 240.0
Setting anodes	14.0 to 49.5	76.4 to 250.9
Beams	10.7 to 49.4	65.8 to 269.5
Tapping and trimming	8.2 to 39.2	116.7 to 254.8
Adding cryolite	11.5 to 55.5	No data
Cranes	7.6 to 40.7	No data
Dipping	8.7 to 37.3	No data

Note: These values were obtained with equipment that was developed prior to the more sophisticated equipment that followed and which is now commercially available. The values are likely to be higher than those recorded here. Minute volumes and peak inspiratory air flow values were not obtained at the same time (as is now possible).

Minute volumes ranged from 8.2 to 55 L/min, and peak inspiratory air flows ranged from 50-270 L/min.

Table 4.1: Minute Volume and Peak Inspiratory Air Flows during key tasks in the portooms of an aluminium smelter.

[14] This equipment uses small airborne particulates in the atmosphere and coats them with alcohol to increase the size. These are then passed over an ionisation detector and the number counted. By both measuring the particulates inside and outside the respirator being worn, a value of "fit factor" is able to be derived. Subjects during the test are normally required to exercise, move the face in various directions and talk.

[†] These are every-day activities in an aluminium smelter completed by employees in the potline.

Figure 4.1: Upper and Lower Ranges of Minute Volume during work at an Aluminium Smelter

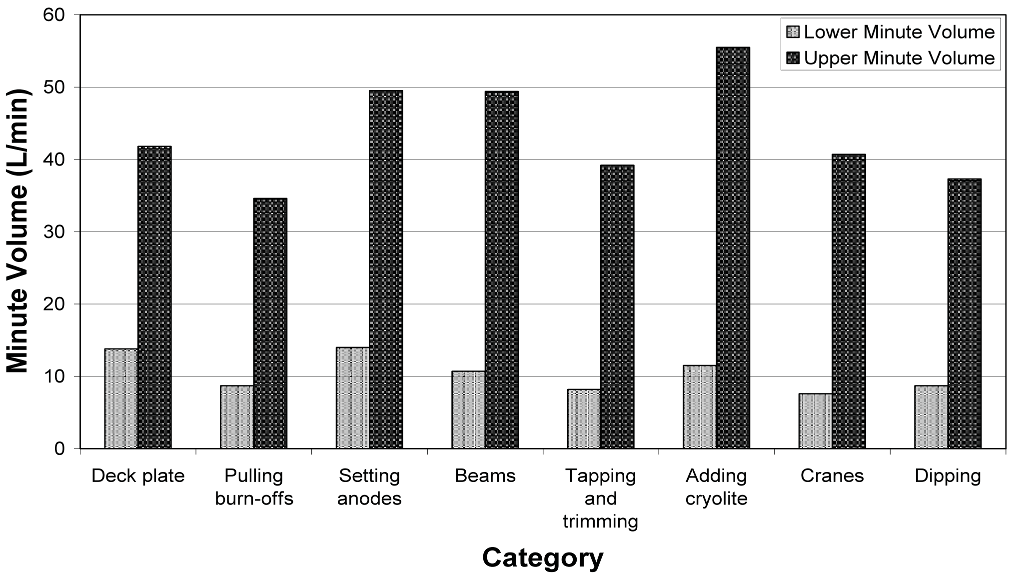


Figure 4.1: Minute Volume and Peak Inspiratory Air Flow during key tasks in the potroom of an aluminium smelter/

Figure 4.2: Upper and Lower Ranges of Peak Inspiratory Air Flow during work at an Aluminium Smelter

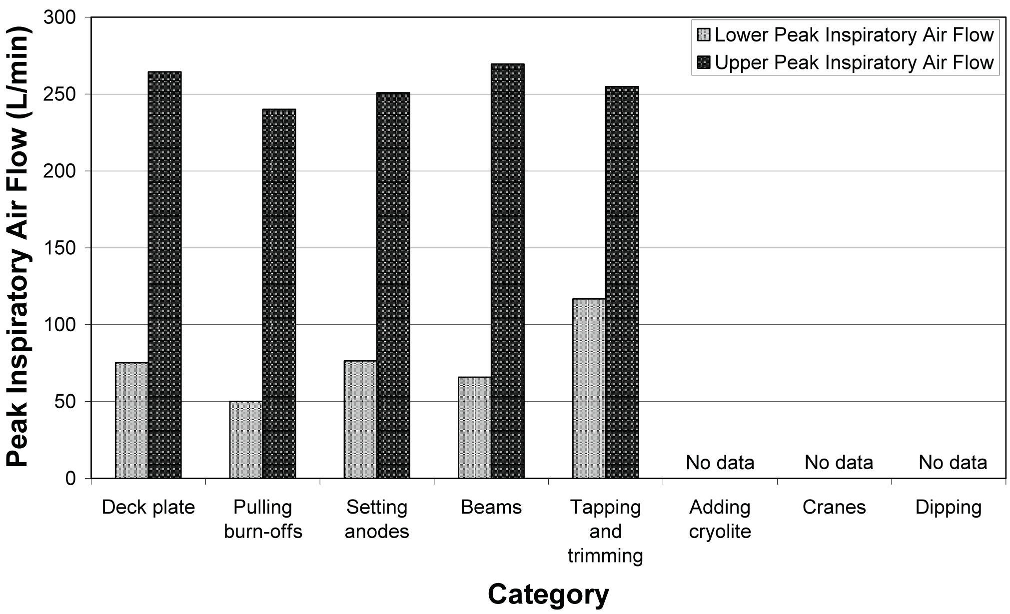


Figure 4.2: Upper and lower ranges of Peak Inspiratory Air Flow during work in in the potrooms of an aluminium smelter

4.3 Discussion

The minute volume data in the above Table shows that activities in the smelter range from 6-175 l/min, which can be classified from "resting" (6-

7 L/min) to very high workloads (43-56 L/min).[389] The Peak Inspiratory Air Flows range from 50-270 L/min. Some of these are very high values, and sufficient to impair the ability of some respirators to supply air through the filter to workers. Under such circumstances, air will either not be available, or the respirator will fail, and air will leak around the filter, around the respirator, or is present, around the valves.

There are significant advantages in using PAPR type of equipment that are becoming well recognised throughout the literature.[390,391,392] However, work at SEA and elsewhere has shown that the air flows being delivered by current equipment is inadequate to meet the needs of users in the workplace.[393,394] This may result in negative pressure inside the respirator with resultant likely contaminant entry into the facepiece.

This work although reported in summary form here provided the impetus for the work conducted in the rest of this thesis.

4.4 References

382 Lund, M.B., Oksne, P.I., Hamre, R., Kongerud, J. Increased nitric oxide in exhaled air: an early marker of asthma in non-smoking aluminium potroom workers? *Occupational and Environmental Medicine* **57:** 274-278, 2000.

383 Chan-Yeung, M., Wong, R., MacLean, L., Tan, F., Schulzer, M., Enarson, D., Martin, A., Denniss, R., Grzybowski, S. Epidemiologic health study od workers in an aluminium smelter in British Columbia: Effects on the respiratory system. *American Review of Respiratory Disease* **127:** 465-469, 1983.

384 O'Donnell, T.V., Welford, B., Coleman, E.D. Potroom asthma: New Zealan experience and follow-up. *American Journal of Industrial Medicine* **15:** 43-49, 1989.

385 Winder, C., Yeung, P. Health problems in aluminium smelter workers: Hazards, exposures and respiratory disease. *Journal of Occupational Health and Safety - Australia and New Zealand* **5:** 391-402, 1989.

386 Taiwo, O.A., Sircar, K.D., Slade, M.D., Cantley, L.F., Vegso, S.J., Rabinowitz, P.M., Fiellin, M.G., Cullen, M.R. Incidence of asthma in aluminium smelter workers. *Journal of Occupational and Environmental Medicine* **48:** 275-282, 2006.

387 Kongerud, J., Rambjor, O. The Influence of the helmet respirator on peak flow in aluminium potline. *American industrial Hygiene Association Journal* **52:** 243-248, 1991.

388 De Roza, R.A Powered air purifying respirator study. *Journal of the International Society of Respiratory Protection* **8:** Pp 15-36. 1990.

389 Grandjean, E. *Fitting the Task to the Man: A Textbook of Occupational Ergonomics,* fourth edition. Taylor and Frances, London, 1988, pp 83-94.

390 Pasternack, A. Journal of the International Society of Respiratory Protection **8:** Winter 1991-1992.

[391] NIOSH. *Guide to Respiratory Protection.* US National Institute of Occupational Safety and Health, Cincinnati, 1992.

[392] Lambert, W.M. The effectiveness of PAPR's for respiratory protection in nuclear plants. *Respiratory Protection Newsletter* **7:** 1991.

[393] Roza da, R.A, Cadena-Fix, C.A and Kramer, J.E. Powered-Air Purifying Study. *ISRP* Journal, **8**. Summer 1990. PP 15-36.

[394] Mackey, R.M.K, Johnson, A.T, Scott, W.H and Koh, F.C. Over breathing a loose-fitting PAPR. *ISRP* Journal, **22**. Spring/summer 2005.

5. CASE STUDY 2: HEART RATES AND MINUTE VOLUMES

5.1 Introduction

The effectiveness of a respirator worn by individuals in the workplace is an important aspect of personal protection. Some respirators of the air purifying type use a filter or absorbent to remove airborne contaminants such as potentially harmful dusts and gases from the air prior to entering the breathing zone of the person. Techniques of contaminant removal include adsorption, absorption or filtration. Such filtration is not required in supplied air respirators, where a respirator uses uncontaminated air from another source to the breather.

It is often assumed by users that respiratory protective equipment removes all of the contaminants, although this is rarely the case. There are numerous considerations that affect protection which includes training of the user,[395] fit of the respirator on the face while in the working environment,[396] characteristics of the design of the respirator,[397] and characteristics of the equipment such as the filtration capacity of the filter against the known contaminants, humidity,[398] contaminant concentration as well as volume of gas passing through the filters. The facial fit (measured as a measure of the contaminant concentration inside and outside the respirator) is influenced by many factors, including the effect of facial moisture from sweating,[399] as well as the understanding of the limitations of the equipment, or insights into the contaminant risks and concerns by wearers.[400]

A number of respiratory parameters are used in designing respiratory function. These include respiratory rate (RR) and respiratory volume (RV). Respiratory rate multiplied by respiratory volume gives the minute volume (MV), or the amount of air inhaled in a minute.

$$RR \times RV = MV$$

Minute volume increases as work increases (see Table 5.1)[401].

Table 5.1: Minute Volume and Work Rate

Work Load	**Minute Volume (L/min)**	**Heart Rate (bpm)**
Resting	6-7	60-70
Low	11-20	75-100
Moderate	20-31	100-125
High	31-43	125-150
Very High	43-56	150-175

Table 5.1: Minute Volume and Work Rate

These values cover a wide range of physiological functions. Most workers are unlikely to work at a very high level, which is seen mainly at an elite athlete level. However, moderate and high levels are possible in some worker groups.

There appears to be variation in the literature about the correct air values to be used in respiratory protection such as air flow and rates including those for cartridge testing. A paper published in 1997 described 40 L/min (litres per minute) minute ventilation as associated with "heavy work".[402] Subsequent papers have described 30 L/min as associated with "light to moderate work"[403]. These values are consistent with the values in Table 5.1 above. However, in general, almost no information is given by manufacturers or is given to users as regards peak inhalation flows.

It is known that there are significant and large variations in minute airflow and peak inspiratory air flow for the same level of exercise by different individuals. These variations will impact on TIL determinations (because increased airflows can result in increased leakage[404]) and will also affect the useful life of filters in the workplace (because the protection afforded by a respirator filter depends on chemical or biological agent and flow rates[405]).

The NATO-standard military filter and many commercial filters are designed and tested at 32 L/min minute ventilation.[405]

It can be seen that the rate of airflow into and out of the respiratory system changes at different parts of the breathing cycle, and at different times, this inhalation (or exhalation) flow can be quite high. The peak inhalation flow, that is, the maximum rate of inward air drawn, will vary with the individual and the work rate being undertaken.

It should also be noted that these values are made from individuals with unimpeded respiration. The addition of a filter on a half-face close fitting respirator will increase the work required by the individual simply by the need to draw air through the filter itself. Work rates in workers undergoing moderate or high workloads who are wearing respirators may require higher minute volumes than a respirator will allow, possibly producing physiological stress and leakage around the respirator or any of its valves. This airflow around respirators and within its valves is called "Total Inward Leakage" (or TIL).

Over many years, standard values for minute volume and peak inspiratory air rates have been used by manufacturers and users or respirators around the world. Most of the values have originated from work dated back to 1943.[406] Even then warnings were made that the values being used were likely to be too low to ensure adequate protection.[406]

Other factors are also critical for effective respiratory protection. The respirator has to fit, and users must undergo "fit testing". This concept has different meaning in the laboratory and in the workplace.

Protection factor, an apparently simple concept, has been the subject of much debate and is scientifically challenging.[407,408,409,410] Most studies are completed by manufacturers for commercial reasons under strictly controlled conditions.[411,412,413] In addition, there are at least nine different definitions of protection factor[414] and the quoted applicable values from Government agencies or Standards organisations in different countries varies (for example, between Australian/NZStandards in 2003[415] and even the more recent NIOSH recommendations in 2003).[416]

The simulated working environment does not represent the true working environment in this and many other situations. It is known that the protection measured in the laboratory bears little relationship to the working environment.[417]

More challenging is the real-time determination of contaminants reaching the inside of respirators worn in the industry environment,[418,419,420] known as the PIMEX method. Also known as video exposure monitoring, this is a method for making workplace exposures visible. The technique offers many improved possibilities such as the identification of key periods of intense hard work with high radiant heat exposure and high possible contaminant exposure. This is generally followed by longer periods- wearing the respirator in areas with less potential airborne exposures while still in the workplace. This type of workplace exposure is difficult to duplicate in the laboratory but because it is “of the workplace”, it can be considered representative of the workplace.

The workload imposed on individuals in the workplace is often outside the control of the worker, at least for limited periods of time. For example, in an aluminium smelter, when removing burnt-out anodes from a cell, there is limited opportunity to moderate the practical workload or alter the worker’s potential exposure to the environmental contaminants. It is assumed that the worker may compensate their workload according to their physical ability but this may not always be possible.

The determination of the Total Inward Leakage (TIL) of assembled respirators on volunteer subjects is one of the fundamental performance tests that are required to be completed by all manufacturers wishing to have their equipment certified as complying with standards such as AS/NZS 1716:2003. This requirement varies in different countries, with the USA not recognising TIL in any of its respiratory regulations[421] for certification of equipment.

The determination of total inward leakage in the standard is a measure of how well the respirator seals on a range of face shapes while the subject simulates work walking on a treadmill at 6.5 kph and carrying out a range of head and facial movements. The inward leakage is detected by measuring the concentration of specified contaminant inside the respirator and compared against the outside ambient concentration by a variety of analytical techniques. In AS/NZS 1716:2003, sodium chloride aerosol of a known particle size range is used to determine the inward leakage of any respirator. The maximum amount of inward leakage permitted varies, and ranges from 22% for a non-powered half-mask with P1 filter to 0.05% for a PAPR fitted with a P3 filter.

A general workforce population will be of both genders and of a wide age range, very different from the normal standard select group. The fitness and other characteristics have a marked influence on the volume and speed of air required. It is likely that the TIL values may be significantly affected. Obviously, in the workplace a wide variety of people with different face shapes, facial hair, ages and both genders will wear respirator; often without any formal training or education in spite of recommendations to the contrary from every agency and manufacturer, and as specified in the standard.

The wider age range and different levels of fitness for example, may result in airflows which are both lower and higher than the TIL test group used for certification purposes. This may have significant implications for respiratory protection in the workplace.

TIL tests are completed to ensure that the equipment meets the minimum inward air leakage requirements under strictly controlled laboratory conditions. This, of course, has no relationship to the practical workplace situation and this is well recognised.[414] However, there is a ready opportunity to relate air flows to the practical work environment for both leakage testing and cartridge life evaluation.

It has been demonstrated[401,423] that there is a close relationship between the heart rate of an individual and the minute volume (and peak inspiratory air volume, discussed in a later Chapter) of air used. It is often also very difficult in situations such as an aluminium smelter, for example, with high radiant heat and strong electromagnetic fields, to carry out field trials with sensitive scientific equipment. However, it is usually an easy task to determine the heart rate with chest or other monitors, particularly during periods of intensive working activity, and because heart rate monitoring equipment is not generally affected by magnetic fields and ambient conditions at the workplace, downloading these values into a PC at the end of a working day, is relatively non-problematic.

Equipment that is commercially available allows the minute volume (as well as peak inhalation values) to be readily measured (see the next three Figures below).

Figure 5.1: Close-up of half-face respirator used. The tube allows the pressure changes to be communicated to the measurement equipment

Figure 5.1: Close-up of half-face respirator used. The tubes allow the Pressure changes to be communicated to the measuring equipment.

Figure 5.2: Photograph of a person exercising at a constant rate and the monitoring in the laboratory showing equipment used to determine minute volumes of air used by each volunteer

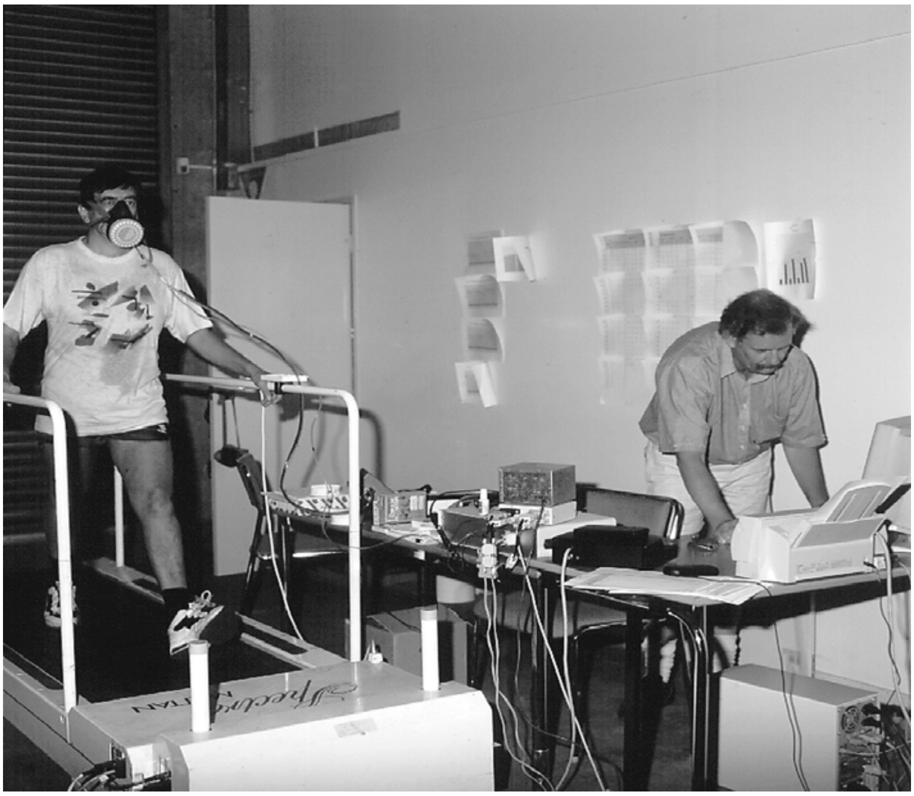


Figure 5.2: Photograph of a person exercising at a constant rate and the monitoring in the laboratory showing equipment used to determine minute volumes of air used by each volunteer

Figure 5.3 : Photograph illustrating the volunteer exercising and measurement equipment in use

Figure 5.3: Photograph illustrating the volunteer exercising and measurement equipment in use

This study was designed to show that a more realistic and practical value of the minute volume (the volume of air used per minute) could be used to determine the real values of minute volume in the laboratory via measured users heart rates in the workplace (that is, use actual minute volumes being used at the workplace). These values can be subsequently used to determine the practical life of respirator filters from air flow values being used at the workplace and more realistic workplace values for TIL can be carried out for every individual.

Using heart rates obtained at the workplace to determine minute ventilation volumes which can be used to give meaningful values for total inward leakage (TIL) in respiratory protection and also for calculating the more useful practical life of respirator gas filters.

5.1.1 Objectives

The objectives of this study was to determine:

- The heart rates that be obtained from workers in the workplace by an older age group individuals;

- The heart rate values to derive the minute air volumes used by the same users (in a laboratory or controlled setting) from the heart rate found;
- The values of heart rates for any individual were consistent over a short period of a few days (so that measurements taken at the workplace could be used in the laboratory to derive minute volumes for the same individuals), i.e., whether the values of heart rate taken at one time could be used again at another time under similar conditions;
- The TIL which more appropriately relies on any individual by measuring the heart rate under different physiological loads to predict the TIL, using these values and relating these to the workplace;
- For a representative type workforce (a typical workforce that could be expected to be found in a workplace is usually older and more varied in ranges of age than a typical standard and selected younger age group used by Standard setting organisations to certify RPE), the values for minute volume are substantially different to that likely used for certification of respiratory equipment and for testing the life of cartridges (breakthrough tests). The group consisted of all volunteer employees of a SME manufacturing organisation producing and marketing RPE.

5.2 Method

Subjects

In this study, 25 volunteers took part in this study. All were employees of the same workplace. No effort was made to select participants as outlined in AS/NZS 1716:2003.[415]

All males were clean shaven. All volunteers had the experimental procedure explained to them, were medically assessed as being able to undertake the tests, agreed to participate and were encouraged to report any discomfort at all (more details are given earlier). They were also encouraged to cease walking or running on the treadmill if they felt uncomfortable. Ethical issues have been decribed previously.

Respiratory Equipment

All subjects were fitted with a Sundstrom® half-face respirator (see Figure below).

Figure 5.4: A Sundstrom Half-Face Respirator (the SR90)

Figure 5.4: The Sunstrom® commercially available half-face respirator used in the experiments.

Equipment used

The Sundstrom® SR-90 half-face respirator was worn fitted with a flow meter, designed, built and calibrated by SEA Pty Ltd in Sydney. A calibrated flow meter was built and fitted to the respirator equipped with a P3 filter.[415] The accuracy of the flow meter was verified with a two-point calibration prior to the commencement of the tests and repeated at the end of each subject test (details of the equipment has been given earlier).

This equipment allowed the real-time determination of minute volume and peak inspiratory air flow to be determined and recorded.

The fit of the respirator checked with Portacount® particle fit tester, which allowed measurements to be downloaded to a computer.

Subjects who passed with a fit value of 100 (1% leakage) or greater were considered acceptable to take part in further trials. All subjects were asked to discontinue if they felt uncomfortable with continuing the test. The ethical protocol used is described elsewhere in this thesis. No volunteers withdrew from the trials.

Subjects were asked to walk at a steady rate of 6.5 kph while heart rate and minute volume were logged electronically. The trials were repeated on at least 3 times on separate occasions for each subject.

The respirator used was a SR-90 ® in two sizes, fitted with a flow meter designed, built and calibrated by SEA Pty Ltd. Calibration was verifiable to a reference standard. The flow meter utilised a pressure drop over a standard P3 Sundstrom ® particulate filter. The pressure drop was measured using a Honeywell Differential Pressure Transducer®.

The respirator was calibrated using a certified Interspiro IPZ test bench at SEA Pty Ltd. Calibration was based on a two-point calibration with a high and low limit flow value. The high value point was obtained by sampling 1500 times over 30 seconds. The low value was obtained similarly after entering the numerical value through a keyboard. Gain and offset values are calculated and stored in a separate file as calibration constants. Calibration was repeated at the end of the test series to check for any change in flow resistance due to contamination. The difference was negligible.

Low and high flows were recorded via a pressure drop across a P3 filter. The calibration procedure was automated in the software. The software requested a high limit value and then averaged 1500 samples over 30 seconds. The numerical value was entered via a keyboard. The process was repeated for the low limit value. Gain and other offset factors were calculated and stored in separate files as calibration constants. Prior to each test, an equipment calibration was performed.

The treadmill used was a Spectra Mattan.

The heart rate was measured using a POLAR S610 heart rate monitors downloaded to POLAR software.

5.3 *Results*

Volunteers

Demographically, the 25 volunteers (20 male; 5 female) had a wide age range of 19 to 50 years, with an average age of 36.7 ± 11.7 years (see Figure 5.5 below).

Figure 5.5: Age and gender of volunteers

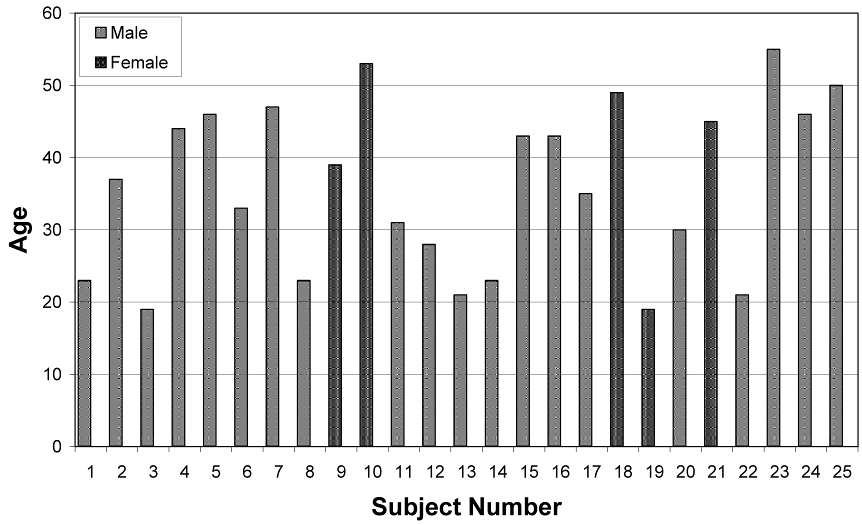


Figure 5.5: Age and gender of volunteers

Heart Rate and Minute Flow Data

Results of heart rate and 1^{st}, $2^{nd,}$ 3^{rd} and (in some cases) 4^{th} minute flows while subjects walked on a level treadmill at 6.5 kph are shown in the Table below.

Table 5.2: Volunteers walking at 6.5 kph, wearing a half mask, on 0 degree slope-heart rate and minute flow results

Subject	Heart rate bpm	Minute Volume				Ave minute flow for the day	Last minute flow for the day	Ave minute flow for all trials	Ave last 3^{rd} minute flows for all trials
		1^{st} minute	2^{nd} minute	3^{rd} minute	4^{th} minute				
10	98	24.9	28.3	31.4	28.2	28.2	31.4		
	99	19.3	19.8	20		19.7	20		
	104	17.1	20.1	18		18.4	18	**22.7**	**23.1**
11	103	22.5				22.5	22.5		
	97	22.4	21.9	23.9		22.4	23.9		
	111	19	22.8	22.3		21.4	22.3	**22.1**	**23.1**
12	103	31.6				31.6	31.6		
	123	26.8	29.7	29.5		28.7	29.5	**29.4**	**29.5**
13	114	37.2	38	39		38.1	39		

Subject	Heart rate bpm	Minute Volume				Ave minute flow for the day	Last minute flow for the day	Ave minute flow for all trials	Ave last 3rd minute flows for all trials
		1st minute	2nd minute	3rd minute	4th minute				
	109	38.1	39.4	41.3		39.6	41.3		
	115	29.9	32.1	36.6		32.9	36.6	**36.8**	**39**
14	103	20.8				20.8	20.8		
	110	17.6	21.1	21.2		20	21.2		
	115	17	20	23.8		20.3	23.8	**20.2**	**22.5**
15	108	27.1				27.1	27.1		
	110	16.9	21.4	29.1		22.5	29.1		
	103	20.7	21.9	20.5		21	20.5		
	113	22.3	27.2	31.7		27.1	31.7	**23.9**	**27.1**
16	102	34.8	37.6	37		36.5	37		
	96	26.3	31.8	31.7		29.9	31.7		
	100	21.4	28.1	32.2		27.2	32.2		
	91	30	31.5	32.9		31.5	32.9	**31.3**	**33.5**
17	129	40.2	49.9	46.7		45.6	46.7		
	122	39.2	44.8	48.6		44.2	48.6		
	130	45.1	50.3	49.8		48.4	49.8	**46.1**	**48.4**
18	118	33.5	33.3			33.4	33.3	**33.4**	**33.3**
19	108	16.5	16.5			16.5	16.5	**16.5**	**16.5**
20	111	17.3	21.4	23.4	25.7	22	25.7		
	110	29.1	27.1	25		27.1	25		
	113	22	25.6	26.8		24.8	26.8	**24.4**	**25.1**
21	129	28.3	29.3			28.8	29.3		
	120	23.9	29.3			26.6	29.3		
	120	24	23.4	22.4		23.3	29.3	**25.8**	**22.4**
23	95	25.6	27.7	29.7		27.7	29.7		
	99	27.4	27.3	25.1		26.6	25.1		
	106	17.8	26.7	29.6		24.7	29.6	**26.3**	**28.1**
24	113	26.5	29.7	33.6		29.9	29.7		
	105	28.7	32.6	37.4		32.9	25.1		
	114	22.9	33	35		30.3	29.6	**31**	**28.1**
25	113	24.3	27.9	32.9		28.4	29.7		
	112	26.5	26.9	27		26.8	25.1		
	105	22.6	24.5	28.4		25.2	29.6	**26.8**	**29.4**
26	110	21.6	23.1	22.7		22.5	29.7		
	108	18.4	22.7	24.1		21.7	25.1		
	102	20.4	23.1	24.4		22.6	29.6	**22.3**	**23.7**
27	88	17.4	19.4	19.2		18.7	29.7		
	93	18.8	18.7	18.8		18.8	25.1		
	112	14.4	17.7	17.2		16.4	29.6	**18**	**18.4**
28	115	15.5	18.1	18.9		17.5	18.9		
	109	14.5	15.8	15.9		15.4	15.9	**16.5**	**17.4**
29	120	22.5	23	22.3		22.6	22.3	**22.6**	**22.3**
30	127	19.1	20.6	22.5		20.7	22.5		
	130	20.3	22.2	21.5		21.3	21.5	**21**	**22.4**
31	102	22.1	23	24.3		23.1	24.3	**23.1**	**24.3**
32	92	21.4	23.6		22.5	23.6			
	98	15.1	20.7	19		18.3	19		
	95	20.4	22.4	21		21.3	21	**20.5**	**20.0**
33	104	23	27.9	27.7	29	26.2	29	**26.2**	**27.7**
34	110	15.4	17	16.9		16.4	22.5		
	115	16.1	17.2	18.4		17.2	21.5	**16.8**	**17.8**

Table 5.3: Volunteers walking at 6.5 kph, wearing a half mask, on 0 degree slope-heart rate and minute flow results.

Very wide ranges in heart rates were experienced for the volunteers at the same workload (see Figure 5.6 below).

Figure 5.6: Heart rates of 25 subjects at the same level of exercise (walking at 6.5 kph on a treadmill) over 3 minutes (25 watts)

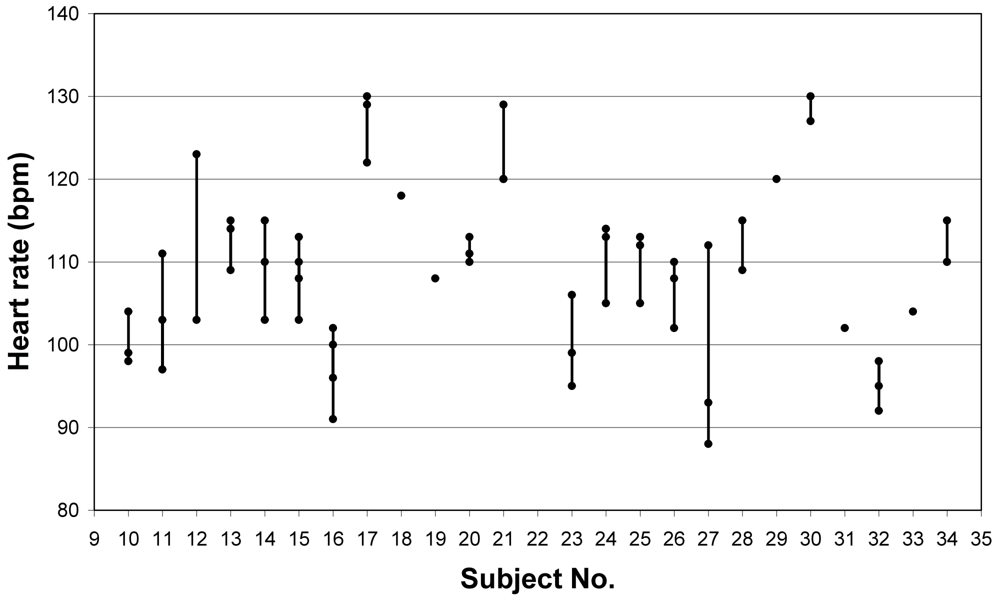


Figure 5.6: Heart rates of 25 subjects at the same level of exercise (walking at 6.5 kph on a treadmill) over 3 minutes (25 watts)

Very wide ranges were also observed in minute volume air flows for the volunteers at the same workload (see Figure 5.7 below).

Figure 5.7: Minute volume of 25 subjects at the same level of exercise (walking at 6.5 kph on a treadmill) over 3 minutes (25

watts)

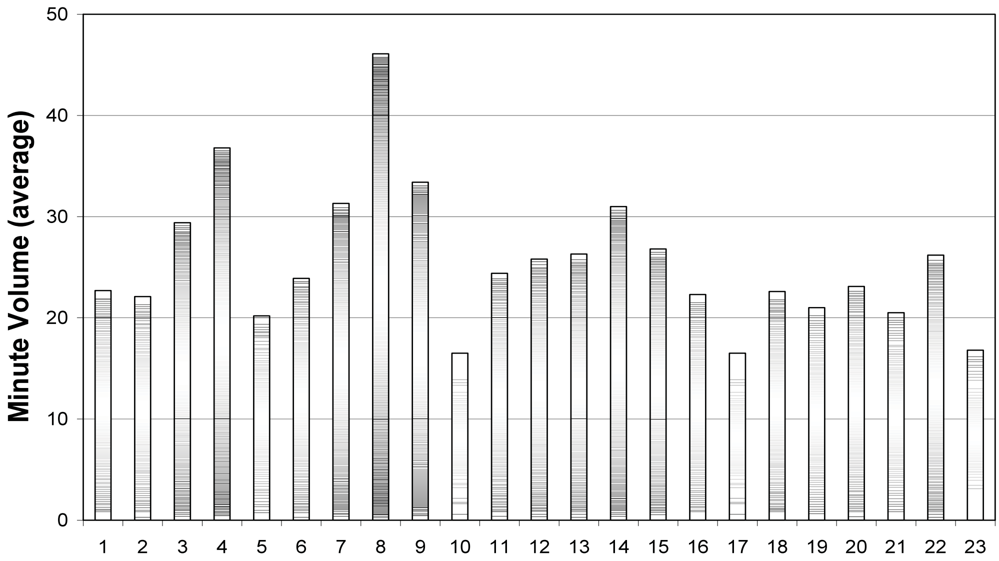


Figure 5.7:Minute volume of 25 subjects at the same level of exercise (walking at 6.5kph over 3 minutes.

Results are summarised in the Table 5.3 below

Table 5.3: Heart rate and Minute Volume (max and min values) results for a group of 25 volunteers of both gender and wide age range at the same level of exercise.

Heart Rate and Minute Volume in the 1st, 2nd and 3rd minute	**1st Minute**	**2nd Minute**	**3rd Minute**
Heart rate (bpm) range of values	Ranged from 88 to 130 bpm		
Minute Volume (lpm) range of values	14.4 to 45.1	15.8 to 50.3	18.0 to 49.8

Figure 5.8: Variation in heart rate and minute volume over each of three minutes in one subject (Subject 10)

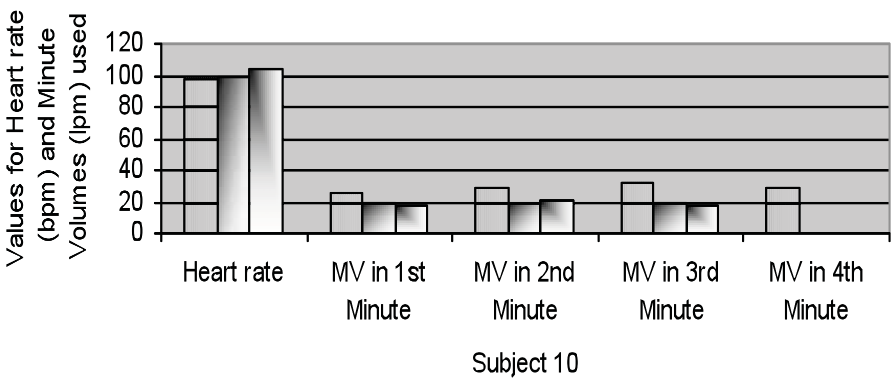


Figure 5.8: Variation in heart rate and minute voume over each of three minutes in one subject (subject 10).

Three subjects were asked to return once per day over the next 10 days and the exercises repeated to observe the range that could be expected from the same individual on different days.

Results are shown in the Table below.

Table 5.4: Repeatability of the Heart Rates and Minute Volumes obtained from 3 subjects over 10 different days-taking measurements once per day.

Subject	Heart Rate and one SD	Average minute volume in the 1st minute and one SD	Average minute volume in the 2nd minute and one SD	Average minute volume in the 3rd minute and one SD
13	110-5	30-6	34-4	35-5
16	91-7	26-5	31-3	32-3
25	109-5	24-2	27-4	29-3

A number of subjects volunteered to repeat the exercise on ten different days. Heart rate and minute flows were measured as before.

Table 5.5: Repeatability of heart rates and minute volumes obtained from 3 subjects over 10 days-taking measurements once per day.

Table 5.5: Repeatability of data gathered from three volunteers, measurements taken once per day over ten successive days

Subject	Heart rate	Minute flow			
		1st minute	2nd minute	3rd minute	4th minute
13	114	37.2	38	39	
	109	38.1	39.4	41.3	
	115	29.9	32.1	36.6	
	108	29.5	35.5	36.1	
	101	27.4	33.7	31.2	
	115	21.6	26.7	27.3	
	105	26.6	34.4	31	
Mean	110	30	34	35	
± St Dev	± 5	± 6	± 4	± 5	
16	103	34.8	37.6	37	

Subject	Heart rate	Minute flow			
		1st minute	2nd minute	3rd minute	4th minute
	96	26.3	31.8	31.7	
	100	21.4	28.1	32.2	
	91	30	31.5	32.9	
	89	24.2	30.8	31.8	
	90	26.9	32.1	33.6	
	86	24.4	30.8	31.8	
	83	17.5	29	26.4	
	91	25.8	31.1	31.9	
	84	23.9	29.5	29.8	
Mean	91	26	31	32	
± St Dev	± 7	± 5	± 3	± 3	
25	113	24.3	27.9	32.9	
	112	26.5	26.9	27	
	105	22.6	24.5	28.4	
	115	20.5	25.9	24.9	
	109	24.9	21.5	28	30.8
	109	24.7	26.7	30.1	31
	101	25	30.9	31.2	
	108	25.5	33	31.4	
Mean	109	24	27	29	31
± St Dev	± 5	± 2	± 4	± 3	

Table 5.6: Repeatability of data gathered from three volunteers, measurements taken once per day over ten successive days

Correlation of Heart Rate and Minute Volume Data

A correlation of average heart rate data and average minute volume data indicates wide data variability (see Figure below).

Figure 5.8: Correlation of Heart Rate and Minute Volume

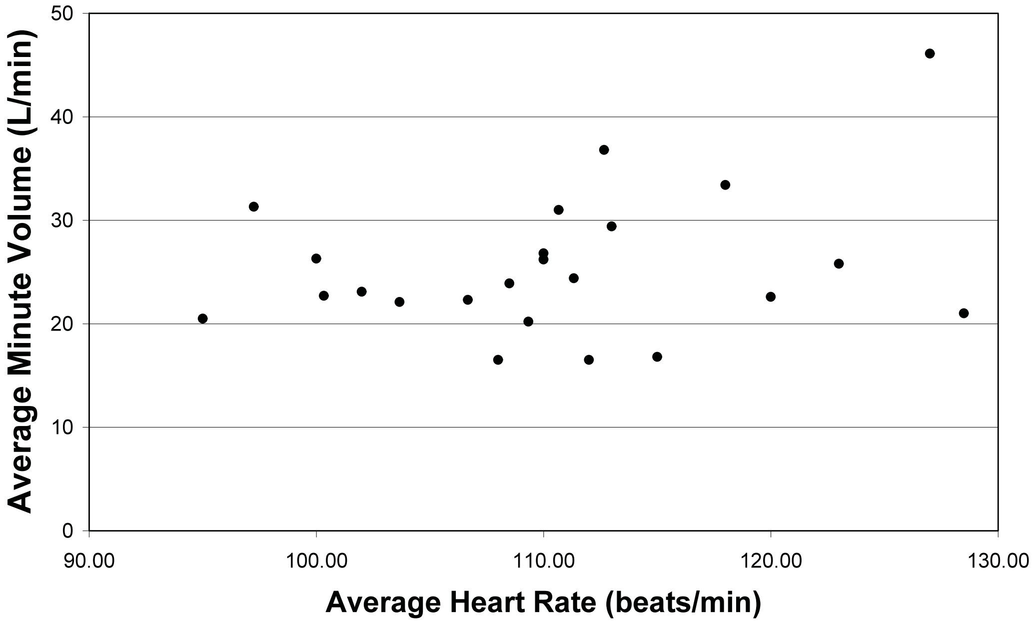


Figure 5.8: Correlation of heart rate and minute volume.

.

The correlation coefficient (using Microsoft Excel XP) for this data is 0.28, indicating a poor correlation.

5.4 Discussion

A wide variation in volunteer physiological characteristics (for example, gender, age, fitness as could be expected in a typical workplace) produced a wide range of heart rates and minute volume air flows for the same level of exercise. No effort was made to measure body mass index or any other parameter as this was outside the direct purpose of these experiments. The key findings obtained were:

- With the group of volunteers of age range 19 to 55, the range of heart rate at only a moderate level of exercise (a fast walk on level ground at 6.5 kph) ranged from 95 to 127 beats/min;
- With the group of volunteers of age range 19 to 55, the range of minute volume at only a moderate level of exercise (a fast walk on level ground at 6.5 kph) ranged from 15.4 to 45.1 l/min (litres per minute);

- Heart rates and minute volumes are poorly correlated with each other (wide variability between individuals);
- For any particular subject, the heart rate and minute volume of air used are within a small range. Heart rates can therefore be collected at the workplace and TIL determined in a controlled setting such as a laboratory at the same peak heart rates. Similarly, the life of gas filters (breakthrough testing) can be determined from workplace values for any individual or range of individuals.

In Australian/New Zealand Standard 1716:2003,[415] respirator cartridges are tested at 30 L/min continuous flow. The minute volume air flow in these tests show that many subjects exceed this value (the volume of air used per minute by the volunteers) even at a moderate level of exercise.

5.5 Conclusion

In most practical industrial situations, highest potential exposure occurs at the same time when the workload is also highest. This is the case in an aluminium smelter when completing such tasks as removing burnt-out anodes from a pot. In these situations with potentially high exposure, it is particularly important that the respirator functions as intended.

While standard requirements stipulate that respiratory equipment needs to demonstrate a maximum value of TIL for certification requirements, the careful selection of subjects means that there is no relation to the work situation. Similarly, gas cartridge testing appears to be completed at air volumes which are too low in many cases and do not reflect the workplace use. This may significantly affect TIL results.

Individual facial fit testing of respirators prior to entering the workplace is recommended or mandatory in most countries, but this is usually completed in a laboratory setting, usually under very moderate workloads of exercise which again bear no relationship to conditions in the workplace.

It is suggested that for every individual at the workplace, the heart rate is monitored over a working day and the peak rates and work activities identified. The heart rates identified can be duplicated in the laboratory. The minute volumes needed by every individual can be measured using the monitoring equipment built into the respirator. These values can be used to determine the TIL of the respirator on any individual at the peak working rates and the potential life of gas cartridges from minute volumes used at the workplace.

The simple methodology would give some comfort that physiological factors measured at the workplace reflect the conditions under which the equipment is expected to function.

The next Chapters will explore the variations in a group of 25 volunteers at increased levels of exercise for both minute volumes and peak inspiratory air flows are investigated under a number of different workloads.

Both minute volume values and peak inspiratory air rates are further important considerations of any respiratory protection program.

5.6 References

[395] Weed, J. Training is the key to a good respirator fit test program. *Journal of the International Society of Respiratory Protection* **14:** 8, 1996

[396] Colton, C.E. 1999. Filtering facepieces: Study supports need for fit-testing. *3M JobHealth highlights.* 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1999. At: http:/www.3m.com/occsafety/html/jhh17_2_99.html

[397] Whitley, J.A., Caretti, D.M. Respirator wear and its effects on visual acuity, depth perception and field of view. *Journal of the International Society of Respiratory Protection* **14:** 9-18, 1996.

[398] Wood, G.O., Lodewyckx, L. 2002. Correlations for high humidity corrections of rate coefficients for adsorption of organic vapors and gases on activated carbons in air-purifying respiratory cartridges. *Journal of the International Society of Respiratory Protection* **19:** 58, 1996, 2002.

[399] Gardner, P.D. The effect of moisture on the facial fit of half-mask respirators. *Journal of the International Society of Respiratory Protection* **20:** pages?, 2003.

[400] Salazar, M.K., Takaro, T.K., Connon, C., Ertell, K., Pappas, G., Barnhart, S. 1999. A description of factors affecting hazardous waste workers use of respiratory protective equipment. *Applied Occupational and Environmental Hygiene* 14: 470-478, 1999.

[401] Grandjean, E. Fitting the Task to the Man: A Textbook of Occupational Ergonomics, fourth edition. Taylor and Frances, London, 1988, pp 83-94.

402 Myhre, L.G. 1997. Physiological criteria for the valid selection of workers who must perform physical tasks while wearing respiratory and/or environment protection equipment. *Proceedings of the Australian Institute of Occupational Hygienists, Albury conference,* 1997, pp 1.

403 Kuklane, K., Holmer, I. Respiratory flow patterns during physical work with respirators. Department of Ergonomics, *National Institute for Working Life*, Solna, Sweden, 2002.

404 Lueth, P., Preuss, G., Schaecke, G., Rimkus, U. Inspiratory safety breathing curves SBCi, no date. www.medizin.fu-berlin.de/arbeit.

405 Kaufman, J.W., Hastings, S.A. Respiratory demand in individuals performing rigorous physical tasks in chemical protective ensembles. Report no. NAWCADPAX/TR-2003/29. *Naval Air Warfare Center Aircraft Division*, Patuxent River, Maryland, 2003.

406 Silverman, L., Lee, R.C., Lee, G., Drinker, K.R., Carpenter, T.M. Fundamental factors in the design of protective respiratory equipment: Inspiratory air flow measurements on human subjects with and without resistance. Departments of Physiology and Industrial Hygiene, *Harvard School of Public Health and the Nutrition Laboratory of the Carnegie Institution of Washington*, 1943.

407 Scanlon, S., Roberts, W., Gray, B. Measurement of operationla fit factors for soldiers wearing the S10 respirator. *Journal of the International Society of Respiratory Protection* **20:** 57-68, 2003.

408 Ncas, M. Some considerations in defining the "protection factor". *Journal of the International Society of Respiratory Protection* **15:** Pp 6-7, 1997.

409 Sherwood, R.J. Recommendations concerning the role of workplace testing of respirators as a condition of certification. *Appalachian Laboratory for Occupational Safety and Health*, Morgantown, West Virginia, 1991.

410 Liu, B.Y.U., Sega, K., Rubow, K.L., Lenhart, S.W., Myers, W.R. In mask aerosol sampling for powered air purifying respirators. *American Industrial Hygiene Association Journal* **45:** 278-283 1984.

411 Johnston, A.R, Colton, C.E, Stokes, D.W, Mullins, H.E., Rhoe, C.R. Workplace protection factor study on a supplied air respirator. *3M Occupational Health and Safety Division*, 3M Ltd, St Paul, MN, 1989.

412 Johnston, A.R, Mullins, H.E. Workplace protection factor study for airborne metal dusts. *3M Occupational Health and Safety Division*, 3M Ltd, St Paul, MN, 1987.

413 Gaboury, A., Burd, D.H. Workplace protection factor evaluation of respiratory protective equipment in a primary aluminium smelter. *Alcan Smelters and Chemicals* Ltd, Arvida Works, Jonquiere, Quebec, Canada, year.

414 Capon, A. Protection factors: Who do they protect? A summary of recent discussions within ISRP on the term "protection factor". *Journal of the International Society of Respiratory Protection* **14:** 19-25, 1996.

415 Standards Australia/Standards New Zealand. *AS/NZS 1716 Respiratory Protective Devices*. Preface. Standards New Zealand, Wellington, 2003.

416 NIOSH respirator selection logic 2004. NIOSH publication No. 2005-100. At: http://www.cdc.gov/niosh/docs/2005-100/chapter 3.html.

417 Bancroft, B., Clayton, M.P., Evans, P.G., Hughes, A.S. Workplace fit of full face mask respirators: A new approach. *Journal of the International Society of Respiratory Protection* **16:** 24-54, 1999.

418 Gunnar, G. 1999. Real-time monitoring instruments for exposure studies: the Pimex method. At: http://www.niwl.se/WAIS/30302/3022134.htm

[419] Archibald, B.A., Solomon, K.R., Stephenson, G.R. Estimation of pesticide exposure to greenhouse applicators using video imaging and other assessment techniques. *American Industrial Hygiene Association Journal* **56:** 226-235, 1995.

[420] Forsman, M., Sandsjo, L., Kadafors, R. Synchronised exposure and image presentation: Analysis of digital EMG and video recordings of work sequences. *International Journal of Industrial Ergonomics* **24:** 261-272, 1999.

[421] ISO. NO13: Review of test methods for the determination of inward leakage into respiratory equipment. International Organisation for Standardisation, Geneva, 23 September 2003.

[423] Astrand, P., Rodahl, K. *Textbook of Work Physiology. Physiological Basis of Exercise*, third edition. New York: McGraw-Hill Book Company, New York, 1986.

6. CASE STUDY 3: HEART RATES, MINUTE VOLUMES, WORK AND TOTAL INWARD LEAKAGE (TIL)

6.1 Introduction

Minute flow air volumes (the volume of air breathed per minute) as used in the workplace by respirator wearers, is one of the important values in respiratory protection airflows. Respiratory equipment, including cartridges, are tested and certified at specified volumes and these must reflect conditions encountered in practical situations. Manufacturers and standards organisations worldwide have typically used minute volume values that were generated by Silverman et al as far back as in 1943.[424,425,426]

The certification process involves TIL (Total Inward Leakage) testing. This is the leakage through and around the respirator when worn under simulated working conditions by a carefully selected test group. This inward leakage will be partly dependant on the volume and rate of air being drawn past the face/respirator contact surface. Similarly, protection factors obtained from laboratory settings are known to differ substantially from workplace results. One of the likely reasons is the wide variation in airflows that can be experienced between individuals at all levels of work, particularly in the workplace setting. The variation in TIL may be removed by the method of "standardising" to an approximately the same values of airflows of test subjects.

Certification to a standard implies suitability for respiratory protection in the workplace by the user but this is often not the case. Certification is used only to ensure that the respirator functions to a minimum standard on very carefully selected subjects under ideal laboratory conditions. It is used to certify the equipment for the manufacturer and not the user. This important distinction is often lost on the customer who may assume because the RPE complies with the particular Standard, that the equipment will provide protection-at least if used in a similar way to that of the Standard's testing regime.[†]

In any given person, there is generally a linear relationship between oxygen uptake and heart rate. Therefore, the heart rate, under certain standardised conditions, may be used to estimate the workload.[427]

6.1.1 Objective

The objective of this work was to:

- Confirm the published minute volume values at various levels of work by a range of individuals;
- Generated a set of values for minute volumes that represented a workforce found in a typical SME whom could be expected to wear the protective equipment, that is, a wide age range and both genders. Standard organisations typically use young student volunteers who will exhibit physiological characteristics different to this, for example, heart rate and minute volumes, at different levels of work.
- The possibility of using an individual's heart rate to establish a rate of work that could be compared with another individual to obtain the same approximate minute volumes. This would allow better comparison with other Standards and standardise TIL results between laboratories and the same classes of equipment over a wide range of practical work outputs.

6.2 Method

In these trials, 25 subjects wore a Sundstrom® half-face respirator while walking at 6.5 kph, first at a level incline and then gradually at an increasing incline of 3, 5 and 7 degrees from the horizontal. The methods used were identical to that of the previous chapter (Chapter 5). The volunteers were all from the same respirator manufacturing company

† Compliance with Standards, whether European, NZ/Australian or USA, is used by manufacturers and distributors to imply suitability for purpose. This is incorrect.

in Sydney and were keen to participate. All subjects had the purpose of the test explained to them and were asked to discontinue the exercise if they felt uncomfortable. The equipment was designed, manufactured and calibrated at the laboratories of SEA Pty ltd in Sydney and is similar to that used in Chapter 2. Ethical protocol for these studies have been described earlier.

6.3 Results

The two Tables below show HR (heart rate) and MV (minute volume) data while subject (25) wore a half-face respirator while doing work (walking on a treadmill at 6.5 kph, inclined at 0, 3, 5 and 7°).

Raw data is shown in the Table below, with a summary Table and two Figures following.

Table 6.1: Results of Heart Rate and Minute Flows when the treadmill is steadily inclined upwards from 0 to 7° while subjects walked at a steady speed of 6.5 kph

Subject ID	Treadmill angle 0°		Treadmill angle 3°		Treadmill angle 5°		Treadmill angle 7°	
	Heart rate (bpm)	Average Minute Volume (l/min)	Heart rate (bpm)	Average Minute Volume (l/min)	Heart rate (bpm)	Average Minute Volume (l/min)	Heart rate (bpm)	Average Minute Volume (l/min)
10	100	22.1	117	25.8	134	29.3	149	32
11	104	22.1	116	29.7	139	38.6		
12	113	30.2	130	28.9	144	29.3	158	34.4
13	113	36.9	134	48	148	66.8	158	85.5
14	109	20.4	125	27.9	138	36.6	158	50.4
15	109	24.4	136	38.6	156	48.5	138	39.3
16	97	31.3	112	43.8	125	51.7	145	64.3
17	127	46.1	150	65.9	156	71.5		
18	118	33.4	140	41				
19	108	16.5						
20	111	24.6	127	29.7	145	32.9		
21	123	26.2	142	30.7	155	40.7		
22			117	31.8	128	38.2	131	43.4
23	100	26.3	121	37.6	135	46.7	155	52.1
24	111	31	142	52.6				
25	110	26.8	127	33.2	138	48.9	162	49.3
26	107	22.3	122	28.4	143	37.5	161	41.7
27	98	18	109	24.6	146	34.4	129	34
28	112	16.5	133	23.1	122	28.1		
29	120	22.6	150	29.8				
30	128	21	148	29				
31	102	23.1	120	29.5	117	28.1		
32	95	20.7	114	28.5	145	31	142	41
33	104	26.2	120	37.1				
34	113	17.2	126	20.5	131	34.4		

Table 6.1: Results of Heart Rate and Minute Flows when the treadmill is steadily inclined upwards from 0 to 7° while subjects walked at a steady speed of 6.5 kph

Table 6.2: Heart rate, minute volumes at various work loads for 25 subjects with an average age of 36.7 years

Upward angle of treadmill	Heart Rate range (bpm)	Minute Flow (L/Min)
0°	95 to 128	17.2 to 46.1
3°	114 to 150	23.1 to 65.9
5°	117 to 156	28.1 to 66.8
7°	138 to 162	34.0 to 85.5

Table 6.2: Heart rate, minute volumes at various work loads for 25 subjects with an average age of 36.7 years.

Figure 6.1: Workload and Heart Rate

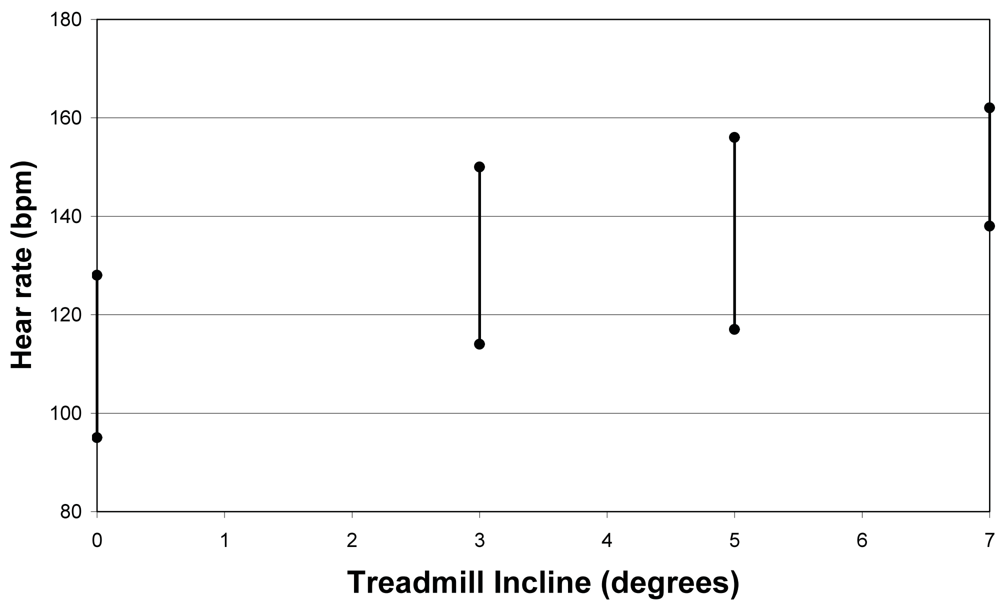


Figure 6.1: Workload and heart rate.

Figure 6.2: Workload and Minute Volume

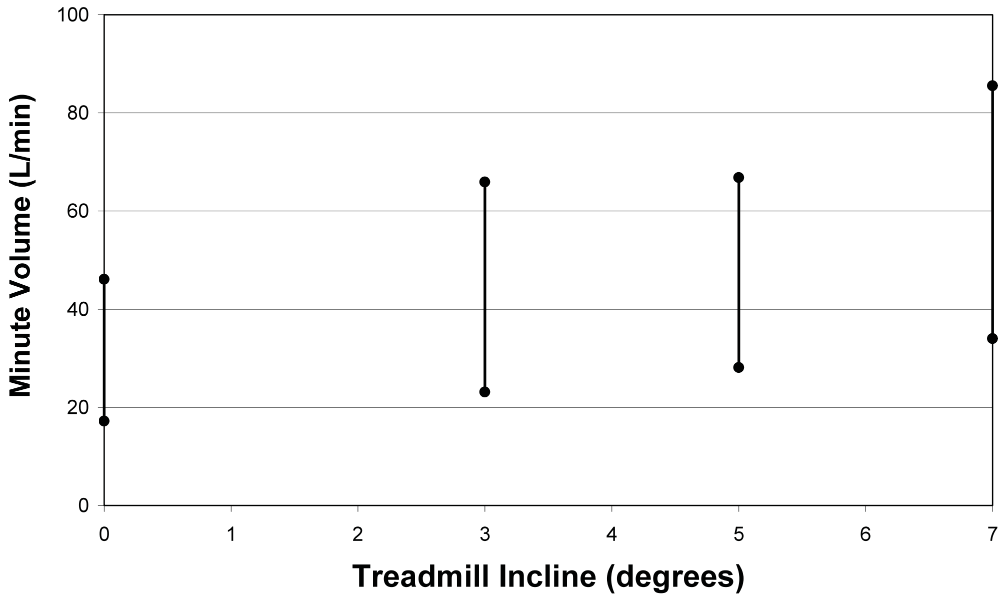


Figure 6.2: Workload and minute volume.

To ensure that the data obtained from the individuals could be repeated, a number of people volunteered to return for 10 days so that the tests could be completed once per day over this period. The same tests were carried out every day and no variations in the testing regime was permitted. Once again, minute volumes and heart rates were recorded while the subjects gradually increased the work load on the treadmill from walking at 6.5 kph at no incline to 7° incline of the treadmill.

A summary of the results is shown below:

Table 6.3: Mean and SD of results for 10 trials, once per day, over 10 days

	Average heart rate	Average minute volume		
		1st minute	2nd minute	3rd minute
Subjects 13 and 16 walking at 3° incline at 6.5 kph				
$Mean_{13}$	110	30.6	34.	35.3
$\pm SD_{13}$	6	6.2	4.6	5.2
$Mean_{16}$	91	25.5	30.9	31.9
$\pm SD_{16}$	7	4.7	3	2.7
Subjects 13 and 16 walking at 3° incline at 6.5 kph				
$Mean_{13}$	130	45	49	50
$\pm SD_{13}$	7	3	1	2
$Mean_{16}$	104	37.4	43.5	44.8
$\pm SD_{16}$	6.4	3.4	3.2	2.7
Subjects 13 and 16 walking at 5° incline at 6.5 kph				

$Mean_{13}$	114	59.8	62.7	66.9
$\pm SD_{13}$	5	6.3	4.1	5.8
$Mean_{16}$	116	46.5	51.2	52.6
$\pm SD_{16}$	7	3.5	5.4	3.9
Subjects 13 and 16 walking at 7° incline at 6.5 kph				
$Mean_{13}$	154	74.6	77.7	81.3
$\pm SD_{13}$	6	6.8	10.5	11.9
$Mean_{16}$	132	56	63.9	65.7
$\pm SD_{16}$	11	3.9	4.2	5.3

Repeatability data for the range of trials for two volunteers are shown in the Table below.

Table 6.3: Mean and standard deviation of results for 10 trials, once per day, over 10 days.

Table 6.4: Results of heart rate and Minute Flow for two volunteers walking at 6.5 kph in gradually increasing incline from 0 to 7^o upwards

Sub ject ID	Treadmill angle 0°				Treadmill angle 3°				Treadmill angle 5°				Treadmill angle 7°			
	HR	MV 1st min	MV 2nd min	MV 3rd min	HR	MV 1st min	MV 2nd min	MV 3rd min	HR	MV 1st min	MV 2nd min	MV 3rd min	HR	MV 1st min	MV 2nd min	MV 3rd min
13	114	37.2	38	39	137	48.7			147	67.9	63.8	74	162	83.7	92.7	97.7
	109	38.1	39.4	41.3	131	48.3	49.3		146	66.5	66.3		159	78.9	82	90.1
	115	29.9	32.1	36.6	136	42.8	49.2	47.7	149	58.3	67.7	70.4	154	77.8	79.9	86
	108	29.5	35.5	36.1	126	41.3	49.4	51.5	144	59.4	60.9	68	148	70.9	77.6	72
	101	27.4	33.7	31.2	120	42.5	47.9	48.4	135	52.1	60.5	62.5	150	64.8	72.6	75.5
	115	21.6	26.7	27.3	127	46.2	51.4	52.2	141	54.7	56.8	59.7	148	71.5	61.2	66.4
	105	26.6	34.4	31	120	42.8	49.2	46.7	133	4.1	52.2	54.1				
Av	110	30	34	35	130	45	49	50	144	60	58	64	154	75	78	81
SD	±5.5	±6.2	±4.6	±5.2	±6.5	±3.2	±1.3	±2.2	±5	±6.3	±4.1	±5.8	±5.9	±6.8	±10.5	±11.9
16	103	34.8	37.6	37	114	43.2	47.8	47.4	129	46.5	50.1	56.7	146	55.1	64.2	69.3
	96	26.3	31.8	31.7	115	36	41.3	44.6	123	46.7	51.2	49.5	143	55	64	69.3
	100	21.4	26.1	32.2	108	39.2	48.3	46.8	122	47.3	58.9	58.2	146	60.1	68.7	73.2
	91	30	31.5	32.9	102		41.2	40.7	115	47.6	51.2	54	128	60.2	66.6	64
	89	24.2	30.8	31.8	101	35.2	40.5	47.9								
	90	26.9	32.1	33.6	105	34.4	42.5	44.4	118	51.3	57.6					
	86	24.4	30.8	31.8	99	35.4	45.5	42.7	115	47.6	53.4	55.3	129	60.4	66	68.3
	83	17.5	28	26.4	95	35.5	40.7	44.3	107	38.7	41.8	50.2	126	54.2	65.1	64
	91	25.8	31.1	31.9	105	42.6	46.9	47.9	112	48.9	51.2	48.9	123	52.6	61.7	59.9
	84	23.9	29.5	29.8	100	35.5	40.6	41.4	107	44	45	48.1	118	50.2	54.8	57.3
Av	91	26	31	32	104	37	44	45	116	47	51	53	132	56	64	66
SD	±6.6	±4.7	±3	±2.7	±6.4	±3.4	±3.2	±2.7	±7.4	±3.5	±5.4	±3.9	±11	±3.9	±4.2	±5.3
HR: Heart rate		**MV: Minute Volume**				**Av: Average**				**SD: St Dev**						

6.4 Discussion

The determination of minute volumes and heart rates for at a range of increasing workloads has been determined in this study. These differ from the published information available probably because the sample population (that is, volunteers) was significantly different to that from previous studies and a wide variation (range) in results has been observed. It is important to sample values from a population which is typical of the workplace, that is, an older age group such as this (a mean of 36.7 years in these trials) and of both genders.

Many studies on ventilation and exercise tend to show data from a younger age group (e.g., 30 years of age)[429]. Work rate (and therefore minute volume and peak inspiratory air flow) may be dependant upon a subject's body weight, age and a range of other factors[430 431].

Few texts or publications discuss peak inspiratory air flows although the peak expiratory air flow is of significant interest in the diagnosis of asthma.

Table 6.5: Minute Volume and Work Rate

Work Load	**Minute Volume (L/min)**	**Heart Rate (bpm)**
Resting	6-7	60-70
Low	11-20	75-100
Moderate	20-31	100-125
High	31-43	125-150
Very High	43-56	150-175

Table 6.5: Minute volume and work rate

The data in these two tables cannot be directly compared as variation in body weight and other physiological characteristics have not been shown. However, at the same heart rate between the two tables, some comparison between the minute volumes is possible. It is important to note that at the same level of work, the range of values from these results is large and much wider and higher than is often illustrated. The value and the range increases as the work load increases. This has implications for the TIL (as there will be a much wider range of airflows used than from a typical test group as used by standard organisations) and for the testing of filters and cartridges which is usually carried out at a low constant flow rate. The practical work environment usually involved people in a wide age group and wide physiological variation which are very different to the traditional age groups selected by

Standard organisations where individuals are carefully selected and those outside the “norm” excluded.

The variation between heart rate and minute volumes are critical values as these are used in the testing and certification of both respirators and cartridges and should reflect the wide range of values used by a typical workforce. In addition, the “worst case” (that is, the highest values) need to be used for respirator testing and certification rather than the lowest as is currently the case.

At present, Standards such as the AS/NZS 1715 use minute volumes which under-represent those from a typical workforce in Australia (30 litres per minute continuous flow).[432] Certification and testing of respiratory equipment including cartridges and filters must reflect true values of minute volumes in the workplace-which is not the case at the present time.

Conclusion

Previous published values for minute volumes appear not to be valid for an older age group more representative of the wide range group found in a typical workforce nor is the wide range group considered at present. As previously indicated, Australian and New Zealand testing regimes require a careful selection of test subjects, i.e., without facial distortion and subjects are typically young (generally about 18-25 years of age). The subjects that could be expected to wear RPE in industry will exhibit a wider range of ages and an older mean age. This has significant implications for the testing, certification and use of respiratory equipment of all types including half-face negative respirators and PAPR equipment. In addition, the range of values expected was much wider than may be expected. For example, the range of values experienced was from 34 to 85 L/min at a heart rate of 138 to 162 bpm. Published figures (as shown in the discussion section) would indicate minute volumes of about 43-56 L/min, a much narrower range than could be expected in a practical Australasian working environment.

It is important to test and certify respiratory equipment at the flow rates that could reasonably be expected in a typical workplace. Inhalation resistance of respirator filters and assembled respirators is tested at 30 and 95 L/min[433], while the filter capacity for gases is tested at 30 L/min continuous flow volume, a very low flow which does not reflect normal usage. Minimum filter lives are then required for certification,[433] but these values are largely meaningless for users. Again, this has serious implications for users of respiratory equipment. Similar concerns have recently been expressed by other authors, increasingly becoming concerned about the low flow air rates being used.[434,435]

The design, certification and use of future respirator development must take into account these higher values and the range of values for minute volumes. In addition, the implications of PIAF (Peak Inspiratory Air Flow) need to be taken into consideration (that is, the flow rate required to meet the inhalation breath speed). This has further serious implications for the users of respiratory protective equipment and forms the subject of the topic in the following Chapter.

Confusion between minute volumes of air used and peak flows further contribute to the mis-match between practical industry and testing regimes.

The wide variation in airflows obtained from a typical Australasian workforce demonstrates the need to "calibrate" test subjects prior to obtaining TIL (Total Inward Leakage) values to remove the wide variation between laboratories situated in different parts of the world and to allow better comparison between laboratory and workplace values of protection factors. This can be achieved by obtaining a heart rate while the employee is working at a range of tasks in the workplace and then allowing the same heart rate to be raised in the laboratory with simulated work. While in the laboratory and with this equipment, the minute volume air flow can be obtained. If this repeated with a number of employees, then the true minute volume air flows for the task can be obtained.

Alternatively, the minute volumes of air used can be standardised amongst a range of people by using the variation in heart rate of the individuals, that is, the subjects can be "calibrated" to use the same volume of minute volume of air.

Incorporating the use of true minute air flows at a task or alternatively "calibrating" subjects so that a known volume of air is used, would give users an improved confidence in the TIL leakage results since the information is obtained from the actual workforce using the RPE under the particular task being considered. In addition, more valid airflow volumes can be used to calibrate respirator filters and cartridges than is currently the case.

6.5 References

424 Silverman, L., Lee, G., Plotkin, T., Sawyers, L.A, Yancey, A.R. 1951. Air flow measurements on human subjects with and without respiratory resistance at several work rates. *Archives of Industrial Hygiene and Occupational Medicine* **3:** 461, 1951.

425 Silverman, L., Lee, R.C., Lee, G., Drinker, K.R., Carpenter, T.M. Fundamental factors in the design of protective respiratory equipment: Inspiratory air flow measurements on human subjects with and without resistance. Departments of Physiology and Industrial Hygiene, Harvard School of Public Health and the Nutrition Laboratory of the Carnegie Institution of Washington, 1943.

426 Silverman, L., Billings, C.E. *Pattern of Airflow in the Respiratory Tract.* Pergamon Press, London, 1961.

427 Astrand, P., Rodahl, K. *Textbook of Work Physiology. Physiological Basis of Exercise*, third edition. New York: McGraw-Hill Book Company, New York, 1986.

429 Astrand, P. Olof and Rodahl, K. (1986). *Textbook of work physiology.* 3rd edition. Pp 229. Auckland: McGraw-Hill Book Company.

430 Astrand, P. Olof and Rodahl, K. (1986). *Textbook of work physiology.* 3rd edition. Pp 360. Auckland: McGraw-Hill Book Company.

431 Mackay, K.R.M., Johnson, A.T., Scott, W.H and Koh, F.C. (2005). *Overbreathing a loose-fitting PAPR.* ISRP Journal, Vol. 22, issues 1 and 2. Spring/Summer.

432 Standards Australia/Standards New Zealand. *AS/NZS 1715 Selection, Use and Maintenance of Respiratory Protective Devices*. Standards New Zealand, Wellington, 1994.

433 Standards Australia/Standards New Zealand. *AS/NZS 1716 Respiratory Protective Devices*. Standards New Zealand, Wellington, 2003.

434 Kaufman, J.W., Hastings, S.A. Respiratory demand in individuals performing rigorous physical tasks in chemical protective ensembles. *Journal of Occupational and Environmental Hygiene* **2:** 98-110, 2005.Kaufman J W, Hastings S A. 2003.

435 Burgess, J.L., Crutchfield, C.D. Quantitative respirator fit tests of Tucson fire fighters and measurement of negative pressure excursion during exertion. *Applied Occupational and Environmental Hygiene* **10:** 29-35, 1995.

7. CASE STUDY 4: PEAK INSPIRATORY AIR FLOWS (PIAF) DURING WORK AND WHEN COMMUNICATING

7.1 Introduction

Peak Inspiratory Air Flows (PIAF) are important values for the designers and users of all types of respiratory equipment.

Early work in healthy volunteers confirmed that young, healthy respirator wearers undergoing hard work generated peak flow rates, minute ventilations, and instantaneous flow rates that consistently exceeded test standards.[437] This study also showed that testing respirators and respirator cartridges using a sinusoidal breathing pattern with a minute ventilation of 135 L/min (peak flow rate approximately 424 L/min) would encompass 99% of the recorded minute ventilations and 99.9% of the predicted peak and instantaneous flow rates.[440]

However, minute air flows in respirators are only generally reported in both the manufacturer's literature as well as most technical reports related to respiratory protective equipment.[438] Researchers working in the health field involving respiratory equipment generally only report that "respiratory protective equipment was (or was not) worn". They are often unaware that there are a range of technical and user issues (discussed in Chapter 1) related to the equipment which either entirely or partially negate the use of the equipment. However, it is well known that loads (or additional physiological work) imposed by respirators include inspiratory flow resistance and dead space.[439] Further, wearing respirators may prolong inspiration, decrease peak inspiratory flow rates, increase tidal volume and affect load sensitivity adaptation.[440] This early work provided support for respirator programs to included training and observation of workers conducting work.

The values of minute volumes have tended to dominate the literature in both Standards and the written publications describing the features of the equipment as distributed by manufacturers. Values of PIAF have almost disappeared from the literature in spite of warnings from the original Silverman reports and subsequent authors.[441] Part of this reluctance may be due to the inability of all current PAPR (Power Assisted Air Purifying Respirator) to meet these high airflow rates.

The respiratory protection working parties of the ISO (International Standards Organisation) are currently debating and incorporating PIAF values in Standards development as a result of this work and that of others.

The focus on minute volume air flows rather than PIAF has influenced recommendations from manufacturers particularly in regards to PAPR (Power Assisted Powered Respirators) which have often, and incorrectly, been referred to as Positive Pressure Respirators. Only minute volumes have ever been reported in the manufacturer's publications. When this type of equipment was shown to result in negative pressure inside the respirator during heavy use, the one respirator manufacturing company reacted in anger and attempted to discredit the research.[442] However, higher flows were frequently reported in other fields such as fire fighters at work.[443]

Although not suspected and mentioned at the time, it is likely that the PIAF had exceeded the capability of the motors in the PAPR generating the air peak flows. Similarly, the values of air flows used in evaluating and testing gas cartridges by numerous standards approval organisations and manufacturers testing laboratories do not consider peak flows and only use very low values of minute air volumes. These do not resemble the values obtained from simulated or practical working environments. There are arguments for having the testing conditions resemble the conditions in which the equipment is used in the working environment. There are further complications in the testing of respirator cartridges, such as the issue of constant air flow (under which the equipment is tested) versus sinusoidal air flow (under which the cartridges are used in the working environment).

Both minute air flows and peak flows are important values in the design of respiratory equipment which will meet the needs of users in the practical environment. Many distributors seem unaware of PIAF values and their significance in respiratory protection. Similarly, discussions with manufacturers tend to express the belief that PIAF values only exceed minute air volumes for a short period of time and the effect is therefore insignificant. Recent research by other groups have shown this belief to be incorrect, with a large percentage of the time workers exceeding minute air volumes particularly during heavy work. When the values of air used exceed the capability of the equipment to deliver the volume and rate of air required by the user, contaminants are likely to enter the breathing zone of the worker.

During the introduction of half-face respiratory protection (with quantitative fit testing procedures), into the aluminium smelting industry in the 1980s, over time, alternative RPE (Respiratory Protective Equipment) was thought to be required, preferably equipment which had purified air delivered to the wearer. It became important to determine not only the minute volumes of air required but also the PIAF, particularly at the high rates of work in high radiant heat periodically required of employees in this type of industry. Similar results could be expected in any industry where respiratory equipment was required to be worn for any length of time.

The need for a more suitable respirator that could be worn for extended periods of time in heavy industry became one of the drivers of the research in this thesis. Among other issues considered was the need to provide airflows to the wearer rather than rely on negative pressure type respirators (where the wearer has to work drawing air through the filter). The additional load placed on workers required to draw air through the filter or cartridge and at the high radiant heat of working in an aluminium smelter gave rise to other safety concerns, particularly at high work loads. Wearers will normally compensate for the additional respirator load by reducing work output required from the task, but this may not always be possible as the task itself may force a certain output, for example, removing burnt-out anodes from the electrolyte in an aluminium smelter.

7.1.1 *Purpose*

The purpose of these trials was to:

- To determine the PIAF rate at various levels of work (determined by heart rate) and compare the experimental results against published data (the values are more often only referred to as "approximately three times the minute volumes");
- To determine the minute volumes of air required at known work loads (as measured by heart rates) and at the same time, determine the PIAF;
- To determine the PIAF increase due to disturbances in the airflow and pattern, at the same work rates (as measured by heart rate) due to communication (it is well known that respiration is affected by speech).

Considerable variation in airflows can be expected when people communicate, but more specifically there is a need to note how the patterns altered and what increases could be expected due to disturbances in the air flow. This would be particularly important in the design of respiratory equipment where individuals have to wear the equipment while shouting warning messages or otherwise communicating as in a typical industrial environment and working at various rates.

7.2 *Method*

A total of 25 volunteers of both gender and average age 36.7 years (generally older than a typical Standard younger test group recommended by organisations such as Standard testing organisations), of both genders were asked to perform a number of exercises as shown below. This more typically represents the workforce required to wear respiratory protection at work.

All subjects were volunteers from the one respirator research and manufacturing facility. All were asked to discontinue the exercises if any discomfort was experienced. All participants were keen participants (in some cases, participation had to be restricted) and were knowledgeable about respiratory protection issues.

All subjects were initially required to complete a face-fit test using Portacount® equipment which measured the airborne particulate present inside the respirator worn by the test subject versus that outside the respirator. A face-fit pass of 100 was considered a minimum to carry out the remainder of the exercises. This was necessary as flow leaks from a badly fitting respirator would result in significant experimental errors. It is also standard practice for determining the pass/fail criteria in the aluminium smelting industry and many other industries. The same conditions were applied in all the experiments on minute volumes and peak inspiratory air flows in the experiments in this thesis. Monitoring of heart rate, minute volumes and peak inspiratory air flow continued throughout all the exercises. The exercises were only completed one per day by each participant, that is, volunteers did not complete more than one exercise per day.

All exercises attemped to duplicat the practical workplace in terms of the activity undertaken. For example, activities were completed standing rather than sitting.

The exercises that were completed by all volunteers were:

- Investigation 1: Standing upright, facing directly ahead, and then talking continually.
- Investigation 2: Simulating light work, that is, picking up a light article from the floor, standing upright and placing the article on a table. This process is repeated at a leisurely pace. The exercise was then repeated while talking.
- Investigation 3: Walking on a treadmill at 6.5 kph set horizontally (that is, no incline). Volunteers were then asked to shout a message. The message was the same in all cases: “Take care- there is a crane on the way!”
- Investigation 4: Some volunteers wanted to repeat the above treadmill exercise while setting the treadmill at a 5° incline

upwards. Again, the exercise was repeated both with and without speaking.

7.3 Results

The Tables below relate to four separate investigations.

Investigation 1 was a study of resting state, with the subject standing upright, looking directly ahead and talking or not talking (that is, no physical work performed) (see Table below).

Table 7.1: Heart rate, Minute Flows and Peak Inspiratory Air Flows for subjects standing stationary, talking or not talking (that is, no external work done)

Subject ID	Baseline; no talking			Baseline; talking		
	HR	MV	PIAF	HR	MV	PIAF
10	65	7.5	31.5	76	8.4	92
11	84	10.4	NR	79	11.1	115
12	90	8.1	35	93	7.6	126
13	58	11.3	25	68	10.9	170
14	80	7	44	94	10.6	127
16	62	9.2	30	66	12	148
17	84	12	53	88	12.2	123
18	101	12.9	37	101	9.7	111
21	98	8.6	39	99	9.2	122
23	75	9.5	108	96	11.6	160
24	73	10.3	51	78	8.4	107
25	60	8.7	37	74	10.8	172
26	86	10.1	54.5	95	11.5	100
27	76	8.2	32	76	8.4	117
28	79	6.5	27	90	6.1	82.5
29	67	7.5	25	82	10.5	133
33	81	6.2	22	78	8.1	60.5
Mean	78.5	9.1	40.7	84.3	9.8	121.5
Standard deviation	12.2	1.9	22.2	11.0	1.8	29.8
HR = Heart Rate (bpm); MV = Minute Volume (L/min) ; PIAF = Peak Inspiratory Air Flow (L/min); NR = Not recorded						

Table 7.1: Heart rate, minute volumes and peak inspiratory air flows for subjects standing stationery, talking or not talking (i.e., no external work done).

Investigation 2 was a study of light work, with the subject conducting a light work task (placing an object from the floor to a table and back), talking or not talking (see Table below).

Table 7.2: Heart rate, Minute Flows and Peak Inspiratory Air Flows for subjects performing light work, talking or not talking

Subject ID	Light work; no talking			Light work; talking		
	HR	**MV**	**PIAF**	**HR**	**MV**	**PIAF**
10	78	11.3	53	78	12.5	142
11	85	15.3	41.5	86	16.9	164
12	93	9.8	55	93	10.3	77
13	86	21.8	77	89	23	228
14	90	10.6	80	89	14.8	168
16	69	12.8	91	69	13.4	123
17	100	18.8	68	100	22.7	160
18	106	21.8	93	110	24.3	135
21	102	13.3	65	106	15.9	160
23	77	17.2	95	74	17.9	118
24	88	17.7	88	87	20	162
25	73	15.6	92	79	13.4	178
26	91	11.6	55	91	13.5	88
27	81	10.8	62	87.5	9.7	61
28	105	12.9	54	137	17.1	111
29	86	15.9	71	96	15	170
33	96	13.4	67	90	15.7	92.5
Mean	89.5	14.8	75.5	93.5	16.4	132.8
Standard deviation	12.1	3.4	15.0	17.5	4.0	37.2
HR = Heart Rate (bpm); MV = Minute Volume (L/min) ; PIAF = Peak Inspiratory Air Flow (L/min); NR = Not recorded						

Table 7.2: Heart rate, Minute Flows and Peak Inspiratory Air Flows for subjects performing light work, talking or not talking

Investigation 3 was a study of light work, with the subject conducting a light work task (walking on a treadmill at 6.5 kph at 0° inclination), talking or not talking (see Table below).

Table 7.3: Heart rate, Minute Flows and Peak Inspiratory Air Flows for subjects walking on a 0° incline at 6.5 kph

Subject ID	Light work; no talking			Light work; talking		
	HR	**MV**	**PIAF**	**HR**	**MV**	**PIAF**
11	111	21.7	70	NR	NR	200
13	101 115 105	30.7 25.2 30.6	140 178 108	NR	NR	260 300 275
14	110	20	78	NR	NR	88
15	108 113	21 27.1	90 118	NR	NR	360 290
16	100 91 90 83 84 91	27.2 31.5 30.9 24.3 27.7 29.6	140 130 138 115 95 185	NR	NR	320 345 308 270 285 270
17	122 130	44.2 48.4	175 165	NR	NR	315 340
20	113	24.8	87	NR	NR	154
21	120	23.3	115	NR	NR	215

Subject ID	Light work; no talking			Light work; talking		
	HR	MV	PIAF	HR	MV	PIAF
23	106	24.7	191	NR	NR	267
24	105 114	32.9 30.3	220 223	NR	NR	325 325
25	105 115 109 109 101 108	25.2 23.8 26.8 28.1 29 30	145 178 165 180 135 130	NR	NR	240 242 320 285 265 260
26	108	21.7	90	NR	NR	305
27	85	18.6	73	NR	NR	180
28	115	17.5	73	NR	NR	NR
29	120	22.6	105	NR	NR	295
30	130	21.3	88	NR	NR	125
31	102	23.1	80	NR	NR	215
32	95	21.3	104	NR	NR	355
33	104	26.9	90	NR	NR	143
34	110 115	16.4 17.2	96 95	NR	NR	161 152
33	96	13.4	67	90	15.7	92.5
Mean	106.5	25.9	125.8	90.0	15.7	254.1
Standard deviation	11.6	6.8	43.7	19.6	3.4	84.9
HR = Heart Rate (bpm); MV = Minute Volume (L/min) ; PIAF = Peak Inspiratory Air Flow (L/min); NR = Not recorded						

Table 7.3: Heart rate, Minute Flows and Peak Inspiratory Air Flows for subjects walking on a 0° incline at 6.5 kph

Investigation 4 was a study of heavy work, with the subject conducting a heavy work task (walking at 6.5 kph on a treadmill at 5° inclination), talking or not talking (see Table below).

Table 7.4: Heart rate, Minute Flows and Peak Inspiratory Air Flows for subjects walking on a 5° incline at 6.5 kph

Subject ID	Heavy work; no talking			Heavy work; talking		
	HR	MV	PIAF	HR	MV	PIAF
11	138	38.7	72	NR	NR	260
13	144 135 141 133	47.4 58.4 57.1 51.8	215 210 225 165	NR	NR	340 335 330 430
14	142	42.3	210	NR	NR	285
15	124	29.5	124	NR	NR	310
20	NR	35.1	138	NR	NR	250
23	135	46.7	210	NR	NR	320
24	162	65.2	315	NR	NR	325
25	138 143 123 147 136 145	38.1 39.8 52.9 47.4 45.8 43.4	190 185 240 180 235 228	NR	NR	190 320 290 290 300 290
26	153 145	32.3 37.2	140 135	NR	NR	230 280
27	124	29.1	123	NR	NR	231

Subject ID	Heavy work; no talking			Heavy work; talking		
	HR	MV	PIAF	HR	MV	PIAF
28	158	27.1	100	NR	NR	147
31	127	35.1	140	NR	NR	283
32	135 125	29.1	108 162	NR	NR	313 410
Mean	138.8	42.3	176.1			287.7
Standard deviation	10.7	10.5	56.4			60.4
HR = Heart Rate (bpm); MV = Minute Volume (L/min) ; PIAF = Peak Inspiratory Air Flow (L/min); NR = Not recorded						

Table 7.4: Heart rate, Minute Flows and Peak Inspiratory Air Flows for subjects walking on a 5° incline at 6.5 kph

Summary data from these investigations are shown in the Table and three Figures below.

Table 7.5: Summary Results of Heart Rate, Minute Volume and Peak Inspiratory Air Flow while talking and exercising up to a 5° incline at 6.5 kph on a treadmill

Activity	Measure	No Talking	Talking
Investigation 1 **Standing upright, looking forward and then talking (that is, no useful work)**	HR	62 to 101	66 to 101
	MV	6.1 to 12.9	6.1 to 12.2
	PIAF	25.0 to 53.0	82.5 to 170
Investigation 2 **Picking up an article from the floor and placing it on the bench.**	HR	81 to 105	69 to 107
	MV	9.8 to 21.8	9.7 to 24.3
	PIAF	55.0 to 95.0	61.0 to 170
Investigation 3 **Walking on a treadmill at a 0° slope uphill at 6.5 kph**	HR	84.0 to 130	No data collected
	MV	17.2 to 48.4	No data collected
	PIAF	124 to 153	125 to 360
Investigation 4 **Walking on a treadmill at a 5° slope uphill at 6.5 kph**	HR	124 to 153	No data collected
	MV	27.1 to 65.2	No data collected
	PIAF	72.0 to 315	147 to 430
HR = Heart Rate (bpm); MV = Minute Volume (L/min) ; PIAF = Peak Inspiratory Air Flow (L/min)			

Figure 7.1: Summary Data, Heart Rate

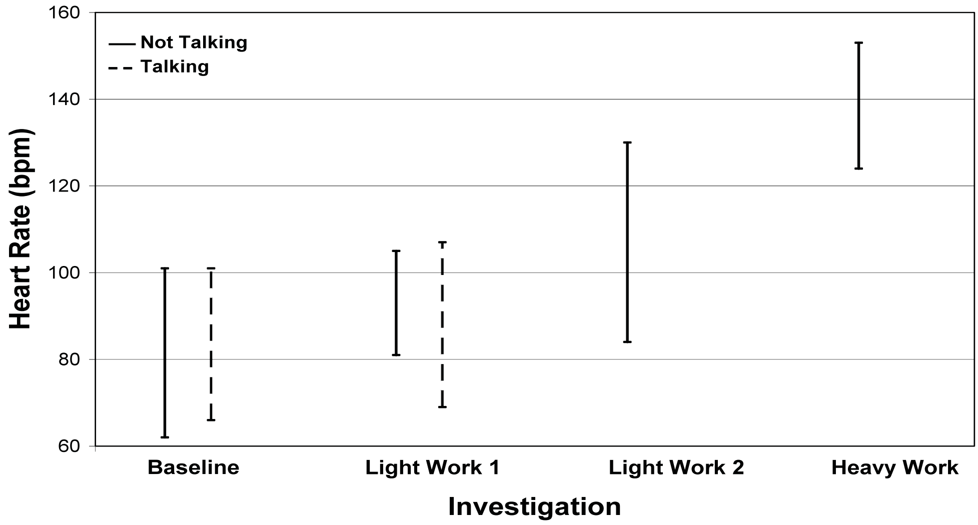


Figure 7.1: Summary data: Heart Rate.

Figure 7.2: Summary Data, Minute Volume

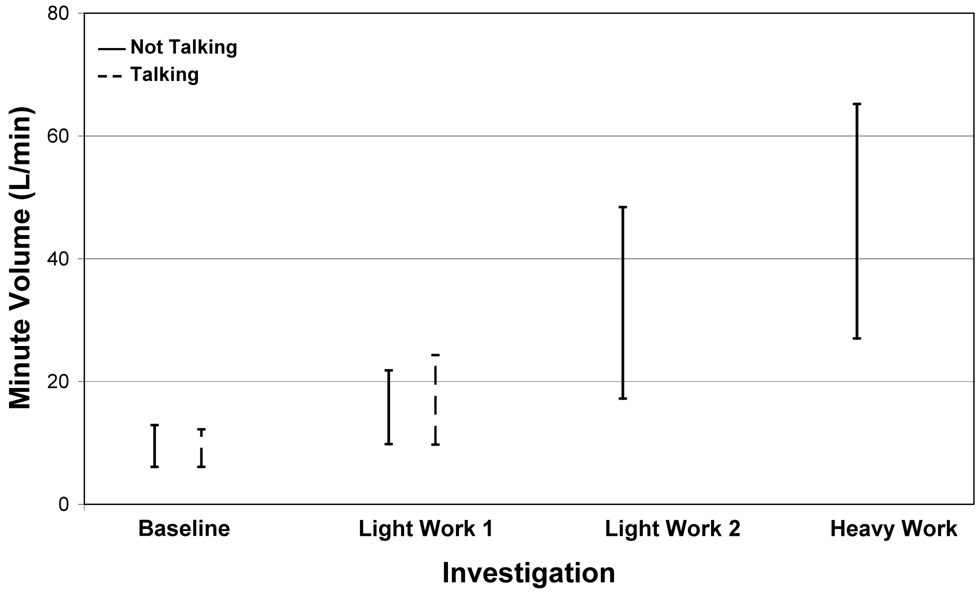


Figure 7.2: Summary Data, Minute Volume.

Figure 7.3: Summary Data, Peak Inspiratory Air Flow

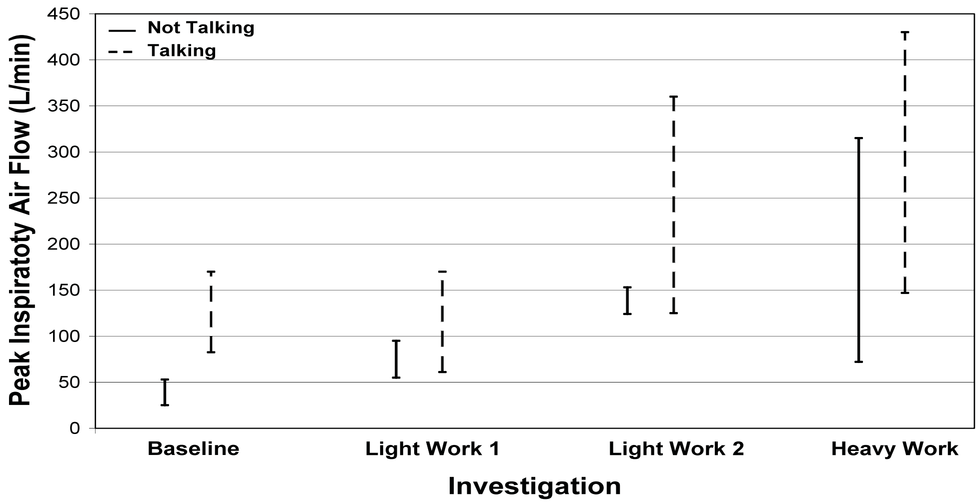


Figure 7.3: Summary data, Peak Inspiratory Air Flow.

7.4 Discussion

There are a range of observations that arise out of the results above. These include that:

- The minute volume range is very large for the same level of work. Individuals exhibit a wide range of requirements for minute volumes. As described in the previous chapters, this has implications for assuming a single flow rate for respirator testing and gas cartridges, particularly when low flow rates are used by Standard organisations in recommendations for respirators. The Standard effectively assumes a low rate of work and little variation in flow requirements by people. The experimental values obtained here bear little relationship to the values used by equipment testing authorities or manufacturers.
- The PIAF rates as well as the range from this work are shown to be very high, again particularly at higher work loads. The values are often much higher than three times the minute volume generally assumed to date. The values climb even higher when shouting (as could happen in a workplace). The values obtained indicate that current PAPR equipment is likely to be unable to

provide air flows when PIAFs exceed the specified rates and would become negative in terms of internal pressure compared to that outside the respirator particularly at higher rates of work). As a direct result, contaminants may potentially enter the facepiece by total inward leakage if PAPR equipment is worn in the contaminated atmosphere. In addition, the pattern of breathing is significantly raised and disturbed from a regular pattern. Neither breathing flow rates or irregular breathing patterns are currently considered by Standard organisations in establishing manufacturing minimum standards for respirators or filters.

Communication is a normal social activity and can be an essential activity while people are wearing respirators in the workplace. In practice, wearers regularly remove the equipment to converse, to communicate instructions or to shout warning messages. All of these needs are important, but in an industrial situation, the need to communicate warning messages may be a critical health and safety issue. There are alternative options available for communicating while wearing respiratory protection (for example, radio) but in large plants with thousands of employees this is often impractical.

Communication has a significant impact on normal breathing patterns and volume. The regular pattern of breathing is disturbed and the rate of air required increases substantially. PIAF can be in excess of 400 litres/minute for individuals walking at 6.5 kph and at an incline of 5° upwards. However at even low levels of work, PIAF values can exceed 170 litres/minute. Most PAPR equipment will deliver no more than 120 litres per minute air volume under ideal conditions (for example, fully charged batteries at the start of a shift and new filters fitted, rather than used filters which offer resistance to the airflow). This ideal situation quickly deteriorates as filters become clogged or the batteries lose their newly charged condition.

PIAF values are much higher than the minute volumes normally quoted and used by manufacturers in the design of PAPR and powered air respiratory equipment. The recognition of both the high PIAF values and the individual variations is becoming recognised as a limited number of manufacturers developing modern respiratory equipment, and standard organisations (such as ISO) become aware of the limitations of the current designs and testing procedures and more seriously, the potential of exposing people to the hazardous environment. There are few workplace studies carried out by respirator manufacturers to ensure that their equipment functions as intended in the workplace. The certification or standard requirements only applies to the equipment meeting limited and minimum requirements in a laboratory setting. This will not protect the worker.

7.5 Conclusion

The determination of the Peak Inspiratory Air Flow (PIAF) is an important value that has been largely ignored to date by both respirator manufacturers and users of the equipment in the workplace. However, even published literature over 30 years ago stated the importance of these values to designers of respiratory equipment. Silverman et al in 1943 reported that in the opinion of the researchers "Peak Inspiratory Air Flow is more important than minute volumes".[424] In spite of this, PIAF values are not normally quoted by manufacturers and all references to flows are minute volumes. Manufacturers do not usually even quote PIAF and industrial users are normally unaware of the importance of the two different values.

Subsequent reported work in this thesis has confirmed the high values of PIAF, even at moderate rates of work. At higher rates of work, for example, at 150 Watts external work (corresponding to "intense activity at fast to moderate pace") 90% of the inhalation sequence is made up of air flows greater than 115 L/min (litres per minute) without speech. In addition, 42% is faster than 200 L/min.[444] These values are becoming critically important. In CBNR (Chemical, Biological, Nuclear and Radiological) type response scenarios it is critical that the respiratory equipment is able to meet the required airflows from the users.[445] Similar arguments can be presented for emergency and military situations.[446]

One study in soldiers engaged in a specific pre-set series of tasks similar to that used as an entry test for fire-fighters to join the brigade. In 99.69% of the cases, at heart rates of approximately 170 bpm, the peak flows were greater than 85 L/min. Other researchers have also expressed concern at the low flow rates of testing equipment internationally.[447] The US military have also expressed concern with peak flows in soldiers often exceeding 300 L/min.[448]

The results of this work and that subsequently of other researchers appears to be having significant impact on the future development of respiratory protective equipment, particularly in fields such as CBRN development. The USA NIOSH (National Institute of Safety and Health) in a draft discussion document “Concept for CBRN Powered Air Purifying Respirator (PAPR) Standard-Draft for Discussion June 2005” now suggests minute volumes of at least 100 L/min for moderate breathing rates and 261 L/min at higher breathing rates.[449]

This work as well as that of others spurned the development of a new type of respirator (the FPBR) that incorporated the much higher flow rates required. This has been successfully evaluated in the asbestos removal industry[450] and lead smelters.[451]

While PIAF values have a direct influence on the expected ability of equipment such as PAPR to meet the needs of users, it has a further importance in the performance of filters as the particulate part of filters is influenced by the velocity of the air moving through it. Further work by other authors has shown that 200 L/min is a minimum value of air flow that would meet the needs of most users at higher rates of work,[452] although other authors have a suggested 130 L/min minute volume.[437] These values are much higher than currently adopted by groups such as Standard organisations when setting minimum values of breathing flows.

As described in previous Chapters, the variation in air flows required between different people is not adequately catered for by the low values currently used by Standard organisations and manufacturers of respiratory protective equipment. There is little relationship between the minute volume and PIAF values obtained in these trials to the values used by Standard to certify respirators, filters or cartridges.

The low flow rates used have little relationship to current requirements even at low rates of work.

Communicating while wearing a respirator resulted in significantly higher values of PIAF and a disturbed the pattern of flow. This has implications for the design, certification and workplace use of respirators. There is a wealth of information which supports the need for people to communicate in the workplace, either without or with the use of respirators.[453] Current respirator design ignores the implications of the increased air flows required and the disturbance in the airflows which has implications particularly for the user of respiratory equipment if the requirements of pattern and peak flows are unable to be met.

Values of PIAF reached over 400 litres per minute are much higher than the capability of any PAPR (Power Assisted Air Purifying Respirator) on the commercial market today. The implications to respirator users are that the airflows from currently available equipment will be insufficient to meet the requirements of users in the workplace, particularly at higher rates of work.

It is likely that respirator cartridges are tested and certified at values which are much lower than is necessary to simulate workplace needs and PAPR respirators in commercial use do not provide sufficient airflow to adequately provide protection to the user, particularly while users are communicating in the workplace setting.

Even while no external work was being performed, PIAF values exceeded 170 L/min for one subject while communicating. As soon as light work was being performed, the PIAF exceeded 228 L/min. When the subjects were walking at a brisk pace of 6.5 kph, the PIAF value increased to 360 L/min and when the subjects were walking on an incline of 5° uphill, this increased to over 430 L/min.

The higher required airflows when working are documented in literature related to airline BA (Breathing Apparatus) in such situations as fire fighting, where subjects may be exposed to high heat and high rates of work for significant periods of time. Yet these same values of airflow are not translated to specifications for PAPR (Power Assisted Air Purifying Respirators) or the certification and testing of half-face respiratory cartridge equipment. Respirator manufacturers do not quote values for PIAF in their literature but invariably quote Minute Flows. The reasons are probably commercial rather than technical, that is, the PAPR equipment may be unable to meet the required air flows. However, all commercially available PAPR is unable to meet the PIAF values, albeit that the latter is considered more critical than minute flows in terms of respiratory protection. For some time, manufacturers have endorsed the misnomer for PAPR of “Positive Air Purifying Respirator”, although this is becoming more difficult to sustain because of increasing challenges.

Some respirator manufacturers have carried out workplace evaluation of respirators to determine the Protection Factor, but carry out the testing in a manner which does not reflect the workplace use of their equipment. For example, the equipment is switched off when volunteers have to remove the equipment and batteries are charged more frequently than would be the case in reality or recommended. In addition, there are considerable practical and theoretical concerns when testing in the workplace, such as the manner in which the contaminant is sampled, the sampling technique and the influence of moisture from exhaled breath and other technical problems which have discouraged much workplace evaluation of respirators.

PAPR equipment does have numerous and significant advantages for the user in the workplace such as a continuous supply of clean air, comfort and the ability to install communication facilities by means of amplifier or radio. The equipment is widely used worldwide in such applications as agriculture, military and industrial uses. Generally, the “protection factors” quoted for PAPR’s are significantly higher than for other respiratory equipment, although many authorities appear to be questioning this assumed approach.

PAPRs have recently been the subject of a more intensive review as various organisations are becoming concerned about the ability of the equipment to meet the demands of the users.[454,455]

It is in recognition of these factors which have the potential to seriously affect the result for preventing respiratory injury and fatalities worldwide that this research was initiated. From the results to date in previous Chapters it appears that these concerns may be well grounded.

7.6 References

437 Coyne, K., Caretti, D., Scott, W., Johnson, A., Koh, F. Inspratory flow rates during hard work when breathing through different respirator inhalation and exhalation resistances. *Journal of Occupational and Environmental Hygiene* **3:** 490-500, 2006.

438 Typical of this is at: http://www3.3m.com/catalog/us/en001/safety/occ_health_safety/node_GSL54N1GF1gs/root_GST1T4S9TCgv/vroot_5SDD44F7DZge/bgel_GSX0RHSXQ5bl/gvel_WRBPCLK8SWgl/theme_us_ohes_3_0/command_AbcPageHandler/output_html where equipment is provided which only measures minute air flows.

439 Harber, P., Tamimie, R.J., Bhattacharya, A., Barber, M. Physiologic effects of respirator dead space and resistance loading. *Journal of Occupational Medicine* **24:** 681-689, 1982.

440 Harber, P., SooHoo, K., Lew, M. Effects of industrial respirators on respiratory timimg and psychophysiologic load sensitivity. *Journal of Occupational Medicine* **30:** 256-262, 1988.

441 Myhre, L.G. Physiological criteria for the valid selection of workers who must perform physical tasks while wearing protective equipment. US Air Force Research Laboratory, Brooks Air Force Base, Texas, 2000.

442 Racal Airstream Inc. *Racal Airstream's Response to the de Roza Report.* Racal Company, Frederick MD 1986.

443 Workwear and personal protection. *Safeguard Magazine*, **29**, 2000.

444 Berndttson, G., Berndtsson, F., Jessup, S., McNamara, T. Peak inhalation air flow and minute volume during a controlled test performed on an ergometer. *The SEA Group,* Warriewood NSW, 2003.

445 CDC presentation. CBRN related topics. US Centres for Disease Control, Atlanta, undated. Obtained from the website http://www.cdc.gov/niosh.npptl/standardsdev/cbrn/escape/meetings/042903/pdfs/cbnrelated.pdf on the 10th September 2005.

446 Berndtsson, G., Howie, R., Kjelberg, B., Simmons, P., Berndttson, F., Berndtsson, K. *Peak inhalation air flow during an agility test performed by the US Marine Corps*. The SEA Group, Warriewood NSW, 2003.

447 Johnson, A., Mackey, K., Scott, W., Koh F. Peak flow rates while wearing respirators. AIAH, 2005. Obtained from the website http://www.aiah.org/abs04/po120.htm on the 11th September 2005.

448 Kaufman, J.W., Hastings, S.A. Respiratory demand in individuals performing rigorous physical tasks in a chemical protective ensemble *Journal of Occupational and Environmental Hygiene* **2:** 98-110, 2005.

449 CDC NIOSH (2005). *Concept for CBRN Powered Air Purifying Respirator (PAPR) Standard.* Centres for Disease Control/National Insttute of Occupational Safety and Health, Cincinnati, June 2005. Obtained from the website on the 11th September 2005. http://www.cdc.gov/niosh/npptl/standardsdev/cbrn/paprcon-062005.html.

450 Howie, R.M. Effectiveness of Safety Equipment Australia SE400AT Positive Pressure Demand Filtering device during asbestos removal operations. Report no. RMH/01/196. Robin Howie Associates, Edinburgh, 2003.

451 Kranenburg, S. Wear time and peak airflow monitoring in a lead smelter. The SEA Group, Warriewood NSW, 2002.

452 Kuklane, K., Holmer, I. Respiratory flow patterns during physical work with respirators. Department of Ergonomics, *National Institute of Working Life*, Solna, Sweden, 2002.

453 Johnson, A.T, Scott, W.H, Caretti, D.M. Review of recent research on communications while wearing a respirator. *ISRP Journal*, **18**. Spring 2000. Pp 31-36.

454 Mackey, K.R.M, Johnson, A.T, Scott, W.H and Koh, F.C. Over breathing a loose fitting PAPR. *ISRP* Journal, **22**. Spring/Summer 2005. Pp 1-10.

455 Janssen, L.L, Anderson, N.J, Cassedy, P.E, Weber, R.A and Nelson, T.J. Interpretation of inhalation airflow measurements for respirator design and testing. *ISRP Journal*, **22**. Fall/Winter 2005. Pp 122-141.

8. CASE STUDY 5: RESPIRATORY PROTECTION IN AGRICULTURE

8.1 Introduction

This chapter outlines a questionnaire survey of farmers about knowledge of respiratory hazards, diseases and controls. A summary of this chapter has been published.[456]

8.1.1 Respiratory Protection

As noted in other parts of this thesis, respiratory protection is a practical measure that reduces inhalation exposure to airborne hazards, especially in workplaces. This becomes necessary where exposure to such hazards constitutes an unacceptable risk and the preferred method of elimination, isolation or engineering controls to reduce exposure to the hazard is not possible.

Respiratory protection is considered to be a primary means of preventing or reducing inhalation respiratory disease, in contrast to the less desirable secondary means of prevention (early detection and intervention) and tertiary prevention (minimizing the effects by administering medications and reducing further exposure).[457] The use of respiratory protective equipment has been suggested might result in the primary prevention or reduction of occupational asthma,[458,459,460,461,462,463] although the results of such studies are not always unequivocal.[464,465]

Further, even the proper use of respirators will not prevent exposure to allergens that can be absorbed across the skin.[466] Successes in the reduction of occupational respiratory disease have been published. In one study related to HHPA (hexahydrophthalic anhydride), the number of asthma cases dropped from 10% to 2%. A variation was noted on the type of respiratory equipment used albeit this was not the intended purpose of the study. None of the subjects in this study who wore a full-face respirator developed occupational asthma.[457] Use of respiratory protective equipment has been reported to prevent occupational asthma among dairy farmers[461] and preventing or reducing "farmers lung".[464,467,468] In addition, the powered respiratory equipment was thought appropriate for long-term use in farming[469] albeit some studies used half-face respiratory equipment with significant positive outcomes for the farmers.[470] In many of these studies, farmers were able to continue farming rather than leave the industry, a finding that was of major benefit to the individual as well as the industry.

The incidence of occupational asthma in agriculture is above that of the general population in many countries where efforts have been made to determine the incidence such as in Europe[471] and in certain sectors of the agricultural sectors of New Zealand (details described in this chapter). However, it is suspected that the true incidence is underestimated. Farmers are geographically isolated and are often reluctant to visit a health professional until the disease has become disabling. In addition, the farmer and his immediate family or the treating physician may not recognize the disease due to the latency period between exposure and onset of symptoms (hypersensitivity induced occupational asthma) as opposed to the immediate symptoms of irritant induced asthma that occurs shortly after a high exposure to an irritant gas, fume or vapour at work. Based on experience in the area of injuries reported to ACC as both "medical" and "entitlement claims", most (90%) of cases of occupational asthma are of the hypersensitivity type.[472] A further issue may be that the physician treating the patient may not recognise the symptoms as being work related. In a 1999 study (in England), the possible link between occupation and symptoms had only been recorded in 18% by physicians in all of the asthma cases diagnosed.[473] .

There is extensive evidence of a direct relationship between occupational asthma and allergen exposure.[474] Further studies have explored the effect on reducing exposure and incidence of occupational asthma. That reduced exposure leads to fewer cases of occupational asthma has been demonstrated with acid anhydrides, detergent enzymes, isocyanates, laboratory animals and others.[474] After reviewing 2500 scientific articles on occupational asthma and prevention, the British Occupational Health Research Foundation (BOHRF), gave the following summary:

- reducing airborne exposures reduces the number of workers who become sensitized and who develop occupational asthma;
- the use of respiratory protective equipment reduces the incidence of, but does not completely prevent, occupational asthma.

The second result may be based on the practical limitations of commercial respiratory equipment as nearly all types will leak contaminant to a lesser or greater extent in practice. Much of the work in this thesis is based on the recognition of this and suggests practical improvements to the equipment and testing methodology focused on trials on respirator air flow rates and human physiology.

Generally, Australian, UK and the USA authorities are more active in the prevention of occupational respiratory disease than Government agencies in New Zealand and have established websites to inform the public about prevention, for example, www.hse.gov.uk/asthma and www.osha-slc.gov/SLTC/occupationalasthma. The Australian Dust Diseases Board has recently been active in identifying and treating cases of workplace asthma in industry using mobile buses travelling to industry locations[475] (the "Lung Bus"). Similar efforts to identify workplace diseases have not yet been seen in New Zealand. It may be that the NZIPS (New Zealand Injury Prevention Strategy) released in June 2005 has increased attention on primary intervention in occupational disease.

Occupational asthma is the most frequently reported work related respiratory disease in many countries.[473,476] Farmers are recognized internationally as being in an employment group having the highest, or one of the highest, incidence rates of occupational asthma.[477]. In New Zealand, specific types of farming has been identified with elevated cases of occupational asthma (described below).

There have been few studies reported that have specifically researched the effect of different types of respiratory equipment (including the different types of equipment provided and the varying levels of protection they provide) on the reduction and prevention of occupational respiratory disease, particularly as it relates to the agricultural community. This is even more significant to people who are sensitized to a particular range of chemicals.

Researchers focusing on respiratory disease generally report that some type of respiratory equipment was worn. This assumes that the equipment functions to remove all contaminants as suggested by the manufacturer or distributor. For reasons already discussed in this thesis, this is not the case in practice. All respiratory protective equipment will leak contaminants into the facepiece to a lesser or greater extent. It is well recognized that the protection available in the workplace is significantly less than during ideal face fit tests in the laboratory under simulated conditions. Respirators do not protect against exposure to contaminant that can be absorbed through the skin. One paper on the issue of respiratory protection for farmers discusses the use of P2 filters (presently being considered in revisions of AS/NZS 1715 and 1716) which allow greater penetration of smaller diameter particles of median size 0.3 μm, and summarises that the failure to protect all exposed subjects is attributable to filter and face-seal leaks.[478]

The elimination of leakage through the design and wearing of improved RPE, through the filter and face seal contact, may provide significant opportunities to reduce occupational respiratory disease in agricultural operations and other occupations in the future.[†] Respiratory equipment can only offer protection when it is worn properly and filters/cartridges maintained or replaced regularly. Brief periods of respirator removal might permit a transient, yet sufficiently high exposure to sensitise a worker and lead to subsequent development of asthma.

It has become apparent that the minimum requirements in many standards for respiratory protection has not yet incorporated much of the

---

[†] This became the basis of the FPBR (Fan supplied, Positive pressure, Breath Responsive Respirator) developed. By providing filtered and air that had passed through at least a P3 filter and had extracted organic contaminants, under a rate

newly available information being generated in research.[479] It is likely that improved respiratory equipment for users and removal of some of the barriers already described will significantly open opportunities to reduce occupational respiratory disease.

While respiratory protection for farmers in agriculture has been recommended by Government agencies in New Zealand (such as the ACC and OSH), farming seminars and training (for example, GrowSafe and FarmSafe) as well as commercial organizations retailing agrichemicals (as is seen in manufacturer derived product safety information such as MSDS), the level of knowledge related to the health risks and associated protection by the agricultural community is not believed to be high.[†] However, the incidence of respiratory disease in the agricultural community, particularly in certain types of agricultural operations as explained below, is suspected to be higher than the non-agricultural community. In addition, the level of knowledge and insights into the different types of respiratory equipment suitable for different tasks appears to have not been adequately understood by this group.

8.1.2 The Agrarian Myth

The agrarian way of life relates to the self perception that that life on the land is full of hardships, but that contact with nature through cultivation of the land, and characteristics of honour, manliness, self sufficiency and self reliance, courage, moral integrity, independence, mean that rural dwellers are have a better lifestyle than urban dwellers.

While selection of lifestyle characteristics are a matter of location and personal choice, the belief that the agrarian way of life is healthy is not borne out by the evidence.

During the performance of routine tasks farmers may come in contact with a variety of substances, including pesticides, solvents, oils and fuels,

---

and volume that the user used it, appeared to provide the best opportunity for success in reducing respiratory disease.

† Personal communication, Department of Labour (Occupational Safety and Health Service) and tutors in the New Zealand FarmSafe program in 2004 and 2005.

dusts, paints, welding fumes, zoonotic viruses, microbes, and fungi.[480] Many of these are irritating or toxic. Because some of these substances are known or suspected carcinogens, the epidemiologic literature regarding cancer risks concerning farmers has been investigated.[481] Farmers have consistent deficits for cancers of the colon, rectum, liver, and nose. The deficits for cancer of the lung and bladder were particularly striking, presumably due to less frequent use of tobacco among farmers than among people in many other occupational groups. Malignancies frequently showing excesses among farmers included Hodgkin's disease, leukemia, non-Hodgkin's lymphoma, multiple myeloma, and cancers of the lip, stomach, prostate, skin (nonmelanotic), brain, and connective tissues.[482,483]

Farmers, despite a generally favourable mortality, appear to experience elevated rates for several cancers, including leukemia, non-Hodgkin's lymphoma, multiple myeloma, soft-tissue sarcoma, and cancers of the skin, lip, stomach, brain, and prostate. The rates for several of these tumors (that is, non-Hodgkin's lymphoma, multiple myeloma, skin, brain, and prostate) appear to be increasing in the general population.[484]

The agrarian myth is a barrier to changing current farming practices to reducing risk on the farm. Farmers often believe that their lifestyle is healthy, risks associated with agriculture are minimal and where they exist, unavoidable. Under this belief system, the effects of long-term effects of exposure to agrichemicals and avoidance of long-term disease may not be taken seriously, particularly when workers in this industry is daily exposed to immediate hazards and consequences that typically present in a farming scene such as kicks from large animals (for example, dairy cattle and horses) or serious injuries or fatalities from farm machinery such as ATVs (All Terrain Vehicles). At present, one third of all New Zealand farm fatalities involve an ATV. Statistics on morbidity from long term disease from occupation are all but absent.

Depending on the type of farm operation, animal intensive operations such as including dairy farms, regard serious animal handling injuries as a normal part of farm operations and comments such as, “it is a horse” or "it is a steer - what do you expect?" are common. Under these practical conditions, concerns related to long-term respiratory disease are likely to be minimal. The unpredictable nature of large animals in close contact with people presents risks which the farming community can readily identify. The effect is immediate, practical initiatives can be implemented directly (for example, culling the animal, improving yards), whereas with occupational respiratory disease there is often no immediate result (disease can take decades to become evident) and the costs of wearing and maintaining respiratory equipment difficult to justify when the effects may be decades in the future.

Farmers are not uncomfortable with risks in business. For example, income from farmed commodities can vary according to prices paid on international markets: this is outside the control of the farmer, and weather variation significantly affects farm profits - in extreme cases destroying a year's work overnight (for example, with fruit crops and damage from hail or floods).

The risk of long-term health effects of agrichemicals may be difficult to quantify often with no immediate impact. Changes are made over generations of farmers as typified by the wearing of hearing protective equipment for the prevention of noise injury, mainly noise induced hearing loss (NIHL). Training institutions and those organizations dealing with the education and training of young farmers require the wearing of hearing conservation in which is only gradually reaching the practicing farmer.[485] NIHL contributes to isolation of the individual from his family and the community and can result in depression related problems, particularly in the elderly. Rural communities in New Zealand, to a large extent, are more aware of this problem today and are taking basic precautions.[†] The same does not appear to be the case for the recognition and prevention of occupational respiratory disease.

---

† The New Zealand Agricultural Health and Safety Council consists of members concerned with occupational health and safety in agricultural New Zealand. This group has an active involvement in various aspects of agriculture and 80% already wear hearing aids .While this may not be truly representative of the

In New Zealand, the Government agency ERMA (Environmental Risk Management Authority) requires farmers handing agrichemicals to be "certified handlers" by January 2007, which will require knowledge of the chemical risks associated with agrichemicals. This may increase the level of awareness of risks and personal protection required in the future for handling chemicals in farming in the future.

The type of respiratory disease resulting from agricultural contaminants in the workplace can vary according to the type of contamination, the organ or tissue within the respiratory system affected and the individual. Epidemiological studies have indicated a greater risk of respiratory disorders in certain types of farming in New Zealand than in non-farming occupations.[486] The effects can be short-term or permanent. In pastural farming or horticultural operations, dust contamination may result in allergic sensitization of the intrathoracic airways (asthma). Lung parenchyma (hypersensitivity pneumonitis) is also possible, whereas in animal farmers, by contrast, endotoxins and gases such as ammonia may pose a bigger risk, leading to non-allergic rhinitis or organic dust toxic syndrome (ODTS). Additional contaminants may result in bronchitis or asthma. Emphasis today is on the avoidance of the contaminant and the use of respiratory protection. Their use has been recommended and ideally supervised by a respiratory or occupational physician.[486] While removal of the individual from the exposure ideally by elimination or isolation from the contaminant is preferred, in practice respiratory protection is the most likely practicable option in most cases. In many practical farm operations, elimination of the agrichemical is often not possible as it is necessary to control weeds and plant pests or insect pests, or fertilise the soil and other agrichemicals are either not possible or uneconomical. Isolation of the farmer from the agrichemical (for example, in the application of fertilizer), isolation from the animals (for example, while milking or handling dairy cows) or the working

agricultural scene in New Zealand, all members recognise that the NIHL problem is of concern and NIHL should not be regarded as a normal part of ageing.

environment (for example, while collecting and making hay) may be impractical.

8.1.3 The Healthy Worker Effect

The Healthy Worker Effect (HWE) is a common selection bias in occupational epidemiology studies. The HWE is characterised by lower relative mortality, from all causes combined, in an occupational cohort[487] and occurs because relatively healthy individuals are likely to gain employment and to remain employed.[488]

The HWE is an example of inappropriate reference group. A population, members of which are currently employed in work requiring skills of hand and brain, must have better health than a general population containing individuals who are unemployed for health reasons amongst others. This results in the underestimation of the true effect of work-related exposure.

Fox and Collier described three factors involved in the Healthy Worker Effect: the selection of healthy members from the source population, the survival in the industry of healthier workers, and the length of time the population has been followed.[489] The Healthy Worker Effect may also be exacerbated by considering subjects lost to follow-up as alive at the end of the study.[490]

The “Healthy Worker” effect, common in other industries such as grain workers or aluminium smelter workers, may not be as prevalent here. It is generally much more difficult to leave the family farm.

Wilcosky and Wing have suggested that the selection of economically advantaged workforces for epidemiological studies could also contribute to the Healthy Worker Effect.[491] Therefore the HWE has various underlying factors which should be identified by researchers at an early stage of an occupational study.

Miettinen has described the Healthy Worker Effect as “a monument to habitual malpractice in the formation of contrasts”.[492] Whenever possible, a more valid reference group should be used, that is, a group that is selected for that specific study on the basis of its comparability.

The HWE is often the result of two different types of selection. In the first place, people with ill-health often avoid a job which they think will not suit their particular health problem and sometimes even a formal pre-placement medical examination has to be passed. Secondly, ill-health might influence length of employment in a particular job. If health plays a role at the time of employment or for the survival in the job this should be taken into consideration.[493]

In the occupational health area, self-selection rules the choice of occupations or jobs. For example, persons having chronic bronchitis tend to avoid dusty jobs, and persons with back problems cannot seek physically demanding jobs. Pre-employment examinations may accentuate this kind of selection.[494]

This HWE Effect may amount to a 10-40% decrease below general population death rates.[495]

The HWE-induced bias has nothing to do with any beneficial effect of the work environment on the health of the workers. Health-based selection into a certain employment, or into the entire work force, is the most important cause of the HWE. Merely being fit to work, becoming employed, and subsequently remaining employed give the worker a better than average life expectancy. In addition to this general rule, there are variations between different jobs, those with higher physical demands also having higher demands for health. The correct comparison category for any employed group should be workers with equal work demands and equal a priori health status, not the general population. There is also health-based selection out of jobs; the less successfully those leaving the job are traced, the more the likelihood of bias. On average, these workers often have poorer health than those remaining.

Farmers generally are in farms owned and operated by the family and traditionally passed on to the elder son, albeit this practice is changing rapidly. Occupational diseases such as asthma are not likely to result in the farmer leaving the farm unless the disease is severe, largely because of the Agrarian myth as well as an obligation to the family. In some agricultural operations such as those operations in enclosed buildings (e.g., piggeries or hen-houses), there is more rapid movement of the operator and is usually not a family operation in this country. The different types of farm operations will probably impact differently in different farm types.on the healthy worker effect.

8.1.4 The NZ Agricultural Sector

The agricultural sector in New Zealand can be in many practical aspects similar to the agriculture practices in many developed nations albeit having differences which affect likely contaminant exposure to the farming community. For example, in Europe animals are often housed indoors in the winter which increases the ambient contaminant concentrations. Both in Europe and in New Zealand, poultry farming and pig raising is carried out mainly indoors and in close confinement.

There are a number of specific hazards and high risks associated with agriculture, and farm workers have often had higher rates of injury compared to other industries.[496] There are also limitations on the reported incidence of occupational injury and disease among farmers as adequate surveillance systems do not exist to collect this information in New Zealand.[497] A recent study of Southland farmers in New Zealand (a major agricultural area) involving farm visits, health checks and face-to-face interviews on 286 farms concluded that chemical related illness, noise induced hearing loss and musculoskeletal issues were the most important issues for intervention by community agencies.[498] While traumatic injuries receive a great deal of public and Government agency attention, the same cannot be said for the longer term effects resulting in workplace disease or other impacts.[499]

In terms of respiratory concerns, 18.3% of the 586 respondents in this geographic area reported that breathing had become uncomfortable during and after handling grain while 18.9% reported these symptoms after handling hay. This is consistent with overseas studies. Farmers and farm workers have been reported as having higher rates than other workers of respiratory disease, certain cancers, acute and chronic chemical toxicity, dermatitis, musculoskeletal syndromes, noise induced hearing loss and stress related mental disorders.[496]

Asthma in farm employees in not new. In 1555, Olaus Magnus had noted the hazards from grain dust.[500] In 1713, Barnardino Ramazzini described the relationship between asthma and inhalation of corn dust. The field of occupational health has been driven since the 18th century on the industrial revolution and a focus on heavy industry.[501] However, relatively little intervention to preventing diseases such as occupational asthma in workers in New Zealand agriculture has been implemented. Even confined space entry risks, well recognised in most industry sectors, appears to be virtually ignored in the agricultural sector.

Few studies available in agriculture have reported occupational hygiene measurements and have attempted to relate these to occupational disease in agriculture, albeit some efforts have been made in New Zealand recently in the region of Southland.[502] Occupational hygiene measurements are helpful in determining the likelihood of workplace health risk and the intervention steps that may be required.

Chemical usage on New Zealand farms is not reported to be high (three-quarters of chemicals used less than twenty days per year, although in dairy farming operations some chemicals were used every day). However, for about half the chemicals used, skin contamination to some degree was reported which would suggest inhalation exposure is likely to be significant. [503]

There are important differences between agricultural practices in countries as to the manner in which animal husbandry is carried out. Many overseas studies related to workplace exposure studies cannot be directly compared to New Zealand conditions and caution needs to be exercised when making comparisons. In many European countries, for example, animals are housed indoors for much of the year which can be expected to raise the concentration of contaminants such as animal hair, manure gases and dusts to which farmers and their families will be exposed. Government agencies in several countries have reported that specific farming exposures, albeit not detailed in occupational hygiene terms such as measured exposure concentrations, are associated with increased incidence of respiratory disease[504] such as asthma, chronic bronchitis and airway obstruction and have recommended intervention by the farming community.[†] In New Zealand elevated prevalence of current asthma has been noted in some types of agriculturally related occupations:

- In the equine industry (16.5%);
- Among pig farmers (18.2%);
- Among poultry farmers (17.4%);
- Among those working with oats (17.4%).

These results compare against 15% in the general population.[504] Significantly in this same survey, 44.4% reported skin allergies from working in poultry sheds. Other recent reports have shown that rates for asthma were higher among arable and horticultural farmers compared to dairy or sheep and beef farmers in Southland, New Zealand. An earlier article described the prevalence of asthma in a random sample of all types of New Zealand farmers to be 13.5% in dairy farmers, 12.8% in cropping farmers, 10.9% in beef farmers and 11.1% in sheep farmers.[504] This compared against the national quoted average of 9%. The differences may be due to the method of detection of the disease (for example, self-reporting of symptoms versus clinical diagnosis by trained occupational physicians).

Studies where people who have become sensitized to the contaminants in chicken sheds (where hens are housed in "batteries" that is, in high numbers) may be able to continue working by wearing respiratory protective equipment. The ability to continue working in a familiar role

---

† In the U.K, the HSE produces many resources targeting occupational asthma and the farming community, for example, http://www.hse.gov.uk/asthma and has several monitoring schemes in operation (for example, the SWORD scheme-Surveillance of Work-Related Occupational Respiratory Disease and other recording systems such as THOR-Occupational Health and Reporting Network since January 2002), while in the USA, organisations such as the NASD-National Agricultural Safety Database http://www.cdc.gov/nasd/docs and many other others.

while also sometimes heavily committed economically (typical of many farmers) has advantages for many people. In some cases continuing to work may the only available practicable option. It is important, however, that the equipment can be worn for extended periods of time and the individual's work related to drawing air through the filters is kept minimal.

The agricultural industry, particularly the primary dairy sector, has the highest number of entitlement claims (serious injury claims) to ACC (Accident Compensation Corporation) in both the self-employed and employer claim accounts and one of the highest rates of all the industry sectors. The majority of those employed in agriculture are self-employed. In addition, self-employed people, particularly farmers, suffer a fatality rate almost double that of employees of organisations.[505] Once every three weeks a farmer is killed at work in New Zealand, while every day approximately eleven are seriously injured on their farm. Farmers are exposed to a wide variety of risks such as those related to machinery and unpredictable large animals, occupational diseases such as zoonosis and agrichemical exposures as well as long hours of work at many times of the year. Farms are places of work but it is often the family home and in this aspect differs from most other workplaces. Legislation designed to protect people from harm in workplaces are often difficult to apply in farm situations. For example, while the driving of forklifts in industry by children is regarded as acceptable, the driving of ATVs and tractors by children as young as twelve is not illegal and accepted as normal practice by the agricultural community. The fatality and serious injury rate of occupational disease is many times that occupational injury, but tends to receive scant attention.

Farmers, by the nature of their work, are often not risk averse-many farm practices result in unknown outcomes due to fluctuating prices, exchange rate fluctuations, draught and flooding. Farmers are often surprised when advised of the seriousness of their mortality and morbidity rates. In addition, the time delay between exposure and effect may further negate efforts by Government organizations to reduce the risk of ill health to the farming community. Individually, farmers are exposed to few serious injuries in their lifetime as individuals and this results in many myths pervading the industry, the most prevalent being the agrarianism myth.[506]

Farmers often accept injury as an inevitable outcome of normal farm practices. The agrarian myth is a consistent value orientation pervasive in rural farm regions which suggests that rural life is natural and healthy, rather than evil and artificial, that ownership of land makes the farmers self-reliant and independent, that agriculture is nationally important and that farming is therefore a virtuous occupation. Farmers may frequently accept injury as an unavoidable reality of their occupation. In fact, farmers often take pride in talking to their peers about their injuries and "narrow escapes".

The rate of fatal injuries in agriculture is generally four times the combined industry rate for New Zealand, even although only 9% of the New Zealand workforce is employed in that sector. Half the total fatal injuries for all industries in New Zealand in the 2004-05 year were from the agricultural sector. The total injury and disease problem, however, is likely to be under-estimated for a number of reasons, including such factors as occupational diseases (occupational asthma or zoonosis) being under-reported and often not recognized as being occupationally related by health professionals. This is not unique to New Zealand, and the NZIPS (New Zealand Injury Prevention Strategy) shows an increased focus on occupational disease interventions. Similarly, the Australian NOHSC (National Occupational Health and Safety Commission) has developed a national strategy in which the third out of five key strategies is an improved focus on occupational disease.[507] In addition, in New Zealand, a new national database is in the initial process of development to include data collection of occupational disease.

Anecdotal evidence from even traumatic events such as reported ATV (All Terrain Vehicle) injuries would suggest that the reported injuries from the agricultural sector is only about a third of all the events that occur. Farmers, in particular, will generally only become involved in visiting a health professional in serious injury events, as the distances and inconvenience factors are significant practical barriers to this population.

In a study in Southland, the ACC entitlement (serious) claim rate was given 21.7 per 1000 farmers per annum, yet a visit survey showed that the farm injury rate (sufficient to prevent the farmer from undertaking their normal farm work) was 180.9 per 1000 farmers a year.[497] While the two values cannot be directly compared, it gives an indication of the under-reporting of injuries and illness in the agricultural community.

The self-employed present unique challenges for injury prevention intervention that have been well documented.[508] The agricultural sector presents a further challenge because of characteristics of the population (for example, risk taking, living with uncertainty such as income due to international markets outside individual control, agrarianism and independence[509]), as well as geographic dispersion and many other factors. Factors unlikely to have an immediate impact are likely to be ignored until they have reached a disabling state. This is not unique to New Zealand. For example, the Canadian Workplace Safety and Insurance Board give detailed advice and subsequent premium reductions to farmers who undertake a farm audit and risk management program, that is, attempt to manage the reduction of farm risk.[510] Farmers who believe that their ability to prevent sickness and injury is limited and who see little benefit in taking preventive action are probably less likely to instigate precautions or use protective devices.[511] Having good knowledge in itself does not necessarily translate into "safer" behaviour.[512,513,514,515]

Improved awareness and education are often suggested by the farming community as the keys to alleviating the farm injury problem. However, work done by the agricultural occupational health and safety community (for example, in Tasmania) does not support the contention that there is an inexorable link between increasing awareness and knowledge and reductions in injury.[516] Education as a stand-alone strategy has been deemed to be marginal.[516,517,518] Even when farmers believe farm equipment accidents to be severe and dangerous, may believe themselves to be invulnerable to these accidents.[519]

8.1.5 Knowledge, Attitudes and Skills in the NZ Agricultural Sector to Safety

Traditional agricultural interventions from a number of organisations have largely been based on compliance with the 1992 NZ Health and Safety in Employment Act and usually involve farm audits. There are requirements under the Act to identify and manage hazards including those on farms. Hazard management programs include the identification of farm hazards and management to reduce future risk. In general, hazard analysis requires the employer to identify hazards.

It should be noted that the preferred term in New Zealand is "hazard management". While the model with dealing with workplace problems in other parts of the world is called "risk management" and encompasses hazard identification, risk assessment, control of risks, review of risk management processes, the concept of hazard identification, hazard assessment, control of hazards and review of hazard management is specified in NZ OHS legislation. While it is possible that there are subtle differences between hazard management and risk management, in OHS, they broadly encompass the same types of activities when dealing with workplace hazards and risks.

In farming, hazard management is almost entirely based on the farmer's knowledge of the hazards. This will be limited in most cases and will tend to focus on traumatic events with which this sector can readily identify, for example, ATV (All–Terrain Vehicles) overturns, tractor accidents and kicks from large animals. Occupational disease issues are not likely to be readily identified or managed as a result.

The requirements of the legislation are more stringent for employers than the self-employed, with most farmers likely to be in the latter category. These continue today, but their effectiveness in reducing injuries has been questioned both in New Zealand and in Australia.[520,521] The impact of workplace prosecution (a major issue for farmers) shows little evidence of success in reducing injuries in this sector.[522] A case in point is OSH prosecution against a farmer who had a bridge on his farm that a beekeeper drove his car across and fell through. The case has drawn much interest and has focussed a great deal of industry antagonism towards the OSH agency. This personal case of the "farmer against the system" has probably raised more attention of the threat of prosecution than any other case. The case occurred a decade ago and still raises strong emotions in the farming community.

Similarly, many other intervention approaches have been generic while it is more appropriate to consider the various sectors of the businesses as uniquely different (for example, dairy farming is different from sheep and beef farming).[516]

Many programs have been based on attempting to change "attitudes" and linking this to behaviour. It is assumed that faulty habits and attitudes are prime injury producers. However, as long ago as 1980, many injury prevention personnel working in the agricultural industry suggested that the high priority given to safety attitude development should be re-examined. Even in 1970, modifying the environment (rather than attempting to change the behaviour of an individual) was considered to be more likely to control processes with high potential for injury.[515] This is often referred to as the ergocentric model of injury and prevention as opposed to the egocentric model (which places the individual at the centre of attention).[523]

In general, most workplace cost of injuries (83%) of the fatal and non-fatal Class 1 incidents (permanent disability) come from only 13% of the events.[523] By far the largest number of injuries are in the Class 2 (Lost Time Injury or temporary disability) category (87% in number but only 17% of the cost). The rising incidence of ATV (All Terrain Vehicles) increasingly used on farms is an example of an agricultural machine that contributes to Class 1 injury events as is an occupational disease such as occupational asthma where the individual may require lifetime professional medical care.

Traumatic and high compensation injury (not disease related) cost vary according the type of farming. For example, in dairy farming, injury by animals is most common (21.8%) followed by vehicles including ATVs (18%), lifting, straining activities (18%), slips, trips and falls (13.6%) and occupational overuse syndrome (OOS) and NIHL (18%). In sheep and beef operations, injuries by animals contributes to 36.5% of all injuries, followed by 11% vehicle related, 28% due to lifting and straining type activities, 7% slips, trips and falls and 7.5% NIHL. In the many different types of horticultural operations, lifting and straining type activities contribute to 29% of all injuries, repetitive type work 23%, slips, trips and falls 19%, vehicles and towed implements 14%, struck by object 11% and others, including chemicals 4%. The problem with this data is that it is derived from ACC data, which largely focuses on traumatic compensable and recognisable damage to people. Therefore, a distorted picture is created of the (under-reported) role of long term diseases.

The main risks can be summarised into major hazard groups:

- Machinery such as tractors and increasingly ATVs (All Terrain Vehicles);
- Pesticides and other chemicals;
- Zoonoses such as leptospirosis and infectious diseases;
- Respiratory diseases such as occupational asthma;
- Manual handling, fatigue and stress;
- NIHL (Noise-Induced Hearing Loss).

However, farms are places of work as well as places of residence. Legislation commonly applied in industry is much more difficult to apply in agriculture. For example, children cannot work in industry until the age of 16 (in New Zealand), but can legally drive a tractor on the farm under instruction at the age of 12. It is common practice that even this age limit is ignored in practice on the farm and children work unsupervised. ATVs are driven by children under the age of 8, albeit recommendations from all manufacturers, distributors and legislative bodies that the minmimum age of operation is 16. Concern over the rising injury rate have repeatedly been made by such bodies as the CPSC (Consumer Product Safety Commission) in the USA, the American Pediatric Society,[524] and similar organisations in New Zealand as well as others but are widely ignored by the farming community. Outside the agricultural community, there is rising concern about the use of children in farm operations. The NZ Police appear to be keen to prosecute in the near future but have been reluctant to do so because of the already high trauma suffered by the parents of children who have died in farm accidents. Typical is the use of the ATV where farmers say that children "will do any farm chore provided it involves the use of an ATV". The pressure that children will bear on the parents to drive an ATV, without comprehension of the dangers, is common and has lead to a number of child deaths. The NZ OSH (Department of Labour) will likely prosecute farmers or their staff who have had a head injury and who were not wearing the approved ATV helmets.[†] While they have been reluctant to do so up to the present time, there appears to be increasing public pressure to legislate and take action to reduce the unacceptable risk and subsequent injury in the farming sector.

8.1.6 Illness, Injuries and Deaths in the NZ Agricultural Sector

The primary source of OHS data on injuries in agriculture in New Zealand is workers compensation data. However, while this source has value, it is also known that significant under-reporting of occupational illnesses and disease in agriculture occurs especially from self-employed farmers. This is not unique to this group. A recent study in the welding population of New Zealand showed that of all the claims that reach ACC from welders, only NZ$70,000 was paid in compensation compared against NZ$4.3M paid to welders from other injuries, such as manual handling, hearing damage and burns. Further, it is fairly difficult to realistically establish the current level of occupational health and safety management practices on farms although it is believed that such standards are not high. ACC has initiated the FarmSafe program in which 12,000 farmers

---

† In New Zealand, NZ Standards, under contract to ACC, have developed the first ATV helmet which addresses some of the concerns that farmers originally had about the heavier motorbike helmets. Over 8000 were distributed in the first year of production.

have attended in just over a year. The overwhelming comments from over 45 tutors is that the current level of occupational health and safety practices on farms is limited and may be well below that of other industry sectors of the same size (for example, the New Zealand construction sector).

There is wide concern (for example, by organisations such as OSH, ACC and the NZIPS) about the level of insights of this community with regard to health and safety. The New Zealand FarmSafe program has recently extended to become increase training in “awareness” programs, “hazard management” programs, “prevention of injuries to children” programs, “HSNO” (Hazardous Substances and New Organisms) programs and many others. In addition, recent articles have been published[525] and a thirty minute Sky TV documentary on respiratory protection was prepared by the ACC. The purpose of these publications and DVDs has been to raise awareness of the need for primary intervention (respiratory protection) rather than secondary and tertiary treatment, particularly in the agricultural sector.

Compensation in the agricultural industry in New Zealand over the 2006-2007 financial period (a typical claim period) is shown in the Table below.

Table 8.1: NZ Accident Compensation Corporation data-number of claims and cost of claims in the agricultural sector (financial year 2006-2007)

2006-2007 Financial Year	**New claims**	**On-going claims**	**Total**
Number of entitlement claims from agriculture	4737	4829	9568
Cost of claims (× NZ$1000)	$31, 135	$40,457	$71,592
Total number of claims in all industry sectors	38,110	28,910	67, 020
Total cost of all industry sectors (× NZ$1000)	$212, 374	$355, 577	567, 951
The agricultural industry as a percentage of all industry sectors (Based on cost)	14.7%	11.4%	12.7%
Note: Claims are entitlement claims only (serious claims) On-going claims are from those injuries that have occurred in previous years, but compensation is still being paid. “New claims” are usually the focus of attention by injury prevention professionals.			

2006-2007 Financial Year	New claims	On-going claims	Total
However, serious injuries normally require compensation over a number of years-in some cases a lifetime. Occupational diseases such as occupational asthma typically fall into this group.			

Table 8.1: NZ Accident Compensation Corporation data-number of claims and cost of claims in the agricultural sector (financial year 2006-2007)

The Figure below indicates the New Zealand agricultural sectors that contribute to the injury problem. The data, because of the New Zealand compensation system, is dominated by traumatic type injuries.

This Figure only gives the total number of claims reported. The rate of injury is dependant on the number of participants exposed to the risk. For the dairy cattle farming and sheep-beef cattle farming sectors these are approximately the same.

Many industry sectors, such as viticulture and horticulture, use casual or transient labour. Injuries and participant numbers in these sectors are difficult to estimate and are usually significantly under-estimated.

Generally, the first two industry sectors shown also have the highest potential exposure to agrichemicals, animal products and confined space environments.

Figure 8.1: Agricultural Sectors within New Zealand contributing most to injury numbers: Total number of entitlement claims and associated compensation costs (× NZ$5000) over the last decade

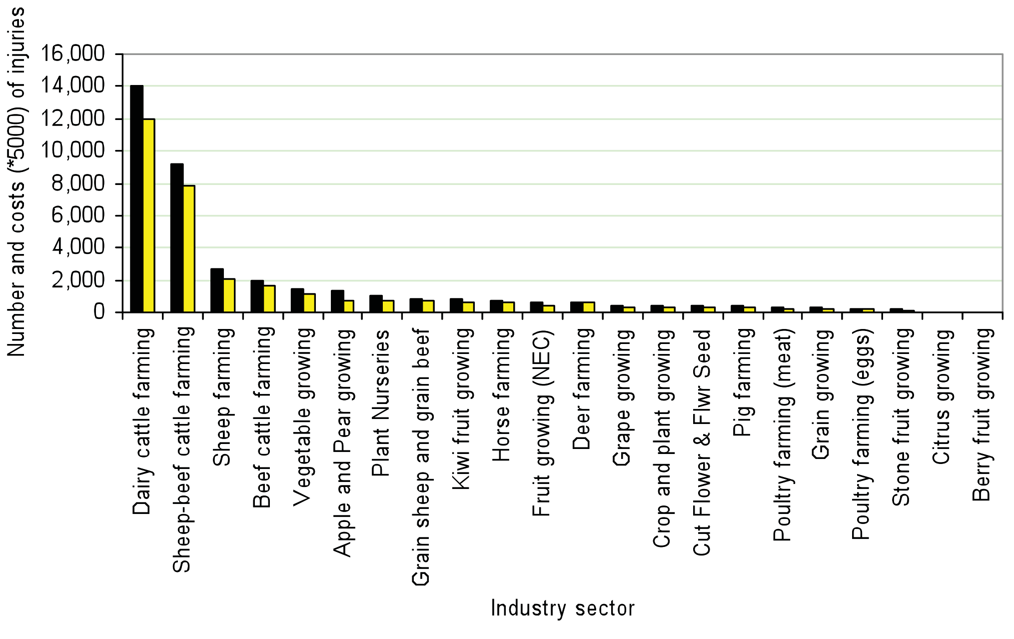


Figure 8.1: Agricultural Sectors within New Zealand contributing most to injury numbers: Total number of entitlement claims and associated compensation costs (× NZ$5000) over the last decade

The Figure below numbers of injuries in the dairy sector over the period 2004-05. From other surveys, the dairy sector typically shows a significant percentage of occupational diseases related to work such as occupational asthma. It is not clearly shown by these statistics but is probably "hidden" in the "Work Property or Characteristics" column or "Other or Unclear Causes".

Figure 8.2: Dairy sector described cause of injury 2004-5 year.

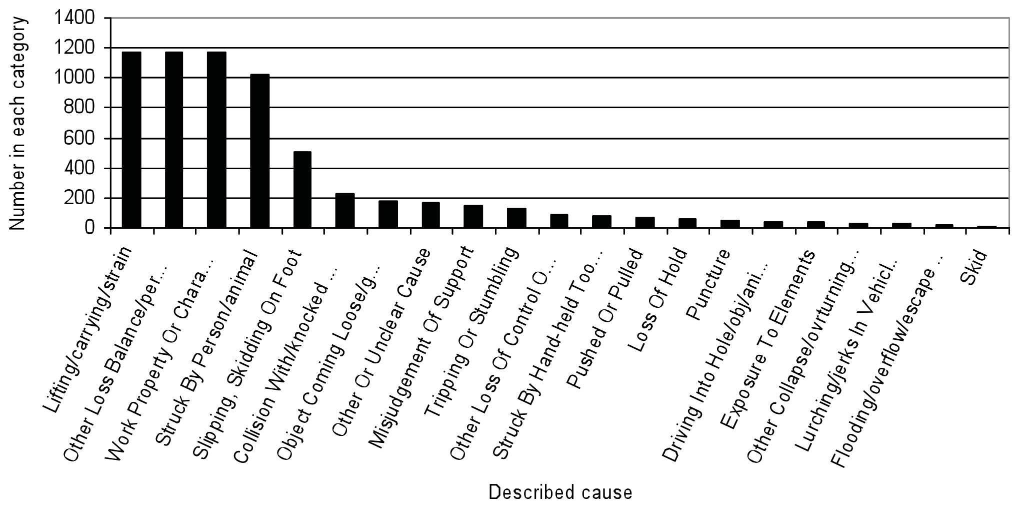


Figure 8.2: Dairy sector described cause of injury 2004-5 year.

About 10% of New Zealand's working population is employed by the agricultural sector (including the dairy sector). The NOHSAC report (2004) estimates that about 1564 new cases of chronic occupational respiratory disease is diagnosed every year. As these are work related, compensation is normally paid to identified cases.[526] These are not clearly shown in the ACC statistics. This results in much injury and disease intervention effort probably being misdirected.

The Figure below shows data for claims received by the ACC for respiratory disease.

Figure 8.3: Occupational respiratory disease recorded by the New Zealand ACC 2006 to 2007 and over the 5 years 2000-2005

	New claims		**On-going claims**	
	Number	**Cost (× NZ$1000)**	**Number**	**Cost (× NZ$1000)**
Respiratory disease 2006-2007	15	$185	48	$1,792
Respiratory claims totalled over 5 years	83	$219	391	$12,279

Notes:
Under-reporting is the main problem in directing focus on intervention efforts based on ACC injury statistics. Even in one industry (aluminium smelting) in New Zealand, 2 or 3 new cases of occupational asthma are diagnosed every year. Many large companies are self-insured but new cases of disease have to be reported to the ACC.

Figure 8.3: Occupational respiratory disease recorded by the New Zealand ACC 2006 to 2007 and over the 5 years 2000-2005

In some industry sectors (for example, metal manufacturing), occupational diseases such as asbestosis are currently the main cause of work related death. The focus of intervention efforts by organizations such as the NZ Department of Labour are still focused on intervention efforts such as machine guarding.

Analysis of one year of the ACC agricultural entitlement claims shows the following with only one case reported as an inhalation exposure (in the mushroom industry) as shown in Figure 8.1. It is known that disease exposure is inaccurately reported and may be reported by HCWs (Health Care Workers) in such classifications as "Work Property or Characteristics", "Other clear/Unclear cause" or "Exposure to Elements". The graph showing these typical classifications for one year is shown in Figure.8.2.

Respiratory disease in agriculture is also known to be under-reported to Government agencies such as the ACC. This is due to a number of reasons which include the lack of recognition of the condition to the workplace environment by both the farmer and treating health professionals, travelling distance to the health professional as well as a likely lack of knowledge about the precautions that can be taken to reduce the incidence of the disease.

The lack of reporting also results in a considerable emphasis in societal and Government effort away from disease in occupations to emphasis on traumatic injury. This has been noted in many publications in both New Zealand and Australia[527,528] as well as elsewhere and there is some emphasis in New Zealand to attempt to correct this situation at Government level.[526] This is in spite of the numbers of suspected occupationally related diseases being well in excess of the traumatic injuries and fatalities. Other agencies such as the DOL report much higher incidence of occupationally related disease owing to a reporting system through physicians (the NODS system), albeit still with suspicions of under-reporting.

Individual research reports have identified very significant numbers of farmers affected by occupationally related disease, including occupational asthma.[505] In the study, farmers reported that breathing became uncomfortable during or after handling grain (18.3%) or hay (18.9%). Although 11.3% reported that their breathing became uncomfortable shortly after work was finished, 5.1% reported that their breathing became uncomfortable some hours after work had finished. There were also 2.2% who reported having "farmers lung". A further study in 1997, in a random sample of New Zealanders it was found that farmers and farm workers had an increased risk for asthmatic symptoms and bronchial hyper-responsiveness.[529]

Overseas agencies in the UK, USA and Europe have repeatedly described asthma and breathing difficulties among the agricultural population in their countries.

Types of compounds known to directly affect farmers are included in the following table:

Table 8.2: Typical compounds known to contribute to occupationally related disease in farming

Compound	Where found	Comments	Ref
Aflatoxin B1	Significant component of feed dust, particularly in respirable dust.	A carcinogen.	530
Animals	Swine workers.	Male swine workers had greater rates of decline of both forced vital capacity and one second forced expiratory air volume.	530
Animal workers generally (including in laboratories)	On farms and in other areas where animals were housed treated or handled.	Related to job exposure. Asthma, hypersensitivity pneumonitis, organic dust toxic syndrome (ODTS), chronic bronchitis.	477, 531
Grain dust	Grain dust handlers on farms and processing plants.	Grain dust exposure has been shown to be associated with significantly reduced average levels of lung function in several cross sectional studies. A high average grain dust exposure (above 9 mg/m^3) was associated with a greater decline in lung function.	532
Pork producers	Pork plants are	Bioaerosols are present from	532

Compound	Where found	Comments	Ref
	generally confined in buildings.	livestock facilities, animals, feces and feed as well as gases from urine. The particles contain about 25% protein and sizes are from 2-50 micron. Other contaminants typically include hair, bacteria, endotoxins, pollen, insect parts and fungal spores. ODTS (Organic Dust Toxic Syndrome) have been shown to have a strong relationship to airborne endotoxins.	
		At least 60% of pork production workers complained in one large study (in Iowa) of at least one respiratory symptom, most of which are acute. These were associated with dust levels as low as 2.4 mg/m^3 and ammonia concentrations at 7 ppm.	530
Chemicals Herbicides Fertilisers	Applicators, storage	Pulmonary fibrosis Mucous membrane irritation Tracheobronchitis	531
Miscellaneous Solvents Fuels Welding fumes	Diesel fuel NO_x, O_3, phosgene, metals	Mucous membrane irritation Bronchitis and emphysema	532
Gases	NH_3, H_2S, NO_2, CH_4, CO, CO_2 Silos, animal confinement facilities, fertilisers	Silofillers disease, acute tracheobronchitis, pulmonary edema, farmer's lung, asphyxiation.	

Table 8.3: Typical compounds known to contribute to occupationally related disease in farming

The incidence of many other types of diseases such as prostate cancer, leukaemia, non-Hodkin's lymphoma and others appear to be in excess in farmers compared to the general population.[532]

8.1.7 Monitoring Studies

There is little occupational hygiene information about the true workplace exposure to farmers in New Zealand. The most recent was part of a study completed in Southland, New Zealand, in March 2000.[498] About 20% of the population in Southland is employed in agriculture, about twice the national average. Most of the farms in the area are dairy farms (45% of the farming population). In the 12 months of the survey, 153 people had suffered 172 “events” which had prevented them from undertaking their full farming duties because of illness or injury. Of these 172 events, 28% were due to injury, 33.1% due to musculoskeletal conditions (including low back pain), 6.4% due to respiratory illness and 29.7% due to (all other) illness and injuries.

A New Zealand occupational hygiene survey included inspirable dust measurements[533]. This was a cross-sectional study, selected from a random sample of farms and over the age of 15 so that all were invited to participate in the study and a total of 200 did so. Apart from a questionnaire, audiometry, spirometry and blood pressure as well as height and weight were also measured. !0% of farms that participated were visited by an occupational hygienist who undertook inspirable dust and noise measurements.

Controls to eliminate, reduce or minimize the risk from these contaminants were not readily evident and respiratory protection was rarely worn. Chemical safety and dust levels found were the most important problems found. Of the farmers surveyed, 10% were exposed to dust levels above the workplace exposure standard (WES) of 5 mg/m^3. The activities with high dust levels include shearing, moving grain using open systems, bagging oats, ploughing, etc on a tractor without a cab, cleaning out sheds and riding on gravel roads on a motorbike. However, this limit does not set a standard for respiratory disease for a number of reasons:

- The above survey used exposure evaluation of areas, rather than personal exposure measurements. WES data can only be assessed from personal exposure evaluation;
- The general TLV (or WES) of 5 mg/m^3 should only be used for dusts of low hazard. Use of such a standard is not scientifically supportable for dusts that have known hazards, such as culturable (for example, bacteria or fungi) or countable bioaerosols (for example, fungal spores, total pollen);[534]

- The recommended time of exposure for application of the TLV or WES is 8 hours. Where exposure is above 8 hours, for example, 12 hours for a farmer working to complete a series of tasks over a limited time period such as haymaking in the summer months, the TLV or WES may not be applicable without suitable correction;
- In cases where the farmer actually resides in the area in which he or she is working (such as the farm), exposure (even at residual levels during rest periods) may be continuous (that is, without a recovery period where no exposure occurs);
- Human responses to many substances such as bioaerosols range from innocuous effects to serious disease and depend on the specific agent and susceptibility factors of each person;
- Atmospheric monitoring does not measure skin exposure;
- People who are sensitised to a compound or series of compounds will suffer respiratory effects at much below these limits.

There is significant evidence that farmers diagnosed with occupational asthma can continue to work satisfactorily provided they use PAPR (powered air purifying respirator) equipment. For example, a retrospective analysis of almost 900 farmers with well documented asthma found that roughly 60% continued to farm; 98% of these had obtained some type of powered air purifying respirator. Sixty-four percent reported complete absence of symptoms while working. Most of the remainder noted incomplete but substantial improvement of their asthma symtoms.[530] It is now known that there are substantial limitations in PAPR equipment, but they offer significant improvements over disposable half-face respirators. Other studies have reported on the value of respirators in preventing asthma in workers with established occupational asthma due to animals.[535] The generally poor compliance with the wearing of respirators due them being cumbersome and uncomfortable. This is a major issue of concern to the agricultural industry and others concerned with reducing occupational disease. With PAPR equipment purified air is supplied to the wearer and no effort needs to be expanded to filter the air inwards on the inhalation stroke. Most of the wearer concerns (for example, overheating, condensed sweat building up inside the respirator) are overcome with PAPR type of respiratory equipment. With the limitations of PAPR and other types of respirators now known (for example, inadequate air rates with PAPR or wearer difficulties with half-face respirators), improvement on the types of respirators available should offer considerable opportunities for increased wearing of the protective equipment while the worker is in the exposed atmosphere. Similarly, a reduction in the incidence of disease such as occupational asthma should follow.

While occupational disease such as occupational asthma is likely more prevalent than ACC compensation statistics would indicate, the means to reduce the impact to large numbers of individuals (10% of New Zealand's population is involved in agriculture) is not difficult. It may be that the awareness of disease and prevention in the target group is low. Anecdotal evidence would suggest that knowledge of protection available for various types of farm contaminants is also low.

This is not surprising. The agricultural sector is not attractive to manufacturers and distributors of PPE (Personal Protective Equipment) because geographic dispersion of farmers make it difficult to gain their attention. The cost/benefit is not attractive to most organisations unless farmers can be grouped together such as at field days, at "shed meetings" or industry sponsored seminars. Knowledge of respiratory and workplace disease is generally low among distributors of PPE in New Zealand and it is the need to comply with legislation that encourages farmers to seek information related to respiratory protection. However, cost of equipment is often the main driver in the absence of other information. Unfortunately, low price is associated with equipment that is not especially effective in providing protection from respiratory hazards encountered on farms. In the further absence of legislative, social, moral or compensation drivers, it appears unlikely that a great deal of effort will currently be expanded in this field.

The lack of knowledge of appropriate respiratory protection in New Zealand farming practices was a research point addressed in the questionnaire surveys outlined in this chapter. Disposable respirators are most frequently used owing to their ease of use and low cost, in spite of the low protection offered. Half-face rubber respirators are often used in confined space environments (for example, cleaning milk vats) when (cost considerations aside) air-line or self-contained breathing apparatus should be used as this type of equipment is the only type which provides purified air, free of contaminants, to the wearer.

There is an increasing awareness in New Zealand as to the real costs associated with workplace disease. In April 2002, representation was made to Parliament in New Zealand by the New Zealand union movement expressing concerns over workplace related disease. It is increasingly evident that public concern over workplace disease is rising and will become one of the political issues in the immediate and intermediate future. The New Zealand Injury Prevention Strategy 2002 has workplace injuries, including disease, as one of the national objectives.[536] The 2003 (October) New Zealand Injury Data Review completed an 18 month study identifying current problems in the recording of workplace injury and disease, and cleared the way for a new integrated database that will record and categorise injuries and workplace disease.[537] A plan of action to 2015 has been implemented by the current New Zealand Labour Government involving several Government Departments and industry stakeholders.

8.2 The Questionnaire Surveys

A study of knowledge and attitudes of respiratory disease and respiratory protection was developed. Using questionnaires targeted to farmers and farm workers.

8.2.1 Background

The questionnaire methodology was chosen because it allowed a rapid response to be gained of the insights of farmers into respiratory protection issues, was anonymous (important because the researcher was often known to the target group), was inexpensive and the results could be obtained within a reasonable time period. There were also limitations, in that the response rate was relatively low, the questions necessarily were sometimes overly technical, was impersonal and the "full story" may not have been made. Other techniques such as interviews, observation, focus groups and case studies were not attempted because of expense and resource limitations (farmers are geographically spread throughout the country) in comparison to the likely additional information that could have been obtained.

The means to reduce occupationally related respiratory disease will have benefits that are not currently recognised by farmers. There have been a number of cases in New Zealand where incorrect use of RPE or no PRE equipment not worn at all have contributed to fatalities or severe cases of exposure in New Zealand agriculture.[538] This may indicate a lack of awareness of appropriate protective equipment in the target populations.

Very few studies internationally have investigated the use of respirators to prevent respiratory disease in workplaces, particularly those in the agricultural sector. While recommendations are occasionally made by both medical practitioners and researchers that "respiratory protection should be worn", a lack of specific detail makes this inadequate advice to prevent or reduce exposure. The knowledge of the medical practitioner and the patient does not normally extend to an adequate knowledge as to the best type of equipment, what should be worn, how, and a range of other important factors more related to the practical application in the workplace.

In New Zealand, in a recent survey of 586 Southland farmers, 87.5% used chemicals, with over 50% being sprayed from a backpack or hand-held pump and 19.8% rated their exposure as medium-high. 21.8% reported one or more acute illnesses associated with chemical exposure with over half being neurological or respiratory. Only 13.6% wore some kind of respiratory protection.[539]

In the normal hierarchy of controls is the elimination of the risk (for example, by substitution to a less harmful substance), followed by isolation, minimisation and use of engineering controls. The most common or practicable means to reduce occupational respiratory disease is by the correct choice and application of respiratory equipment once the these control options have been recognised and considered. The knowledge, practices and beliefs held by the agricultural community about respiratory disease and protection therefore become critical issues.

Government departments including OSH and ACC have for many years advised farmers and issued information throughout New Zealand at many different types of agricultural events, such as show days. Yet there appears to be poor uptake of the advice.

Research to date has often focussed on the farmers and the wearing of respiratory protection assuming that farmers wear the equipment as intended by the manufacturer. However, because of many limitations identified such as inadequate face seal (many farmers were unaware of the effect of facial hair such as beards) or overdue replacement of filters (farmers often did not replace the filters regularly), this is unlikely to be the case. It was not possible to find any papers which identified these sorts of limitations in the research and which would have had a critical impact.

These questionnaires were used to gain more insight into the beliefs and practices of farmers in New Zealand to enable more targeted information to be distributed and barriers to be recognised. Further work in this area will focus on removing the barriers to the wearing of respiratory protection in the workplace.

Work conducted by the New Zealand NOHSAC (National Occupational Health and Safety Advisory Committee) and publications of their technical reports will likely result in a national effort to reduce the incidence of occupational respiratory disease such as occupational asthma.[540] In addition, the NZ Injury Prevention Strategy and associated plans all emphasize the need to reduce the high social and financial costs of occupational disease. It is anticipated that this work and subsequent efforts will contribute to this effort by specializing within the area of respiratory protection interventions.[541]

8.2.2 *Development of the First Questionnaire - A Postal Pilot Survey*

With apparent limitations in the way exposure control to respiratory hazards was handled in the agricultural sector, a questionnaire was developed to determine the knowledge of New Zealand farmers about occupational respiratory disease and means to reduce exposure to respiratory risks.

While there have been many studies to relate agricultural exposure to occupational disease and injury both within New Zealand and elsewhere, there have been few studies to show the effects of respiratory protection-none in New Zealand that the author is aware off. Studies do indicate that respiratory protection should be worn but there is little consideration to:

- The limitations to the user of the existing commercially available respiratory protection equipment which limits their use in preventing occupationally related disease;
- The beliefs of farmers (for example, the Agrarian Myth) which inhibits this occupational group wearing respiratory protection while in either known or unknown contaminated atmospheres.

Specifically, the following insights into the beliefs and practices from farmers were considered relevant to this work (critical factors):

- Under what conditions would farmers use respiratory protection, that is, is the obvious presence of dust or smell the precursor to respiratory protection?
- What was their knowledge and concern about occupational disease? (dust and gas)?
- What could be done to reduce inhalation respiratory disease on the farm?

- ❍ What were the practical barriers to using respiratory equipment on the farm?
- ❍ What equipment would they wear in particular circumstances, such as confined spaces?
- ❍ An insight as to where farmers are most likely to get information about respiratory disease or prevention.

A questionnaire was developed to collect information from farmers on respiratory issues. This Questionnaire is shown in the Appendices section. About 200 questionnaires were sent out to practicing farmers through Federated Farmers of NZ Inc (an organization representing the interests of 18,000 New Zealand farmers, including health and safety) throughout New Zealand. Included with the questionnaires was a paid return envelope with a return address.

The questionnaire was developed by testing the contents via an initial pilot survey to ensure the contents could be understood by the target group and was not onerous in terms of effort required to complete it by farmers in New Zealand. This required the removal of some questions and changes in the text.

Analysis of questionnaire responses is provided in the Results and Discussion section to this chapter. The questionnaire is shown in the Appendices section.

This was a pilot postal survey. The responses were subsequently used to develop a questionnaire for the FarmSafe program, which was handed out during the seminars and responses collected at the same time.

While the pilot survey revealed important information related in the way the questions were phrased, an important finding was the difference between the respondents in a postal and FarmSafe course participant survey which had hitherto not been recognized.

8.2.3 Development of the Second Questionnaire – A Training Program Exit Survey

This survey was conducted differently to the initial postal survey and asked farmers attending the FarmSafe seminars to complete a questionnaire at the conclusion of the seminar. This latter approach resulted in an almost 100% response rate as farmers just added the work to the end of the course, albeit the different purpose was explained in detail. The methodology and results are outlined further in this Chapter.

8.3 Results and Discussion

8.3.1 First Questionnaire Survey

Out of 200 questionnaires sent out to different types of farms throughout New Zealand, 41 were returned by mail (a response rate of 20%). The questionnaires were distributed by staff of Federated Farmers of NZ Inc. A prepaid addressed envelope was enclosed. The questionnaire was voluntary, and apart from local farmer contact by staff from Federated Farmers of NZ Inc for requests to return the completed questionnaires, no other follow-up calls were made.

This initial questionnaire was used to enable a more specific and comprehensive survey to be designed from the results obtained. It was not known what likely response would be obtained from the type of questions asked in the survey, although 20% is generally regarded as an average response rate that can be expected from this kind of survey without follow up.[542]

Most farmers are not likely to be risk averse. Agricultural operations are subject to weather, flooding and drought as well as disease and fluctuations in commodity prices in both the national and international markets. In addition, injuries are often seen as an unavoidable part of farming and the agrarian myth further distracts attention from the real problem of occupational injury and disease to farmers and their families in agriculture.

There are about 60,000 farms in New Zealand, of which 18,000 members currently are members of Federated Farmers of NZ Inc. Agriculture comprises many different types of farming, for example, dairy farming or kiwi fruit growing. Most of the 41 respondents were from sheep and beef farms although the reason for this is not clearly understood. The survey gives only a "snapshot" of the main agricultural groups who responded to the questionnaire. However, the answers given are thought to be representative of the larger group. Fortunately, this would be confirmed in the second questionnaire, given to a larger sample size with a much better response rate through the FarmSafe program.

The questionnaire focussed on gaining insights into the practical issues in relation to farming and the wearing of respirators on the farm.

This Questionnaire is shown in the Appendices section.

8.3.2 *First Questionnaire Survey: Results and Discussion*

Question 1

The question was primarily to collect demographic information. Information was obtained from such questions as:

- Whether the respondent was a farmer or an employee. Results were likely to be different between employers and employees.
- The geographic region in the respondent was lcated. The main types of farming vary throughout the country and because the socio-economic factors related to agriculture and practices vary also, it was hoped that if sufficient replies were received that an analysis of the data would be possible.
- The age of the respondent (in a range). It was thought there could be significant differences in insights and beliefs about occupational disease and respiratory protection between the different age groups. This has been observed anecdotally in the wearing of PPE such as noise attenuation equipment on farms. Younger people who have attended formal training rather than only on-the-

job training are often more aware of the health and safety issues than that of the older established farmer without formal education. Similarly, younger farmers are frequently members of organisations such as Young Farmers of New Zealand who tend to have as their focus agricultural health and safety.

- The gender of the respondent. It was believed that could be a difference between the responses of the genders. In New Zealand for example, women often attend local groups such as Rural Women of New Zealand who (as does the New Zealand Young Farmers organization) spend a great deal of time on farm safety issues.

This question also collected information related to farming activities:

- The practical experience of farming of the respondent. It may have been possible to determine the differences in beliefs and practices between the age groups.
- Knowledge relating to farm hazards and their control, particularly PPE.

All of the 41 responses returned out of 200 surveys posted (20%) were all completed by the female partners on the farm. This may indicate that the administration of the farm accounts and other paperwork is generally completed by the partners on the farm, whereas the male partner may focus on the practical aspects of farm work. This has implications for any questionnaires seeking a response on day-to-day farm practices where the partner may be an observer in some of the on-farm activities albeit closely involved in the farming operations performs different functions. This has been noted internationally, as the partner is increasingly recognized as the business partner in family businesses.[543] In some types of farming, for example, dairy operations, partners are usually also the business partners with both involved in the milking operations, sometimes employing other staff in bigger operations.[†]

Most of the practices on the farm involving operations requiring respiratory protection would likely be on-farm practical work which may indicate that the decisions as to the type of equipment worn, when to change cartridges, maintenance and other decisions related to PPE may be made by the administrative partner in the relationship. This could have important implications to influencing future practices on the farm by using such organizations as the Women's Division of Federated Farmers.

The age of respondents predominated in the 40-49 and 50-59 groups. This may indicate that individuals in this age group are more concerned with occupational health practices on the farm perhaps through increased exposure of past practices.

As the remainder of the responses tend to indicate, this age group appears largely unaware of recommended respiratory protection practices on the farm in spite of numerous public awareness education programs in the past. For example, most farmers were unaware of the correct respiratory equipment to be worn and recommended procedures prior to entering confined space type environments, albeit many enter these every day albeit there a large number of publications available specifically related to respiratory protection directed at the agricultural sector.[†]

The experience of farmers who responded was extensive-most had practiced farming ranging from 31-50 years and were therefore very experienced farmers. However, this knowledge, while well established, may not have been current with modern trends in occupational health and safety. Farmers tend to be motivated by compliance requirements motivated by a fear of fines or perceived regular visits by inspectors.

---

† Typically, operations exceeding about 250 cows for milking will employ additional labour.

† Both the ACC and the DOL in New Zealand have specific agricultural publications available distributed at events like field days and the website from both

This response was apparent with knowledge of OHS responsibilities, and contemporary procedures for the assessment and control of farm hazards.

Results are shown in the Figures below.

Figure 8.4: Respondent farm location

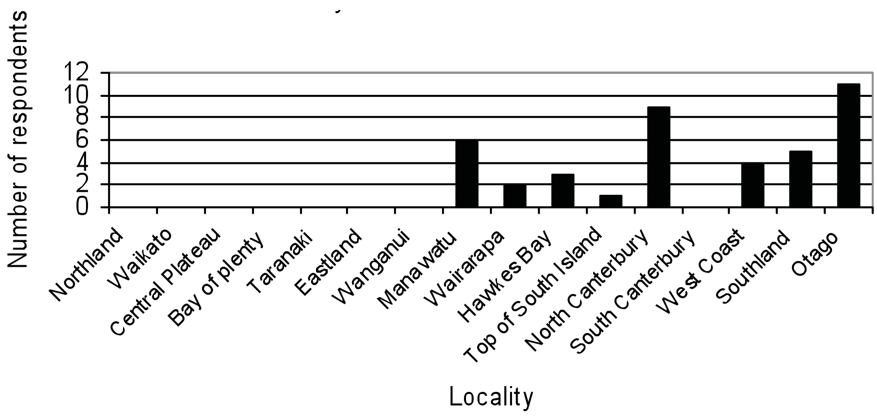


Figure 8.4: Respondent farm location.

Figure 8.5: The age of the respondents

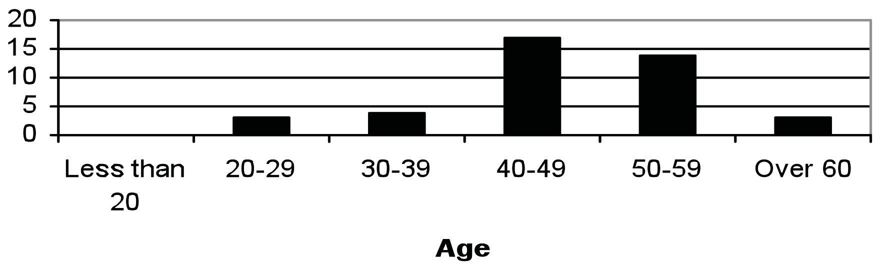


Figure 8.5: The age of respondents.

Figure 3.6: Years of farming experience

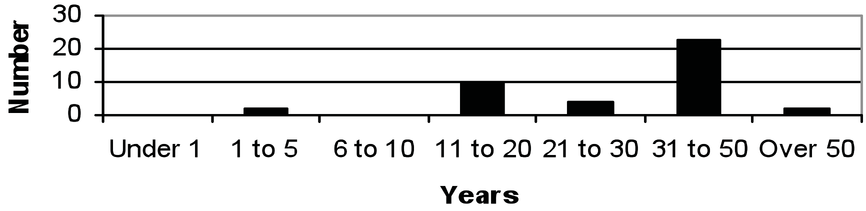


Figure 8.6: Years of farming experience.

organisations show information related to precautions to be taken in confined spaces.

__Figure 8.7: Gender of the respondents.__

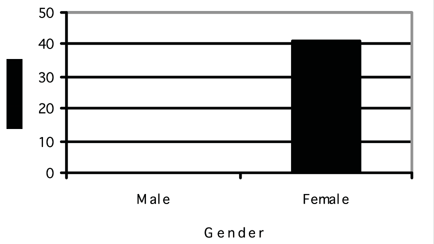


Figure 8,7: Gender of respondents

Question 2

This question asked what type of farming the farmer was primarily engaged in. In New Zealand, most farms dominate as one or mixed types (for example, sheep farming operations or dairy farm operations) but do have smaller operations of other animals. For example, a sheep farmer will often have beef cattle as well. Similarly, a dairy cattle farming operation will normally have sheep as well. On many types of farms, crops are also grown either for domestic animal feed or under contract for domestic use, for example, wheat or barley.

It was anticipated that the response to the questions could be different according to the principal operation. Dairy farms are generally highly technical operations while sheep and beef operations are less so. The exposure potential could therefore vary.

Most of the respondents were from sheep or beef operations followed by dairy cattle farming operations and others. Accordingly, the type of risk to workers to occupational disease may vary. Dairy farmers enter confined spaces such as holding milk vats frequently for cleaning. Sheep and beef farmers enter other confined areas less regularly, but are exposed to many contaminants on the farm such as animal hair and hay during haymaking or during de-horning operations. Those working in relatively close quarters with animals such as chickens and pigs which are generally housed in close quarters are likely to be more exposed but none returned the questionnaire.

It is often difficult to compare overseas studies on agricultural disease with those in New Zealand because the farming conditions vary, for example, in many European operations cattle are housed indoors, sometimes below the living quarters of the family.

The number of responses obtained (40 in total) precluded an analysis of the responses by principal farm type.

Figure 8.8: Primary farm operation of the respondent

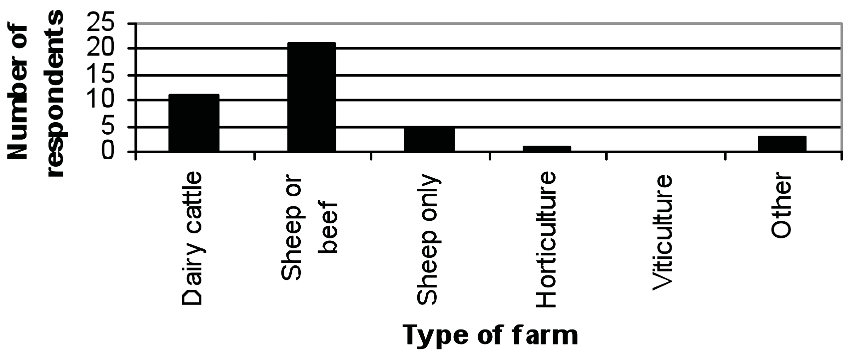


Figure 8.8: Primary farm operation of the respondent.

Question 3

This question asked whether respiratory disease and its prevention was a topic of concern to them (as the farmer) at the present time. The responses, albeit limited in number, generally expressed the view that respiratory disease and protection was not an issue for them (72%).

Most farmers appeared to be familiar with some respiratory equipment and protection because of agrichemical applications, for example, pesticides (in New Zealand, many horticulture farmers have to participate in the "GrowSafe" training as part of requirements for horticultural produce for export). It has been suggested by personnel from NZ FarmSafe and others that this is an effective means to have farmers participate in farm safety and raise the awareness of some of the basic health and safety issues.[†] In order to export their produce, buyers want to be ensured that the products have undergone growing conditions that they can be satisfied with in terms of consumer demands, for example, the rate and type of agrichemicals used, animals have been raised

---

† Personal communication, FarmSafe personnel.

humanly and treated well, that farm labour has been reasonably paid and that modern health and safety criteria have been met.

Examples mentioned of where RPE might be used included enclosed animal areas or pig sheds particularly for those sensitized to the contaminants. Many of those that were more aware of the respiratory issues had family members with asthma (although this was not necessarily occupationally related).

The agrarian myth persists. Occupationally related disease does not appear to be a major concern for farmers, in spite of the available information which suggests that the incidence in some types of farming appears to be significantly higher than the non-farming control group population.

Question 4

This question asked whether the respondent was aware of any cases of respiratory disease in the immediate family, colleagues or workers in the industry that they thought was attributable to the workplace. It was thought that where there was immediate knowledge of respiratory disease on the farm, there would be an increased awareness of respiratory protection and related issues (see Figure below).

Figure 8.9: Are you aware of any cases of respiratory disease in family, colleagues and workers in NZ agriculture thought to be attributable to the workplace?

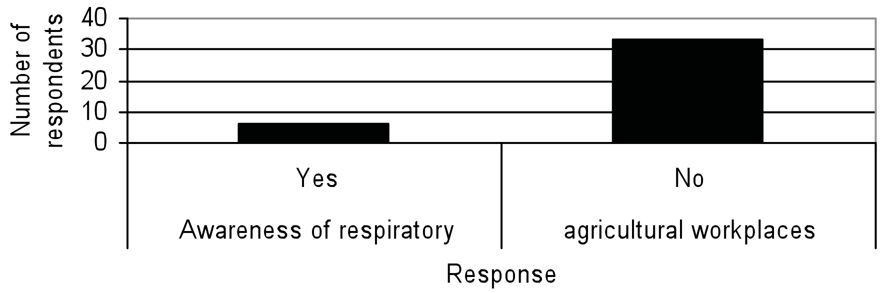


Figure 8.9: Are you aware of any cases of respiratory disease in family, colleagues and workers in NZ agriculture thought to be attributable to the workplace?

The vast majority (85%) of respondents appeared to be unaware of respiratory disease in the agricultural workplace. This may be another example of the common health and welfare myths held in agriculture such as the agrarian myth and positive health outcomes from working "on the land".

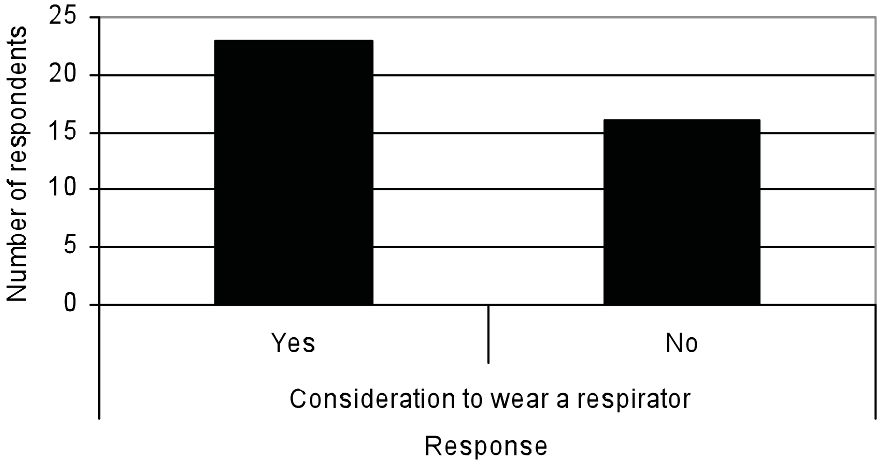
This result is however, surprising. There have been many studies and awareness programs related to respiratory protection required on farms in New Zealand with specific tasks such as spraying agrichemicals and storage of chemicals by various Government agencies.[544] One of the major problems in encouraging the need to wear correct respiratory protection is the long time interval between exposure and many health effects from exposure to airborne contaminants (that is, there is often no immediate feedback to the wearer of not wearing the equipment or incorrectly wearing it). The conclusion may that current Government and commercial advisory programs advising farmers of the risks and counter-measures for occupational disease are not reaching the target group.

Question 5

This question asked whether during specific tasks being carried out on the farm such as cleaning vats on a dairy farm, whether the respondent would consider wearing respiratory protection.

Approximately 79% of respondents said they would. There appeared to be awareness by many farmers related to agrichemical usage albeit animal hair exposure, auger use and silo use were mentioned in specific comments to the question. Most respondents appeared to be concerned about immediate effects of not wearing respiratory equipment rather than preventing a long-term occupational disease (see Figure below).

Figure 8.10: Would you wear a respirator when doing specific tasks?

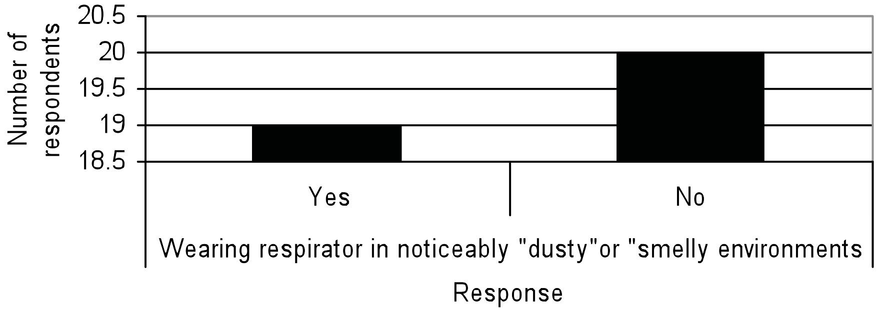


<u>*Figure 8.10: Would you wear a respirator when doing specific tasks?*</u>

Question 6

This question related to whether farmers would wear a respirator when the physical conditions would visibly show that it may be advisable. About half the respondents said that they would wear a respirator in noticeably ”dusty” or “smelly” working environments in a range of different farm environments. While it is probable that without adequate training in the use of respiratory protection, many are probably worn incorrectly, at least some awareness was evident with many different types of farm applications (se Figure below).

Figure 8.11: Would you normally consider wearing a respirator when working in visibly“dusty” or “smelly”environments?



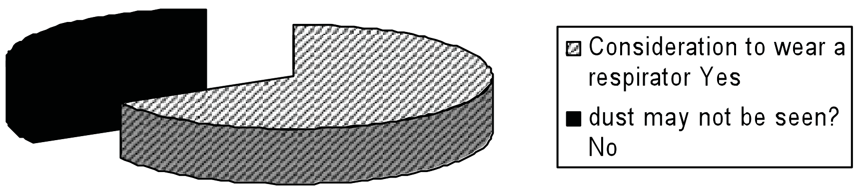
<u>Figure 8.11: Would you normally consider wearing a respirator when working in visibly “dusty” or “smelly” environments?</u>

The difficulty is that many farm contaminants are not visible (dusts which are in the inhalable particle size range and only become visible only under certain conditions, such as with the "Tyndal effect" when a light beam through a window reflecting off the particles) or have no odour or have a detectable odour above a workplace exposure threshold).

Question 7

This question asked whether farmers would wear a respirator when their knowledge would suggest that it was advisable, even although no visible dust or detectable odours could be detected. While 67% thought they would, there appears to be no direct link between the reasons for doing so in terms of respiratory disease (see responses to Question 4 - Little awareness of occupational respiratory disease), but more with the direct immediate effect of agrichemical usage. It is worthy to note that even under the conditions posed in the question, 33% said they would still <u>not</u> wear a respirator (see Figure below).

Figure 8.12: Consideration to wear a respirator in situations where dust could not be seen or smelled, but knowledge would suggest advisability?



<u>Figure 8.12: Considerations to wear a respirator in situations where dust could not be seen or smelled, but knowledge would suggest advisability?</u>

This finding poses a number of key questions for legislators and others. Agriculture in New Zealand employs one of the largest numbers of people (about 10% of the total workforce), a third of whom would still not wear a respirator under ideal conditions, that is, knowledge available and suitable equipment options.

Whether farmers would wear respiratory protection when even they said they would may be open to question. (The questionnaire was written by a representative who could have been identified as from ACC and many farmers would probably respond in the manner they perceived that the organisation wanted to hear). Even in urban engineering enterprises, in a survey of 299 organisations visited by the NZ Department of Labour in 2002, 69% used respiratory protection in welding applications (a well known respiratory risk in the industry), of which only 22 (1% of the total) had chosen an effective respirator.[545]

Question 8

This specific question related to the practices by farmers when working in confined spaces. About 56% said that they would wear a respirator, but many made comments that would suggest that knowledge about what a confined space was is limited. Nearly all farms have these on their property, for example, milking vats or pits. In New Zealand there have been deaths from farmers and other occupational groups in confined space situations, usually also involving the partner and even children-usually as a result of rescue attempts.**Refs** It may be that the risks of working in confined spaces are not recognised by this community.

While 56% of respondents said they would wear respiratory protection, 44% would not (see Figure below).

Figure 8.13: Wearing respiratory protection in confined spaces

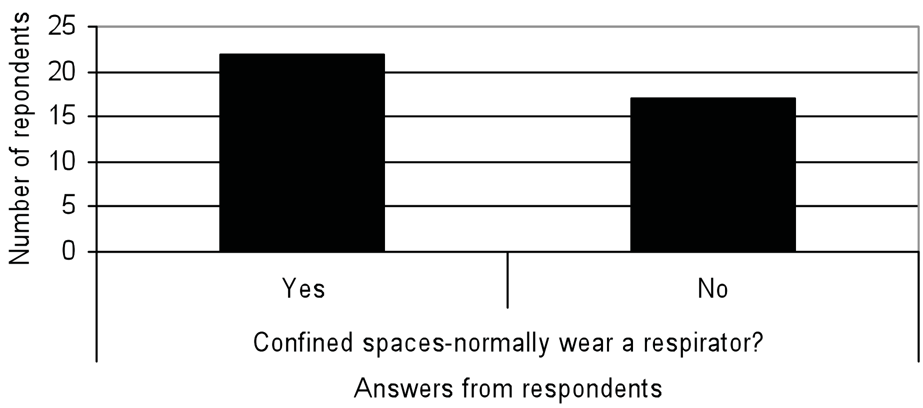


Figure 8.13: Wearing a respiratory protection in confined spaces.

This is a real concern and probably not recognised by Government agencies working in this field. While confined space entry procedures are thought to be widely known and adhered to in industry, on farms there appears to be limited awareness of the risks involved. Information and advice related to confined spaces on farms are widely publicised and promoted by both the ACC and OSH in New Zealand, but appear to be widely ignored.

In a study conducted in 2002 by the Department of Labour concerning the adherence of 299 urban engineering organisations employing welders, only 30% had adequate information about welding in confined spaces and only 50% of those using respiratory protection could have said to have made effective choices.

In some farm applications, for example, milking vats, automated cleaning facilities that clean the vats holding the milk for collection is becoming more common. However, there are other situations, for example, wheat bins or pits where it is still necessary to enter a confined space area.

About 10% of all general work-related fatalities involve a confined space area, many of which are on farms and often more than one person is involved.[546] Confined space precautions are well recognized in industry, yet almost all respondents in this survey gave incorrect responses to the question.

Question 9

The question asked what type of respirator would normally be used by the farmer when working in confined spaces. The answers to this question were particularly interesting. In industry the issue of confined spaces is treated with care and there is a great deal of formal recommendations covering their use. No such guidance appears to be available to farmers.

On New Zealand farms, 38% of farmers suggested that a disposable respirator was the appropriate form of respiratory protection and 36% recommended half-face rubber respirator protection. None recommended air line protection or SCBA - the only types of respiratory equipment recommended by the NZ Department of Labour Occupational Health and Safety Service and others. A further 21% did not use any type of respiratory protection at all (see Figure below).

Figure 8.14: When working in confined spaces, what type of respirator would normally be worn?

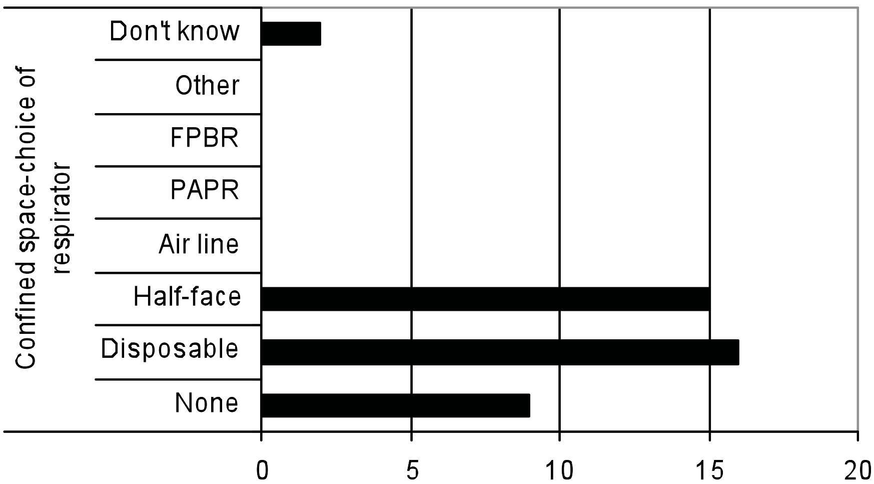


Figure 8.14: When working in confined spaces, what type of respirator would normally be worn?

In spite of all the public awareness campaigns over the years, the links between exposure, control of exposure and health problems does not appear to have been understood by the agricultural community. Specific requirements related to precautions to be taken in confined spaces have not been understood by this community. This is in spite of numerous education campaigns and issues of advisory pamphlets and other resources by both the New Zealand Department of Labour and the Accident Compensation Corporation.

Examples of confined spaces on farms abound. Milk vats are used on every dairy farm to hold the milk prior to collection by the tanker. These have to be cleaned regularly. There is usually a small utility-hole at the side and top of each tank. These are clearly a confined space environments according to New Zealand regulations and guidance on confined spaces.

Question 10

The question asked if information was readily available about respiratory disease on farms, would it be read and action taken to reduce the possibility of disease.

The answers to this question are in direct conflict with the responses obtained to date. All the respondents said that they would take action if the correct information related to respiratory protection was available, yet none took any action on the recommended practices as regarding confined spaces or occupational disease. All the respondents said that they would take action on the information if it was supplied to them albeit this is considered unlikely. A great deal of information has in the past been supplied to reduce occupational disease to farmers by various agencies but there appears to be still a significant gap between knowledge and application. This gap in practices has been noticed by other researchers, that is, simply supplying information is inadequate. The farmer needs to be involved , for example, in formal discussion groups, farm visits or some other way and direct person to person contact is preferred by this group.[508]

Question 11

In response to this questionnaire, 56% said that they were aware of the limitations of wearing respiratory equipment, that is, the effect of beards or moustaches on the face fit which would allow contaminated air into the respirator. Anecdotal evidence over the years would suggest that the limitations of wearing respiratory equipment are not widely understood. Approximately 43% of respondents said that they were not aware of the limitations of facial hair (see Figure below).

Figure 8.15: Respondent awareness of the limitations of Respiratory Protective equipment

Figure 8.15: Respondent awareness of the limitations of Respiratory Protective Equipment.

This is of concern as the respirator worn would provide little or no respiratory protection while they may believe that it does and take risks that they might otherwise not take. Anecdotal evidence in industry in general would suggest that the limitations are not understood by a much larger percentage of the working population in New Zealand.

Question 12

This question asked what consideration was most important to the respondent, price of the RPE, comfort, ease of maintenance or health and safety.

This question was trying to probe the relative importance placed by the agricultural community on respiratory health and the cost of the equipment. In general, simple disposable types of respiratory equipment are cheap but provide limited protection (that is, the face seal is insufficient or the respirator will allow gases or particulates through the unit). More comprehensive and expensive equipment will provide a better face seal (which can be verified by the wearer), but require more maintenance and understanding of the equipment itself such as the need to replace cartridges. Often the practical choices are related to price or protection, assuming that other means of reducing the risk of inhalation risk (elimination or isolation) are not possible (se Figure below).

Figure 8.16: Most important consideration when purchasing Respiratory Protective Equipment (RPE)

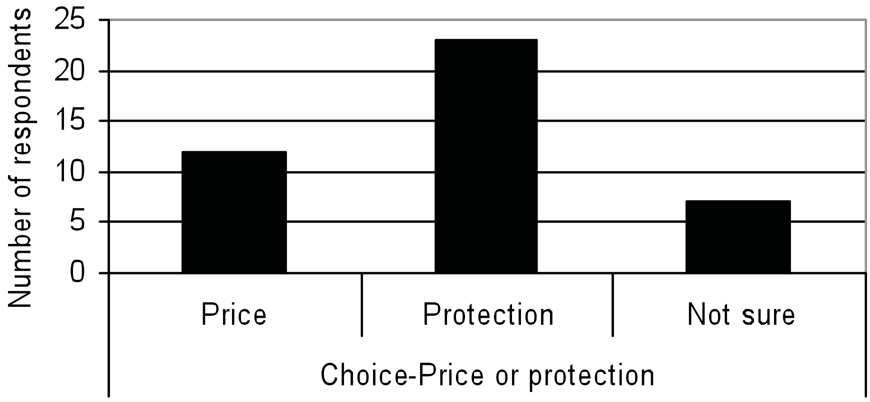


Figure 8.16: Most important consideration when purchasing Respiratory Protective Equipment (RPE).

Question 13

This question asked whether the farmers thought that the type of respirator and cartridge to purchase was a difficult choice in practice. There are many considerations in the purchase of respiratory protective equipment, much of which is necessarily technical and some of which requires specialised knowledge.

About half the respondents said they found the choice difficult (see Figure below).

Figure 8.17: Difficulty in purchasing choice of respirator and cartridge

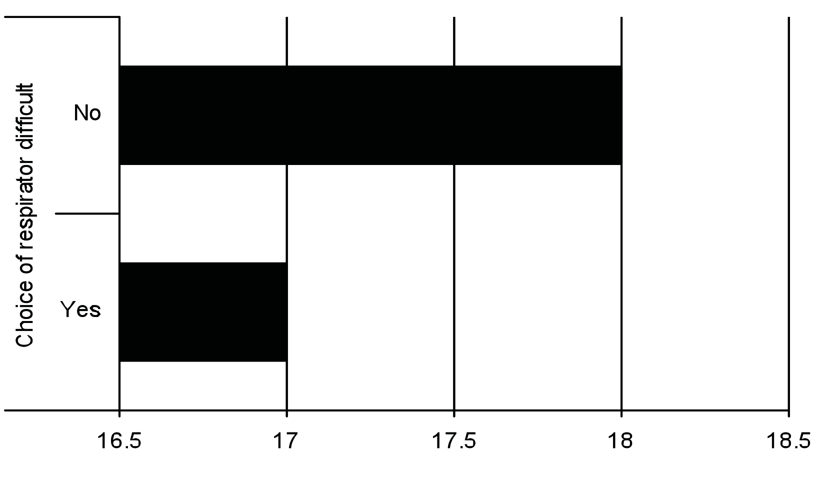


Figure 8.17: Difficulty in purchasing choice of respirator and cartridge.

Comments received back would indicate that there is considerable confusion. A number of farmers commented that they thought the information should be more readily available and one commented that just completing the questionnaire had raised their awareness of the issues.

In general, most farmers received their advice from the retailer. The latter group have been found to often lack the knowledge to give this advice which has given rise to legislation in New Zealand. The group that thought that the choice was not difficult are likely to be underestimating the complexity of the subject.

Unless the difficulties of the different types of agrichemicals, exposure data and appropriate types of respiratory protection are known to the farmer, the choice of protection will be limited. Information will be possible from reading appropriate literature, contact with other farmers, information and advice from bodies such as the MAF (Ministry of Agriculture and Forestry), OSH and ACC or the distributor of the equipment. As most farmers appear to get their information from the distributor, the choice of equipment offered may be very narrow, that is, the knowledge of agrichemicals and personal protection required by distributors in the field is normally limited in New Zealand. It may be useful for Government agencies to upskill the knowledge of distributors as the first point of contact with farmers (usually when they purchase other farm needs). This would have to be done on an impartial basis with no particular bias of equipment manufacturer.

Question 14

This question tried to determine where farmers got most of their information in regard to respirator selection. Most respondents said that they obtained their information from the distributor. Other sources of information are other farmers and lastly, Government departments such as ACC and OSH (see Figure below).

Figure 8.18: Sources of information about respiratory protection for the farmer

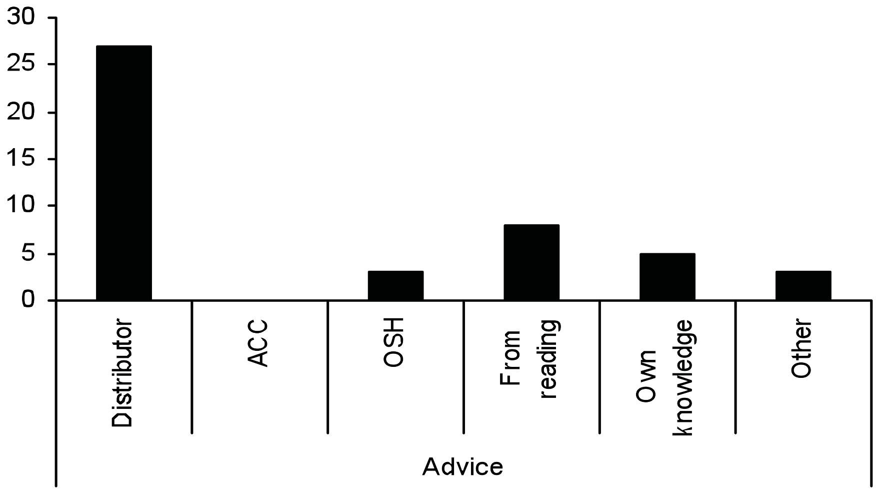


Figure 8.18: Sources of information about respiratory protection for the farmer.

Most farmers purchase personal protective equipment as well as other farm requirements on regular visits into town to obtain supplies. They would normally purchase replacement equipment unless there was information that would require a change, such as price (“specials”) or advice that a particular product (including PPE) that was “better” or innovative products that would make the farming role simpler. Similar concepts are employed at agricultural fieldays which are popular with farmers. It is also a chance to socialise with others in the agricultural community.

There is often a conflict of interest in distributors promoting a particular product or service since they are required to promote their own organisation's stance or products to the agricultural community. While independent publications or video materials highlighting particular safety or health issues can be circulated through distributors, farmers in general, similar to most self-employed people, do not favour extensive reading of publications outside immediate application to a particular need. Most farmers prefer direct one-to-one contact and word or mouth exchange of information. However, generally, representatives of equipment and materials distributors have little knowledge of toxicology, agrichemicals, MSDSs, occupational hygiene or respiratory protection. In the main, sales staff do not have to undertake any formal training or education and the emphasis is generally on achieving sales outputs of a particular product range.

The New Zealand FarmSafe program (local seminars on agricultural health and safety at which over 11,000 farmers have participated in the first year and is now the largest agricultural intervention program in the OECD group) as well as the GrowSafe program (focussing on horticultural health and safety) allow for almost a one-to-one contact with the farming community. They also allow for interaction between farmers. This may be one of the effective means to distribute information on respiratory protection and its selection.[†]

The challenge is that farmers do not currently perceive respiratory protection to be a critical issue and this perception needs to be altered if there is to be an improvement in equipment use and disease reduction. Farmers are generally more concerned with the immediate impact of

---

[†] The ACC prepared a 30 minute documentary which was screened on Sky Digital TV Channel 90 in August 2005 related to the use of respiratory protection, particularly in agriculture. This program screened a number of times a day during

traumatic events such as kicks from animals or tractor accidents or overturns from ATVs (All Terrain Vehicles). These events inhibit the development of safer farm practices and in some cases, prevent farming altogether and hence immediate income. In this environment, obtaining sound information and implementing practices that prevent long-term occupational disease do not appear to be priorities.

Question 15

This question asked from the farmers themselves what they thought the barrier to the wearing of respiratory equipment was. Comfort of RPE was raised by 76% of the respondents, which is a very large response rate, while a lack of knowledge was the next barrier thought to be most important. Farmers commented that they thought inadequate information was available and that the delay between exposure and ill health was a further practical barrier (see Figure below).

Figure 8.19: Barriers to wearing respiratory equipment by farmers in New Zealand

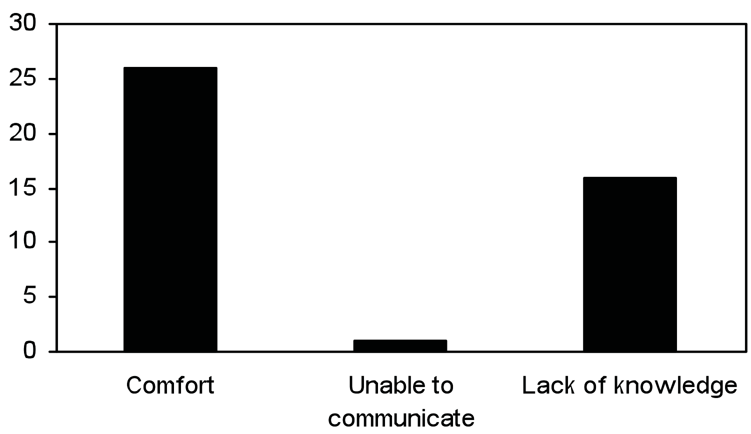


Figure 8.19: Barriers to wearing respiratory equipment by farmers in New Zealand.

This response was not unexpected and was one of the reasons why the wearing of PPE and minimisation of the exposure is recommended as a last resort after elimination and isolation of the contaminant. This barrier

the month The aim was to raise awareness of correct respiratory protection by farmers in New Zealand.

was also seen in the aluminium smelting industry, particularly when people were required to wear a respirator for an extended period of time.[†]

Recognition of this and other barriers gave the impetus to the work in the first three case studies outlined in this thesis. In general, these reasons are genuine barriers to the wearing of any type of respirator by workers in both the agricultural and industrial sectors.

Removal of these barriers is likely to be one of the most significant practical steps that can be taken to encourage correct and long-term use of respiratory protection and to decrease the potential for the reduction of occupational respiratory disease.

Question 16

This question asked how often farmers disposed of the different types of respirators and cartridges used on the farm.

This was a difficult question for most farmers to respond to as many different types and labels might not have been understood. Disposable respirators are required to be immediately disposed off after use but many did not appear to do so. Filters on half-face respirators were changed even less frequently than once per season. Depending on the type of contaminant it is unlikely that the filters would be effective after more than a season's use (for example, the recommended shelf life of an unused filter is about six months), particularly gas filters exposed to the ambient atmosphere.

The responses specifically were:

Disposable respirators

Only 11% (two respondents) said they changed their disposable respirators every day, 18% said they changed their respirator once per week while 24% said they changed the respirator one per month. The

---

† Respiratory protection was introduced into the New Zealand aluminium smelting industry in 1985. This is a 24-hour, 2 shift operation of 12 hours per shift. It

majority (55%) said they changed them less frequently than this (see Figure below).

Figure 8.20: Response to the question as to how often disposable respirators were disposed of

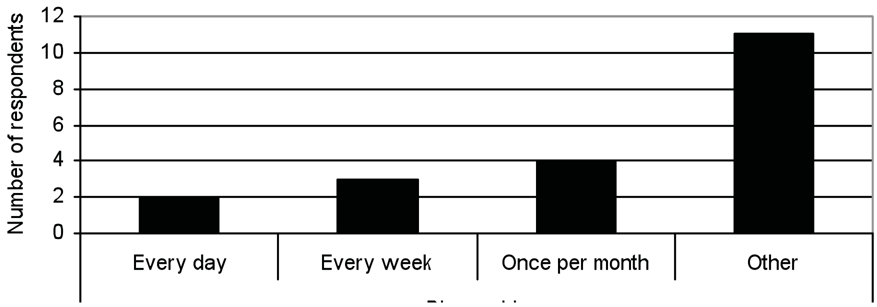


Figure 8.20: Response to the question as to how often the disposable respirators were disposed of.

The responses are of concern in terms of the likelihood of incomplete and inadequate respiratory protection for farmers.

It may be that the question was not understood by the target group, that is, the distinction between the different types of respirators was not known and needed to be explained.

Disposable respirators are normally used by dairy farmers in such areas as the milking shed when mixing caustic chemicals. When working with agrichemicals such as fertilisers, half-face respirators are often used.

Half-face respirators

Only 13% said they changed their respirator cartridges once per month, while 41% said they changed them once per season. The remaining respondents changed them less frequently than this (see Figure below).

---

quickly became evident that wearing this type of equipment for extended periods of time was almost impossible for wearers.

Figure 8.21: Response to the question as to how often half-face cartridges or filters were disposed of

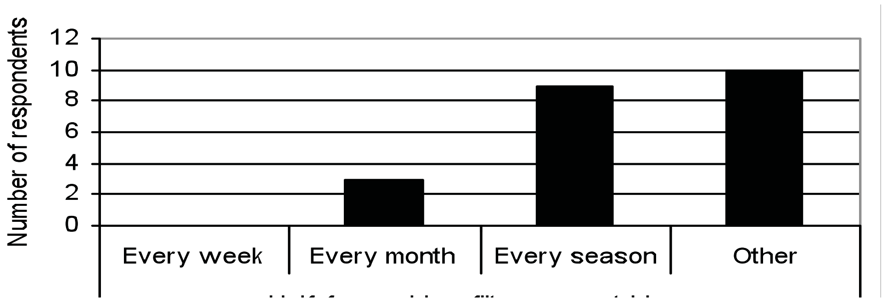


Figure 8.21: Response to the question as to how often half-face cartridges or filters were disposed of.

Considering that respirators are not normally well maintained or stored on farms, the likelihood of incomplete and inadequate respiratory protection is high.

It is also possible that the question was also not well understood, that is, that the distinction between the different respirators types and cartridges was not identified by farmers.

Full-face respirators

There were so few respondents that replied to this question (a total of seven) that this question was not analysed further (see Figure below).

Figure 8.22: Response to the question as to how often full-face cartridges or filters were disposed of

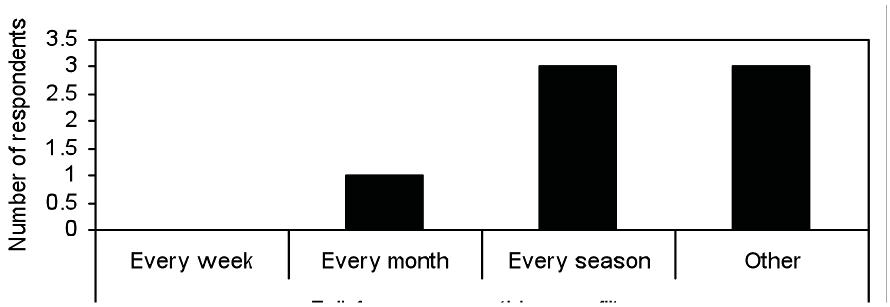


Figure 8.22: Response to the question as to how often full-face cartridges or filters were disposed of.

It may be that the question was not understood or that very few farmers use this type of equipment on farm. However, full face respirators are recommended PPE (personal protective equipment) for some agrichemicals.

Question 17

This question asked only how often farmers disposed of respirators, after each time worn, after six months or less often. The question did not ask for the type of respirator and was therefore a lot simpler to answer than the previous, more detailed question.

The responses were similar to that obtained above. Out of the 22 farmers who responded, 68% said they changed the respirator less than at 6 monthly intervals, while 22% said they changed the cartridges every 6 months (see below).

Figure 8.23: How often are cartridges or filters disposed of?

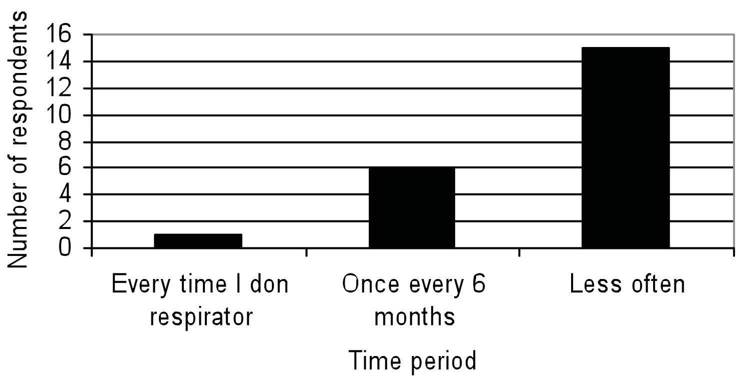


Figure 8.23: How often are cartridges or filters disposed of?

The results indicate a significant health and safety problem. The importance of respiratory protection by the agricultural community appears to be not well understood or practiced.

Unless respirators are well maintained, cartridges replaced regularly (depending on time worn and exposure to contaminants and a number of other variables) and respirators stored in an air-tight container, as well as being worn correctly and fit tested, it is unlikely that the equipment will perform as intended.

8.3.3 First Questionnaire Survey:

8.3.4 First Questionnaire Survey:

Main findings

There appears to be a considerable lack of knowledge and practical experience of respiratory protection, occupational respiratory disease and confined space entry requirements in the agricultural community. This is in spite of the large volume of detailed information that is available through both ACC and OSH, both websites and numerous publications distributed over many years at such events as agricultural field days throughout New Zealand at different times of the year.

The results of this survey suggest that little of the literature has any serious impact at present on the target group. However, the FarmSafe program, at which the second questionnaire was distributed has been and continues to be independently evaluated. This relies on small groups of local farmers getting together and discussing key interventions in the farming community.

The questionnaire was posted or handed to the farmer by the local Federated Farmers of NZ Inc representative. In all cases, the form was completed by the female partner rather than the farmer himself. This suggests that much of the paperwork on the farm is completed by the spouse. This may have meant that the person completing the farm work and using the respiratory equipment was not the person who completed the questionnaire. This is an aspect that has not been noted before in any other survey and may have previously been overlooked but be critical to gaining correct insights.

Limitations

While some reasonable findings were identified in the first survey, there were a number of limitations which became evident as a result of posting the questionnaire out to farmers through the National and Regional Offices of Federated Farmers of NZ Inc. These included poor selection of means of questionnaire distribution, the target respondents (farmer's partners instead of the farmer), low response rate, lack of incentive to complete the survey, lack of follow-up, the wording of some questions, and so forth.

The questionnaires (120) in the first survey were posted out to farmers through regional Federated Farmers of NZ Inc offices after being distributed by the national office. A self-addressed and stamped envelope was enclosed. A total of 41 were returned by post to the author for analysis.

In general, surveys sent by post to farmers have been followed by extensive follow-up, for example, subsequent telephone calls or letters. This was not done in this survey and only surveys completed were subsequently analysed. It may be that this group is a self-selecting group in that they were sufficiently interested in the topic or felt compelled to answer the survey for other reasons as compared against the group of farmers that did not respond. Therefore, it cannot be stated with any certainty that this group were representative of the farming community from which they were drawn.

A higher rate of return may also have been gained by the use of incentive such as a prize draw. While the rate of return appears to be normal for this kind of voluntary postal survey, different types of farmers (for example, dairy or sheep and beef) returned the survey. These distinct groups had different perspectives on respiratory protection and also used the protective equipment in different ways. Agriculture is a variety of different types businesses and the range of requirements can be very varied. All of these different businesses have needs for many different types of respiratory protection as well as different types of equipment.

In addition, because of international marketing requirements such as Eurogat, there are significant health and safety requirements imposed on producers (requirements are becoming increasingly stringent - for example, it must be shown that the farm animals have been raised in a humane way and that people associated with the raising of the animal have complied with reasonable health and safety requirements).

Different geographic areas of New Zealand predominate in certain types of farming (for example, dairy farming in Southland or kiwi fruit growing in Northland), and the knowledge of respiratory protection may be varied according to external requirements placed on farmers, for example, attendance at GrowSafe courses or Eurogat requirements for exporting produce to Europe. As insufficient number of responses were obtained to complete a separate survey for each agricultural sector (for example, dairying versus kiwi fruit growing) the responses were aggregated. By doing so, information has been lost. It is probable that the different groups have different perspectives and insights into respiratory disease, agrichemicals and respiratory protection.

The questionnaire did not give a detailed introduction as to the reasons for the interest in occupational respiratory disease in the agricultural population of New Zealand.[†] This has been found useful in other settings and may have increased the return rate.

The first questionnnaire, because of the low response rate of about 20% and the relatively limited number of replies received was used to evaluate the type of responses received and to determine whether the questions were able to be largely understood by the target audience.

These limitations were taken into account in the preparation of the second questionnaire (the second part of this work). The second questionnaire was distributed, completed and collected from farmers at the end of a FarmSafe seminar. The latter survey close was completed

---

† There are different points of view on this. Farmers in NZ receive about 1.5 kg of written material per week and most remains unread due to time constraints as well as other reasons.

by the practicing farmer rather than the administrative partner to an almost 100% return rate as the responses were completed at the end of the FarmSafe seminar prior to respondents leaving.

It is likely that the respondents themselves are a group that is more concerned about the issue of occupational respiratory disease than other farmers, that is, they are a select group with others following or lagging in opinion. Even the likely more concerned group however, had limited awareness or concerns related to occupational respiratory disease and prevention, including the requirements for the safe entry and use of confined spaces.

There have been very few studies in New Zealand that have attempted to gain insights into the practices of farmers with regards to awareness and practices related to occupational disease and none that could be found that relied solely on a postal survey. The most recent postal study was that of Firth, McBride, Feyer, Herbison, Eason and Wright (2000)[547] in the Southland district of New Zealand but this was followed by a telephone call by an occupational health nurse. Using this approach, a 65.4% return rate was received.

Discussion

There is little recent research into the beliefs and understanding of farmers in relation to occupational respiratory disease and the appropriate respiratory protection in New Zealand or elsewhere. Most researchers investigating respiratory protection appear also to assume that once farmers wear any kind of respiratory protection that the group under study have a lower exposure to agrichemicals and other airborne hazards than the control group, but depending on how the equipment is maintained and worn, this may not be the case. Judging by the responses received in this pilot survey, few farmers maintain respiratory equipment (if worn at all) or change cartridges or filters as required. It is likely that true exposure is much higher than thought or assumed, even when respiratory protective equipment is worn.

A higher response rate would have been preferable but it is believed that the responses received are typical of the farming communities response rate internationally using the postal survey employed in this first questionnaire.

A recent report on the estimated incidence of occupational injury and disease in New Zealand estimates that there are about 700-1000 deaths annually from occupational disease, principally cancer, respiratory disease and ischaemic heart disease with 17,000-20,000 new cases determined annually. A significant major occupational group affected are sectors of farming.[548] The prevention of occupationally respiratory disease is of significance to both legislators concerned with preventing disease, the farmers themselves and the agricultural sector as a whole.

The numbers of returned questionnaires as well as the responses to some of the questions may suggest that the issue of occupational respiratory disease and respiratory protection is not one of major concern to the target group at present. However, there is major concern (see the recent report quoted above) with occupational diseases among farmers by legislators and the New Zealand Government.[548] It is likely that considerable efforts and public funding will be devoted in the immediate future to reduce the future burden and raise the awareness.

Peer influence (what other farmers consider important) and case studies (the practical experience of other farmers) may be the most effective means of communicating educational messages to the target groups.

There are many ways of communicating the importance of the topic such as fridge magnets or sticky labels such as “confined space” stickers commonly supplied freely to industry. There are existing ACC and OSH literature products that have been freely circulated to farmers in large amounts (thousands) at field-days and other agricultural events that describe the need for respiratory protection. The difficulty is that there is little evidence or evaluation that these are responded to by farmers. In New Zealand, farmers receive about 1.5 kg of promotional mail a week and anecdotal evidence is that most is discarded.

In any event, it is suspected by the ACC Communication and Marketing Division that the most powerful tool to reach an audience in farming is likely through television. To this aim, DVDs prepared by the ACC with a TV station, Southland TV in 2005 and was screened through the Sky Digital Channel 90 network. The program was screened at least once per day for a month in August 2005, and are believed to have had some impact.

In the New Zealand “FarmSafe” program in which over 600 seminars have been conducted around New Zealand, over 11,000 farmers have participated and it is now the largest agricultural intervention program ever undertaken in this country. It appears that there is some concern by farmers with regard to occupational safety, but this may be largely due to concerns as an employer since nearly all farms employ labour if only for a very short period of time (for example, during peak periods or contract labour). Independent evaluation of this program by the New Zealand Injury Prevention Unit of the Otago University Medical School in Dunedin has shown that over 75% of farmers who attend the FarmSafe program make changes back on the farm to reduce the risk of injury.

Farmers who responded to this voluntary survey were all experienced farmers. As such their views are probably well held beliefs and evidence of the practical application of respiratory equipment. It appears that beliefs are well entrenched in the agricultural community.

Government agencies concerned with farmer welfare need to take heed of the lack of knowledge and application of respiratory equipment for on-farm applications to prevent deaths from confined spaces or respiratory disease.

Difficulties with the respondents answering the questions was noted (for example, questions related to the type of respirator used). Also, categorising farmers in one classification of farming is sometimes problematic as farmers may run different farming operations.

The response to Question 15 (barriers to wearing respiratory protection) would suggest that the importance of comfort and other requirements of users need to be explored in more detail if occupational groups are to be encouraged to wear correct respiratory protection. The practical needs of wearers, some of whom are required to wear the equipment for extended periods of time (for example, 10 or 12 hours) may be not necessarily be the main focus of respirator manufacturers. Similar concerns have been expressed by other occupational groups. The ability of users to wear RPE, particularly for increasing periods of time (e.g., shift work today is often 12 hours instead of 8 hours), is important. Barriers can include discomfort issues such as facial heating and breath condensation or insufficient delivered air supply in the case of a PAPR). The typical types of barriers have been described earlier in this thesis.

The recognised "hierachy of controls, that is, elimination, isolation and minimisation" of contaminants does not appear to be widely practiced, for example, seeking alternative and less harmful products or enclosing the cab from airborne contaminants rather than PPE.

There are numerous ways to introduce and implement the subject of respiratory protection in the agricultural community. Practical assistance with purchasing of equipment at point of sale by ACC may be one option and at the same time, additional information can be transmitted, for example, literature or fridge magnets.

Most farmers indicated that respiratory protection was not an issue (72%) for them, in spite of the recent published information from researchers working in this field and the advise of Government agencies such as ACC or OSH in New Zealand and distributors of agrichemicals and others. The reports (described previously) indicate a higher than average incidence of occupational asthma in certain sectors of the agricultural community. Airborne monitoring in farms in Southland (primarily dairy farms) have also shown high concentrations of particulates in specific operations on farms.

Standards such as AS/NZ 1715 and 1716:2004 are very important as they set the minimum standards for the operation of respiratory protection in the workplace. The requirements of the Standards could be usefully summarised in a leaflet or brochure specifically targeted at each of the agricultural sectors. This could address some of the key issues such as the need to maintain the different types of respirators and the need to requirement cartridges at regular intervals because of their limited life span. This kind of information distribution would have to be supported by other awareness raising efforts such as TV and radio promotion.

There appears to be a need (pointed out by a number of farmers) about occupational disease and respiratory protection. A number of farmers responded that by even filling out the questionnaire, that their awareness of the issues had been raised.

Recent media attention related to the New Zealand HSNO (Hazardous Substances and New Organisms) Act and practices related to agricultural practices may lead to increased awareness of the need for respiratory and other practices on the farm. Under the New Zealand Hazardous Substances and New Organisms Act and subsequent requirements under this Act, there is a requirement that farmers handling most common agrichemicals must hold a “certified handler” certificate by January 2007. Training for this is conducted by the FarmSafe program and includes topics related to PPE and RPE. It is likely though, that the level of knowledge and insight by the trainers is limited at the present time and ACC is currently reviewing the training of the trainers to ensure that sufficient technical knowledge is being provided. In addition, it is hoped that the publications of the NZIPS (New Zealand Injury Prevention Strategy) and “action timelines” will increase attention on the need to improve attention to such issues as respiratory protection.

The Agrarian myth continues to dominate much of New Zealand agriculture with farmers generally unconcerned about occupational respiratory disease. While the concerns about this and other occupational safety and health issues expressed in recent efforts such as those of the NZIPS and the HSNO Act, other work will be necessary to raise attention to the prevention of occupational respiratory disease in agriculture.

On the basis of the results and experience gained in the first survey, the second questionnaire survey was commenced which utilised a different approach.

8.3.5 Second Questionnaire Survey

On the basis of the relatively low return rate of the first questionnaire and results received from the first questionnaire, the second questionnaire was distributed at the FarmSafe seminars held throughout New Zealand in 2004. Farmers were asked to respond at the end of the seminar and the purpose of the questionnaire explained to them. This methodology ensured an almost 100% response rate.

The second survey took into account issues raised with the first questionnaire such as the difficulties farmers had in responding to the type of respirator used as many did not know the differences between different types of equipment and their purpose.

The second survey was different from the first and raised an important issue from the perspective of any agricultural survey. While the first was a postal survey which was in fact, largely completed by the farm partner (often the female partner on the farm), the second survey was completed by the participant on a FarmSafe program (normally the male partner concerned with practical day-to-day hands-on farming). The responses shown are different and some comments on the likely impact are given. The difference in likely responses (that is, postal surveys being completed by the administrative partner on the farm, while the “on-farm farmer” does not complete the survey) has significant implications for future surveys in the agricultural sector.

8.3.6 Second Questionnaire Survey: Results

Question 1

In the previous survey, almost all the respondents were from sheep and beef farm operations. This is surprising, since the survey distributed by Federated Farmers of NZ primarily focuses on dairy farms in New Zealand. The second survey with over a 100 respondents gives a more representative response from a wider distribution of farm types and includes a wider representation from the dairy sector (see Figure below).

Figure 8.24: What type of farm best describes the one you are working on

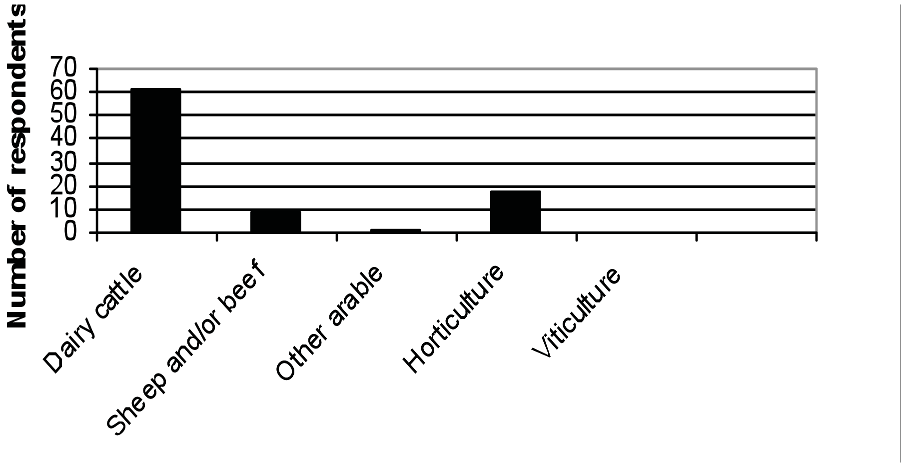


Figure 8.24: What type of farm best desribes the one you are working on?

Most of the respondents (over 60) were from dairy farms. These are typically a “husband and wife” type operation, that is, both family partners are actively involved in the operation of the farm. In this respect, this differs from sheep and beef or horticultural farms.

Dairy farmers regularly enter milk vats for cleaning. These are classified as confined spaces, often with removable side utility-covers for entry. No respiratory protection is generally used, but if it is considered, is limited to half-face disposable respirators or half-face rubber respirators (which would not assist in providing fresh air in a low oxygen environment). There is a need by Government agencies to address this issue as the risk of fatality, and possibly, multiple fatality, is present. Modern milk vats tend to have automated cleaning equipment which does not require daily entry into the vats, although manual cleaning may still be required periodically. The issue of confined space precautions by farmers is discussed in more detail below.

Horticultural farmers have often attended the New Zealand GrowSafe seminars and are more likely to be conscious of respiratory protection because of the application of insecticides and pesticides common in this type of business.

There may be an association between age and the wearing of PPE. Many younger farmers wear, for example, noise attenuators, mainly as a result of having attended agricultural training programs such as those by the AgITO (Agricultural Industry Training Organisation) in New Zealand which today focus on aspects of occupational health and safety in farming.

Question 2

Most of the respondents were the owner or part-owner of the farm. This may have influenced the responses as farm managers or the farm workers who have little long-term financial stake, ownership or long-term stake in the farming industry may respond differently in this type of questionnaire.

Dairy farmers are generally in a share-milker situation, that is, they have ownership of the stock while the owner manages the farm. The two businesses are separate, that is, not a contract employment relationship. Generally, the sharemilker would manage the operation such as cleaning the vessels, while the farmer would spread fertiliser and other agrichemicals. The responses may vary according to the type of chemicals being used and the questionnaire was not able to distinguish between these.

Farm workers today often attend farm training courses or programs and may be exposed to the need for PPE and gain other insights which established owners do not. Anecdotally, from farm trainees on farms in New Zealand, this is often a source of conflict on the farm, where farm workers may not be issued with PPE or encouraged to wear these by their peers. In addition, the employer knowledge, insights and behaviour with regards to PPE, including respiratory protection, often determines the approaches taken by others on the farm (that is, as influencers).

Figure 8.25: Type of farm ownership

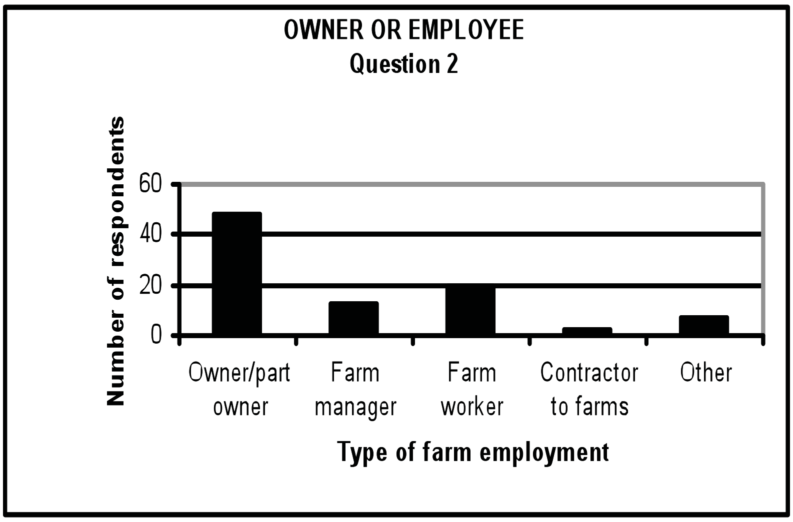


Figure 8.25: Type of farm ownership.

Question 3

The majority of farmers (62%) did not consider respiratory disease to be an issue (see Figure below), although there have been many publications on respiratory risk to farmers in farm literature and in publications by the NZ Department of Labour, ACC and others.

Figure 8.26: Is work related respiratory disease and protection an issue for you?

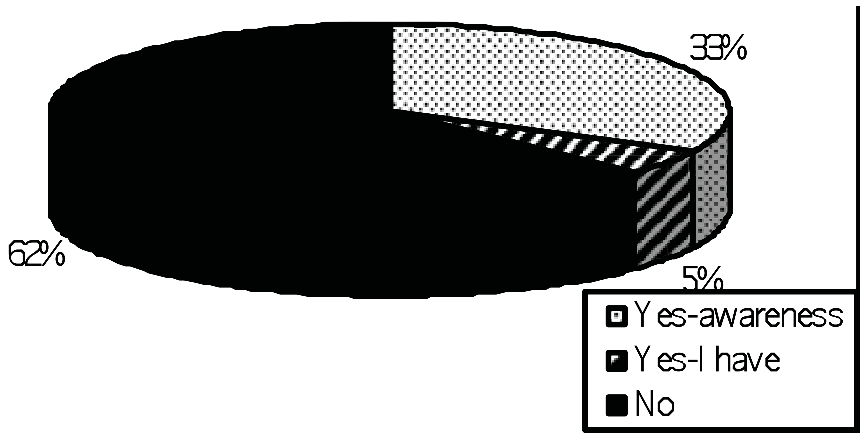


Figure 8.26: Is work related respiratory disease and protection an issue for you?

In most situations, the lack of immediacy of effect (that is, many respiratory diseases may have long latency periods) and the pressure from immediate operational needs results in the risk being ignored in the presence of other more immediate and pressing needs for farmer attention.

The horticultural industry appears to be more conscious and aware than other agricultural sectors. This is probably due to the effects of the GrowSafe program, which emphasis respiratory protection as part of spraying crops with agrichemicals, as well as the requirements of overseas markets such as EuroGat. The latter ensures that people working in New Zealand agriculture have had a minimum level of exposure to risk management principles and that produce has not been grown under "Third World" conditions, for example, employment of children, animals raised in sub-standard conditions or workers exposed to agrichemicals.

Only 33% of respondents thought that respiratory disease was an issue. Most of these people appeared to have personal knowledge of someone close to the family or farm that was affected.

Question 4

The question asked what types of respirator was available on the farm. In general, the most readily available type of respirator was the disposable type, followed by a half-face respirator or none at all (see Figure below).

Figure 8.27: Type of respiratory protection available on the farm

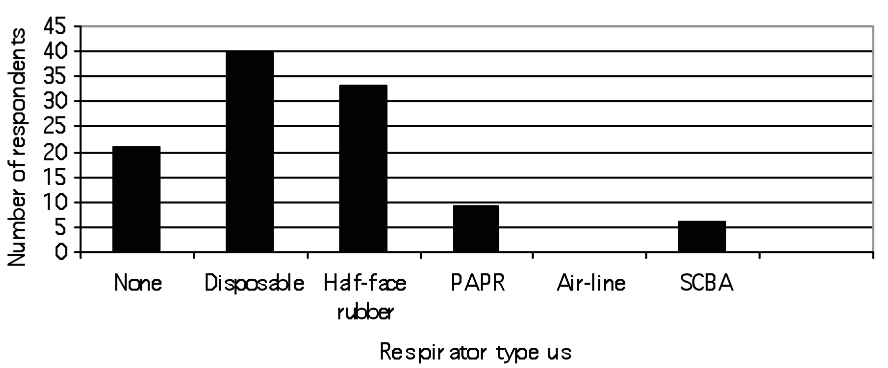


Figure 8.27: Type of protection available on the farm.

The type of respirator chosen and most commonly used may be of concern to legislators, distributors of chemicals and ACC. Disposable respirators are readily available and sold in large quantities throughout

New Zealand in all industry sectors as well as other sectors such as to health. While these currently have the same level of "protection factor" quoted in New Zealand and Australian Standards as the more robust half-face rubber respirators, there are increasing concerns that this may not be correct and that the factor should be dropped to half that of the former.

Limitations of the type of respiratory equipment and the effect on effective protection as a result of lack of training in their use is rarely explained and it is often difficult to do so in practice. For example, farmers may purchase respirators along with other items and the opportunity for a discussion may not be available at the time. It is assumed that the respirator works completely when donned, although it is known that this is not reality. It appears that much better information and distribution of essential information is needed.

Disposable respirators, depending on their classification, are allowed to pass over 20% contaminants directly through or around the respirator. In practice, and particularly without any training, the lack of face seal and the manner in which the respirator is worn will likely result in leakage well in excess of this.

The impact of direct and indirect leakage using protective equipment which the wearer probably believes is protecting completely, has serious implications for those involved in the prevention of respiratory disease in agriculture. There currently appears to be little thought given to the effect of various types leakage of respirators or the effect of wearer fitting errors in the literature.

Question 5

Most of the respondents (23 out of 39 that answered the question) said they would wear a respirator if harmful dusts were present all the time or when warranted (see Figure below).

This may be more of an immediate logical response to the question and less reflecting of the real situation. An explanation of "harmful dusts" was given in the question. Many dusts will not be visible (where they may be of the respirable size range or smaller). Apart from visible harmful dusts, farmers may not be aware of what constitutes harmful particulates, particularly where these are well known materials that the target group comes into contact with frequently, such as wheat dusts or animal products rather than the more identifiable agrichemicals.

Figure 8.28: Consideration to wear a respirator where harmful dusts and gases may be present

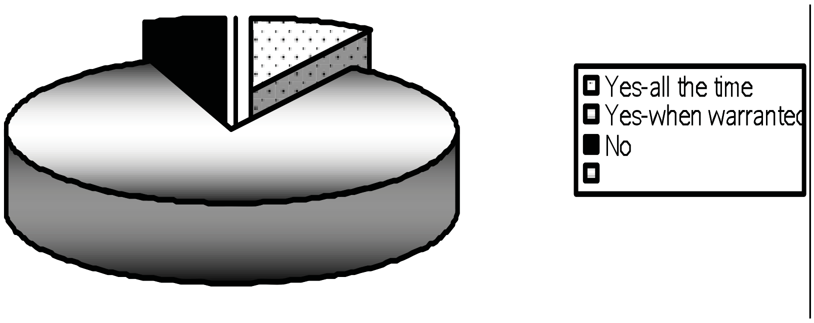


Figure 8.28: Consideration to wear a respirator where harmful dusts and gases may be present.

Question 6(a)

Respondents were asked if they were aware of some of the limitations of wearing respiratory equipment such as the effect of beards or facial hair. Only thirty-eight percent replied that they were aware of the loss of protection due to lack of face seal (see Figure below).

Figure 8.29: Awareness of limitations of respiratory protection

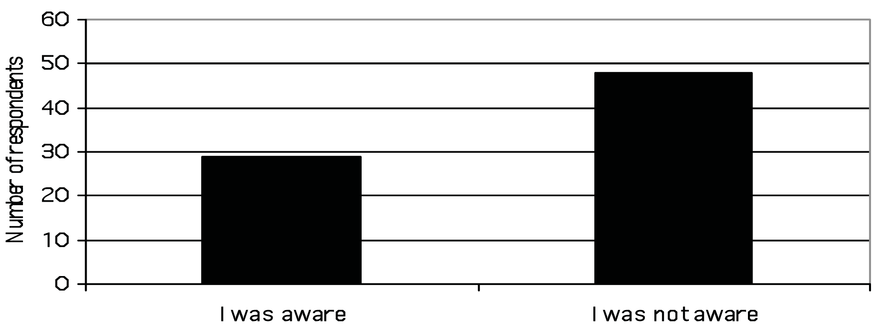


Figure 8.29: Awareness of limitations of respiratory protection.

In the last decade, most distributors have published articles on this particular topic in their magazines, ACC has provided awareness information on their websites as has the NZ OSH.[†] In spite of this, two-thirds of the target group were still not conscious of this limitation and likely other practical issues related to the wearing of respiratory equipment.

This remains a significant concern, and raises issues with Government agencies and legislators as to the need to improve information reaching this group, particularly some sectors of the farming community with higher than average occupational respiratory disease such as asthma (for example, in pig, horse and chicken farm operations). This type of limitation is important-people may expose themselves to respiratory contaminant risk that they otherwise would not.

Question 6(b)

Most people (50 out of the 60 that responded) said that they did not have any formal training in the wearing of respiratory protection. Farmers are geographically isolated and generally do not get together with others with the exception of local social events, sales or field-days. Most organisations, both commercial and non-commercial, tend to use written resources such as leaflets which are mailed or specific agriculturally directed TV programs such as "No. 8 Wire" (a national TV program which screens on weekends). As a direct result, farmers are unlikely to receive training or education in the use of respiratory equipment particularly when the chance of respiratory disease is not perceived as high risk.

Some agricultural sectors are required to attend formal training programs such as Growsafe® in the horticulture (an agricultural sector that extensively use respiratory protection with agrichemicals such as fungicides on fruit crops). Education and training in the use of respiratory equipment is likely to be more successful if it is tied to marketing requirements imposed by sales in an overseas market or similar external

---

† The ACC site receives about 15,000 hits from the agricultural sector each month.

needs. Similar arguments can be held for the EuroGat requirements (that is, producer requirements for exporting primary products to Europe).

Practical limitations in the use of respiratory equipment and the appropriate care and replacement of cartridges are all critical components of any respiratory protection program if protection is to be achieved. It is likely that in practice, only partial or no protection at all, is attained.

Figure 8.30: Formal training in the limitations of respiratory protection

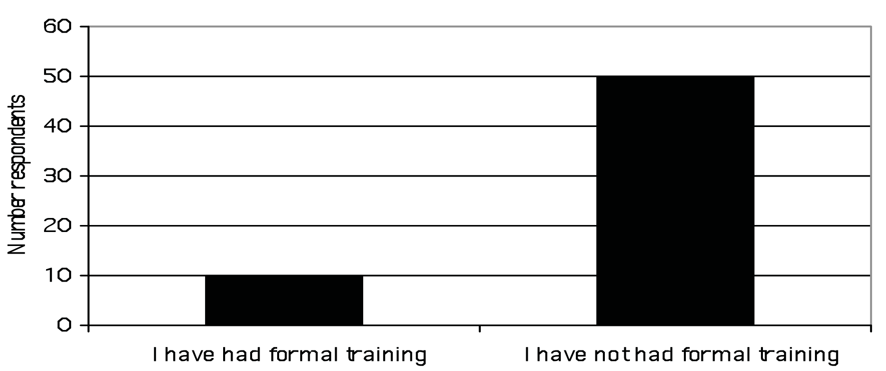


Figure 8.30: Formal training in the limitations of respiratory protection.

Question 7(a)

This three-part question asked the type of respirator would be worn in a number of different applications on the farm.

The first part of the question related to the type of respirators worn in confined spaces on farms.

Confined space environments exist widely on farms (for example, on dairy farms the vats used to hold the milk prior to collection), horticultural operations (containers in packing sheds used to hold products) or pits of various types. Vats such as those used on dairy farms are entered almost daily to be cleaned are confined spaces. In modern sheds the regular cleaning is often automated, albeit from time to time, manual entry is still required. While confined space entry procedures are carefully controlled in industrial sites, on farms little knowledge or procedural precautions are normally encountered.

The responses received from the questionnaire are of concern. Air-line or SCBA are normally recommended in confined space environments as well as air monitoring and other precautions such as a stand-by person in communication contact with the person inside the confined space and many other requirements. However, this was not the preferred respirator selected.

Farmers in general are unaware of the serious risks of entering confined spaces on their farms. Of more concern is the respiratory protection used to enter these areas, that is, those that thought that respiratory protection was not required at all, others thought it was not applicable (24%). Further answers were varied. No respirators were worn by 32% of the respondents, disposable respirators (17%) half-face negative pressure respirators (17%), while the recommended air-line respirators and SCBA equipment encountered for only 7% (see Figure below).

Figure 8.31: Types of respirators normally worn in confined space environments on the farm

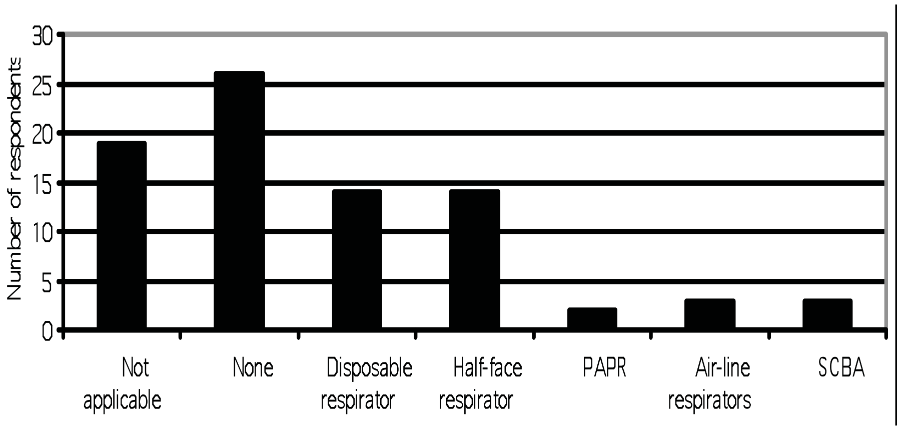


Figure 8.31: Types of respirators normally worn in confined spaces environments on the farm.

While recently concern was expressed by the NZ Department of Labour, in general the problem remains under-recognised by SMEs and self-employed people in an environment where legislation is difficult to enforce.[†] While websites of both ACC and the DOL give specific advice about confined spaces in agriculture, this is generally ignored by the agricultural sector possibly because the risk is not identified as significant particularly when compared against other risks and priorities on the farm as perceived by this group.

Question 7(b)

This part of the question was concerned about the type of respiratory protection worn when mixing agrichemicals on the farm. Depending on the chemicals in use, respiratory protection is generally recommended by the manufacturer of the chemical, and may even recommend specific types. A large number of respondents (42%) said they wore half-face respiratory protection with another 30% said they wore disposable respirators. These responses are surprisingly high which may indicate that the risks are more recognised as a result of publications over the years directed at this target group.

Figure 8.32: Types of respirators worn when mixing agrichemicals

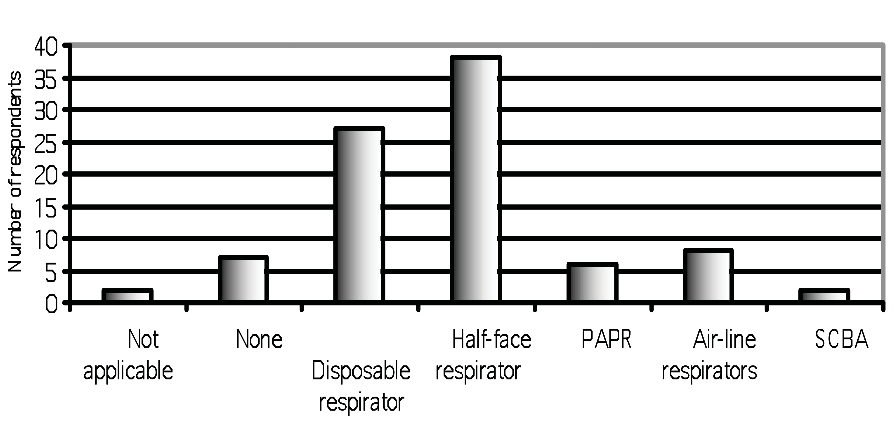


Figure 8.32: Types of respirators worn when mixing chemicals.

Question 7(c)

This question asked what type of respiratory protection was worn during farm operations where respiratory protection would be advisable. The

---

† Personal communication, the DOL, August 2004. The same issue arrises with children on farms where the boundaries between what constitutes a work environment and the home environment is blurred.

disposable respirator still dominates with usage at 46% while another 38% either did not wear a respirator and did not think it was needed (see Figure below).

Figure 8.33: Types of respirators worn in normal farm operations when harmful (vapours, mists) are present

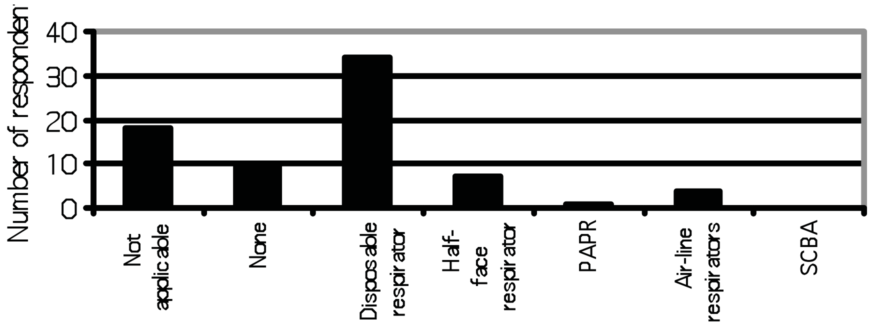


Figure 8.33: Types of respirators worn in normal farm operations when harmful (vapours, mists) are present.

In many farm operations, respiratory protection is recommended, particularly when working in open pits and during specific farm operations such as cleaning out manure in piggeries or mixing chemicals. Many dusts and gases are not directly visible or can be detected by odour and while long-term effects may not be immediate, the direct feedback on the positive effects of wearing respiratory protection may not be evident.

It appears that mostly disposable type respirators were used or in some cases none at all.

This is of concern to legislators and those concerned with the prevention of respiratory disease in agriculture. Many contaminants would be gaseous such as ammonia or hydrogen sulphide and most disposable respirators would be inappropriate in these circumstances.

Question 8

This question related to what farmers thought the barriers to respiratory protection was from their own experience. About 49% thought that comfort issue was a major concern and this is well recognised in this and other industries such as in aluminium smelting (see Figure below).

Figure 8.34: Barriers to wearing respiratory protection

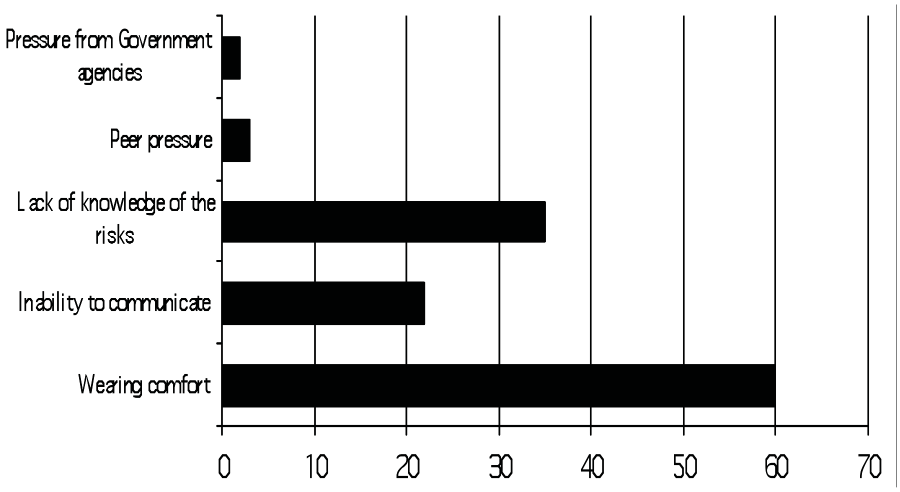


Figure 8.34: Barriers to wearing respiratory protection.

The concern is mostly related to the close fitting of the respirator (some people find it uncomfortable or claustrophobic) and the need to expend energy in drawing air through the respirator filter, particularly when people are working at physically high rates, that is, drawing air at maximum volume and rate through the filter. The barrier can largely be overcome by equipment such as a PAPR (Power Assisted Air Purifying Respirator) or FPBR (Fan Supplied Positive pressure Breath Responsive Respirator) where filtered air is supplied to the wearer. Particularly the PAPR equipment is widely used in the horticultural industry owing to the belief that it provides better protection than a half-mask respirator.

Another 29% of respondents thought that a lack of knowledge of the risks was a major factor as to a barrier to the wearing of respiratory equipment on the farm. This was a significant percentage of the target group who recognised lack of knowledge as an issue. To some extent this barrier could be overcome by promotion of the issue among farmer groups by organisations such as the NZ DOL. ACC claims and associated costs are low at present (respiratory disease claims are more likely in the future with the exception of asbestosis and some specific industry related occupational asthmas) and there is a more general focus on traumatic injuries to farmers. The NZIPS (New Zealand Injury Prevention Strategy) has a strong focus on the prevention of occupational disease and this will help to shift the focus nationally to the prevention of disease rather than only traumatic injuries by a variety of means.

A further 18% of the respondents thought that the inability to communicate with others was a further barrier to the wearing of respirators on the farm. These issues have to some extent been overcome by technology (radio communication devices are an example) but are probably underutilised in workplaces such as New Zealand farms, although common in other workplaces where communication is critical (for example, in the potlines of an aluminium smelter).

Most of these barriers are known, but little serious effort appears to have been made by manufacturers by address the problems for users. Addressing these barriers is however critical so that users will more likely use the equipment when needed.

Question 9

About 59% of the respondents said that they would like to receive more information on the prevention of occupational respiratory disease, while the remainder said they would not (see Figure below).

Figure 8.35: Farmer interested in receiving more information about respiratory diseases and prevention

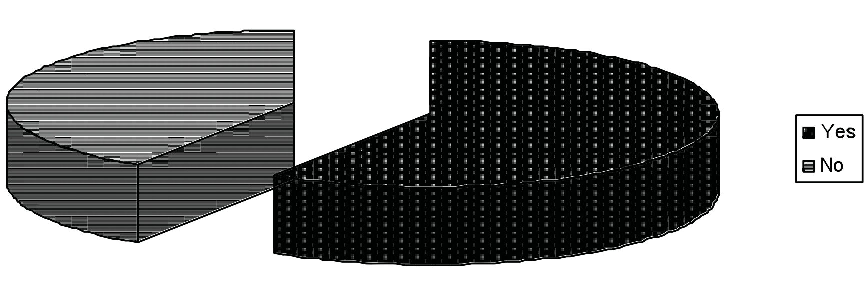


Figure 8.35: Farmer interest in receiving more information about respiratory diseases and prevention.

The large number of respondents who did not want to receive more information would likely suggest that the risks are not generally regarded by this community as significant, which is in agreement with the agrarian myth that persists in New Zealand agriculture. For legislators and educators this result is significant. It is difficult to raise attention and focus on an issue that is not regarded as important by the target group and attention will have to be paid to increasing the importance of the issue in comparison to other risks on the farm-such as income fluctuation which directly affects immediate livelihood. Farmers are also used to taking a long-term view of farm operations as well and will spend current income to improve stock or pasture in the future or plant timber with an income 25 years away. It is in this environment that the occupational disease risk has to be communicated to prevent long term affects and compensation claims.

An additional factor is that most farmers are self-employed (about 75% in New Zealand) using labour or contracting when required at various times during the year.

Question 10

This question asked if information was provided that would show that respiratory disease could be reduced or prevented by the wearing of appropriate respirators, would they (as farmers) adopt and encourage the wearing of respirators on the farm. About 65% of respondents said they would encourage the use of respirators, while another 35% said they already did. The remainder said they would not (see Figure below).

Figure 8.36: If information was available, would this encourage wearing of appropriate respirators

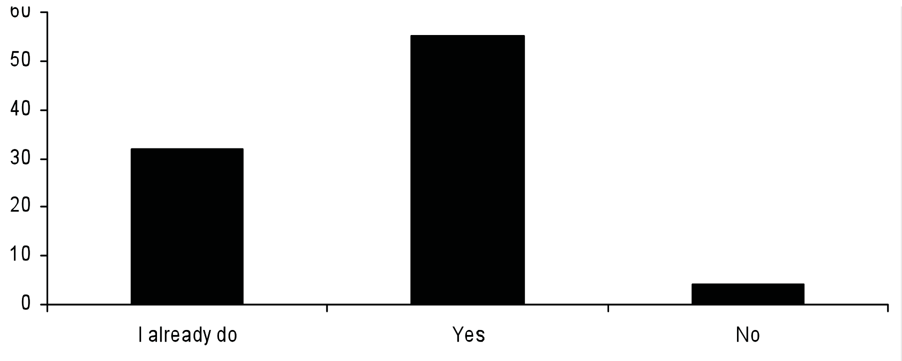


Figure 8.36: If informationwas available, would this encourage wearing of appropriate respirators.

Some of the comments that were made (in free text) indicted that farmers felt that the choice should be their own (that is, no enforcement), older farmers did not think it was likely that they were affected in any case (the risk was perceived as no longer significant) and that respirators should not be worn for short term exposure conditions.

This typically highlights some of the difficulties in working with the farming sector, that is, independence, suspicious of the intent of information supplied by Government agencies, a need to understand the risk in comparison to other risks on the farm (for example, international prices paid for primary produce or kicks from large animals) and the acceptance of a somewhat fatalistic perception that farming in the long term would result in ageing and acceptable effects such as “bad backs” or NIHL (Noise-Induced Hearing Loss).

The responses indicated that farmers generally lacked knowledge of the real hazards of airborne contaminants and of respiratory disease in farming. Those that had attended formal training such as the Growsafe program for horticulturists had their awareness raised and this sector is also used to working with agrichemicals for spraying crops. The appropriate precautions were not always selected an used, probably because they use external labour not under a contract of employment. This has implications for farmers as employers (which is different to the responsibilities as a self-employed person under the 1992 NZ Health and Safety in Employment Act).

In some agricultural sectors in New Zealand the risks of occupational respiratory disease are significantly higher than the general population (for example, those working in piggeries, working in the equine industry, or working in enclosed spaces such as battery hen houses) where respiratory protection would be advisable (and in some cases essential).

On many other types of farms where open spaces are the norm in New Zealand (and very different to typical European enclosed farm operations) respiratory protection would be advisable in specific farm applications (for example, high grain or hay dust environments) or working with specific chemicals. Any education program has to recognise the differences in the various agricultural sectors, the specific applications being considered and communicate the risks in the "language" of farmers.

Question 11

This question asked if the respondent found it difficult to make the decision considering the multitude of different designs and choices available. About 28% of respondents said that this decision was not applicable (presumably because they did not wear a respirator) while 46% said that that it was not difficult to make this decision in their view (see Figure below).

Figure 8.37: Is correct purchasing a difficult decision

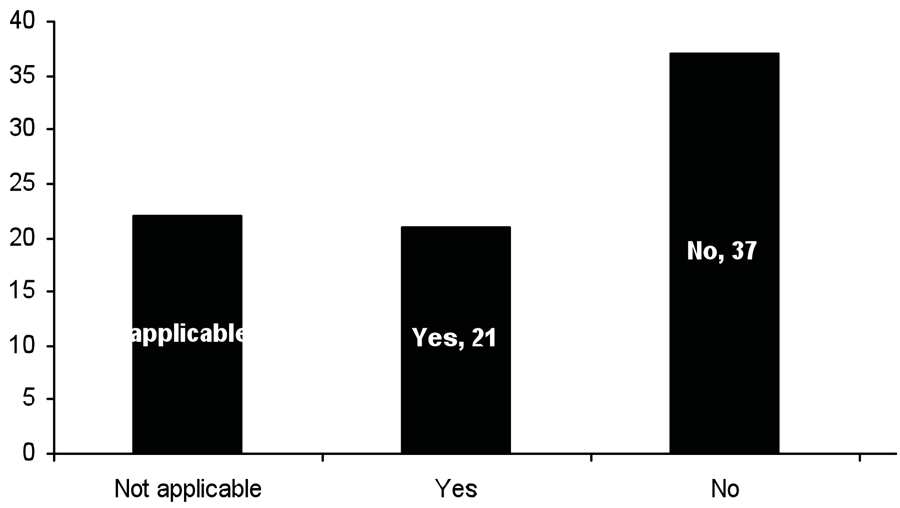


Figure 8.37: Is correct purchasing a difficult decision?

This response is interesting because the choice of equipment is not easy and often requires specialist knowledge in a number of different scientific disciplines. There are a number of technical publications including those produced by US NIOSH and others, giving flow charts of the decision steps required in the choice of suitable respiratory equipment. These are relatively complex and unless farmers were familiar with them, it is not likely that the choice of the correct respiratory equipment is going to be simple. It is more probable that farmers are unaware of the complexity of the topic and the decision matrix is restricted to the different manufacturers of the same equipment, for example, a decision on the types of disposable respirators and probably price considerations. Lastly, because of this complexity, the farmer will leave the decision to someone else (for example, a supplier) who may be informed enough to make a sale, but not well enough informed to make the right decision.

There is little published in the occupational hygiene literature in New Zealand on the ambient and personal exposure of farmers while carrying out different roles on the farm, for example, haymaking, spraying agrichemicals in the field or mixing chemicals in more enclosed areas such as farm sheds. The limited overseas available data cannot always be directly applied to New Zealand because of the variation in farming practices. Most of the exposure data refers to contaminant levels inside buildings whereas most New Zealand farming is in open spaces, albeit with the exception of certain types of practices such as poultry operations and piggeries. In the correct determination of the type of respiratory equipment to be worn, this type of exposure data is important. It is important that typical exposure data on farms is obtained in the future in order to recommend the wearing of PPE in specific farm applications.

About 26% of respondents said that they did have problems making the choice of correct respirator. It may be that these respondents were more aware of the challenges in deciding the respirator choice.

Government agencies are probably the agencies with sufficient motivation and funding to affect change by public awareness campaigns- since farming organisations are not currently affected.

Question 12

From the previous survey, most farmers had difficulty with the correct purchase of respiratory equipment. This question asked what factors most affected the farmers choice of purchase of respiratory equipment. The question asked whether factor was most important in their choice of equipment and gave a number of options, that is, comfort, price of purchase, ease of maintenance and health and safety reasons. Most respondents replied that comfort (30%) was the main choice decision after health and safety reasons (49%), followed by price considerations (16%). Only 12% thought that ease of maintenance was an issue, but this could be expected given that such as a large number of farmers use disposable type of respiratory equipment (see Figure below).

Figure 8.37: Most important consideration in purchasing decision

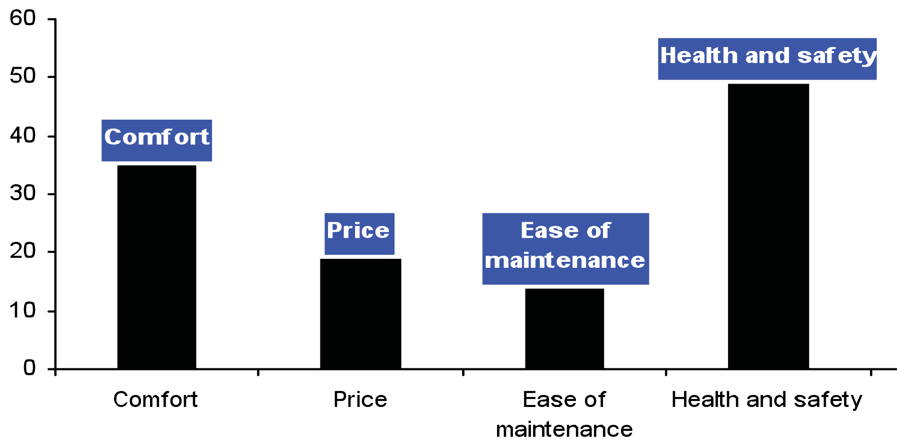


Figure 8.37: Most important consideration in purchasing decision.

The meaning behind the most popular choice of "health and safety" is interesting in terms of the likely meaning to farmers. Most would probably think the choice is made on the basis of the prevention of occupational injury and yet the response to previous questions have suggested that this is not a serious issue of concern to farmers. It may be that respondents thought that this is the most appropriate response to the question in the context of completing the questionnaire. It may have been helpful if the question had been asked differently as the term "health and safety" was not specific enough.

There is a paradox also here with the current equipment. The most comfortable equipment such as disposable respirators provide limited protection because face seals cannot be ensured and they are probably badly fitted in practice. Disposable respirators appear to be the equipment of choice for the farming community (see the previous questions responses).

The fact that the wearer is using a respirator may give a false sense of security, especially if it is worn incorrectly. Wearing a respirator does not necessarily mean that protection is ensured.

Other types of respiratory equipment are available such as PAPR (Power Assisted Air Purifying Respirator) or the FPBR (Fan supplied Positive pressure Breath responsive Respirator). These are at substantially higher cost to the farmer and are generally viewed with suspicion as to their value (information on cost was collected from answers to the next question).

Question 13

The majority of farmers (63%) said that they would not purchase the more expensive type of respiratory equipment, that is, about $2,000 (the price of PAPR or FPBR). This means that 37% said they would (se Figure below).

Figure 8.38: Would the farmer spend $2000 on a respirator?

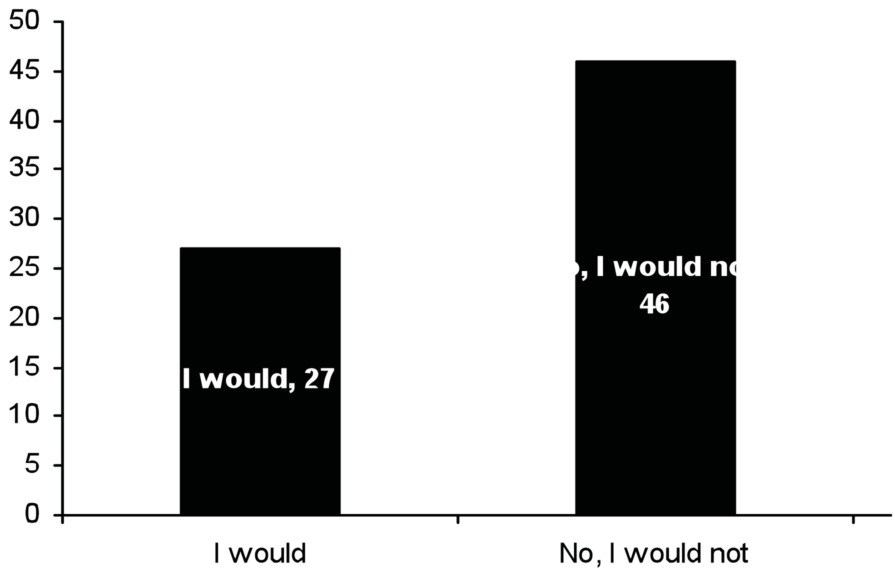


Figure 8.38: Would the farmer spend $2000 on a respirator?

Horticultural farmers often use PAPR equipment in the belief that this gives better respiratory protection than other types generally available. The equipment is generally quoted as having higher protection factors than half-face respirators in a number of countries and is more comfortable to wear than half-face respiratory equipment.

This question raised the most free text comments of all the questionnaire topics. Farmers were generally concerned that the level of protection implied (for example, warning systems) was generally not warranted on the farm. Most thought that the cost was prohibitive (probably in comparison to disposable respirators which cost a few dollars for ten respirators) in spite of the longer lifetime use of the product. A variety of warning systems to let the wearer know of equipment failure, while considered critical by some industrial groups such as aluminium smelting, was not commented on by the farming group. Further, bearing in mind the range of airborne contaminants that may be encountered on farms, such warning systems are probably too difficult to install.

Respiratory protective equipment which will provide a higher level of respiratory protection than disposable respirators will be at a greater cost than the range of disposable equipment and this provides a significant barrier in the purchase decision to many farmers. This is particularly true with the potentially long lead times of respiratory type diseases, that is, there may no immediate negative feedback on wearing a respirator which allows leakage of contaminants particularly if those contaminants have no odour or other detectable characteristics.

Question 14

This question asked for the source of information that farmers used to purchase respirators. More than half the respondents (56%) said that the distributor was used as their source of information about the purchase of respiratory equipment (see Figure below).

Figure 8.39: Source of information in purchasing decision

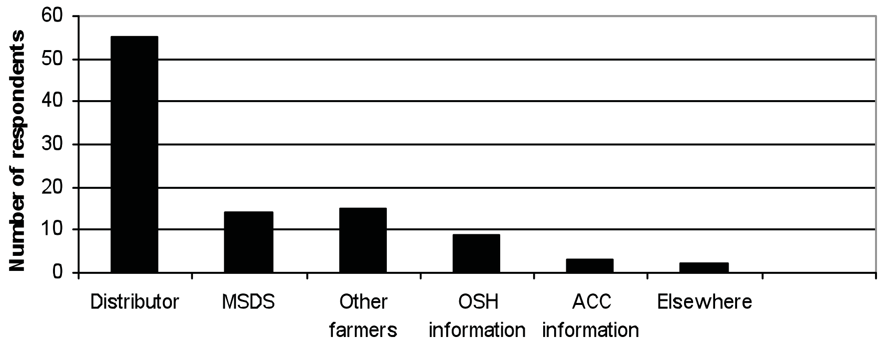


Figure 8.39: Source of information in purchasing decision.

Normally, the farmer would purchase the equipment from a company that supplies farm products such as agrichemicals, fence posts and all manner of equipment and often this would include respirators and other PPE. These organisations normally have little specific knowledge of respiratory disease or prevention although access to information is readily available.

There is limited information on each of the respirator types but this is inadequate without other information and training (as per AS/NZS 1716:2003).

Other farmers (peers) are also used as a source of information (15%), but this group would be unlikely to be knowledgeable about this specific field and hence would not move the science forward in this community.

About 14% of respondents said that the MSDS was used as the source of information. This is an appropriate source for recommendations of the correct PPE, but is often not specific about PPE and may require more detailed knowledge to interpret the data.

For legislators, the results are significant in terms of efforts at improving working conditions and reducing the incidence of respiratory disease on farms, but current means of distributing information is probably not appropriate. Most farmers do not currently appear to regard respiratory disease a significant risk in comparison to other farm risks, that is, there is little awareness of the short-term or long-term effects on the health and welfare on farmers and as a result, little practical concern about respiratory protection. However, there are significant concerns about farm respiratory health in New Zealand, with a range of occupational respiratory diseases such as occupational asthma in certain types of farming remaining unrecognised and under-acknowledged as a national burden.[549] Much of the current focus of New Zealand legislators and other national organisations is on the traumatic farm events, which tend to dominate newspaper, radio and TV coverage. Yet the respiratory disease situation is very significant, particularly among certain farm types and operations, such as deer and goat farming, equine, poultry, pig and crop farming. Dairy farmers appear to be particularly prone to ODTS (Organic Dust Toxic Syndrome).[532]

Asthma is recognised in New Zealand as the most common occupational related respiratory disorder. Notification is poor, and notification to the New Zealand NODS (DOL National Occupational Disease System) is also poor, indicating a further under-recognition of the problem at various levels including agricultural stakeholders.[549]

The type of farming and associated occupational respiratory disease may be important as sheep farming is declining in New Zealand (down to 40 million sheep from 75 million a decade ago) with an increase in dairy, pig, poultry and deer farming operations.

Question 15

This question was related to the demographics of the respondents. Most respondents who attended the FarmSafe seminars and filled in the questionnaire were male. This differed from the previous postal questionnaire where the respondents were mostly the partners on the farm (see the next Figure).

Figure 8.40: Respondents: Gender

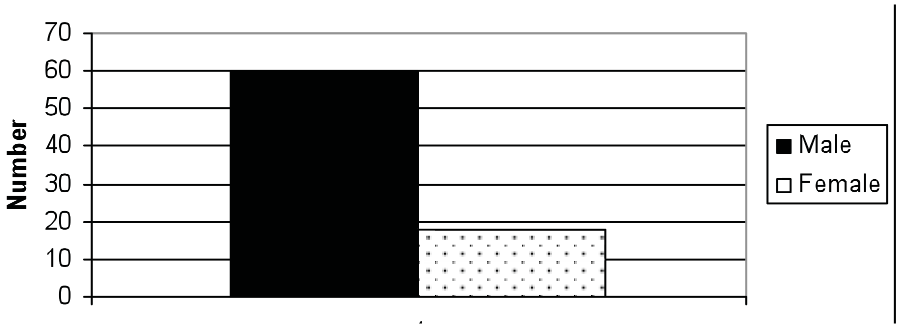


Figure 8.40: Respondents: Gender.

Age-wise, most respondents were in the 36-55 year age group, (see the next Figure).

Figure 8.41: Respondents: Age

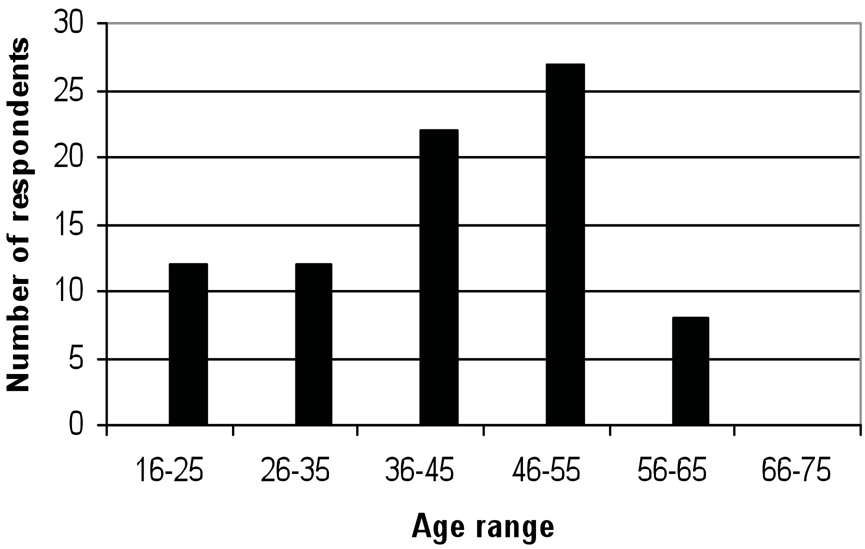


Figure 8.41: Respondents: Age

The characteristics of this response group may be significant from the agricultural sector as a whole. It may be that younger farmers may be more aware of farm occupational risks as the group are more likely to attend farm safety seminars as part of formal training for farm manager or similar roles.

The responses in this group were from respondents at a FarmSafe seminar, that is, they were at a five hour seminar where farm safety had been discussed so that their level of awareness of farm safety and health risks may have been elevated. However, comparison between the respondents from a postal survey (where the respondents were generally the female partner in the farm) showed less concern from the predominantly male farm population in the FarmSafe program.

The question also asked for the experience of farmers in farming. Most respondents had at least ten years experience. The next dominant group had up to twenty years experience followed by up to thirty years. The dominant farming group was relatively inexperienced (see next Figure).

Figure 8.42: Respondents: Years of Farming

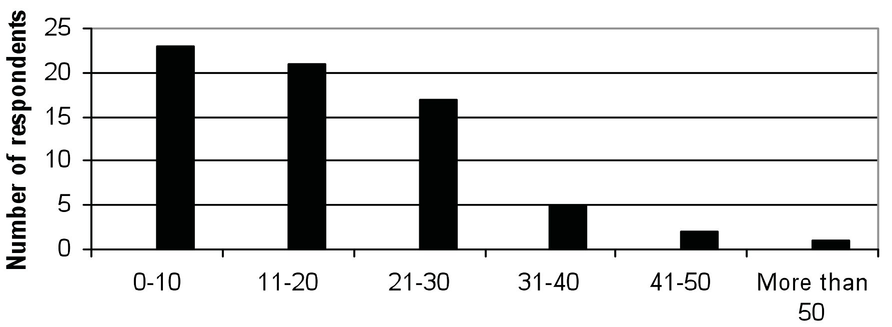


Figure 8.42: Respondents: Years of farming.

8.3.7 Second Questionnaire Survey: Limitations

There are some limitations in the survey which include:

- ❍ The topic language may be complex to the target audience, particularly to those not familiar with the technology or the terminology. While the questionnaire was written so that this should not have presented any major barriers, many of the question topics would be new and farmers may not have given the topics a lot of thought before.
- ❍ The questionnaire was completed at the end of a five-hour interactive FarmSafe seminar. This program focused on raising the awareness of key factors that contribute to the main farm injuries. As a result of attending this, farmers may have had an increased awareness of farm health and safety issues prior to completing the questionnaire for this study and this may have influenced the responses.

- Increasing the number of respondents may have assisted in analysing the responses from different sectors of the industry. The responses from dairy farmers could be expected to be different to those from horticulture because the latter are required to attend a GrowSafe seminar (which covers specific health topics such as the handling of agrichemicals) whereas dairy farmers do not have to attend similar type seminars.
- The response rate was close to 100% in this survey because farmers who attended the FarmSafe program regarded the questionnaire as part of the seminar. However, the group that attended are also self-selected in that they tend to be farmers concerned with farm health and safety issues-the reason they attend the programs. The respondents may therefore be a group that are more interested in farm health and safety issues than those that did not attend and have no intention of attending the FarmSafe program.

8.3.8 Second Questionnaire Survey: Findings

Main findings

The level of knowledge apparent on the farm, even by very experienced farmers, about respiratory protection and agricultural occupational disease is low. This is a concern because personal protection is often the only practical and realistic option to reduce occupational disease after all other options of exposure control have been eliminated (and few can be applied in the farming environment). There is little doubt that a major and different programme of intervention is needed to influence the farming population of New Zealand and that a more intensive and comperehensive approach is needed.

Limitations

Farmers that had participated in the New Zealand FarmSafe program were asked to complete the questionnaire at the end of the seminar.

This approach was different to the first postal survey when most of the respondents were the partners of the farmer. The responses from the two groups were often very different. There are advantages and limitations in this type of appraoch. One of the advantages is that all the farmers are in one room and are therefore directly able to be approached. However, these farmers have just attended a FarmSafe course and may be motivated to respond differently. The FarmSafe course does not cover any issues related to disease and is only focussed on traumatic (often sudden) events but this may have still influenced their responses.

The aspect of who actually responds to the survey on the farm may be an important aspect to be considered in all other future surveys of this type. If the purpose is to get the practicing farmers responses, postal surveys may not achieve this. Generally, the partners in the farm business will complete the paperwork or administration of the farm. This is particularly true of certain types of farming such as sharemilker dairy cattle operations where both partners are normally heavily involved in day-to-day operations of the farm.

A further limitation was that the respondents were motivated to attend a farm safety course (albeit with prompting by telephone by local co-ordinators) prior to being requested to complete a survey. They may therefore be regarded as a biased group although this was not verified.

Discussion

In New Zealand, the long-term strategy of the NZIPS (New Zealand Injury Prevention Strategy) and the subsequent report “Reducing the burden of occupational disease and injury” (REFS) both emphasize the importance of reducing the incidence of occupational disease, including occupational asthma. This work is important as a specific application on the current level of knowledge of respiratory disease and protection of a major industry sector employing 10% of New Zealand’s workforce. This will be further reinforced it the New Zealand farming sector by the requirement of all farmers to hold a “Handler’s Certificate” under the HSNO (Hazardous Substances and New Organisms) Act 1996. Among other requirements, this requires farmers to be aware of basic health and safety issues, including PPE (Personal Protective Equipment).

Of further concern was the lack of knowledge and appropriate protection recommended by Government agencies in New Zealand for confined spaces. Confined spaces exist on all farms in New Zealand and there has been wide publicity regarding the risks and precautions required-for some decades now. In spite of this, the level of awareness remains low.

Future interventions to reduce the exposure to highlight the hierarchy of controls including respiratory protection need to be very sector specific, for example, explain the need and substance for interventions that are directly applicable to dairy farmers (and written in the language of dairy farming practices). Sheep and beef farmers, horticulturists as well as other types of farms and their practices need to be addressed differently.

The number of questionnaire responses from the second questionnaire may be regarded as relatively low (over 100 obtained) but it is believed to reflect the true level of knowledge on these issues in this industry.

Major efforts are required on a number of separate but related issues, such as:

- Increasing the level of insights and understanding of the barriers to wearing respirators and develop better equipment to overcome these barriers where this is appropriate;
- Altering Standards (both nationally and internationally) to better reflect the newer insights into breathing rates and volumes (most currently used information is obsolete);
- Communicate the inhalation risks to farmers and other occupational groups and means to reduce the risks;
- Increase the communication appropriate to the wearing of respiratory equipment such as wear time, the need for

maintenance and training, education and other minimum requirements.

Increase research is needed in areas such as:

- The specific respiratory protective needs of different occupational groups;
- Developing better communication with the target groups and communicating the understanding the risks in relation to the main occupational respiratory diseases;
- The true level of protection obtained by different types of respiratory equipment such as “disposable” respirators (researchers and practitioners often assume that the protective equipment functions as intended);
- TIL (total inward leakage) of contaminant into the respirator;
- The different needs of SMEs as compared against larger enterprises, albeit most agricultural organisations in New Zealand fall into the former classification.

These and other topics are becoming even more important with the increasing potential of biological warfare and the CBNR (chemical, biological, nuclear and radiological) type respirators.

It is important that users are particularly involved in all of the research and development. Manufacturers, who are more likely to be involved, generally are not impartial and often do not have the perspective of the user, who may have to use the equipment for an extended period of time in conditions which are often not ideal.

The results from this work will be published in both technical journals and agricultural specific media such as the New Zealand *Straight Furrow* magazine. In addition, it will be used as a basis to sponsor more applied research in New Zealand. A major intervention program by ACC and OSH will commence to raise the awareness of respiratory disease and its prevention in New Zealand, including agriculture, in at least the years 2005, 2006 and beyond.

8.4 References

[456] Wallaart, J., Winder, C. A survey of New Zealand farmers' knowledge about the risks and prevention of occupational respiratory disease. *Journal of Occupational Health and Safety - Australia and New Zealand* **23:** 469-479, 2007.

[457] Grammer, L.C., Harris, K.E., Yarnold, P.R. Effect of respiratory protective devices on development of antibody and occupational asthma to an acid anhydride. *Chest* **121:** 1317-1322, 2002.

[458] Venables K M. Prevention of occupational asthma. *European Respiratory Journal* 13: 768-778, 1994.

[459] Laraqqui, C., Harouate, K., Balamallen, I. Occupational respiratory risk in workers exposed to enzymes in detergent. *Revue des Maladies Respiratoires* **13:** 485-492, 1996 (English summary).

[460] Fabbri, G. The prevention of occupational asthma in industries. *Journal of Investigations in Allergy and Clinical Immunology* **7:** 377-379, 1997.

[461] Taivainen, A.I.,Tukiainen, H., Terho, E.O., Husman, K. Powered dust respirator helmets in the prevention of occupational asthma among farmers. *Scandinavian Journal of Work Environment and Health* **24:** 503-507, 1998.

[462] Obase, Y., Shimoda, T., Mitsuta, K., Matsuse, H., Kohno, K.R. Two patients with occupational asthma who returned to work with dust respirators. *Occupational and Environmental Medicine* **57:** 10-14, 2000.

[463] Liu, Y., Stowe, M.H., Bello, D., Woskie, S.R., Sparer, J., Gore, R., Youngs, F., Cullen, M.R., Redlich, C.A. Respiratory protection from isocyanate exposure in the autobody repair and refinishing industry. *Journal of Occupational and Environmental Hygiene* **3:** 234-249, 2006.

[464] Slovak, A.J., Orr, R.G., Teasdale, E.L. Efficacy of the helmet respirator in occupational asthma due to laboratory animal allergy (LAA). *American Industrial Hygiene Association Journal* **46:** 411-415, 1985.

[465] Lofgren, D.J., Walley, T.L., Peters, P.M., Weis, M.L. MDI exposures for spray-on truck bed lining. *Applied Occupational and Environmental Hygiene* **18:** 772-779, 2003.

[466] Bello, D., Redlich, C.A., Stowe, M.H., Sparer, J., Woskie, S.R., Streicher, R.P., Hogood, H.D., Liu, Y. Skin exposure to aliphatic polyisocyanates in the auto body repair and refinishing industry: II A quantitative assessment. *Annals of Occupational Hygiene* 2008 (epub ahead of print)

[467] Muller-Wening, D., Horts, R. Investigation on the protective value of breathing masks in farmer's lung using an inhalation provocation test. *Chest* **95:** 100-105, 1989.

[468] Muller-Wening, D., Neuhauss M. Protective effect of respiratory devices in farmers with occupational asthma. *European Respiratory Journal* **12:** 569-572, 1998.

[469] Nuutinen, J., Terho, E.O., Husman, K., Kotimaa, M., Harkonen, R., Nousiainen, H. Protective value of powered dust respirator helmet for farmers with farmer's lung. *European Journal of Respiratory Disease Supplement* **152:** 188-196, 1997.

[470] Muller-Wening, D and Neuhauss, M. *Protective effect of respiratory devices in farmers with occupational asthma.* European Respiratory Journal, **12**. Pp 569-572. 1998.

[471] Kogevinas, M., Anto, J.M., Sunyer, J., Tobias, A., Kromhout, H., Burney, P. Occupational asthma in Europe and other industrialised areas: A population based study. European Community Respiratory Health Survey Study Group. *Lancet* **22:** 1750-1754, 1999.

[472] De Bono, J., Hudsmith, L. Occupational asthma: A community based study. *Occupational Medicine* **49:** 217-219, 1999.

[473] Nicholson, P.J., Cullinan, P., Newman-Taylor, A.J., Burge, P.S., Boyle, C. Evidence based guidelines for the prevention, identification, and management of

occupational asthma. *Occupational and Environmental Medicine* **62:** 290-299, 2005.

474 BOHRF. *Oasis and occupational asthma. BOHRF Occupational Asthma Guidelines: Prevention.* British Occupational Health Research Foundation. Retrieved from the website, 29 June 2005 At: http://www.occupationalasthma.com/bohrf/preventionshtml.

475 News article. DDB hosts major international conference on occupational respiratory health. *Occupational Respiratory Health Report*, Sydney September 2000.

476 Meyer, J.D., Holt, D.L., Cherry, N.M., McDonald, J.C. SWORD 98. Surveillance of work-related and occupational respiratory disease in the UK. *Occupational Medicine* **49:** 458-459, 1999.

477 Karjalainen, A., Kurppa, K., Virtanen, S., Keskinen, H., Nordman, H. Incidence of occupational asthma by occupation and industry in Finland. *American Journal of Industrial Medicine* **37:** 451-458, 2000.

478 Mukker-Wening, D., Neuhauss, M. Protective effect of respiratory protective devices in farmers with occupational asthma. *European Respiratory Journal* **12:** 569-572, 1988.

479 Gorman, T. 2005. Trends and research into respiratory protection. Retrieved on 25 June 2005: http://www.safetysolutions.net.au/safety/feature_article/item _042005a.asp.

480 Dich, J., Zahm, S.H., Hanberg, A., Adami, H.O. Pesticides and cancer. *Cancer Causes Control* **8:** 420-443, 1997.

481 Axelson, O. Pesticides and cancer risks in agriculture. *Medical Oncology and Tumor Pharmacotheraputics* **4:** 207-217, 1987.

482 Blair, A., Malker, H., Cantor, K.P., Burmeister, L., Wiklund, K. Cancer among farmers: A review. *Scandinavian Journal of Work Environment and Health* **11:** 397-407, 1985.

483 Hardell, L., Eriksson, M. A case-control study of non-Hodgkin lymphoma and exposure to pesticides. *Cancer* **85:** 1353-1360, 1999.

484 Blair, A., Zahm, S.H. Agricultural exposures and cancer. *Environmental Health Perspectives* **103 Suppl 8:** 205-208, 1995.

485 The author is involved in practical intervention programmes as a Programme Manager-Injury Prevention with the Corporate Office of the ACC in Wellington, New Zealand. As part of tis role, extensive consultation is necessary with the agricultural and other industry sectors of New Zealand.

486 Radon, K., Nowak, D. Farming. Chapter 26. Occupational Disorders of the Lung. 2002. Available through the USA NADS website.

487 McMichael, A.J. Assigning handicaps in the mortality stakes: an evaluation of the "healthy worker effect". *Journal of Occupational Health and Safety - Australia and New Zealand* **4:** 207-215, 1988.

488 Adami, H.O., Trichpoulos, D. Epidemiology, medicine and public health. *International Journal of Epidemiology* **28:** S1005-1008, 1999.

489 Fox, A.J., Collier, P.F. Low mortality rates in industrial cohort studies due to selection for work and survival in the industry. *British Journal of Preventive and Social Medicine* **30:** 225, 1976.

490 Vena, J.E., Sultz, H.A., Carlo, G.C. Sources of bias in retrospective cohort mortality studies: A note on treatment of subjects lost to follow-up. *Journal of Occupational Medicine* **29:** 256-261, 1987.

491 Wilcosky, T., Wing, S. The healthy worker effect: Selection of workers and workforces. *Scandinavian Journal of Work Environment and Health* **13:** 70-72, 1987.

492 Miettinen, O.S. Theoretical Epidemiology: Principles of Occurrence Research in Medicine. John Wiley, New York, 1985.

493 Olsen, J., Merletti, F., Snashall, D., Vuylsteek, K. *Searching for Causes of Work-Related Diseases: An Introduction to Epidemiology at the Work Site*. Oxford University Press, Oxford, 1991.

494 Hernberg, S. *Introduction to Occupational Epidemiology*. Lewis Publishers, New York, 1992.

495 Marsh, G.M. Epidemiology of occupational diseases. Chapter 5 in: *Environmental and Occupational Medicine*, second edition, Rom, W.N., editor. Little, Brown and Co, Boston, 1994, pp 725-731.

496 Runyan, J.L. *A review of farm accident data sources and research: A review of recently published and current research*. National Agricultural Safety Database (NASD), 1999. At: http://www.cdc.gov/niosh/nasdhome.html.

497 ACC. 2005. *Statistics Reports: Workplace injury data.* Accidents Compensation Commission, Wellington, 2005. At: http://www.acc.co.nz.

498 Firth, H., Herbison, P., McBride, D., Feyer, A.-M. Health of farmers in Southland: an overview. *New Zealand Medical Journal* **114:** 426-428, 2001.

499 Driscoll, T, Mannetje, A, Dryson, E, Feyer, A-M, Gander,P, McCracken, S, Pearce, N and Wagstaffe, M. *The burden of occupational disease and injury in New Zealand.* NOHSAC technical report. ISBN 0-478-28011-4.

500 Schenker, M.B. Respiratory hazards in agriculture. *American Journal of Respiratory Critical Care Medicine* **158:** S1-S76, 1998.

501 Schenker, M.B. Preventative medicine and health promotion are overdue in the agricultural workplace. *Journal of Public Health Policy* **17:** 275-305, 1996.

502 Fith, H, Herbison, P, McBride, D, Feyre, A-M. *Health of farmers in New Zealand: an Overview.* New Zealand Medical Journal. Pp 426-428. September 2001.

503 Firth, H.M, McBride, D, Feyer, A.M, Herbison, G.P, Eason, M and Wright, J. *Health of farmers and farm workers in Southland.* Department of Preventative and Social Medicine, University of Otago. 2000. ISBN 0-09582127-0-8.

504 Kimbell-Dunn, M., Bradshaw, L., Slater, T., Erkinjuntti-Pekkanen, R., Fishwick, D., Pearce, N. Asthma and allergy in New Zealand Farmers. *American Journal of Industrial Medicine* **35:** 51-57, 1999.

505 IPRU/NZEOHRC. *Work related fatal injuries in New Zealand 1985-1994: Descriptive Epidemiology.* Injury Research Prevention Unit and NZ Environmental and Occupational Health Research Centre, Dunedin School of Medicine, University of Otago, Dunedin, 1999. At: http://www.osh.dol.govt.nz/order/catalogue/pdf/epidemology.pdf

506 Wadud, S.E., Kreuter, M.W., Clarkson, S. Risk perception, beliefs and prevention and preventative behaviours of farmers. *Journal of Agricultural Safety and Health* **4:** 15-24, 1998.

507 NOHSC. *National OHS Strategy*. National Occupational Health and Safety Commission, Canberra, 2001.

508 Mayhew, C. OSH challenges in Australian small businesses: Old problems and emerging risks. *Safety Science Monitor* **4:** 1-12, 2002.

509 Day, L., Cassell, E. Constraints on the adoption of safety measures on Australian farms. *Journal of Occupational Health and Safety – Australia New Zealand* **14:** 447-456, 1998.

510 OAHRC. *The Agricultural Safety Audit Program: A Management Tool for Employers.* Ontario Agricultural Human Resource Committee. At: www.farmshow.net/oahrc.

511 Wadus, S.E., Kreuter, M.W., Clarkson, S. Risk perception, beliefs about prevention, and preventative behaviour of farmers. *Journal of Agricultural Safety and Health* **4:** 15-24, 1998.

512 Elliot, N., Crump, J., McGuire, A., Chambers, S. Knowledge, attitudes and behaviour towards HIV infection among family planning clinic attendees: changes between 1991 and 1997. *New Zealand Medical Journal* **112:** 121-123, 1999.

513 Elkind, P.D. Attitudes and risk behaviour. In: Surgeon General's Conference on Agricultural Safety and Health, 1991. *MMWR* **41:** 11-12, 1992.

514 Elkind, P.D. Correspondence between knowledge, attitudes and behaviour in farm health and safety practices. *Journal of Safety Research* **24:** 171-179, 1993.

515 Murphy, D.J. Farm safety attitudes and accident involvement. *Accident Analysis and Prevention* **13:** 331-337, 1981.

516 Mather, C., Lower, T. Preferred methods to reduce farm-related injury. *Journal of Occupational Health and Safety – Australia New Zealand* **17:** 301-307, 2001.

517 Caple, D, Hodgson, R., Greig, J. Dissemination of OHS information into small businesses. *Journal of Occupational Health and Safety – Australia New Zealand* **13:** 157-159, 1997.

518 Mayhew, C. Barriers to implementation of known occupational health and safety solutions in small business. A report on a research project conducted through a partnership between Worksafe Australia and the Queensland Government Department of Training and Industrial Solutions, Brisbane, 1997.

519 Witte, K. Preventing tractor-related injuries and deaths in rural populations: Using a persuasive health message framework in formative evaluation research. *International Quarterly of Community Health Education* **13:** 219-251, 1993.

520 Pye, M., Cullinane J. A survey of health and safety knowledge and understanding amongst farmers and farm workers in Waikato: Research Report, *University of Waikato*, 1995.

521 Calver, R., McGrath, A. Managing farm safety. *Journal of Occupational Health and Safety – Australia New Zealand* **15:** 465-470, 1999.

522 McLean, C. The impact of prosecution on workplace prevention. Journal of Occupational Health and Safety. *Journal of Occupational Health and Safety – Australia New Zealand* **14:** 517-521, 1998.

523 Kahler, R. Major incident investigation using analysis reference tree trunk. *InterSafe Pty Ltd*, Brisbane, 1999.

524 AAP. All-Terrain Vehicle injury prevention: Two, three and for-wheeled unlicensed motor vehicles. American Academy of Pediatrics. *Pediatrics* Vol. **105:** 1352-1354, 2000.

525 These were prepared by the author and are on the New Zealand Accident Compensation Corporation website (currently being reviewed)Http://www.acc.co.nz.

526 Driscoll, T., Mannetje, A., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., Pearce, N., Wagstaffe, M. The Burden of Occupational Disease and Injury in New Zealand: Technical Report. At: http://www.nohsac.govt.nz. *NZ Occupational Health and Safety Council*, Wellington, 2004.

527 Driscoll. T.R. Are work-related injuries more common than disease in the workplace? *Occupational Medicine* **43:** 164-166, 1999.

529 Fishwick, D., Pearce, N., D'Souza. W. Occupational asthma in New Zealanders: a population based study. *Occupational and Environmental Medicine* **54:** 14-21, 1997.

530 Donham, K.J., Rautiainan, R., Schuman, S.H., Lay, J.A. *Agricultural Health and Safety: Recent Advances.* Haworth Medical Press, Binghampton, 1997.

531 Schenker, M.B. Preventative Medicine and health promotion are overdue in the agricultural workplace. *Journal of Public Health Policy* **17:** pages?, 1996.

532 McDuffie, H.H., Dosman, J.A., Semchuk, K.M., Olenchock, S.A., Sethilselvan, A. *Agricultural Health and Safety.* Lewis Publishers, New York, 2000.

533 Firth H M, McBride D I, Feyer A M, Herbison G P, Eason M and Wright J. (2000). Health of farmers and farm workers in New Zealand. New Zealand Environmental and Occupational Health Centre, Dunedin School of Medicine, Otago Medical School, Dunedin.

534 ACGIH. 1995-1996 Threshold Limit Values (TLVs) for Chemical Substances or Physical Agents and Biological Exposure Indices (BEIs). *American Conference of Governmental Industrial Hygienists*, Cincinnati, 1997.

535 Bernstein, L.I., Chan-Yeung, M., Malo, J.-L., Bernstein, D.I. *Asthma in the Workplace*. Marcel Dekker Inc, Boston, 1993.

536 NZ Government. New Zealand Injury Prevention Strategy, Wellington, October 2002.

537 NZIDR. New Zealand Injury Data Review. At: www.statistics.govt.nz/injury.

538 Typical examples from New Zealand are at: http://www.nzma.org.nz/journal/118-1213/1414/, or http://www.acc.co.nz/PRD_EXT_CSMP/groups/external_ip/documents/internet/wcm000360.pdf.

539 Rothstein, D., Firth, H., Herbison, P., McBride, D. Chemical use among farmers. *Journal of Occupational Health and Safety – Australia and New Zealand* **20:** 459-464, 2004.

540 Pearce, N., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., Wagstaffe, M. The Burden of Occupational Disease and Injury in New Zealand. Report to the Associate Minister of Labour. *NZ Occupational Health and Safety Advisory Council*, Wellington, 2004.

541 The New Zealand Department of Labour has a strong Government directive to investigate means to reduce occupational disease and the New Zealand Accident Compensation Corporation has the reduction of occupational disease as a national priority for 2008 onwards.

542 Jackson, W. Research Methods: Rules for Survey Design and Analysis. Prentice Hall, Ontario, 1988.

543 Meeker, B.J., Carruth, A., Holland, C.B. 2002. Health hazards and preventative measures of farm women. *American Association of Occupational Health Nurses Journal* **50:** 2002.

544 These have been produced extensively over the last decade by the New Zealand Department of Labour and the New Zealand Accident Compensation Corporation and are available on their respective websites, i.e., http://www.dol.govt.nz and http://www.acc.co.nz.

545 Walls, C.B., Dryson, E.W. Failure after five years of self-regulation: A health and safety audit of New Zealand engineering companies carrying out welding. *Occupational Medicine* **52:** 305-309, 2002.

546 ACC. Working with Chemicals, Confined Spaces and Respirators: ACC406. *Accident Compensation Council*, Wellington, 2003.

547 Firth, H., Herbison, P., McBride, D., Feyer, A.-M. Health of farmers in Southland: an overview. *New Zealand Medical Journal* **114:** 426-428, 2001.

548 Pearce, N., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., Wagstaffe, M. The Burden of Occupational Disease and Injury in New Zealand. Report to the Associate Minister of Labour. *NZ Occupational Health and Safety Advisory Council*, Wellington, 2004.

549 Holt, S., Beasley R. The Burden of Asthma in New Zealand. *The Asthma and Respiratory Foundation of New Zealand*, Wellington, 2001.

Part 4: Discussion, Conclusions and Recommendations

9. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

9.1 Discussion

Entry of workplace contaminants into the human body is primarily through the inhalation route as opposed to other means of entry such as dermal exposure. In addition, the contaminants are able to quickly interact or be absorbed into the bloodstream through the alveoli of the lung. In accordance with the normal hierarchy of control, if elimination is not possible, then isolation or minimisation techniques need to be introduced to protect the worker.

Successful minimisation techniques such as respiratory protection are critical to the future reduction of respiratory diseases such as occupational asthma. Occupational diseases are more common than is generally realised with about 17,000 to 22,000 new cases estimated to be introduced each year in New Zealand (or about 55 per day) with approximately 2,500 to 4,500 severe cases diagnosed each year (or about 10 per day).[550] Occupational asthma is probably the most common work-related respiratory disorder in the industrialised countries[551] and its incidence is stable or increasing.[552] The disorder is becoming increasingly recognised as a large and common occupational risk for workers. About 15% of adult asthma is believed to be work related[553,15] albeit later reports from Australia would indicate a much higher percentage likely.

The severe cases in particular have traumatic effects on the individuals, their families and the communities with quality of lives harmed and an enormous social and financial cost to New Zealanders. Currently, about 15% of total ACC compensation costs are related to occupational disease but this figure is known to significantly underestimate the true

---

15 Occupational asthma is among the top 5 diseases of concern to the New Zealand ACC (Accident Compensation Corporation) at the present time (2008).

incidence.[16] Occupational disease diagnoses are also expected to increase dramatically over the next decades as public and health professionals become more aware of the relationship of the effects occupational exposure. Currently occupational diseases related to the use of asbestos, PCB (polychlorinated biphenol) and dioxin are well recognised, but those related to the use, for example, of agricultural products do not appear to be so well identified with occupational exposure.

The true likely incidence will be well in excess of those reported to New Zealand organisations such as the Accident Compensation Corporation (ACC) or the Department of Labour and far exceed traumatic reported events that are often of great public and industrial concern. The future compensation costs are expected to be large as awareness and public pressure increasingly focus on occupational diseases. At the present time in New Zealand, there is a wide and extensive programme of education to be undertaken with health providers to relate occupational exposure to disease awareness (at the time of writing, March 2008). Previous surveys by ACC have shown limited awareness of the work and disease relationship by health providers and the public. [554] Occupational asthma is a particular concern because of it's prevalence in many occupations, including certain types of farming and aluminium smelting in New Zealand.[555] This is typical of other parts of the world where similar industries appear to be contributing to this disease,[556] albeit considerable care has to be taken not to draw direct comparisons as many practices, for example in agriculture, differ.

Respiratory protection and respiratory protective equipment (RPE) are important as the last defence barrier to the entry of airborne contaminants into the lung and is therefore a critical issue in the prevention of occupational respiratory disease. In practice, it is the only

---

16 In New Zealand, if the disease is deemed to be work related, it would be compensatable under the ACC personal accident insurance cover system. Current records indicate a significant under-reporting of occupational asthma and other diseases when compared against the numbers likely from the NOHSAC 2004 reports.

realistic option remaining after elimination and isolation principles have been exhausted, for example in some types of welding operations, construction or farming.

Surprisingly, little apparent research has taken place over the last decades to improve RPE with most of the focus by manufacturers into:

- producing variations of disposable type respirators to improve comfort for wearers (a major sales aspect) but with little recognition of the subsequent protection such respirators probably do not provide;
- variations in PAPR RPE (but with limited consideration to the subsequent protection for the wearer);
- variations in the types of compound used to manufacture half-face rubber or silicone respirators.

Manufacturers are generally focussed on comfort issues, rather than necessarily protection issues for the wearer as this assists in the sales of a particular product. This is a critical aspect of respirator wearing but other considerations are also important. Usually, In New Zealand compliance with a Standard such as AS/NZS 1715:1994 and 1716:2003 is demonstrated including TIL (Total Inward Leakage) albeit with the most widely used type, the disposable type respirator, is challenging because of the difficulty in achieving an adequate face seal. In New Zealand, all types of respirators manufactured overseas are able to be sold, certified or otherwise, which adds considerably to the misuse of respiratory protective equipment and protection likely to be afforded.

There are many complex and scientifically challenging issues with determining the protection offered in the practical workplace by respirators (workplace protection studies). Manufacturers and others[557] have published studies on the use of RPE in workplace environments[558, 559] but these are usually completed under carefully controlled conditions which may not reflect what happens under normal working conditions. Similarly, fit factors are known not to generally reflect assigned protection factors[560] albeit there have been exceptions published.[561] Also, sampling protocols are known to be important.[562]

Research has more recently tended to focus on the need to improve respiratory protection for wearers. These have included the need for respirator standards (on which the minimum performance requirements of respirators are based) to reflect the requirements of use of the equipment in the workplace rather than to meet the minimum requirements of manufacture. In contrast, manufacturers are generally active on committees of standards organisations rather than users and manufacturing standards tend to reflect the manufacturer's ability to produce RPE with previous or current technology. This has been compounded by the users, many of whom in Australasia are small enterprises (for example, 45% of organisations in New Zealand employ less than nineteen people) often being unaware of the technical issues surrounding minimum requirements for the use of respirators. Compounding this further are the technical challenges in determining the protection offered by respirators in the workplace.

In the last five years there have been increasing concerns expressed by users as to the ability of the equipment to meet the needs of users as a result of a number of recent high profile events. These include the respiratory disease issues suspected as a result of the effect of:

- "Twin Towers" 9 November 2001 New York event in which thousands of fire-fighters who attended the catastrophy were inadequately prepared for respiratory protection on the scale of the event;[563,564]
- The SARS (Severe Acute Respiratory Syndrome), "Bird Flu", anthrax and infectious diseases of international concern;
- The increasing international threat of biological and chemical warfare and protection. [565,566,567,568]
- In New Zealand the publication in 2003 and 2004 produced by NOHSAC focussing on the high incidence of occupational disease from work related exposures, with about 50 people per day

affected through their occupation including about 10 workers per day affected by severe occupational disease.[569]

These events have again focussed public attention in New Zealand on the adequacy of current respirator equipment and standards.

Organisations that produce manufacturing standards such as AS/NZ 1715:1994 and 1716:2003 (which refer to respiratory protection) set the minimum standards for manufacture and guidance for use. There are significant limitations that have been identified in these standards now identified in the preface of the document which include the need to more comprehensively consider the physiological needs of the user largely ignored in current documents[17]. A similar approach has also been adopted by European standards setting organisations. This includes noting the difference and implications of both minute volume flows and peak inspiratory air flows to the user and the effects of peak inspiratory air flows on the practical life of cartridges and filters. This effort is currently being led by the working parties of the ISO (International Standards Organisation) which is likely to bring about significant changes in future standards in this field.

Users, whether SMEs or the New Zealand Government tend to be unaware of these standards developments happening off-shore. In this thesis, surveys in the agricultural sector has shown that farmers (who collectively comprise at least 10% of the working population in New Zealand) are generally unaware of issues surrounding respiratory protection and the minimum requirements for protection-including respirator requirements for entering confined space areas. On another level, recommendations from Government agencies in New Zealand to protect the public from threats such as ”Bird Flu” (Avian Influenza), SARS (Severe Acute Respiratory Syndrome) or Anthrax. Recommendations from these agencies tend to be modelled on the advice given by organisations such as NIOSH (US National Institute of Occupational

---

[17] This came about as a result of the work by the author and submissions made to the Australian technical committees of these respirator standards.

Health and Safety). Generally recommendations relate to the issue of N95 disposable respirators as a protection against these types of potential pandemics. In high risk situations, PAPR equipment is recommended in spite of research which has demonstrated that this type of equipment can be over-breathed readily.[570]

The results in this thesis are important in the field of respiratory protection. The topic is becoming increasingly significant in the prevention of occupational respiratory disease, CBRN biological and chemical warfare situations as well as national pandemic situations such as “Bird Flu”. The field is fraught with myths that pervade even the health sector in New Zealand such as the recent public advice issues for personal protection by the New Zealand Ministry of Health which is still recommending surgical masks as protection for health care workers.[18]

With the advent on new information that is now available, the testing methodologies used for disposable respirators are being questioned. Current methodology requires a flow rate of 30 L/min while a more acceptable rate may be about 220 L/min to refect the conditions used in the workplace. This may have a significant impact on respirator design and manufacture, and ultimately, on use.

Perhaps a reflection of the concerns about the true protection of respirators is that protection is again being questioned. For example, a recent paper related to half-face respirators has suggested that the assigned protection factor has suggested that be reduced from 10 to 5.[571]

There are problems in the methods used for TIL suggested in this research. Invariably, the work tends to be more time consuming for any industry sector and generally outside the scope of SMEs. However, the true TIL related to the actual work being done, incorporating the wide variability in individual physiological requirements is a preferred direction. The need to obtain a better representation of what protection is being

---

[18] Personal correspondence and training sessions held by the author to representatives from the NZ Department of Health and others in 2007.

offered at the tasks of the work for any individual is challenging but important.

The quality of the data obtained was possible by the modern advent of computer and micro-processing equipment, enabling very fast and repeated measurements to be taken-a factor not available to the earlier investigators. This was particularly important in the analysis of peak inspiratory air flow measurements, where the ability was present to analyse the breathing pattern and rates over very short micro-second periods.

It is suggested that the current AS/NZS 1716:2003 methodology for determining the TIL is not suitable for practical use by users and that it is focussed on manufacturer requirements for certification. This methodology has complications for users. It is unlikely that the values obtained have any real value to users of the equipment, although it is inferred by many in the industry SMEs who tend not to carry out quantitative or even qualitative facial fit testing. The methodology suggested may be more useful for users and would also help in education and further research in industry on the practical values derived from RPE and the need for appropriate protection.

The work here on PIAF has already had significance in the work of the physiological groups of the ISO technical committees and is to be followed up further in the immediate future with the technical committees of the Australian and New Zealand Standards.[572] The work has now been repeated elsewhere in the world to a limited extent, primarily as a result of the interest by ISO technical committees as to the implications of future worldwide standards, but has now also been developed by respirator manufacturers keen to ensure that their equipment is suitable for use and that certification of cartridges and other equipment is still appropriate.

PIAF increase further when communicating in the workplace. The RPE should encompass this requirement as it is essential in the workplace.

The surveys in the agricultural sector of New Zealand are believed to be representative of the major population of this employment group, albeit the sample size was limited to several hundred people. The results are of concern to legislators and others in New Zealand, as there appears to be very limited knowledge of the correct RPE to use in different agricultural activities or of inhalation disease of particular interest to ACC. This is significant, as there have been decades of education programmes conducted by these organisations, but it appears that little impact has been made. Future work will need to change the approach and likely be much more encompassing and comprehensive.[573] The results also have wide implications beyond the agricultural sectors of New Zealand and extend to the other SME sectors (about 45% of the workforce).

Further research should also focus on aspects of investigating the further use of the TIL methodology in the light of the work carried out in this thesis, but applied to different and key industry sectors such as aluminium smelting or agriculture, taking account of the wide variation between people and MV and the implications for RPE standards and industry applications, incorporating the values of PIAF in all new respirator equipment and cartridge certification criteria by various national and international bodies, and manufacturers noting the values and implications of PIAF with technical literature of their equipment, incorporating the PIAF values and implications from communicating in the workplace and more comprehensive and improved intervention methods in agriculture and SMEs generally. This is essential is the incidence and prevalence of occupational disease is to be reduced in the future of New Zealand.

9.2 Conclusions: The Findings of this Thesis

The work in this thesis has moved the body of knowledge and practice in the minimum requirements for adequate respiratory protection forward in a number of key areas that have also been supplemented by other authors and now also by the working parties of the ISO.

The findings are shown in the Table below.

Table 9: Main Findings of this Thesis

Key focus	Chap	Significant conclusions	Comments
Alternative methodology for Total Inward Leakage testing for every individual wearing the RPE.	4	The relationship between the heart rate of any individual in the workplace and the minute volume of air used can be utilised to give a good estimation of the TIL (Total Inward Leakage) for any RPE. This proposed methodology accurately reflects the needs of the RPE user. Current methodology sets artificial standards that bear little relationship to the physiological needs of users. Current methodology meets manufacturing requirements, but not those of the user.	Current manufacturing and testing criteria set a low value of minute volume of air used and do not reflect the actual physiological requirements of wearers in the workplace. Manufacturing and testing standards must estimate true working requirements. The range of minute volumes required is much greater and in many cases is higher than is undertaken currently by standard setting organisations such as AS/NZ 1715 and 1716 in setting the minimum testing requirements for filters and cartridges. Current standard testing requirements use ten carefully selected young subjects. This does not reflect the needs of the working environment.
Minute volume air flow requirements.	5	The range of minute volume requirements in a typical workforce is higher than is currently used by standard setting organisations.	Both the range and higher values are significant and current testing requirements reflect neither the practical working physiological needs of users or in setting minimum testing requirements for filters. Manufacturing Standards should enable the equipment to meet the requirements of almost all users. This is not the case at the moment. There is confusion in the literature generated by manufacturers and organisations setting minimum testing requirements between minute volume and peak inspiratory air flow rates.
Peak inspiratory air flows at various levels of work and when communicating.	6	Peak inspiratory flow rates are significantly higher than used by all current standard-which reflect minute volume requirements-particularly under high work loads and when communicating. The values are even much higher when speaking. The work in this thesis has been followed and supported by the work of many subsequent researchers and is now being used by the	Peak inspiratory air flows are considered more important than minute volumes, yet have been ignored in much of the RPE literature. Manufacturing standards currently only reflect minute volumes of air. Filters and cartridges should be tested at air flow values about ten times the current values used. The much higher volumes of air needed is critical in the design

Key focus	Chap	Significant conclusions	Comments
		current working parties of the ISO on physiological requirements of RPE users.	and testing of RPE. PAPR equipment is now known to be inadequate to meet the requirements of users even at moderate work loads. While original comments to this effect were met with manufacturer's criticism, the latest results demonstrating the same issue, have been accepted. It is likely that almost all current PAPR RPE will be regarded as obsolete in a short period of time and that filters and cartridges have a much shorter working use than is currently the case.
Respiratory protection in Agriculture	7	Respiratory protection knowledge is lacking and protection practices in the New Zealand agricultural industry appear to be in need of extensive education and training in spite of a number of previous education campaigns by both ACC and OSH. The postal survey (the first survey) showed that this type of response was normally completed by the partner on the farm rather than the practicing farmer. This has implications for future surveys of this type. The partner may give a different response to the farmer. Some of the key issues for the future that arose out of an analysis of the survey include: A need to understand the barriers to respiratory protection for farmers and develop respirators to meet these requirements. Current respiratory equipment lacks the ability to protect farmers in many practical applications. Standards have to be developed to simulate the needs of farmers. Current standards do not reflect the use of RPE by farmers. The need to increase communication of the risks of respiratory disease and RPE in their individual sectors (for	This sector is widely exposed to a range of agrichemicals and carry out a wide range of activities that normally require respiratory protection in urban industry but are lacking in the rural sector. Currently, in New Zealand, both the NZIPS (New Zealand Injury Prevention Strategy 2003) and the HSNO (Hazardous Substances and New Organisms) Act 1996, emphasize the need to reduce the burden of occupational disease. This is unlikely to be achieved without adequate means to control exposure, including improvements in respiratory protection equipment (for example, PAPR-mainly used in agriculture) and practices. This sector employs 10% of New Zealand's workforce, but is also focussed on the SMEs or self-employed. The needs of this sector is different to that of larger organisations.

Key focus	Chap	Significant conclusions	Comments
		example, dairying versus horticulture). This also needs to reflect the needs of SMEs in general.	

9.3 Conclusions: Moving the body of knowledge forward in terms of respiratory protection

Proper use of respiratory protection is a common and useful measure for reducing exposure to airborne contaminants in the workplace.

Respiratory protection can also be very effective in preventing illness. However, physicians and other health and safety professionals should not undertake protection efforts without an adequate understanding of all the components involved, including health surveillance, adequate training, fit testing and monitoring programs.[574]

Current in-laboratory testing programs generally over-estimate the protection afforded in the workplace.

Further issues for future discussion and applied research should include the following topics.

9.3.1 Comparison of International Standards on Respiratory Protection: The Need for International Standards

Standards are critical to the development of PPE including respiratory equipment (RPE). Standards specify the minimum requirements that have to be met before it can be marked as meeting the requirements of that Standard. In practice, Standards have evolved differently in a variety of countries, there is as yet, no international standard in spite of the equipment being marketed across many continents,[575,576] globalisation in general[577] and efforts by many organisations,[578] standards can be biased towards a particular manufacturer's products, testing procedures are often unreliable and most seriously, standards may not reflect real-life conditions in the workplace,[579] such as the need to communicate[580] and a host of other factors (for example, radiant heat or workplace obstructions hindering the use of certain types of RPE). Standards are then used to seek approvals such as those by NIOSH in the USA to produce the Certified Equipment List.[581,582,583] The end-user is normally not qualified to judge the suitability for compliance. Design of respirators may not take into account actual use conditions and their limitations, in spite of computer modelling and more modern techniques that are now entering the field.[584]

Certification through Standards implies compliance with known physiological requirements of humans. This may not be true, thus possibly exposing the end-user to an airborne risk they may not be aware of. Laboratory evaluation of equipment may bear no resemblance to the protection in the workplace, albeit workplace protection factors are often quoted. This is in spite of there being no standard method for determining the factor in the workplace and testing results can be biased towards a respirator manufacturer methodology.[†]

An independent study is required to determine the criteria for Standards that can be agreed internationally. Recent work, particularly in the USA, has shown a much more comprehensive approach.[585] Although recent, this document still fails to identify some of the critical scientific information, such as Peak Inspiratory Air Flow requirements.[586] This is may be due to the inability of all but a few types of respiratory equipment to meet the air flow speed requirements of the practical work-place and the reluctance of manufacturers to highlight deficiencies.

Various standards impose different criteria, for example in aircraft priming, supplied air hoods and helmets have assigned protection factors (APF's) that vary from 25 (NIOSH) to ANSI Z88.2 value of 1000 within the USA alone.[587] If the same work is performed outside the USA, different protection criteria apply, such as in Australia where a factor of 50 may be designated. These differences are substantial and significant.

---

† This can be very difficult to pick up in published work and usually requires the reader to have substantial knowledge of the workplace, the testing procedure and the limitations of both.

As respirators are used, manufactured and exported worldwide, the need for common understanding of the requirements and protection offered is critical to the end-user. This thesis has identified some of the critically important factors, and suggests that modern techniques should be used to measure and evaluate the equipment in the occupational environment. This approach is radically different to what exists at present, with respirator manufacturers, through standards, setting the criteria to which their equipment may comply without necessarily being concerned with what happens in the workplace or physiological requirements of the end-user.

This part of the research would be aimed at identifying the criteria that are important in respiratory standards and suggesting possible means to measure the chosen factors in the laboratory and workplace. It will be very important to determine the protection in the workplace environment for the end-user, who is subjected to additional stressors such as high heat, high humidity, long hours and heavy work rates.[588] This type of data is not currently available at the present time. Practical laboratory environments could include developing test chambers with known contaminant concentrations in question being measured inside and outside the respirator as well as known Minute Flow and Peak Inspiratory Air Flow factors determined from the workplace.

A review of respiratory protection standards demonstrates the confusion that exists internationally and has been included previously.

9.3.2 Protection Factor (PF) Issues: Protection for whom?

The concept of a "protection factor" for PPE is very important for the user as well as others, and is part of the information used to determine if equipment is suitable for the workplace application. Unfortunately, there are at least nine different definitions and understanding of what protection factor means internationally.[589] In addition, different organisations, sometimes in the same country, have assigned different values to the same type of equipment (for example, NIOSH and ANSI in the USA[590]). Workplace values obtained for protection factors may be very different (and lower) to the APF (Assigned Protection Factor) by such bodies as NIOSH.[588] The definition commonly assigned to "Workplace Protection Factor" seems simple as, "the workplace protection factor is a measure of the protection provided in the workplace by a properly selected, fit tested and functioning respirator when correctly worn and used".[591] While this definition appears simple, the analytical determination of the values is complex and fraught with practical complications. Examples are the impact of exhaled breath moisture on the behaviour of inhalable particles, particularly when applied to half-face respiratory equipment. There are further complications which are analytical and practical in obtaining values for the concentrations inside and outside the respirator particularly in the workplace, such as the positioning of the sampling head inside the respirator.

Fit factor, a measure of how well the equipment seals against the face, (usually obtained prior to entering the workplace), bears little relationship to the protection factor in the workplace and many countries have no requirement for fit testing requirements.[592]

Understanding can also be motivated by various perspectives of the RPE manufacturer or distributor. For example, "Nominal PF (Protection Factor) - What the Standard says", "Assigned PF - What the lawyers expect" or "Workplace PF What happens".[593] In other cases, the meanings are not assigned.[594]

These factors are not well understood by distributors of PPE, many of whom have accountability for a range of PPE products, of which RPE is only one. Unfortunately, users are often heavily dependant on the distributors and manufacturers for selection of equipment,[595] particularly in the case of smaller organisations or those that are self-employed. Invariably, much confusion exists in the workplace in addition to inadequate training and maintenance of RPE as well as terminology.

Some respirator manufacturers have conducted workplace tests to determine a protection factor in a number of workplace settings with a variety of particle sizes, for example, respirable particle concentrations in a lead smelter.[596] Further examples include the workplace performance of half-mask high efficiency filter respirators against aluminium smelting aerosols,[597] workplace protection factors of half-masks in different environments,[591] workplace protection in the aircraft industry,[598] workplace protection factors for a powered air purifying respirator,[599] loose fitting hoods during furnace tear down[591] and full-face respirators at a lead smelter.[600] However, there is no standard methodology for determining the different values.

Historically, protection factors assigned to various types of respirators have been based primarily on laboratory evaluations of respirator performance,[601] albeit there has been an increasing emphasis on the application of workplace evaluations in the past.

An analysis of the different terminologies is required and the most useful interpretation for the end-user needs to be defined. The means to determine the concentration values both inside and outside the respirator, what needs to be analytically determined and how also needs to be recommended. Since the focus is on the worker in the workplace environment, measurements should preferably be in a workplace environment with pre-determined low-hazard contaminants to which the worker is potentially exposed, for example, while working, at high heat and while sweating (because this affects the face seal).

There are many complications to an apparently simple technique which include the effects of moisture on the particles being measured, the need to collect respirable dust samples rather than large particles,[602] and a number of other occupational hygiene measurement concerns need to be considered.

The most appropriate technique needs to be investigated and recommended as a standard methodology. In addition, the definition and measurement technique of workplace protection factor is required to be finalised.

9.3.3 Fit Factors

There have been many discussions about the value of quantitative and qualitative fit testing of respirators. Most of the published articles point out that there is no relationship between the quantitative fit factors obtained in the laboratory and the protection obtained in the workplace, which begs the question: Why conduct laboratory based measurements?

Many other discussions have centred on the value of qualitative and quantitative fit testing. Qualitative testing is usually carried out with a strong testing agent such as saccharin or odour agents such as "banana oil" or others. Quantitative fit testing has a number of significant advantages which include the derivation of "hard" data and allowing easier comparisons to be made. A further advantage includes immediately identifying a bad fit and allowing possible corrections to be made and therefore has value in education and training. Ill-fitting equipment is immediately identified. With qualitative approaches using compounds with strong odours or tastes, it is difficult to test individuals immediately after the first test as the odours or taste tend to persist for some time.

9.3.4 What Needs to be Agreed Internationally before Progress can be made to Improve Respiratory Protection Standards with Regard to Protection Factor

In Britain, the revised BS4275-1997 allows for the selection of RPE (Respiratory Protective Equipment) based of APF's (Assigned Protection factors) derived from observed performance demonstrated in real workplaces when worn by wearers carrying out their normal duties. The Assigned Protection Factor (APF) is not a direct measurement - it is derived from other measurements, coupled with opinion, of what protection factor should be expected in the workplace. Workplace Protection Factors are derived from direct measurements.[593] In addition, for a given wearer, the WPF varies from wearing to wearing and it is generally assumed that an individual's WPF distribution is lognormal.[603]

The consequence of selecting RPE on the basis of APF is that the previously assumed levels have been very substantially reduced for all nominally high performance devices. For example, the assumed PF (Protection Factor) of conventional full-facepiece powered respirators fitted with P3 filters has been reduced from 2000 to 40. The consequence of such an action is substantial in areas such as asbestos work.

In Australasia, AS/NZS 1715:1994 discusses the "required protection factor", which is defined as the ratio of the measured ambient airborne concentration of a contaminant to an acceptable exposure level or standard. There are variations based on the type of filter, whether the particles are thermally or mechanically generated and the type of head piece attached to the respirator assembly. However, the values can range to greater than 100. There does not appear to be any scientific basis for quoting these values. Of even greater concern is the statement that powered respirators deliver air "generally under positive pressure" when this is known to be incorrect.[604,†] In fact, the equipment must operate for most of the time in negative pressure mode allowing contaminated air to be drawn into the operator breathing zone. Even some manufacturers are becoming cautious. The 3M company note "it is interesting that the term positive pressure has become part of the accepted respirator terminology without a formal definition and over the years people have become to regard PAPR's as "positive pressure respirators."[605] However distributors of the equipment regularly conduct courses throughout New Zealand quoting that the equipment supplies "positive pressure".[†]

The Summer 1999 journal of the International Society of Respiratory Protection, discussed the Lawrence Livermore Test. WPF studies allowed NIOSH to assign PAPR PF's of 25, albeit the same article quoted that workplace analysis in an aluminium smelter gave WPF's of

---

† Wallaart J. 1997. "Calibration of test subjects", A study of how speech affects peak inspiratory air flows at various levels of work and how the test results spread between individuals in a test group" and "A study of the relationship between heart rate and minute breathing volume at various levels of work demonstrating the spread between individuals in a group and the implications in industry". http://www.sea.com.au

† The most recent as in June 2001. Users were invited to attend training sessions throughout the country.

275. This study may be in conflict with practical experience, where practical workplace protection factors can be low.

There are other important factors in assigning a Protection Factor. Respirators must be designed for continuous use and the respirator must be designed to be able to be worn 100% of the time. The work of the current ISO working parties on respiratory protection will be critically important in setting the minimum standards for the future.

9.3.5 Protection Factors: Laboratory versus Workplace Values

There appear to be little, if any, valid comparison between the values derived from laboratory-type environments and workplace analyses. Generally, the performance obtained in the workplace is substantially lower.[606,607,608,609,610,611] This has been well recognised, particularly with regard to PAPR's which were shown not to be achieving the levels of performance that had been predicted.[585] Comparison of changes in AFP (Assigned Protection Factors) in 1989 compared to 1980 showed reductions from APF of 3000 to 25 for some types of PAPR combinations.[590]

9.3.6 Smaller organisations and the self-employed workplace

The self-employed and smaller organisations present special challenges in terms of occupational health and safety.[620] Self-employed people are often constrained by time and resources and may regard safety as a additional and optional luxury.[†] The result of a serious injury and fatality can have serious consequences to a self-employed person such as loss of income due to the inability to work. In a recent study was conducted in New Zealand with a focus groups of people in the construction industry, most self-employed believed that they took "extra care" and were

---

[†] This is from internal ACC work carried out with self-employed farmers in New Zealand.

particularly safety conscious in their work.[‡] However, statistics recently published in New Zealand show that the work related fatality rate for self-employed has been approximately double that of employees for the last ten years.[621]

Many organisations worldwide (for example, National Occupational Health and Safety Commission in Australia, or the Workers Compensation Board in Canada) concerned with preventing injury to self-employed and smaller companies recognise that the needs of this group is vastly different to that of larger groups.[622] Injury and disease prevention in farming, for example, has traditionally relied on the provision of information to change or improve attitudes, beliefs, practices and behaviours.[623] Agriculture in New Zealand has both the highest number of work related fatalities compared with other industries and the highest number of ACC (Accident Compensation Corporation) work injury claims.[624]

In New Zealand, there are 350,000 self-employed people working, with about 85,000 of those working in agriculture and 45,000 in construction related work (the figures vary according to the source). Of the total working population, 85% are engaged in work organisations of less than five people.[625] Employers and employees in this group are advised by health and safety practitioners to wear personal protective equipment and yet many surveys show that many do not.[626] For example, in a recent USA study, two-thirds of farmers do not use or maintain many of the protective devices that have long been recommended through safety campaigns, safety education programs and activities. A New Zealand study in 1994 found that although 77% of farmers use agricultural chemicals, on average, only 22.4% wore respirators. The percentage significantly increased on horticultural farms as opposed to dairy farms.[627]

---

‡ The focus groups were part of a study conducted by the Business Research Centre limited here in Wellington to study the beliefs of self-employed construction people in relation to the workers compensation market. The study was conducted in the Auckland area in June/July 1999.

Many occupations increasingly are characterised by uncertainty, greatly influenced by factors which are outside the control of the individuals, for example, in farming, weather, crop disease, national economics and international politics. Farmers will accept such difficulties as their "cross to bear" (the "Agrarian Myth"[628]) and if this translates to beliefs about their own health then they may be expected to have generally fatalistic views of work related disease and injury. As such, it seems likely that diseases which have little impact on short-term ability to work may be disregarded until they have progressed to a disabling state.[629] Farmers and others who view their ability to take preventive action as limited and who see little immediate benefit are probably less likely to take precautions or use protective devices while on the job.[630,631] In addition, lack of knowledge related to both occupational asthma and respiratory protection would indicate that the risks are not well understood. Knowledge is necessary before the risk can be understood, similar to the the public's perception about airbags and vehicles.[632] In addition, delayed or progressive effects such as can be the case with occupational asthma, may result in the risk being regarded as beyond control (outside the locus of control). A resultant fatalistic resignation to possible disease, similar to the case with construction workers and skin disease (as opposed to the immediate reaction of falls) may result.[633]

Among the most common preventable problems affecting this population are respiratory diseases, noise induced hearing loss and skin cancer (reported by a USA study).[634] In similar study, farmers report that their major concerns are with stress, trauma and respiratory problems.[635] Workers compensation insurance claims in New Zealand for the agricultural sector is small in relation to other workplace claims, but this will increase as awareness of diseases like occupational asthma increases in the self-employed sector.[†] The data from the Australian NOHSC places Australia in the top five nations with the highest

---

† Analysis of ACC statistics in relation to injuries from self-employed and employers. Both sets of data do not show a high incidence of respiratory

prevalence of asthma in the world. The proportion of occupational asthma is estimated to be about 2% to 30%, with recent estimates tending toward the higher end of the range.[622] Potentially, the number of people affected in New Zealand, with similar conditions, could be over 25,000 agricultural employees. This is far in excess of any other form of workers compensation type claim at present.

The prevention of workplace asthma is generally centered on respiratory protection after all other options such as engineering controls have been exhausted (with the possible exception of removal of sick workers from further exposure). As mentioned above, in practice, physicians generally are not trained in the limitations of respiratory protection equipment, and workers themselves often do not wear respiratory protection for a variety of reasons which are based on physiological barriers and psychological barriers.

The onset of occupational asthma may not be immediate. In many cases the person has been subjected to the exposure for many years prior to any recognition of the disease. Hence, the delayed effects do not give an immediate positive feedback. In fact, there may be significant peer or other pressure to do otherwise. Non-supportive and incorrect beliefs,(for example, no immediate practical evidence that wearing respirators reduces disease) complicate the situation.[636] According to the theory of DeJoy,[637] predisposing factors (beliefs, attitudes), enabling factors (any part of the environment or system that promotes or blocks safe behaviour) and reinforcing factors (reward or punishment) are all areas that may influence whether an individual will wear protective equipment.

Behaviour based approaches have promised much in the workplace[638,639,640,641,642,643,644] including references to changing organisational cultures,[645,646,647,648,649] to changing “safety values” in people or organisations,[650] improving safety and health performance[651,652] and the need for intervention support[653] but the

---

disease. This is likely to be due to under-reporting rather than a true incidence. It is unlikely that this will continue in the long-term.

fundamental practical barriers for the wearer are not considered or attempts made to overcome them. If selected inappropriately, or worn incorrectly, the respirator can provide no protection at all to the wearer. Some authors at least recognise the limitations of equipment in failing to reduce injury or disease.[651,654,655] Most wearers do not recognise that removing the equipment for only a short period, say thirty minutes in an eight hour shift,[656] much of the protection will be lost.

Effective use of respiratory equipment depends on a range of factors that affect the workers use of equipment and are critical to the prevention of disease. A taxonomy of concerns and barriers to safety in a large hazardous waste plant (12,000 employees) fell into three categories: knowledge, attitudes, physical and psychological effects as well as external influences: knowledge, beliefs and attitudes.[657] Such barriers need to be more fully explored with a view to overcoming them. Some behavioural approaches towards respiratory protection concentrate on immediate benefits of certain types of behaviour. The wearing of respirators is fraught with lack of immediate obvious benefits in many cases of occupational disease.[658]

Barrier removal has focussed at the level of behaviour of the individual, generally employees of large organisations, but it is also important to identify practical workplace-based solutions to overcome these, and present these to management in simple, easily recognisable ways, for example, Pareto charts on investigating operational activities and “what to do now” checklists.

Respiratory protection for the self-employed generates a different set of challenges which are quite distinct from employees of larger organisations. This group is vulnerable in terms of occupational disease and injury as they tend to have limited expertise, time and resources to devote to preventive measures. In many cases, such groups may lack interest in safety measures, and may even actively avoid compliance. Examples of the occupational groups which are in this category are the workers in the agricultural sector and the subcontractors in the construction sector - both of which also have high rates of claims (and therefore serious injury) with insurance companies.[659]

While the wearing of protective equipment in large organisations tends to be carefully monitored, the same cannot be said for self-employed or smaller organisations. Workers at this level are particularly difficult to influence and a range of strategies commonly able to be used elsewhere cannot be so readily used with this group, for example, incentives, enforcement,[660] disciplinary action, fear messages or behaviour modelling.[661]

The agricultural sector has a known high incidence worldwide of occupational respiratory disease and the numbers are increasing. Known factors are dusts from plants and grasses as well as a wide variety of materials used on the farms, including fuels, acid and alkali cleaning chemicals and pesticides.

There are barriers to the reduction of disease contributed to by individuals that need investigation but there are also barriers presented by large organisations which are substantially different and may be due, for example, to lack of knowledge and cost. It is critically important to identify and overcome these barriers as the employees themselves may have little knowledge and no power to influence purchasing decisions. The need to influence the decision based process in large industries also needs to be investigated. At present, it is likely that purchase decisions are made by people who are poorly equipped to make decisions based on health and safety issues.

Characteristics of the group is to obtain access to information which are perceived as important only, tend to prefer one-to-one personal contact and directly relevant. An overarching priority may also be given to cost minimisation which can also affect outcomes. Many SMEs are focussed on day-to-day survival rather than long-term planning and the focus of attention is limited on health and safety issues. Material needs to be brief and only address the key points.

Almost all statistical information collected by different agencies (such as workers compensation organisations) is collected and collated for different reasons and drawn on in different ways. One problem is a lack of consistency is what is actually collected, making comparisons difficult. A detailed summary of the key injury factors and contributory factors is not available in most of the present literature, particularly in the target self-employed sectors, but is a key topic in understanding and targeting injury prevention efforts for these major groups. Lastly, there is a tendency that workers compensation is the only source of information on workplace morbidity and mortality, ignoring the well known underestimate that such data actually supplies.

Workplace investigations lend themselves to a mixture of the questionnaire approach, taxonomy and intervention studies. It is important to recognise the different sets of situations in which respiratory protection should be worn, for example, the self-employed working largely by themselves (such as farmers) and those working in large organisations (such as in large manufacturing facilities). The barriers and means to overcome these will be different.

A taxonomy is useful to group similar concerns together and gain major further insights into the major issues.

9.4 Recommendations

Recommendations for further research, especially for future respirator development include:

- PAPR equipment needs to be manufactured that is able to meet the airflows required, that is, minute volumes of 100 L/min and peak flows of 350 L/m for the time periods needed during high physiological loading. The (ISO physiological working groups groups have at present tentatively agreed on a lower value of 200 l/m PIAF). Air flows and rates that are typically obtained from the workplace must be used for the design and development of respiratory equipment.

- The current capability of PAPR equipment must continue to be challenged.
- The emphasis in design and testing must change from the manufacturer's requirements to those of the user, including physiological requirements.
- Filters and cartridges need to be tested under realistic conditions of airflow that is experienced in the workplace. Current low flows do not reflect air flows typically obtained from the workplace, particularly under high physiological loading.
- Current Standard methodology of TIL testing uses the results of ten carefully selected people who do not reflect the typical users or the subsequent work airflows required. This needs to change if an improvement is to be made in the effectiveness of current RPE.
- The Pimex technology holds considerable promise in gaining better insights into the true and real-time evaluation of the contaminants reaching the wearer under work-place conditions. Particularly with the advent of new monitoring cells that are being developed at present will allow improvements to be made in this field.
- The Pimex method of evaluating in real time the contaminants inside and outside the respirator in real time, has significant advantages over current averaging occupational hygiene monitoring methods. Its importance lies in the real-time capability and video recording of the activity which is critical to future insights into improvements in respirator development and design.
- Disposable respirators for which a close face seal is not possible, must be discarded as the most common respirator in use today in favour of equipment which is able to protect people under known conditions in the workplace. In New Zealand, the purchase of low grade, uncertified respirators is possible and this will hinder any future efforts to reduce the occupational disease incidence in this country. While cost and convenience remain the main reason for

selection of this equipment by users, awareness about their utility in preventing exposure (and therefore, injury and illness) will assist in eroding the use of such RPE.

- End-of-service life indicators for filters and respirators must be further developed.

- An increased emphasis on education and training must be placed by Government agencies and industry on raising public and specific industry awareness of the need for adequate respiratory protection and the associated issues that prevent protection from airborne contaminants.

9.5 References

550 Driscoll, T., Mannetje, A., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., Pearce, N., Wagstaffe, M. *The Burden of Occupational Disease and Injury in New Zealand: Technical Report*. At: http://www.nohsac.govt.nz. NZ Occupational Health and Safety Council, Wellington, 2004.

551 Chan-Yeung, M. *Occupational asthma-Global perspective.* Allergy Clin. Immucol Int-J. World Allergy Org. **15.** Pp 203-207. 2003.

552 Driscoll, T., Mannetje, A., Dryson, E., Feyer, A.-M., Gander, P., McCracken, S., Pearce, N., Wagstaffe, M. *The Burden of Occupational Disease and Injury in New Zealand: Technical Report.* NZ Occupational Health and Safety Council, Wellington, 2004. At: http://www.nohsac.govt.nz. Respiratory diseases (non-malignant).

553 *Safeguard Magazine*, **15**; No 272, August 2005.

554 Survey of health providers and the general public in New Zealand on the relationship between work exposure and disease. Conducted by Research NZ Ltd for the Accident Compensation Corporation. March 2007.

555 Holt, S. The burden of asthma in New Zealand. *Asthma and Respiratory Foundation of New Zealand*. 2002. Report is available at: http://www.asthmanz.co.nz

556 Contact Blosser, F. New leads for lung-disease prevention offered in NIOSH study that charts areas of high prevalence. CDC NIOSH. At: http://www.cdc.gov/niosh/lungdisprev.html.

557 Meyers, W.R, Peach, M.J, Cutright, K, Iskander, W. Workplace protection factor measurement on powered air-purifying respirator at a secondary lead smelter: Results and discussion. *Am. Ind. Hyg. Assoc*. J. **45**. Pp 681-688. 1984.

558 3M. Workplace protection factor study-half mask high efficiency respirator. 3M *Occupational Health and Environmental Safety Division*. MN 55133-3271. 1993.

559 Weber, R.A, Mullins, H.E, Colton, C.E, Bidwell, J.O, Fipp, B.A. Gas/vapour workplace protection study-phase 1: Protocol development. *3M Occupational Health and Environmental Safety Division*. Presentation at the AIHA conference, Boston, USA. 1992.

560 Nicas, M and Neuhaus, J. Variability in respiratory protection and the assigned protection factor. *Journal of Occupational and Environmental Hygiene*, **1**. Pp 99-109. 2004.

561 Zhuang, Z, Coffey, C.C, Jensen, P.A, Campbell, D. L, Lawrence, R.B, Myers, W.R. Correlation between quantitative fit factors and workplace protection factors measured in actual workplace environments at a steel foundry. *AIHA Journal*, **64**. Pp 730-738. 2003.

562 Fisher, J. Points of consideration for workplace performance studies on RPD-test and sampling protocol. ISO94-15-1. Summary paper.

563 See various articles at: http://cityroom.blogs.nytimes.com/2007/11/28/survey-sees-rise-in-childrens-asthma-from-911-dust/, http://www.nytimes.com/2007/08/28/nyregion/28registry.html.

564 The author submitted information related to respiratory protection to the RAND Science and Technology Policy Institute following the Twin Towers post analysis. This was requested in the document: Jackson, B.A, Peterson, D.A, Bartis, J.T, LaTourette, T, Brahmakulam, I, Huser, A and Sollinger, J. Conference proceedings. Protecting Emergency Responders. Lessons learned from the terrorist attacks.

565 NIOSH-DOD-OSHA sponsored chemical and biological respiratory protection workshop report. At: http://www.cd.gov/niosh/2000-122.html.

566 NIOSH. CBRN Respirator Standards Development. At: http://www.cdc.gov/niosh/npptl/standardsdev/cbrn/default.html.

567 CDC. Interim recommendations for the selection and use of protective clothing and respirators against biological agents. (Not dated)

568 NIOSH. Concept for CBRN Escape Respirator Standard. Part 1: Concept for CBRN Air-Purifying Escape Respirator Standard. At: http://www.cdc.gov/niosh/npptl/aperconjun30.html.

569 Driscoll, T, Mannetje, A.T, Dryson, E, Feyer, A-M, Gander, P, McCracken, S, Pearce, N and Wagstaffe, M. The burden of occupational disease and injury in New Zealand. 2004. ISBN 0-478-28011-4.

570 Mackey, K.R.M., Johnston, A.T., Scott, W.H., Koh, F.C. Over-breathing a loose-fitting PAPR. *Journal of the International Society of Respiratory Protection* **Vol:** 1-10, 2005.

571 Nicas, M and Neuhaus, J. Variability in respiratory protection and the assigned protection factor. *Journal of Occupational and Environmental Medicine*, **1**. Pp 99-109. 2004.

572 See Preface to AS/NZS 1716:2003.

573 Wallaart, J and Winder, C. A survey of New Zealand farmers' knowledge about the risks and prevention of occupational respiratory disease. *Journal of Occupational Health and Safety*-Aust and NZ, **23**. Pp 469-479. 2007.

574 American Thoracic Society-Medical Section of the American Lung Association. *American Journal of Respiration and Critical Care Medicine* **154:** 1153-1165, 1996.

575 Bancroft, B. Dead-space measurement in RPE-European Test House Results, Problems and Solutions. *Journal of the International Society of Respiratory Protection* **17:**1999.

576 Bostock, G.J. ILEE-The European experience. *Journal of the International Society of Respiratory Protection* **17:** page 21, 1999.

577 Berndtsson, G. Harmonising Standards in a shrinking world. *Journal of the International Society of Respiratory Protection* **17:** page 18, 1999.

578 Myers, R. Overview of the Canadian Standards development activities. *Journal of the International Society of Respiratory Protection* **16:** page 53, 1999.

579 Berndtsson, G. Tomorrow's standards-Where are we heading? A case for objective, performance based, internationally applicable standards in respiratory protection. *Journal of the International Society of Respiratory Protection* **17:** page 7-9, 1999.

580 Caretti, D.M, Scott, W.H., Johnson, A.T. Respirator design and communication effectiveness: How important is a speech device. *Journal of the International Society of Respiratory Protection* **17:** page 25, 1999.

581 NIOSH testing and certification branch respirator approvals for 1995. *Journal of the International Society of Respiratory Protection* **13:** page 18-67, 1995.

582 NIOSH testing and certification branch respirator approvals, Oct 95-March 1996. *Journal of the International Society of Respiratory Protection* **14:** page 32-111, 1996.

583 Meriar, T.R., Terry, S.L. NIOSH SCSR Certification program. *Journal of the International Society of Respiratory Protection* **17:** 1999.

584 Caretti, D.M, Grove, C.M., Cohen, K.S. Respirator design tools for the next millennium. *Journal of the International Society of Respiratory Protection* **17:** page 24, 1999.

585 OSHA. *Respiratory Protection; Final Rule: Part 2.* US Occupational Safety and Health Administration, Department of Labor, Washington, 1998.

586 Backman, L. Respiratory protection: Airflow requirements. *Journal of the International Society of Respiratory Protection* **17:** page 17, 1999.

587 Nelson, T.J, Wheeler, T.J., Mustard, T.S. Workplace performance of a supplied air hood during priming. *Journal of the International Society of Respiratory Protection* **17:** Page **54,** 1999.

588 Bien, C.T. The Lawrence Livermore Test. *Journal of the International Society of Respiratory Protection* **17:** page 7-11, 1999.

589 Jova-Sevic, M., Stojanovic, B. A comparison of anthropometric panels used for respirator normal protection factor evaluation. *Journal of the International Society of Respiratory Protection* **13:** page 4346 , 1995.

590 Roza de, R. Status of ASI Standards on respiratory protection. *Journal of the International Society of Respiratory Protection* **8:** page 37-41, 1990.

591 Colton, C.E, Mullins, H.E, Bidwell, J.O. *Workplace protection factor study on an air-line respirator with a loose fitting hood during furnace tear down.* 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1993.

592 Han, D.H. Fit factors for quarter masks and facial size categories. *Annals of Occupational Hygiene* 44: 277-234, 1999.

593 Capon, A. Protection factors-who do they protect? *Journal of the International Society of Respiratory Protection* **14:** page19-25, 1996.

594 SNZ. AS/NZ Standard 1715: *Selection, Use and maintenance of Respiratory Protective Devices.* Standards New Zealand, Ellington, 1994.

595 Alston, S., Powell, L., Stroud, P., Brown, R.C. A workplace study of the use and maintenance of respiratory protective equipment against vapour. *Journal of the International Society of Respiratory Protection* **15:** 1997.

596 Lenhart, S.W and Campbell, D.L. Assigned protection factors for two repirator types based upon workplace performance testing. Ann. Occup. Hyg. **28**. Pp 173-182. 1984.

597 Burd, D.H and Gaboury, A. Workplace protection factor evaluation of respiratory protective equipment in a primary aluminium smelter. Internal document. Alcan Smelters and Chemicals Ltd, Quebec, Canada.

598 Johnston, A.R, Mullins, H.E. *Workplace protection factor study for airborne metal dusts.* 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1987.

599 Colton, C.E, Mullins, H.E., Rhoe, C.R. *Workplace protection factors for a powered air purifying respirator.* 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1990.

600 Colton, C.E, Mullins, A.R., Rhoe, C.R. *Workplace protection factor study on a full-face respirator.* 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1989.

601 Johnston, A.R, Colton, C.E, Stokes, D.W, Mullins, H.E., Rhoe, C.R. *Workplace protection factor study on a supplied air respirator.* 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1989.

602 Colton, C.E, Mullins, H.E., Rhoe, C.R. *Workplace protection factor study on a half-mask respirator in a foundry.* 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1990.

603 Ncas, M. Some considerations in defining the "protection factor". *Journal of the International Society of Respiratory Protection* **15:** 7-?, 1997.

604 De Roza, R.A Powered air purifying respirator study. *Journal of the International Society of Respiratory Protection* **8:** page 15-41, 1990.

605 Janssen L. Title? 3M Occupational Health and Safety Division, 3M Ltd, St Paul, MN, 1997. At: Http://www.3m.com/occsafety/html/vol15_no1_1997.html

606 Colton, C.E, Johnston, A.R, Mullins, H.E, Rhoe, C.R. Workplace protection factor study on a half-mask dust/mist respirator. Poster session at the AIHA Conference, Orlando, 1990.

607 Colton C.E, Mullins H.E, Rhoe C.R. Workplace protection factors for a powered air purifying respirator. Poster session at the AIHA Conference, Orlando, 1990.

608 Howie, R.M., Johnstone, J.B.G., Weston, P., Aitken, R.J., Groat, S. Effectiveness of RPE during asbestos removal work. *HSE Contract Research Report No 112/1996.* HSE Books: Sudbury, 1996.

609 Howie, R.M., Simpson, K. Evaluation of the field performance of a tight fitting powered air-purifying respirator when worn during the removal of asbestos insulating material. Proceedings of the 5th Annual Conference. *Journal of the International Society of Respiratory Protection.* 1991.

610 Meyers, W.R., Peach, M.J. 1983. Performance measurements on a powered purifying respirator made during actual field use in a silica bagging plant. *Annals of Occupational Hygiene* **27:** 251-259, 1983.

611 Meyers, W.R., Peach M.J., Allander, J. Workplace protection factor measurements on powered air-purifying respirators at a secondary lead smelter-test protocol. *American Industrial Hygiene Association Journal* **45:** 236-241, 1984.

620 Mayhew, C. *Barriers to implementation of known occupational health and safety solutions in small business.* Worksafe Australia National Occupational Health and Safety Commission and the Queensland Government Department of Training and Industrial Relations. May 1997.

621 IPRU/NZEOHRC. Work related fatal injuries in New Zealand 1985-1994: Descriptive Epidemiology. Injury Research Prevention Unit and NZ Environmental and Occupational Health Research Centre, Dunedin School of Medicine, *University of Otago*, Dunedin, 1999. At: http://www.osh.dol.govt.nz/order/catalogue/pdf/epidemology.pdf

622 NOHSC. Small business updates. Worksafe News. National Occupational Health and Safety Commission, Sydney, October 1998, P 13.

623 Murphy, D.J., Kiernan, N.E., Hard, D.L., Landsittel, D. The Pennsylvania Central Region Farm Safety Pilot Project: Part 1-Rationale and Baseline results. *Journal of Agricultural Safety and Health* **4:** 25-41, 1998.

624 Internal ACC document. An outline of the data is available at http://www.acc.co.nz.

625 Documentation available from the New Zealand Department of Internal affairs relating to SMEs. 2008 data.

626 Internal ACC documentation. This work is currently being repeated as part of a wider survey (March 2008) by Research NZ Ltd (Wellington, New Zealand).

627 Houghton, R.M., Wilson, A.G. 1994. The prevention of injury among farmers, farm workers, and their families: a program for development of interventions for rural communities. Farm Survey Findings (no. 3 in a series of four reports. University of Otago Consulting Group, Dunedin, July 1994.

628 Kelsey, T.W. The agrarian myth and policy responses to farm safety. *American Journal of Public Health* **84:** 1171-1177, 1994.

629 Wadus, S.E, Kreuter, M.W., Clarkson, S. Risk perception, beliefs about prevention and preventive behaviours of farmers. *Journal of Agricultural Safety and Health* **4:** 15:24, 1998.

630 Bandura, A. Toward a unifying theory of behaviour change. *Psychological Review* **84:** 191-215, 1977.

631 Becker, M.H. The health belief model and personal health behaviour. *Health Education Monographs* **2:** 324-473, 1974.

632 Nelson, T.F, Sussman, D., Graham, J.D. Airbags: An exploratory survey of public knowledge and attitudes. *Accident Analysis and Prevention* **31:** 371-379, 1999.

633 Holmes, N., Lingard, H., Yesilyurt, Z., De Munk, F. An exploratory study of meanings of risk control for long term and acute effect. Occupational health and safety risks in small business construction firms. *Journal of Safety Research* **30:** 251-261, 1999.

634 Wadud, S.E, Kreuter, M.W., Clarkson, S. Risk perception, beliefs about prevention, and preventive behaviours of farmers. *Journal of Agricultural Safety and Health* **4:** 16, 1998.

635 Thu, K., Donham, J., Ogilvie, L. The farm family perception of occupational health. A multistate survey of knowledge, attitudes, behaviours and ideas. *American Journal of Industrial Medicine* **18:** 427-431, 1990.

636 Dougherty, T.M Reinforcing safety values in people. *Professional Safety* Month? 1997, pages?.

637 Peters, R.H. Strategies for encouraging self-protective employee behaviour. *Journal of Safety Research* **22:** 53-70, 1991.

638 Hidley, J.H Critical success factors for behaviour based safety. *Professional Safety* Month? 1998, pages?.

639 Du Pont. *STOP (Safety Training Observation Program).* E.I. du Pont de Nemours and Company, Wilmington, Delaware, USA, 1997.

640 Pasquale, J.P., Geller, E.S. Critical success factors for behaviour based safety: A study of twenty industry wide applications. *Journal of Safety Research* **30:** 237-249, 1999.

641 Cooper, D. 1996. Promoting effective behavioural change. Presented at the RoSPA Health and Safety Congress, National Exhibition Centre, Birmingham, 21-23 May 1996. .

642 Eckenfelder, D. It's the culture, stupid. *Safeguard Magazine* Jan/Feb 1998.

643 Krause, T.R. Presenting a balance sheet. *Professional Safety* August, 1998.

644 Loafman, B. Power Pitfalls. *Professional Safety* August, 1998.

645 Lamendola, M. Developing a safety culture in your business. *Electrical Construction and Maintenance (EC&M)* May, 1999.

646 Bartholomaeus, N. FutureSafe 98: "Thinksafe" in behavioural and cultural change campaign. *Journal of Occupational Health and Safety – Australia and New Zealand* **14:** 481-486, 1998.

647 Peterson, D. The four C's of safety: Culture, competency, consequences and continuous improvement. *Professional Safety* April, 1998.

648 Manuele, F.A. Observation of ASSE'S behavioural safety symposium. *Professional Safety* August, 1998.

649 Peterson, D. Accountability, culture and behaviour. *Professional Safety* October, 1997.

650 Gardner, R.L Benchmarking organisational culture: Organisational as a primary factor in safety performance. *Professional Safety,* 1999.

651 Sundstrom-Frisk, C. Understanding human behavior: A necessity in improving safety and health performance. *Journal of Occupational Health and Safety – Australia and New Zealand* **15:** 37-45, 1999.

652 Komaki, J., Barwick, K.D., Scott, L.R. A behavioural approach to occupational safety: Pinpointing and reinforcing safe performance in a food manufacturing plant. *Journal of Applied Psychology* **63:** 434-445, 1978.

653 Beaudin, B.P., Jacoby, L., Quick, D. Promoting safe behaviour-theoretical foundations. *Professional Safety* April 1997, 29-32.

654 Walters, H.A. Identifying and removing barriers to safe behaviours. . *Professional Safety* Month? 1998.

655 Ostberg, O. 1990. Risk perception and work behaviour in forestry: Implications for accident prevention policy. *Accident Analysis and Preventio***n 12:** 189-200, 1990.

656 See article written by the author for the ACC (Accident Compensation Corporation). At: http://www.acc.co.nz/PRD_EXT_CSMP/groups/external_ip/documents/internet/wcm000360.pdf

657 Salazar, M.K., Takaro, T.K., Connon, C., Ertell, K., Pappas, G., Barnhart, S. A description of factors affecting hazardous waste workers use of respiratory protective equipment. *Applied Occupational and Environmental Hygiene* **14:** 470-478, 1999.

658 Whiting, J. On safe behaviour. *Australian Safety News* 64: August, 1993.

659 Internal ACC statistical information. Summaries can be obtained from http://www.acc.co.nz.

660 NOHSC. National Occupational Health and Safety Commission, Canberra, 2000. At: Http://www.nohsc.gov.au/publications/misc/spotfines/spotsum.htm

661 Peters, R.H. Strategies for encouraging self-protective employee behaviour. *Journal of Safety Research* **22:** 1991.

Part 6: Appendices

10. APPENDICES

10.1 Appendix 1: First Farmer (FarmSafe) Survey Questionnaire

Work Related Inhalational Hazards in the NZ Agricultural Sector

Introduction

I am a PhD student working from Wellington. I have a particular interest in the health and welfare of farmers in New Zealand. One of the projects that I am currently involved with involves reducing the incidence of occupational respiratory disease to groups such as farmers in New Zealand. Part of this involves:

- Gaining an understanding of the current knowledge and concerns of farmers about work related respiratory disease,
- Practical knowledge and information to farmers about what can be done to prevent occupational respiratory disease.
- A knowledge of and what respiratory protection is appropriate for tasks on the farm.

If you are able to assist with this project, this would be appreciated. It should not take more than a few minutes of your time. Could you return your reply in the enclosed pre-addressed and paid envelope by the

Please indicate with a tick or cross those that are most applicable in your opinion.

The information is confidential and no records of names are asked or will be collected. Analysis of the data will be used to gain a better understanding of what may needed to help farmers themselves prevent occupationally related disease.

The Questionnaire

Demographic Information:

- **Are you a farmer or employed on a farm?**

  Yes , No ,

  If you answered no to this question, please return the questionnaire to the address below.

  If you answered yes, please continue answering questions below.

  What area of NZ do you farm in?

Northland	ƒ
Waikato	ƒ
Central Plateau	ƒ
Bay of Plenty	ƒ
Taranaki	ƒ
Eastland	ƒ
Wanganui	ƒ
Manawatu	ƒ
Wairarapa	ƒ
Hawkes Bay	ƒ
Top of the South Island	ƒ
North Canterbury	ƒ
Mid Canterbury	ƒ
South Canterbury	ƒ
West Coast	ƒ
Southland	ƒ
Otago	ƒ

  How old are you:

  Under 20 , 20-29 , 30-39 , 40-49 , 50-59 , over 60 ,

  How many years have you worked in farming:

  Under 1 , 1-5 , 6-10 , 10-20 , 30-50 , over 50 ,

  What is your gender:

  Male , Female ,

2. **Which of the following type describes your farm most accurately?**

   Dairy cattle farming ,

   Sheep and/or beef farm ,

   Sheep (only) farm ,

   Horticulture ,

   Viticulture ,

   Other (please specify) ✍

Information about respiratory diseases

3. Is respiratory disease and it's prevention a topic of concern to you at present?
Yes , No ,
If yes, explain why ✍

- Are you aware of any cases of respiratory disease in family, colleagues, or workers in the NZ agricultural industry thought to be attributable to the workplace?
Yes , No ,
If yes, provide details ✍

Information about respiratory protection

5. During your daily work, or during specific tasks such as cleaning vats (e.g., on a dairy farm) do you consider wearing respiratory protection (i.e., a respirator)?
Yes , No ,
If yes, describe what you use ✍

6. Would you normally consider wearing a respirator when working in visibly "dusty" situations or "smelly" environments (e.g., cleaning manure pits)?
Yes , No ,
If yes, describe when you would use a respirator ✍

7. Would you consider wearing respirators in situations where dust could not be seen or where there was no detectable smells, but your knowledge would suggest that protection was advisable?
Yes , No ,
If yes, describe when you would use a respirator ✍

8. When working in environments normally classified as "confined spaces" (e.g., vats, pits or anywhere where gases or fumes could accumulate), would you normally wear respiratory protective equipment?
Yes , No ,

9. When working in "confined spaces" what sort of respiratory equipment would you normally wear?

None ,
Disposable respirator ,
Half-face rubber respirator fitted with cartridges ,
Air-line supplied respirator ,
PAPR (Power assisted Air-line Respirator) ,
FPBR (Fan supplied Positive Pressure Breath responsive Respirator) ƒ
Other ,
Don't know ,

10. If information was readily available about respiratory diseases on the farm, would you read it and take action to reduce the possibility of disease?

Yes , No ,

11. By putting on a respirator, you may not be at all protected because of beard growth, facial hear or inadequate fit of the respirator to the face. Are you aware of these sorts of limitations of the equipment?

Yes , No ,

Information about purchasing decisions

12. In your choice of any type of respiratory equipment, is the prime consideration the price of the equipment or the best protection available?

Price is the prime consideration ,
Protection is the prime consideration ,
Not sure ,

13. Do you find the choice of respiratory protective equipment and appropriate filters and cartridges a difficult choice to make (different types of work and possible exposure may require different types of protective equipment)?

Yes , No ,

If yes, explain why

14. Where do you get advice from as to the most appropriate selection of respiratory equipment?

Distributor ,
ACC ƒ
Occupational Health and Safety (OSH) ,
From reading ,
Own knowledge ,
Other ,

Other (explain from where)

15. From your own experience what are the barriers to the wearing of respiratory equipment by yourself or other people you are aware of?

Comfort ,
Unable to communicate ,
Lack of knowledge of hazards ,

16. Is there any other information you would like to add?

17. How often do you dispose of respirators?

Disposable

Every day ƒ
Every week ƒ
Once a month ƒ
Other ƒ

Half-face rubber filters or cartridges

Every week ƒ
Every month ƒ
Every season ƒ
Other ƒ

Full face respirator cartridges or filters

Every week ƒ
Every month ƒ
Every season ƒ
Other ƒ

18. How often do you dispose of cartridges or filters?

Every time I don the respirator ƒ
Once every 6 months ƒ
Less often ƒ

Any comments you would like to make that you think might help me reduce the incidence of respiratory disease to the agricultural community?

Thank you for your time

Please enclose your reply in the attached pre-paid envelope.

10.2 Appendix 2: Second Farmer (FarmSafe) Survey Questionnaire

Respiratory protection to reduce occupational disease in agriculture

Introduction

This questionnaire is requested on behalf of an agricultural research project designed to provide an insight in the situations and different types of respirators that are mostly used by farmers in their work.

The questionnaire is completely voluntary, and anonymous. There are no right or wrong answers: we are looking for your opinions so that we can get a picture about respiratory protection on farms.

The purpose of the research project is a survey of knowledge, attitudes and practices regarding the use of respirators on farms. It is hoped that the survey will better identify barriers to the use of respiratory protection, which in turn may assist inthe reduction of respiratory disease in farming and better design of respiratoryprotective equipment.

The Questionnaire

Please answer the following questions:

(1) Which type of farm best describes the one you are working on? (if you have a mixed farm, tick the box that covers the largest proportion of farming your farm carries out)

- Dairy cattle farming ❐
- Sheep and/or beef cattle farming ❐
- Other arable farming ❐
- Horticulture ❐
- Viticulture ❐

Other ______________________________

- Do you own (sole owner, partnership or other owner arrangements) or work as an employee on the farm?

  - Owner or part-owner, of the farm ❐
  - Farm manager ❐
  - Farm worker ❐
  - Contractor (to a number of farms) ❐

Other ______________________________

(3) Is work related respiratory disease to the farming community and its prevention a concern to you at present?

Yes (I am aware of people with respiratory problems from farming) ☐

Yes (I have respiratory problems from farming) ☐

No ☐

Comments ____

____

____

(4) Do you have respiratory protection available on your farm? (tick as many as you need, check key below for explanation)

None ☐

Disposable respirator ☐

Disposable respirators are generally made from a stiff cloth or paper like substance, covering the mouth and nose, which is disposed off after use.

Half-face rubber respirator ☐

Half-face rubber respirator is generally made from a plastic or rubber material and covers the nose and mouth. They can be fitted with a variety of single or twin filter cartridges.

PAPR (Power Assisted air Purifying Respirator) ☐

PAPR (Power Assisted air Purifying Respirator) is a respirator in which the air flow is directed to the wearer generally through a belt mounted air blower and filters.

Air-line respirators ☐

Air-line respirator is a respirator in which the air is blown to the wearer by means of an electrical pump or other source of air situated away from the wearer.

SCBA (Self-Contained Breathing Apparatus) ☐

SCBA (Self-Contained Breathing Apparatus) is generally equipment in which the air is delivered to the wearer through cylinders of air worn by the wearer.

Others (please specify) ____

(5) Would you consider wearing a respirator in situations where harmful dusts or gases or vapours may be present? (Harmful dusts are often not visible to the naked eye. Harmful gases include gases which displace air such as could occur in a confined space.)

Yes, I do all the time ☐

Yes, when the situation warrants ☐

No ☐

Comments ____

____

____

(6) A two-day stubble and a beard will prevent a disposable or half-face respirator sealing on the face. Are you aware of these sorts of limitations? Have you had any formal training on the use of respirators, including maintenance and limitations of respirators?

I was aware of this limitation	❑	I have had formal training	❑
I was not aware of this limitation	❑	I have not had formal training	❑

(7) If you would wear a respirator, and if yes, what type of respiratory equipment would you wear for these situations:

	Confi ned space entry operatio ns (eg milking vats (e.g, grain handling, tanks and pits)	Mixing/applying agrichem icals (eg harmful vapours, mists and dusts)	Other farm enclosed animal areas)
Not applicable	❑	❑	❑
None	❑	❑	❑
Disposable respirator	❑	❑	❑
Half-face rubber respirator	❑	❑	❑
PAPR)	❑	❑	❑
Air-line respirators	❑	❑	❑
SCBA	❑	❑	❑

Comment ____

____

(8) From your own knowledge experience, what are the barriers to the wearing of respiratory equipment on the farm by yourself or others on the farm?

Wearing comfort	❑
Inability to communicate effectively with others	❑
Lack of knowledge of the risks (some effects can take many years to become evident)	❑
Peer pressure from other people on the farm	❑
Pressure from government safety agencies	❑

Other ____

(9) Would you be interested in receiving information about the sorts of respiratory diseases common in farming and the ways in which they could be prevented on the farm?

Yes, ❑

No ❑

Comments ____

(10) If information was provided that would show that respiratory diseases in farming could be reduced or prevented by the wearing of appropriate respirators, would you adopt and encourage the wearing of respirators if you do not already?

I already wear respiratory protective equipment when necessary ☐

Yes, I would ☐

No, I would not ☐

Comments ____

____

____

(11) If applicable, do you, as the farm manager, find purchasing respiratory equipment for your farm difficult (for example, multitude of different designs types and range of filters)?

Not applicable ☐

Yes ☐

No ☐

Comments ____

____

____

(12) When purchasing respiratory equipment, what factor is MOST important to you:

Comfort ☐

Price of purchase ☐

Ease of maintenance ☐

Health and safety ☐

Other ____

____

____

(13) Would you spend $2000 on a respirator that will last a lifetime and provide improved wearer comfort because filtered air is supplied and there are numerous warning systems to let you know of failures in the equipment?

I would purchase and use this type of equipment ☐

I would not purchase this type of equipment ☐

Comments ____

____

____

____

(14) What sources of information do you use when purchasing respirators for the farm?

- Normally from the distributor of the safety equipment (e.g., the store) ☐
- Normally from the MSDS or labels supplied by the manufacturer ☐
- Normally from experience or talking to other farmers ☐
- Normally from information supplied by OSH ☐
- Normally from information supplied by ACC ☐
- Elsewhere ☐

Comments ____

(15) Lastly, some demographic information. Please could you provide us with details of:

Your age group?		Gender?		How long have you been farming?	
16-25 years	☐	Male	☐	0-10 years	☐
26-35 years	☐	Female	☐	11-20 years	☐
36-45 years	☐			21-30 years	☐
46-55 years	☐			31-40 years	☐
56-65 years	☐			41-50 years	☐
66-75 years	☐			more than 50 years	☐

(16) Lastly, if you would you like to make any other comments, please do so below:

Comments ____

____

____

____

____

Thank you for your time and assistance

- Your assistance with this research is much appreciated. The results will help in the future to improve the design of respiratory protective equipment for use on New Zealand farms and improve the provision of appropriate information.
- Please hand in your response to the presenter at the end of the FarmSafe seminar or post to:

Mr John Wallaart
Programme Manager-Injury Prevention
ACC Corporate Office
110 Featherston Street
Wellington

10.3 Definitions used and sources

Term used	Explanation	Reference
Minute Volume (MV)	The volume of air used by an individual over one minute. Usually expressed as litres per minute.	ISO Working groups (WG15).
Peak Inspiratory Air Flow	The maximum rate of air inhaled by an individual. By convention, the units are litres per minute, but latest recommendations are in litres/second, recognising that the time of measurements are short.	ISO working groups (WG15).
Respirator	A personal protective device which is designed to prevent the inhalation of contaminated air.	AS/NZS 1716:2003.
FPBR	An advanced type of PAPR with sufficient air to deliver positive pressure inside the respirator.	SEA Pty Ltd literature on the SE400 AT® (Sydney).
Disposable respirator	A respirator device for which maintenance is not intended and which is designed to be discarded after excessive resistance, sorbent exhaustion, physical damage or end of service life renders it unsuitable for use.	AS/NZS 1716:2003
PAPR (Powered Air Purifying Respirator)	A device incorporating a half facepiece, full facepiece or head covering which provides the wearer with air passed through a powered filtering unit, comprising one or more filters and an electronically operated blower unit. It is often, but incorrectly,	AS/NZS 1716:2003

	described as a positive pressure respirator.	
Filter capacity	This is a test under which filters are subjected to a specified test gas under controlled conditions. In AS/NZS this occurs at 30lpm at RH 70%+/-5%, temperature 23^0 +/-3° C.	AS/NZS 1716:2003
Selecting test panel for assembled respirators (for TIL)	Test subjects are carefully selected, shaven, excluding unusual face shapes and psychologically unsuitable.	AS/NZS 1716:2003.
TIL (Total Inward Leakage)	In AS/NZS 1716:2003 this occurs with NaCl of particle size 0.3micron to 0.6 micron particle size. 10 carefully selected subjects are chosen (as above).	AS/NZS 1716:2003.
Protection factor	There are at least 9 different definitions of PF in use. The term used should be accompanied by a methodology or interpretation.	A useful article on this is: Capon, A. *Protection factors-who do they protect?* ISRP journal, **14**. Pp 19-25.
"Positive Pressure Respirator"	Term in common use by industry, but the term is not used by NIOSH and approval system to 1997. "Overbreathing" PAPR is likely when physiological demands are high.	Janssen, L. *What is a positive pressure respirator?* 3M Laboratories. At: http://www.3m.com/occsafety/html.
RPE	Respiratory Protective Equipment	
Air-purifying respirator	A device which filters contaminants from inhaled air.	

10.4 Wallaart, J and Winder, C. (2007). *A survey of New Zealand farmers' knowledge about the risks and prevention of occupational respiratory disease.* J Occup Health and Safety. Aust NZ. Vol.23(5). Pp 469-479.