

**AIOHQLD  
2016**



# **HYGIENE THAT WORKS**

December 3-7 2016 RACV Royal Pines Resort, Gold Coast

Australian Institute of Occupational Hygienists Inc  
34<sup>th</sup> Annual Conference and Exhibition




## **Proceedings**

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**AIOHQLD  
2016**   
**HYGIENE THAT WORKS**

34<sup>th</sup> Annual Conference & Exhibition of the  
Australian Institute of Occupational Hygienists Inc

3 - 7 December 2016

RACV Royal Pines Resort  
Gold Coast, Queensland, Australia

**2016 CONFERENCE PROCEEDINGS**

Editor

*Carolyn Topping*

[www.aioh.org.au](http://www.aioh.org.au)

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## A NOTE FROM THE 2016 AIOH PRESIDENT



On behalf of the AIOH Council and staff, I extend a very warm welcome to delegates, speakers and trade exhibitors, to Australia's premier occupational hygiene and health conference.

The theme of this conference is 'Hygiene That Works'. One of the critical pillars to building a better Australia is having healthy, efficient, productive workplaces. No other profession is better equipped to provide industry with practical solutions to control workplace health risk than occupational hygiene.

This conference aims to raise your awareness of and ability to use practical and innovative approaches to control health risks at work. Note the emphasis here is on solutions. To make a difference our profession must provide advice and recommendations that reduce risk. This is the benchmark minimum standard for occupational hygiene.

This conference will illustrate successful case histories that show how occupational hygiene and health can deliver financial, social and environmental value. Conference presenters will share practical and cost effective solutions, and how to frame a successful business case for reducing workplace health risk. All of which you can take home, adapt, and apply in your own workplace.

The conference committee has organised a strong programme of professional development with twelve continuing education sessions. This is another opportunity to invest in yourself, absorb new knowledge, or perhaps undertake a much-needed refresher.

The trade exhibition is an important part of this conference. Please introduce yourself to our exhibitors and ask them to show you their instrumentation, equipment and services. You will be impressed with the latest innovations, all of which can help you to do a better job.

If this is your first occupational hygiene conference, welcome to the occupational hygiene community. I encourage you to make the most of the wonderful combination of education, networking and social events that is unique to our conference.

The annual conference is not only about learning something new and catching up with colleagues. It is also a time to take stock, re-energise yourself and renew your commitment to your career. I hope you embrace this important opportunity and enjoy a successful 2016 conference.

Congratulations to Simon Worland and his conference committee, staff, volunteers, presenters, sponsors and supporters for your involvement in organising the 2016 Royal Pines Resort Conference.

**Caroline Langley, COH, FAIOH**  
**2016 AIOH President**

## A NOTE FROM THE 2016 ORGANISING COMMITTEE CHAIR



On behalf of the conference organising committee, it is my great pleasure to welcome you to the 34th annual Australian Institute of Occupational Hygienists' Conference on the Gold Coast in Queensland, the Sunshine State. Many of our delegates and speakers have travelled a long distance to be at the conference and for this we are most grateful.

Our conference venue, the RACV Royal Pines resort will be our "one stop shop" for all plenary and concurrent sessions, continuing education seminars, social events and accommodation. Our aim is to keep conference delegates together for longer and deliver an enriched experience. The Royal Pines is located a short distance from the white sandy beaches of Surfers Paradise and the lush beauty of the

Gold Coast Hinterland. The resort also boasts manicured gardens, a championship golf course along with many other options for children and partners.

The theme for the 2016 conference is "Hygiene That Works". Our goal is to showcase practical and innovative approaches to control hazards, reduce risk and protect worker health. We also aim to enable hygienists to be effective leaders of change through influence to deliver improvements in the workplace.

You will find a practical thread weaved through the entire scientific program. We are honoured to have eight keynote and plenary speakers who will address a broad scope of topics including hand-arm vibration (HAV), noise control, dermal exposure, biological monitoring and dust control to name a few. The keynote and plenary sessions will be supported by continuing education seminars and a wide range of concurrent session papers and poster presentations which we hope will promote discussion and interaction among delegates. Additionally, the extensive trade exhibition provides an excellent opportunity to network with our supply partners and see the latest advances in technology relating to our great profession.

Our long term AIOH major sponsors along with our 2016 sponsors have set this year's conference up for success. We deeply appreciate each and every sponsor for without their support we could never provide such a comprehensive conference. I would also like to say thank you for all the employers who see value in sending their employees to the AIOH conference year on year.

To my conference committee, I thank you for your efforts to help bring this conference to fruition. I have been very lucky to have such a professional and supportive team to work with.

The aim of the "Hygiene That Works" scientific program is to demonstrate how occupational hygiene adds value to business. I encourage delegates to take away as much as they can from this conference and direct their energy on working with others to implement solutions that protect worker health.

A very warm welcome.

**Simon Worland**  
**2016 AIOH Conference Organising Chair**

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## BIOGRAPHICAL NOTES OF THE KEYNOTE & PLENARY SPEAKERS

### Dennis Driscoll



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Dennis has both a Bachelor of Science and Master of Science degrees from North Carolina State University. Since 1980, his specialties in acoustics include measurement of equipment noise levels and employee noise exposures, the design of engineering controls, and environmental surveys. From 1980-1988 he managed Amoco and BP Corporation's hearing conservation program, and has been an acoustical consultant to industry since 1988.

Toward professional certification, he is a registered professional engineer and a board certified noise control engineer. He is a past President of the National Hearing Conservation Association (NHCA), a fellow member of the American Industrial Hygiene Association (AIHA), and past Chair of the AIHA Noise Committee. Finally, Dennis is one of the editors and participating author of The Noise Manual, 5th and 6th Editions, by AIHA.

### Peter Wilson



Peter has over 30 years of hands-on experience in noise and vibration. He has not only developed a number of unique and innovative noise and vibration control techniques (including an award winning fan noise control technology), but he also developed the IOSH competency training courses in both noise and hand-arm vibration. He was also asked to provide the best practice hand-arm vibration management presentations on the HSE road-shows to launch the HAV regulations across the UK. Peter is in demand as an entertaining, and sometimes controversial, regular contributor at conferences for organisations such as the BOHS, IOSH, EEF, IOM with a refreshingly pragmatic and practical approach to the subject of noise and vibration management.

### Dr Emily Haas



Emily has a PhD in Health Communication from Purdue University, Indiana, and an MA/BA from the University of Dayton, Ohio. She has worked for 4 years with the Pittsburgh Mining Research Division in the Human Factors Branch. Dr Haas' research uses mixed-methods approaches to solving complex issues of risk management and behaviour in the mining industry. She has led research efforts on multiple projects resulting in interviews with over 130 mineworkers, mine site leadership, or mine safety trainers across mines of various commodities. Her research continues to produce reports to inform the scientific community and industry stakeholders about new efforts and recommendations to ensure the health and safety of mineworkers through continued improvements in risk mitigation processes. She currently leads a research project that involves developing, implementing, and evaluating organizational interventions with an emphasis on improving mineworker and management engagement, communication, and risk management. These interventions have helped facilitate healthier work behaviours and reduce environmental barriers to sustaining those behaviours by way of new mine technologies. Her research is published in journals including Safety Science, Safety and Health at Work, International Journal of Qualitative Methods, Journal of Higher Education Outreach and Engagement, American Journal of Health Behavior, International Journal of Motorcycle Studies, and Cases in Public Health and Communication Marketing. She is also the author of a health and safety qualitative research methods textbook titled, "Metatheory and interviewing: Harm reduction and motorcycle safety in practice" which discusses interviewing methods in applied field settings.

---

**Dr Deborah  
Glass**



Associate Professor Deborah Glass MA, Cert Ed, MSc, PhD, Dip Occ Hyg, FAIOH COH graduated from Cambridge University, obtained a Masters in Occupational Health and Hygiene and worked in industry as an occupational hygienist, a consultant occupational hygienist, and a lecturer in occupational hygiene at Birmingham University.

She came to Australia in 1995 and worked on the Health Watch petroleum industry cohort completing a PhD with Deakin University based on this work. She joined Monash University in 1998 and works in the field of exposure assessment for epidemiology, including benzene and LH cancer risk, immunological effects of exposure to nanoparticles and a cohort study of cancer and mortality in firefighters.

She is a member of the AIOH, on the editorial board of the Annals of Occupational Hygiene, the Cancer Council of Australia occupational cancer working party and is on the ACGIH TLV committee.

---

**Dr Rob  
McDonald**



Rob is the vice president health and hygiene with BHP Billiton and a director of BHP Billiton Sustainable Communities (BSC). He is a member of the International Council of Mining and Metals Health and Safety Committee as well as the Minerals Council of Australia Health and Safety Committee. Rob is a Fellow of the Australasian Faculty of Occupational and Environmental Medicine and a graduate of the Australian Institute of Company Directors.

---

**Dr Victoria  
Arrandale**



Dr Arrandale works at the Occupational Cancer Research Centre in Toronto, Canada and is an assistant professor in the Dalla Lana School of Public Health at the University of Toronto. She holds an MSc in Occupational Hygiene and a PhD in Medical Science (Occupational Health). Dr Arrandale's work to date has considered skin and respiratory exposure and disease in a variety of occupations and industries. Her current research focuses on the evaluation of skin and inhalation exposures in the emerging industries of electronic waste recycling and nail salons, as well the improvement of exposure assessment in an ongoing cohort study of hard rock miners. Dr Arrandale's work is supported by a career development award from the Canadian Cancer Society Research Institute and grants from the Ontario Ministry of Labour.

---

**Kate Jones**



Kate Jones is an analytical chemist working as a principal scientist in HSL's biological monitoring team. She has wide experience and expertise in the biological monitoring of organic compounds, this includes skills in: the use of specialist analytical techniques and instrumentation such as GC, GC-MS, HPLC and LC-MS; method development; toxicology; and gaining approval for and running human volunteer studies.

Kate is actively involved in disseminating her work through peer-reviewed publications, presentations at relevant scientific and stakeholder conferences and at research workshops. She was the joint recipient of the 2014 BOHS Thomas Bedford Prize for a large intervention study on control of isocyanates in the motor vehicle repair industry.

Kate is currently chair of the Royal Society of Chemistry's toxicology group and ICOH's scientific committee on occupational toxicology. She also serves on the Council of BOHS.

---

**Dr Ian  
Gardner**



Dr Ian Gardner is an Australian medical specialist with more than 35 years global experience in environmental, occupational and public health medicine. His current major appointment is as principal medical adviser, Department of Veterans' Affairs in Canberra. Ian transferred to this SES Band 2 senior leadership position in June 2015.

From 2001 to 2015, Ian was Defence's senior physician in occupational and environmental medicine, at the Defence Centre for Occupational Health and Safety, Canberra. Prior to this appointment, Ian worked for IBM Asia Pacific for 13 culminating in appointment as program director, health safety and environment management, IBM Asia Pacific, Japan. Previous jobs were with IBM Australia, ICI Australia and Alcoa of Australia. He has significant senior management and consulting experience in both the public and private sectors, and holds a number of part-time advisory positions in occupational and environmental medicine with major Australian companies and state governments.

Ian has degrees in medicine and surgery as well as a Master's Degree in Public Health and professional fellowships from Australia, the UK and the USA. He has held an academic appointment as Adjunct Professor in Occupational & Environmental Medicine at the University of Queensland. He has also been a visiting professor and external examiner in occupational medicine at the National University of Singapore and the Chinese University of Hong Kong in Shatin, HK.

Ian has twice been elected as president of the Australasian Faculty of Occupational and Environmental Medicine (AFOEM) of the Royal Australasian College of Physicians. He is a joint editor of the textbook, "International Occupational & Environmental Medicine". He was the government- appointed medical member of the New South Wales "Workers Compensation and Occupational Health and Safety Council until 2012, and chairs the NSW Public Service Commission's Health Review Committee. He is the ministerially appointed Commonwealth representative on the Asbestos Safety and Eradication Agency Council, and until 2015 was also a member of the Specialist Medical Review Council.

Ian is a Fellow of AFOEM, a Fellow of the American College of Occupational and Environmental Medicine, a Fellow of the Royal Society of Medicine, and a member of the International Commission on Occupational Health. In 2013, he was awarded the College Medal by the Royal Australian College of Physicians.

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## KEYNOTE & PLENARY

### HEARING LOSS PREVENTION – WHAT IT IS, WHAT DOES IT COST, AND WHAT DOES IT TAKE TO SUCCEED

*Dennis Driscoll*

Associates in Acoustics, Inc., USA

#### ABSTRACT

No one should ever be injured by occupation noise, as noise-induced hearing loss (NIHL) is 100 percent preventable. Procedures to prevent NIHL have evolved significantly since their early inception in the 1950s. This presentation will describe the essential components of an effective hearing loss prevention (HLP) program, quantify the on-going costs, and describe barriers and solutions to implementation of effective HLP programs. Solutions include examples of several program game changers, such as hearing protection fit testing, determining the return on investment to eliminate the risk, and a handful of mitigation homeruns to help jump start a noise control program. Finally, my experience with successful programs will be described, including a few personal examples.

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## HAND ARM VIBRATION MYTH MANAGEMENT

*Peter Wilson*

Industrial Noise & Vibration Centre Limited, UK

### ABSTRACT

The depressing evidence is that a substantial proportion of the time and resources designated by industry for hand-arm vibration risk management programmes is wasted. Despite the best of intentions, the subject still appears to offer a minefield of opportunities for risk management mistakes based on misinformation and myth. Moreover, you could be forgiven for having the impression that virtually the only requirement is to carry out a risk assessment – or perhaps yet another risk assessment - as modifying activities, processes and management techniques to reduce risk is more difficult. Unfortunately, a high proportion of HAV risk assessments are not of merchantable quality. This presentation provides a summary of the common myths and issues associated with assessment and the best practice elements that must be incorporated into any effective HAV risk management programme.

## USING DUST ASSESSMENT TECHNOLOGY TO DIRECT HEALTH AND SAFETY INTERVENTIONS

*Dr Emily Haas*

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### ABSTRACT

To manage mine health and safety (H&S) performance, consistent, fundamental interactions among various levels within an organization are necessary. To identify critical components of these interactions, NIOSH researchers implemented interventions facilitating mineworker and management discussions to address respirable dust exposure. Interventions at several mines used dust assessment or control (i.e. Helmet-CAM or Continuous Personal Dust Monitor) technology to evaluate and bridge communication efforts between managers' H&S leadership practices and mineworkers' subsequent H&S behaviours. Each intervention consisted of two mine visits to collect dust exposure data while workers completed routine work tasks. After researchers debriefed exposure data with mineworkers, management received results accompanied with possible engineering controls and procedural considerations to discuss with their workers, which were reassessed on the follow-up visit. Mineworkers also completed pre- and post-climate surveys and interviews about susceptibility to dust exposure and subsequent protective behaviours. Data collected at coal, metal, and non-metal mines throughout the United States are discussed including:

- Workers' organizational and personal barriers that contribute to respirable silica and coal mine dust exposure;
- Changes in workers' everyday practices to reduce exposure (e.g., worker positioning relative to a piece of equipment, better pre- and post-shift housekeeping, adopting new clothes cleaning techniques, reorganization of work space, etc.);
- Sources of exposures due to deficits in engineering controls; and
- Differing viewpoints between workers and managers in their stages of technology acceptance.

The purpose of this plenary is to help mine operators understand ways to educate and support workers' health maintenance behaviours through the tangible application of assessment technologies.

## REVIEW OF THE RESPIRATORY COMPONENT OF THE QUEENSLAND COAL MINE WORKERS' HEALTH SCHEME

*DC Glass, R Cohen, M Roberts, K Almborg, L. Go MR Sim*

Monash University

### ABSTRACT

Monash University in collaboration with the University of Illinois Chicago reviewed the respiratory component of the Coal Mine Workers' Health Scheme, identified problems with its design and operation, and proposed measures to improve the scheme.

The measures identified in the review include:

- A more clearly articulated purpose of the scheme.
- A smaller number of credentialed and experienced doctors approved to undertake the respiratory health assessments.
- Initial and ongoing training about coal mine dust lung disease (CMDLD) for approved doctors.
- Clinical guidelines to inform diagnosis and management of CMDLD.
- More standardised and consistent criteria to determine who requires a chest X-ray (CXR).
- A more complete and better designed respiratory component of the scheme with data collected online.
- Better standard of CXR referral, interpretation and reporting using the ILO criteria.
- Better standards of spirometry testing and interpretation.
- Clinical audit of collected health data.
- Greater accessibility of previous job history and health assessment records to allow easier monitoring of workers over time.
- Inclusion of former mine workers, in whom CMDLD is most likely to be seen.
- Robust industry-wide health surveillance data to inform dust control measures, including review of occupational exposure levels.
- A research framework to provide estimates of the prevalence of CMDLD.

Medical screening and surveillance is not a substitute for effective dust control, which is the primary protection against CMDLD. This is particularly important because CMDLD can progress even after dust exposure has ceased.

These findings have implications for medical screening in other industries.

## MANAGEMENT OF DIESEL EXHAUST EXPOSURE: MAXIMISING THE PROTECTION OF OUR PEOPLE

*Dr Rob McDonald*

BHP Billiton

### ABSTRACT

Diesel exhaust exposure is one of the important health risks we manage in our operations. We proactively engage with industry experts and monitor research to ensure we are up to date with the most current information on this issue, and continually evaluate the effectiveness of our controls.

Several recent studies suggest that there are health risks from exposure to diesel exhaust over a working life at levels considerably below common regulatory occupational exposure limits.

This presentation will discuss the findings of independent quantitative risk assessment performed for BHP Billiton by the Institute of Occupational Medicine (IOM) and changes we are implementing to our management of diesel exhaust exposure in seeking to protect the health of our workforce to the highest standard.

## SKIN EXPOSURE IN THE WORKPLACE: RECOGNITION, EVALUATION AND CONTROL

*Dr Victoria Arrandale*

Occupational Cancer Research Centre, Canada

### ABSTRACT

Skin exposure in the workplace is common yet frequently goes unrecognized by workers and occupational health professionals until a problem arises in the form of skin irritation or allergy. Skin disease is one of the most common occupational diseases but is preventable through improved control of skin exposure in the workplace. Many methods have been used to evaluate skin exposure but often these are impractical for routine use in the workplace. The interpretation of results is challenging as there are no quantitative exposure limits. Semi-quantitative and qualitative assessment methods may be more useful. New methods under development aim to provide simpler options for workplace application. At the same time, exposure control methods need to consider all of the sources and routes of potential skin exposure. If relying on personal protective equipment (PPE) extra consideration is required as PPE can enhance exposure and can be a hazardous exposure unto itself. Following this talk attendees will have a better understanding of how to recognize, evaluate and control skin exposure in the workplace.



## BIOLOGICAL MONITORING THAT WORKS!

*Kate Jones*

Health and Safety Executive, UK

### ABSTRACT

Biological monitoring can be a straightforward means of assessing exposure, improving control and changing behaviours. Whilst there are many factors that can influence the value of biological monitoring (exposure duration and frequency, sampling times, toxicokinetics, individual variability, different biomarkers), it is possible to standardise testing such that it can be useful across a broad range of situations.

Exposure to isocyanates has long been a leading cause of occupational asthma, with paint sprayers in the motor vehicle repair industry being at particular risk. Many of these workers are employed in micro-businesses and are often the only sprayer. Such workplaces are therefore difficult to reach with health and safety messages and also have limited financial means. However biological monitoring has been accepted as an achievable means of assessing control – levels of monitoring have increased significantly in recent years and exposures are decreasing with the raised awareness.

Generating large data sets of routine monitoring is a cost-effective way of benchmarking achievable control practice across an industry and using a ninetieth percentile concept can drive exposures down over time in a manageable way. For example, exposure to MbOCA (a recognised human carcinogen) has been reduced by three-quarters over the last 28 years and blood lead levels have reduced by half in twenty years.

A non-invasive sample taken at the end of shift is a simple means of checking that controls 'in the round' are working. If they are not working, that's where the work of the professional occupational hygienist begins...

## CASE STUDIES: OCCUPATIONAL HYGIENE AND OCCUPATIONAL MEDICINE WORKING TOGETHER

*Dr Ian Gardner*

### ABSTRACT

This presentation highlights some excellent examples from my recent experience working with Defence where close cooperation between Industrial Hygienists and Occupational Medicine specialists helped to solve significant work related health issues – with resulting good outcomes for workers and enhancement of critical Defence capabilities.

## CONCURRENT

### ASSESSING A MINER'S OCCUPATIONAL NOISE EXPOSURE USING PERSONAL NOISE DOSIMETRY

#### Respirable Crystalline Silica Exposures of Restoration Stonemasons

*Vasos Alexandrou, Peter Teague*

Vipac Engineers and Scientists Limited

#### ABSTRACT

The Australian mining industry has amongst the highest levels of time lost and compensation paid in relation to occupational exposure and health effects. Occupational noise is one of the most prominent health risks that mine workers in particular are exposed to, and personal noise monitoring forms a vital part of the critical processes conducted by the industry to determine noise exposure for personnel.

More than 500 personal noise dosimetry samples have been measured by Vipac Engineers & Scientists Ltd, spanning a 4 year period. Each noise dosimetry sample was assigned a Similar Exposure Group and assessed against the requirements set out in the Coal Mining Safety and Health Act 1999. Using these personal noise dosimetry samples, consideration of extended work shift adjustments and exposure to ototoxic substances has provided Vipac with a greater understanding of a miner's noise exposure.

This review demonstrates that noise dosimetry is a key hygiene process that works to deliver critical information on the health performance of an employee, when assessed against their Similar Exposure Group, the noise exposure standard and industry average noise exposure levels.

#### 1. Introduction

Workers in the mining industry have long been exposed to workplace hazards, occupational noise is just one of these hazards. Noise Induced Hearing Loss (NIHL) is a consequence that occurs when the human ear is subjected to long term exposure to high noise levels, and exposure to very high peak noise. Part of the ever-growing focus on Work Health and Safety (WHS) within Australia involves the assessment of workplace health risks. A key responsibility within the mining industry is understanding these health risks and mitigating them where possible.

National legislation states that employers must ensure employees are not exposed to noise levels within the workplace that exceed the national exposure standard (NES) for noise; i.e.  $L_{Aeq,8h}$  of 85 dB(A) or  $L_{Cpeak}$  of 140 dB(C). One common method used by industry to understand and assess occupational noise exposure is that of personal noise dosimetry sampling.

Unavoidable high noise exposure is common for most exposure groups within the mining industry. Vipac Engineers and Scientists Ltd (Vipac), a medium sized engineering consultancy that specialises in the measurement, assessment and control of occupational noise, has amassed an extensive noise dosimetry dataset from various mine sites. A statistical analysis and risk ranking of the measured dataset was evaluated and assessed against the NES to provide a greater understanding of occupational noise exposure across mine sites. Extended work shift penalties were also evaluated to determine the level of impact the adjustment has on noise exposure within the mining industry.

#### 2. Background

The Australian Worker's Compensation Statistics state that the median compensation claim made for sound related injury or disease was \$8,700 in 2013/14, with a median lost time due to injury at four weeks per year (1). Occupations with the highest rates of workers' compensation claims for noise-induced hearing loss over the three-year period 2008 to 2011 include: engine & boiler operators, tradespersons and miners (2).

Permanent NIHL can be one of the most prevalent and serious occupational health conditions within the mining industry, it is irreversible and can be minimized or eliminated through an understanding of ongoing measurement data and effective noise management. Operations typically involve extended periods of exposure to major noise sources such as engines, exhausts,

generators, hand-tools, welding, exhausts, pumps, ventilation and flow noise. It has become industry practice to conduct regular personal noise dosimetry monitoring of personnel. The objectives of personal noise dosimetry allows for:

- An assessment of existing noise exposure to personnel during the course of a typical work shift
- Establishment of baseline levels for comparison against future noise levels
- Identification of noise sources and activities that contribute to excessive noise exposure
- A risk ranking for each Similar Exposure Group (SEG).

Given the high number of employees at some mines, it is neither feasible nor practical to measure every employee over an extended work shift. As such, representative samples are conducted using a variety of methods. A key performance indicator of personal noise dosimetry sampling is to assess the number and percentage of individuals in a SEG who have a daily exposure above the NES.

### 3. Health Effects

The health effects of occupational noise exposure vary from person to person, however physiological and psychological responses are known effects. The primary physical health effect of prolonged exposure to high noise levels is noise-induced hearing loss (NIHL). Excessive noise can also cause ringing in the ears (i.e. tinnitus), which is a temporary effect but can become permanent. This ringing can be very distracting and cause difficulties in concentration or sleep. Irritating background noise and high noise levels can also lead to stress resulting in:

- An increased metabolic rate which can also lower an individual's resistance to noise
- Tiredness, irritability and aggression
- Increased blood pressure and headaches which can place the heart under strain
- A lack of balance and dizziness

All of these symptoms can affect worker performance and quality of life in addition to temporary and permanent hearing loss.

### 4. Criteria and Applicable References

Work health and safety in the mining industry is regulated by states and territories. In Queensland, the Coal Mining Safety and Health Act 1999, and Regulation 2001, provides the legislative framework that a coal mine is required to adhere. The references used for assessment and measurements are listed below and include:

- Coal Mining Safety and Health Regulation 2001 (3)
- WHS Regulations 2011 (4)
- Australian Standard AS/NZS 1269.1:2005 Occupational Noise Management – Measurement and Assessment of Noise Immission and Exposure (5)

The acceptable noise exposure (4) for individuals is assessed using two metrics for the Noise Exposure Standard (NES):

- eight hour equivalent continuous A-weighted sound pressure level  $L_{Aeq,8h}$  of 85 dB(A)
- a peak noise, C-weighted sound pressure level not exceeding  $L_{Cpeak}$  140 dB(C).

Australian Standard 1269.1 provides an adjustment for work shift durations of 10 hours or greater. This extended work shift adjustment is typically +1 dB(A) for coal mine workers who generally work between 10.5 and 12.5 hour shifts.

#### 4.1 Coal Mining Regulation 2001

The Coal Mining Safety and Health Regulation states that a coal mine worker's exposure to noise should be kept to an acceptable level and not exceed the noise levels stated in the WHS Regulation. The health management system of a coal mine must include the provision for the monitoring and recording of noise levels in the work environment.

Noise measurement surveys should be done by a competent person in accordance with AS/NZS 1269.1. Other points referenced in the 2001 Regulation also apply, including: the supply of personal protective equipment for persons in the work environment; keeping records in an easily accessible location; and identifying by way of an appropriate sign, where there are excessive noise levels at the mine.

#### 4.2 AS/NZS 1269 Standard

Requirements for, and guidance on, the types of noise assessments, details on suitable noise measuring instruments and procedures for the measurement of noise levels are detailed within AS/NZS 1269 (5). A personal sound exposure meter (PSEM), also known as a noise dosimeter is considered a common instrument for the measurement of noise exposure over a work period. The standard highlights the inherent shortcomings through the use of PSEMs which include, shouting and tapping across the microphone, taking the meter off for short periods, not directing the microphone at the noise source, and a reliance on personnel who are untrained and unskilled at carrying out noise measurements, often in uncontrolled areas. Despite these limitations, when used properly PSEMs provide a good foundation for the identification and assessment of personal noise exposure for workers.

#### 4.3 Ototoxic Substances

Exposure to ototoxic substances such as Volatile Organic Compounds (VOCs) from paints and fuel can lead to hearing loss. Hearing loss can be exacerbated through combined exposure to both noise and VOCs. There are three major classes of ototoxic substances: solvents, heavy metals and asphyxiates. Activities where these substances may become an issue include painting, construction, fuelling, degreasing, weapons firing and fire-fighting. Ototoxic substances can be present at a mine, specifically maintenance personnel who are often exposed to fuels, metals, solvents and carbon monoxide.

The WHS Code of Practice; *Managing Noise and Preventing Hearing Loss at Work* (6) states that where workers are exposed to ototoxic substances, unprotected exposure to noise levels should not exceed an  $L_{Aeq,8h}$  of 80 dB(A) or an  $L_{Cpeak}$  greater than 135 dB(C). Vipac's assessment method has allowed for a 5 dB(A) penalty adjustment for personnel exposed to a combination of high noise and ototoxic substances.

#### 5. Similar Exposure Groups

Personnel working in the same field/area are typically exposed to similar noise levels and thus are categorized into Similar Exposure Groups (SEGs). This classification of workers allows for a greater understanding and determination of a risk profile of employees based on noise dosimetry measurements. Naming of Similar Exposure Groups can vary depending on the coal mine, however generally speaking they follow a similar naming system. The three most common SEGs have been used for assessment and comparison purposes as outlined in Table 1. Note that most personnel at a coal mine work within the Production SEG, and for analysis purposes, this SEG includes coal hauling and overburden removal, as noise exposure for each group is considered equivalent (i.e. vehicle generated noise dominates).

Table 1 – Key Similar Exposure Groups

SEG	SEG Description
Production	Operation of vehicles, excavators, dozers for the removal and relocation of dirt and coal.
Maintenance	The repair and maintenance of field equipment, vehicles and plant maintenance, including boilermaker activities
CHPP	Coal sampling, processing, handling and washing. Plant inspections and stockpile dozer operations.

## 6. Methodology

Vipac always maintains a consistent and best-practice measurement and assessment methodology to limit variables as much as practically possible when conducting noise dosimetry measurements. The occupational noise exposure of an individual comprises all the noise to which they are exposed at work. In the mining industry, this is typically vehicle generated noise (in-cabin and external), hand tools, plant and machinery noise. Contribution to cumulative noise exposure also occurs from the use of various alarms and communication systems. The most common source of noise for most personnel is the presence of entertainment radio, communication systems (two-way radios) and engines/exhaust noise. All measurements used for this evaluation are considered representative of typical noise exposure within a mine.

### 6.1 Instrumentation

The same model and type of Personal Noise Dosimeter was used during measurement to ensure consistency; a Class 2 Quest Edge 5 Dosimeter. Field calibration (reference level) of 114 dB at 1 kHz was always conducted with a Quest QC-10 Calibrator both prior to and at the end of each measurement period. Any variations were noted on the site datasheet. All instrumentation was in current laboratory calibration as per the requirements of IEC 61672 (9) and IEC 60942 (10) standards. All noise dosimeters were fitted with a custom made windscreen for added protection against knocks and wind/air-flow noise. Where measurements had a discrepancy of greater than plus or minus 0.5 dB to the reference level, the measurement was considered invalid.

### 6.2 Noise Dosimetry Methodology

Noise dosimeters were typically fitted to personnel at the commencement of their working shift and retrieved at the end or very close to the end of their shift. Microphones were always positioned (when practicable) approximately 0.1 to 0.2 metres from the entrance to the ear canal. The  $L_{Aeq}$ ,  $L_{Ceq}$  and  $L_{Cpeak}$  noise metrics were always measured in 1-minute sampling resolution. The measurement period typically varied between 8 and 12 hours depending on the working shift length.

### 6.3 Hearing Protection Devices

Two methods were used for determining hearing protection requirements. The Classification method was used for  $L_{Aeq,8h}$  noise levels up to 110 dB(A), and the octave-band method was used for exposure greater than 110 dB(A). Based on these two methods and the measured data, appropriate hearing protection was selected for use and application by exposed workers. This typically ranged between Class 4 and Class 5 hearing protection devices (HPDs), in the form of ear plugs or ear muffs. It is noted that quite often throughout a measurement survey workers either do not wear the correct HPD (or properly fitted), do not wear any HPD and/or are not aware of HPD requirements – the resultant insufficient attenuation can cause excessive exposure. This is a general problem that occurs within the industry and it is the responsibility of the employer to train its employees, but also a responsibility of the worker to understand noise and its effects on health.

### 6.4 Extended Work Shifts

Extended work shifts greater than a typical 8 hour working day are prevalent within the coal mining industry. Shift durations greater than 8 hours impose a higher health risk to exposed workers. The increased health risk occurs from the additional damaging effect that continued exposure to noise has, once the maximum temporary threshold shift is reached, and a reduced

recovery time between successive shifts is considered. AS/NZS 1269 provides a penalty adjustment to the normalized  $L_{Aeq,8h}$  noise exposure level. The adjustment according to shift length is provided in Table 2.

Table 2 – Extended Work Shift Adjustment

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

## 7. Measurement Results

Noise measurement data spanning four years from 2012 to 2016, from eight Australian coal mines were used for this assessment. Personal noise dosimetry samples were performed over a representative work shift, normalized, adjusted for an extended working shift and adjusted for exposure to ototoxic substances (where necessary). The final calculated noise exposure was then assessed against the regulatory NES; namely,  $L_{Aeq,8h}$  85 dB(A) and  $L_{Cpeak}$  140 dB(C).

### 7.1 Sample Size

A statistically relevant dataset was measured for each SEG, with recommended sample numbers derived using the NIOSH Occupational Exposure Sampling Strategy Manual (9). In accordance with the NIOSH Manual, the recommended sample numbers to ensure at least one worker from the sampled group will be in the top 10 percent of the exposures occurring in the population group to a confidence limit of 95%, is presented in Table 3.

Table 3 – Adopted NIOSH Sample Size Recommendations per Group Size

For Groups of Size (N)	12	13-14	15-16	17-18	19-21	22-25	26-27	28-31	32-35	36-41	42-50	>50
Samples Required (n)	11	12	13	14	15	16	17	18	19	20	21	29

Note: Where the Group Size (N) <12, then the Number of samples, n = N. However, the minimum value of n = 6.

A breakdown of noise dosimetry samples measured per SEG and the average SEG distribution found in the industry shown as a percentage is produced in Table 4.

Table 4 – Breakdown of Noise Dosimetry Samples per SEG

	Production	Maintenance	CHPP
# Noise Dosimetry Samples	298	157	58
% Noise Dosimetry Samples	51%	35%	14%
% SEG Distribution (Industry avg.)	60%	30%	10%

Table 4 shows that the number of noise dosimetry samples measured was close to the percentage distribution of employees per SEG when compared against industry average levels.

## 7.2 Average Noise Level Summary (LAeq,8h)

Each of the 513 noise dosimetry samples for each SEG were normalized and adjusted, as required, specific to their respective shift lengths and exposures, with a summary of  $L_{Aeq,8h}$  data presented in Table 5.

Table 5 – Summary Table of  $L_{Aeq,8h}$  Noise Data

	Production	Maintenance	CHPP
Minimum, dB(A)	64.4	67.5	79.8
Maximum, dB(A)	103.3	109.5	100.7
Mean, dB(A)	86.6	86.9	87.8
Samples above NES	204	104	48
% above NES	68.5%	66.2%	82.8%
LCL, dB(A)	86.1	86.1	87.0
UCL, dB(A)	87.0	87.7	88.7

Figure 1 presents the statistical analysis of the noise dosimetry samples by plotting the mean  $L_{Aeq,8h}$  noise level with the minimum and maximum levels for each SEG.

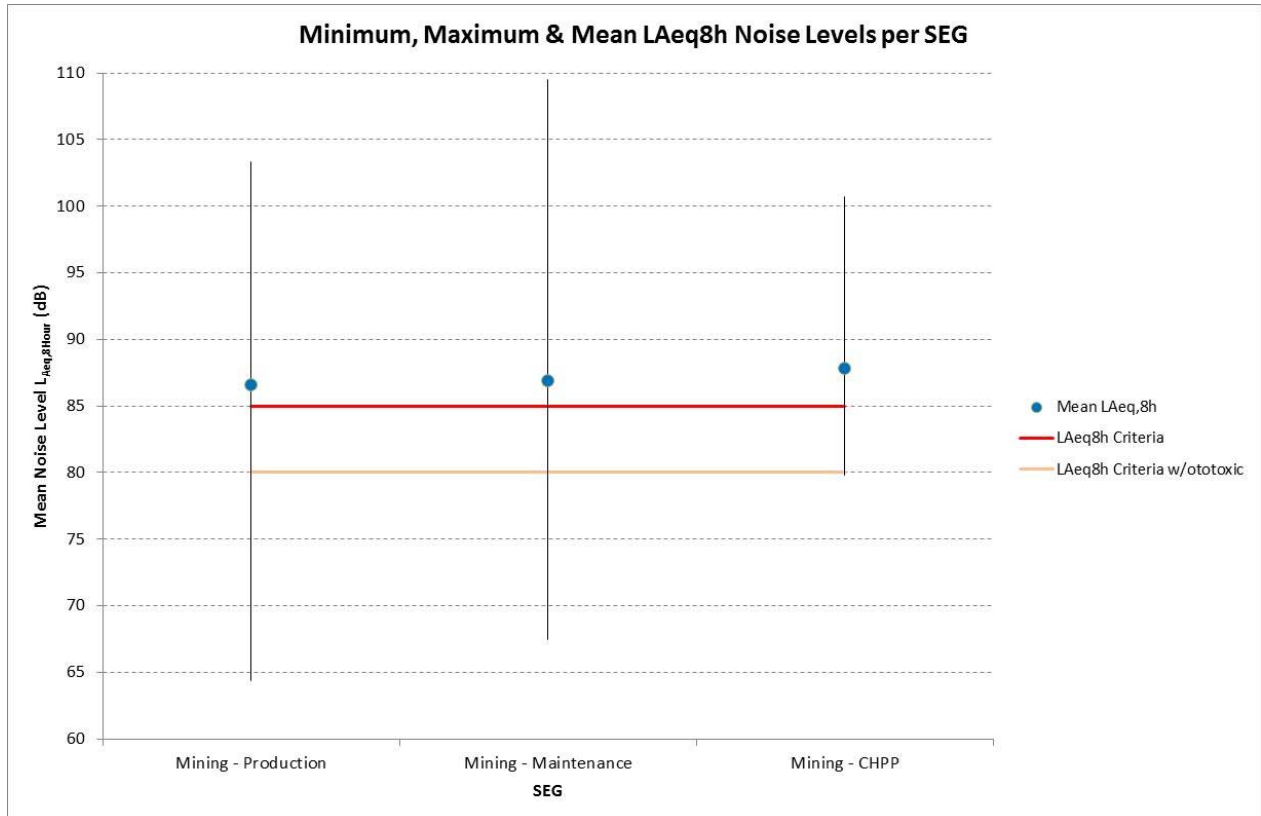


Figure 1 – Normalised and Adjusted  $L_{Aeq,8h}$  (mean, min & max)



Noise exposure levels varied between each SEG, however the mean 8-hour equivalent  $L_{Aeq,8h}$  noise exposure level exceeded 85 dB(A) for each. The following conclusions are derived from the dataset:

- The CHPP SEG had the highest mean noise exposure level of 87.8 dB(A), almost 3 dB(A) higher than the NES
- Mean noise exposure levels for the Production and Maintenance SEGs were within 0.5 dB(A) of each other and 2 dB(A) higher than the NES
- 69% of Production samples measured, exceeded the NES
- 66% of Maintenance samples measured, exceeded the NES
- 83% of CHPP samples measured, exceeded the NES

The highest noise exposure for maintenance personnel was related to boilermakers who can often be exposed to high noise levels of greater than 105 dB(A) for long periods throughout a work shift. Given the high percentage of exceedances and high risk to workers within the maintenance SEG, noise control solutions must be considered and administered as part of the employer's responsibility. Engineering noise controls are not always practical, and as such PPE requirements and administrative controls, such as job rotation and limitation of exposure time, are usually implemented.

### 7.3 Impulse Noise Summary (LC<sub>peak</sub>)

Impulse noise is measured and indicated by the  $L_{Cpeak}$  metric. This data can be easily contaminated by extraneous events and knocks, the resultant value may consequently exceed the measurement range threshold of the dosimeter, and therefore may not be a reliable indicator of the actual health risk.

### 7.4 Risk Ranking

Noise dosimetry data can provide good supporting evidence for a risk assessment. The sampling data used for this assessment was used to categorise the likely health risks associated with occupational noise exposure for each SEG. Table 6 shows the risk ranking determined for each SEG in accordance with a ranking system derived by Vipac.

Table 6 – Risk Ranking per SEG

Risk Ranking	Production	Maintenance	CHPP
% Very Low	6%	5%	0%
% Low	7%	13%	0%
% Medium	22%	18%	19%
% High	65%	64%	81%

Based on the measured samples, the following conclusions are made regarding the risk ranking of each SEG:

- 81% of CHPP workers are rated a high risk of developing health risks if their hearing is not protected during their work shift
- 65% and 64% of Production and Maintenance workers respectively are rated a high risk of developing health risks if their hearing is not protected during their work shift

The risk ranking of workers rated high risk, allows employers to:

- Target and prioritise work areas for noise control
- Determine correct and suitable HPDs for use in high noise areas
- Establish a schedule and determine workers who require audiometric testing

### 7.5 Effects of Adjustments

The data used for this evaluation was also assessed not taking into account the adjustments for extended work shifts or exposure to ototoxic substances. The following conclusions were made from the analysis:

- The mean noise exposure level drops between SEGs; 85 dB(A) for CHPP, 83.8 dB(A) and 84.1 dB(A) for Production and Maintenance respectively
- A reduction of 17 to 18% of workers are rated a high risk of developing health risks if their hearing is not protected during their work shift – when extended work shifts and ototoxic substances is not considered

### 8. Noise Controls

One of the objectives of conducting noise dosimetry sampling is to identify work areas and SEGs exposed to high noise. Where noise controls are required from the measurement dataset and subsequent risk assessment, the hierarchy of noise control should be considered. Engineering noise control is the preferred method of noise reduction, however this is not always practicable. As such, the implementation of mandatory personal protective equipment (PPE) usage and administrative controls are normally applied and used widely within industry.

Administrative control measures recommended and applied throughout industry include job rotation, work scheduling, changing work processes, limiting exposure times for high noise tasks, minimum rest periods, limiting distances from noise hazards, limiting exposure to ototoxic substances and hand-arm vibration and equipment maintenance. Observations made throughout most site surveys were the improper fitting of HPDs. Improper fitting can mean that the HPD will not achieve the attenuation it is designed to provide, and that wearers could be under-attenuating noise levels by up to 10 to 15 dB. Therefore incorrect fitting of HPDs has the potential for workers to be exposed unknowingly to unacceptably high noise levels and subsequent health risks.

As such, a recommended action is for training for the use of, and fitting of HPDs for all workers. Personal hearing protectors should be selected and maintained in accordance with WHS Regulation 44, the Code of Practice and AS/NZS 1269.3 (10). Employers should involve workers in the selection process and offer a reasonable choice of hearing protector types. Ensuring that workers are comfortable with the HPD of choice is important, as an uncomfortable HPD is likely to lead to improper use or no use at all.

As part of the WHS legislation, workers exposed to high noise levels also require regular audiometric testing. Basic noise controls observed within industry for some of the work processes includes; buying quiet equipment, installing acoustic screens in high noise areas (e.g. boilermaker area, workshops etc.), applying silencers and low noise fittings to applicable applications/tools. All of these solutions have proven effective in reducing occupational noise exposure for high noise SEGs within mining work processes.

### 9. Conclusions

When considering adjusted mean exposure levels, all SEGs do not demonstrate legislative compliance with the NES. Thus, noise dosimetry sampling confirms that:

- 1) High noise exposure areas exist throughout the coal mining industry
- 2) There is widespread exceedance of the noise exposure standard throughout all SEGs

- 3) A significant number of workers are exposed to a high risk of health effects for unprotected noise exposure in their respective workplaces
- 4) Adjustments to normalised noise levels for extended work shifts and ototoxic substances have a significant combined effect on measured noise exposure levels.

Based on these results, it is clear that regular noise monitoring of workers and the implementation of targeted noise control are a significant priority for the coal mining industry to effectively reduce the widespread high levels of noise.

#### 10. References

1. Safe Work Australia Australian Workers 'Compensation Statistics 2013-2014; 2014
2. Safe Work Australia Occupational Disease Indicators; 2010
3. Coal Mining Safety and Health Act 1999, and Regulation 2001
4. Work Health and Safety (WHS) Act and Regulations 2011
5. AS/NZS 1269.1:2005 Occupational Noise Management – Measurement and Assessment of Noise Immission and Exposure; 2005.
6. WHS Code of Practice Managing Noise and Preventing Hearing Loss at Work; 2011.
7. AS IEC 61672 Electroacoustics - Sound Level Meters; 2013.
8. AS IEC 60942 Electroacoustics - Sound Calibrators; 2004
9. NIOSH Occupational Exposure Sampling Strategy Manual; 1977.
10. AS/NZS 1269.3-2005 Occupational Noise Management Part 3: Hearing Protector Program; 2005.

## SAFE WORK AUSTRALIA'S EVALUATION OF WORKPLACE EXPOSURE STANDARDS

*Elaine Beale*

Safe Work Australia

### ABSTRACT

Australia's existing list of exposure standards was adopted largely from the American Conference of Governmental Industrial Hygienists by Safe Work Australia's predecessor, the National Occupational Health and Safety Commission (NOHSC), in 1995. A small number of exposure standards were reviewed in the late 1990s but the majority have never been updated, largely due to the time and cost associated with reviews.

Safe Work Australia commenced a review of exposure standards in 2012. The scope of the review was to provide an effective and efficient regulatory framework for exposure standards. The review sought to answer questions such as:

- how should exposure standards be regulated, and
- how can Safe Work Australia review them and keep them up to date?

In late 2015, Safe Work Australia published a discussion paper on *The Role of Chemical Exposure Standards in Work Health and Safety Laws*. The paper noted that many exposure standards are out of date and outlined the challenges for Safe Work Australia in reviewing and updating them. It also asked questions on the role and use of exposure standards, whether they should be mandatory or advisory and how they could be effectively and efficiently updated.

Forty-six submissions were received from a range of stakeholders. Feedback indicated that there is support for mandating a smaller number of exposure standards on the basis of risk. Many submissions also suggested the need to streamline the list of exposure standards by determining which standards are still relevant, and to update the standards to reflect current knowledge of health effects.

After the public comment period, it was decided that an evaluation of individual exposure standards was necessary as the next step in the process. Following an open tender process, Golder Associates Pty Ltd was engaged in September 2016 to undertake this work.

The evaluation phase of the project includes:

- a) developing a methodology for the assessment and evaluation of workplace exposure standards
- b) assessing the current 644 exposure standards using this methodology to develop a revised list
- c) developing criteria for mandatory exposure standards based on risk and recommending a set of mandatory exposure standards using the criteria
- d) considering whether an updated standard is required for each chemical in the revised list, and if so, recommending a new level for the standard
- e) reporting on the key findings and recommendations, and
- f) stakeholder information and consultations.

A methodology for the review has been developed with input from experts. Golder Associates will provide a more detailed description of the methodology as part of the presentation at the conference.

Once the evaluation is finished, Golder Associates will deliver a report to Safe Work Australia which will be peer reviewed and published on the Safe Work Australia website in mid-2017.

Safe Work Australia will also be developing a Consultation Regulatory Impact Statement (Consultation RIS) on three proposed options for exposure standards. The options Safe Work Australia will put forward for consideration are:

1. mandatory exposure standards
2. advisory standards, and
3. a mix of mandatory and advisory standards.

The Consultation RIS will include the list of exposure standards for each option and set out an approach for how Safe Work Australia would update and maintain exposure standards for each option.

This is the biggest overhaul of exposure standards in Australia for more than twenty years and a huge undertaking for Safe Work Australia. It is essential that the outcomes of the project enable Safe Work Australia to keep exposure standards up to date into the future.

There will be several opportunities for AIOH members and other interested parties to have input on the future of exposure standards in Australia, including at stakeholder information and consultation sessions in early 2017 and during the public comment period after the Consultation RIS has been published.

Safe Work Australia encourages interested parties to subscribe to the 'Chemical exposure standards' mailing list on its website to be informed about the progress of this work.

## THE FRENCH ARDUOUS WORK REGULATIONS: A VIEW FROM OUTSIDE.

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### 1. Background

France has recently introduced new regulations briefly translated as the *Arduous Work Regulations*. These regulations have been formulated over a period of many years with the near final implementation taking place in 2016. These regulations will require massively increased resources in occupational hygiene monitoring in France and will add considerably to the bureaucratic OHS burden currently placed upon industry.

In principle, these regulations are to address the differences in life expectancy without disability that is observed between highly skilled workers, independent professionals and workers in jobs that have exposure to risk factors that “could leave lasting, identifiable and irreversible effects on health” (Latif, 2015). In France, arduous work was defined as the exposure to work factors that are likely to irreversibly and seriously reduce the ability of a worker to lead a normal professional and home life (Struillou, 2003). In essence, any workplace where exposure to organizational, physical (includes ergonomic) or chemical risk factors exceed defined limits, the *Arduous Work Regulations* will require implementation and enforcement.

The publication of work by Cambois et al (2008a, 2008b) has been cited to support the need for the regulations. In Table 1 below it seems reasonable to conclude that there is a strong link to years of life expectancy and survival with good health post 50 years of age.

**Table 1: Life expectancies and healthy life expectancy in men**

MEN	Life expectancy at age 50	Life expectancy in good health at age 50	
	Years	Years and confidence interval	%
Highly skilled workers	32.2	22.8 (21.8 – 24.0)	71
Farmers	30.9	16.5 (15.0 – 18.2)	53
Independent professions	30.2	19.3 (15.6 – 20.6)	64
Operatives	27.4	13.7 (12.9 – 14.5)	50
Inactive	20.2	6.2 (4.3 – 8.3)	31
<b>TOTAL</b>	<b>29.0</b>	<b>16.9 (16.4 – 17.3)</b>	<b>58</b>

The defining feature of these regulations that is foreign to the English speaking world is that they link exposure during the working life of an individual with their retirement benefits. This link is made in a way such that the more exposure an individual accumulates in the workplace to specific agents, the greater the early retirement benefits. A worker can retire up to 2 years earlier if he or she accumulates more than 100 points over the course of his or her working life.

The main aim of the French regulators is compensation with a further aim, to create an incentive for employers to reduce workplace exposures so that the defined limits are not exceeded and this will reduce future disability and claims. However, to date, this belief is not supported by a robust body of research evidence and may be fallacious.

### 2. The Regulations

Beginning in 2010, pension reforms began the process of linking the working environment of a worker with benefits in their pension scheme. In 2011, arduous factors and occupational diseases / injuries lists were developed. In 2012 the government outlined a format for Individual traceability with arduous factors based on intensity and duration, published in 2014. The law, Decree No.2014-1156, was enacted in January 2014 and, in 2016, individual accounting became a requirement for acquired points and use, with financial employer contributions.

Points are allocated to an individual worker according to data in their work history starting on 2015's exposure, depending upon their exposures over their working life. The maximum points an individual can accumulate over a working life is 100 points. The first 20 points must be spent on training. A further 80 points will entitle the worker to two years early retirement or two years part time work paid full time. Other benefits include 500 hours training once a worker accrues 20 points or more together with a reduction in work time. The points system is structured such that 4 points is allocated per year for one criterion (exposure), 8 per year for two or more criteria. The company must notify the Department of Social Security annually of the accrued points and these points will be summed across different employers if the employee changes employer.

The regulations do not apply to self-employed workers, a significant proportion of the workforce. Recent findings in France indicate that self-employed workers and farmers are more likely to undertake physically demanding work (Raoult et al, 2013). The regulations will not only apply in France but to all French citizens that are employees in French multinational companies (French work contract). This means that it applies to French companies with Australian sites that employ French citizens. Individual risk assessment is also conducted and registered for State employees (5,6 million), without compensation of points.

### 3. Documentation and Records

The regulations will require employers to provide risk assessment documentation and traceability for individual employees. Some large French enterprises have already developed sophisticated software packages to data manage the implementation of the regulations. In 2015 at the IOHA Conference in London, one such company, Solvay, presented their data management system (Berne, 2015). The exposure records are recorded on an individual basis and are linked to the company HR databases. Solvay stores and extracts its hygiene data from software called Socrates (Solvay Occupational Risk Assessment Tool to EmployeeS) which it collects across 130 sites across the world, 19 located in France.

Employers must provide all data to the government and must provide details regarding homogeneous exposure groups or similar exposure groups (HEGs/SEGs) based data or, if available, individual monitoring. It is expected that the large enterprises will cope with this increased data recording and reporting, but documentation and record keeping by small and medium enterprises (SMEs) may be more problematic. Generic profiles of exposure by job can be proposed, validated by the State, to be applied by companies without resources for individual risk assessments.

### 4. Monitoring and hygiene requirements

The occupational hygiene requirements required for the regulations will require monitoring across a range of agents or factors. The current hazards that are included in the regulations are manual handling, arduous posture, vibration, noise, chemical agents, heat stress, hyperbaric and shift work. Exposure will be assessed by risk assessment using HEGs/SEGs or individual exposure assessment results, where they exist.

The arduous factors list consists of some of the following:

- Noise: Daily noise exposure level ( $L_{Aeq8h}$ )  $\geq 81$  dBA with PPE, 600h/y; or Peak sound pressure ( $L_c$ )  $\geq 135$  dBC, 120 peaks/y
- Thermal stress:  $-5^\circ\text{C} \leq \text{Temperature} \leq 30^\circ\text{C}$ , 900h/y
- Vibrations: Hand, arms  $A(8) \geq 2.5 \text{ m/s}^2$ , 450 h/y; Whole-body,  $A(8) \geq 0.5 \text{ m/s}^2$ , 450h/y
- Arduous posture: keeping arms above shoulders, squat, kneeling position, torso twist to  $30^\circ$ , torso flexed to  $45^\circ$ , cumulative 900 h/y
- Manual handling of loads: Push or pull,  $\geq 15 \text{ Kg}$ , 600 h/y; Lifting or carrying,  $\geq 250 \text{ Kg}$ , 600h/y; Cumulative weight, 7.5t/day, 120 days/y, Moving a load from down or top level,  $\geq 10\text{Kg}$ , 600h/y
- Alternating shift work: Midnight  $\leq 1$  hour of work  $\geq 5\text{am}$ , 50 nights/y or Night shift work: Midnight  $\leq 1$  hour of work  $\geq 5\text{am}$ , 120 nights/y
- Repetitive work : 15 technical actions by repetitive cycles less 30 seconds or 30 technical actions by minutes
- Chemical agents: H phrase selection, Details include OEL, duration  $> 150 \text{ h}$ , Engineering control and PPE usage, inhalation and skin contact, source of emission,
- Work hyperbaric: 1200hPa, 60 times/y

A workers exposure to all of these factors will have to be recorded on an individual basis for the duration of their working years with a specific employer. This means all SEGs will have to be fully assessed for all factors and this will place great demands upon workplaces where there exists a complex mix of exposures. In addition, psychosocial risks are not included in the factors nor are ionizing radiation or sedentary activity. Factors are not adjusted for the age of the worker and this will mean that older workers may be disadvantaged (Benke, 2006).

## 5. Other countries in OECD

Many other OECD countries have specific requirements based on job, industry or service sectors. In Table 2 below the requirements are listed, many have early retirement concessions dependent upon job, and/or industry worked, but none link the individual exposures to their retirement benefits (Zaida and Whitehouse, 2009). Interestingly, Canada is the only English speaking OECD country that has any retirement concessions based on occupation in the private sector, but the UK and USA do have some concessions in the public sector. Notable exceptions without concessions are countries with strong economies such as Germany, Japan, Denmark, Australia, Netherlands, Sweden and Switzerland.

**Table 2: Retirement regimes in OECD countries**

Country	Whether special pension schemes are offered at all?	Early retirement concessions because of workers' jobs, occupations or industry?		
		Job	Occupation	Industry
Australia	N			
Austria	y	*		
Belgium	y	*	*	
Canada	y		*	
Czech Republic	n			
Denmark	n			
Finland	y		*	*
France	y		*	
Germany	N			
Hungary	y	*		
Ireland	y	*	*	
Italy	y	*	*	
Japan	n			
Luxembourg	y	*		
Mexico	n			
Netherlands	n			
New Zealand	y		*	
Norway	y	*	*	
Poland	y	*	*	*
Portugal	y	*	*	
Slovak Republic	y	*		
Spain	y	*	*	
Sweden	n			
Switzerland	n			
Turkey	y		*	*
United Kingdom	N <sup>1</sup>		*	
United States	N <sup>1</sup>		*	

y Yes N- Not applicable - (1) public sector only



Special pensions in Table 2 offered for specific jobs include retirement at 60 years in Spain for ballet dancers and bull-fighters. In Hungary, work performed under conditions which exceed the limits specified in the Hungarian standard, where the rate of energy expenditure is more than 5,200 kilojoules in a single shift, is also deemed as arduous.

## 6. Discussion

The Arduous work regulations are now in place in France and the first round of reporting was completed in 2016. Workers may access their individual reports and contest results of points awarded. In essence these regulations link the working environment of the worker with their pension benefits in a manner foreign to English speaking countries.

The underlying reason for the regulation is questionable in respect of recent findings elsewhere in Europe. Findings of a recent Finnish study indicate that the differences between workers in arduous jobs and non-arduous jobs (a surrogate for occupational class), is also dependent upon non-occupational factors. They found that individuals of higher occupational class are consistently in a better position to avoid health risks and to seek more timely and effective health interventions. Factors such as job security and lifestyle may also adversely affect the manual and lower manual class workers (van Raalte et al, 2014).

Will the regulations improve occupational health and safety in France? One would expect so from the point of motivating employers to assess and control hazards in the workplace. However, at what cost? Whether the goals of the regulations could be achieved more cheaply via other interventions does not appear to have been adequately investigated. Interestingly the Germans and some other EU countries have decided not to adopt similar regulations, deciding to continue their current OHS practices.

The full impact of these regulations may be assessed in future years but unfortunately the French government did not undertake a regulatory impact statement, cost/benefit or cost effectiveness analysis prior to their implementation. Critiques of the regulations have been published in recent years, in particular Latif (2015) points to three main negative effects of the regulations that may arise. The first is the loss of competitiveness of French industry, with an extra marginal cost to business that Frances economic competitors do not suffer. The second is the obvious lack of expertise in France to properly assess workplace exposures to the risk factors. With only 30 registered occupational hygienists in France in 2016, risk assessment needs clearly out-strip resources. The Société Française des Hygiénistes du Travail (SOFHYT) has been very active in training basic hygiene principles via the IOHA approved Occupational Hygiene Training Authority (OHTA) one week basic principles course. However, these efforts are likely to be inadequate for current industry requirements. Thirdly, litigation may increase since workers can challenge their assessments and it is in their interests to do so.

Changes in the profile of France's workforce due to the impact of the regulations will perhaps be visible in the short-term for some industries and only in the long-term for others. Exposures which have chronic disease outcomes with long latency e.g. hearing loss from noise will take many years to emerge. Will workers wish to remain in exposed jobs to make full use of the system? A quick response to eliminate a hazard may not be in the best interests of the worker. In addition, some workplaces will find it impossible to conform with an effective noise exposure limit of  $L_{A,eq,8hr} \leq 81$  dBA with PPE, so all workers they hire will accrue points in an environment considered low risk in other countries i.e. below  $L_{A,eq,8h} \leq 85$  dBA. How is this enforced for French workers abroad, where they will be working beside non-French workers where the local standard is 85 dBA?

In addition to the likely negative effects outlined above, Latif also points out a seeming disconnect with the aims of the regulations and recent recommendations by the OECD of raising the age of retirement (OECD, 2014). This is also the aim of the current Australian government, where legislation is before parliament to raise the retirement age to 67 in 2023 and 70 in 2035 (DHS, 2015).

Will similar regulations be considered in Australian states or territories? Our view is that similar regulations to the French *Arduous Work Regulations* are most unlikely to be implemented in Australia soon, or even the distant future. The socio-industrial climate in Australia is considerably different to France and Australians would be more concerned about the possible negative impacts as outlined.

In conclusion, the linking of a workers exposure to hazards in the workplace with a net benefit at retirement is a paradigm shift that may be questionable and France is leading the world in this experiment.

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## RHYTHMOMETRY ANALYSIS OF A REAL-TIME FATIGUE DETECTION TECHNOLOGY DATA AND CHANGE-POINT ANALYSIS OF VEHICLE INCIDENTS AT TWO COAL MINING OPERATIONS

### Running title: Real-time fatigue detection technology and vehicle incidents at two coal mining operations

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Fatigue is involved in 21% of the vehicle incidents in which a person was killed. Emerging real-time monitoring technology is a potential future important control. A recent review included the lack of field information outlining the limitations of the current available technology. Objectives of the present study were to explore the rhythmicity of SmartCap (a relatively recent technology) data at workplace in relation to the melatonin circadian phase described in previous studies, and to analyze the vehicle incidents in two mine sites with similar Fatigue Risk Management Systems with the only difference in the length of implementation of SmartCap. **Design:** Retrospective correlational study.

**Methods:** SmartCap (from 2014 to 2015) and incident (from 2013 to 2015) databases of a coal mining company were reviewed. Cosinor regression analysis was applied to hybrid cross-sectional fatigue data time-averaged for every SmartCap user at every calendar hour (man-hours of use) of the studied period; users were workers at normal operational duties. Parametric and non-parametric tests were used to establish phase differences between fatigue levels and melatonin phase markers. Change-point analysis and non-parametric tests considering a Poisson distribution were used to explore the effect of time and mine site on fatigue levels and incidents.

**Results:** More than one million of man-hours with an appropriate operating time (>20 min) collected from 1461 users showed significant rhythmicity in both a single ( $p < 0.001$ ; 24-hour period) and a multiple ( $p < 0.001$ ; 24-hour, 12-hour and 8-hour periods) component cosinor models (S-CM and M-CM, respectively); the acrophase ( $\alpha\phi$ ) in the S-CM had temporal similarity to the  $\alpha\phi$  reported for melatonin (both at 1 am) in the reviewed literature, though orthophase ( $\sigma\phi$ ) in the M-CM was closer to the phase peak marker 'melatonin mid-point' (3 am vs 4 am;  $p < 0.001$ ). One of the sites had lower fatigue level (mesor site A 26.7 vs site B 28.5) and showed a decrease along the time (mesor Q1 28.6 vs Q5 25.2 and Q6 25.7). Significant change points for mean and variance were detected showing a nearly simultaneous increase in the use of SmartCap, decrease in fatigue alerts (level 4) and decrease in vehicle incidents involving potential injuries approximately one year after SmartCap implementation at the site with lower fatigue level, whereas in the other mine site where vehicle incidents remain unchanged, an increase in the use of SmartCap accompanied by an increase in the fatigue alerts were observed. Non-parametric tests confirmed a significant decrease in the median of the vehicle incidents rate at the first site (9.79 vs 7.18;  $p < 0.031$ ) and not at the second (11.99 vs 8.47;  $p < 0.219$ ) one year after.

**Conclusion:** SmartCap fatigue data followed a circadian rhythm consistent with relevant literature. The utilization of SmartCap could contribute to drop vehicle incidents though by itself appeared to be insufficient; there is a potential role for SmartCap in the Fatigue Risk Management System for vehicles driving as long as it is recognized as an objective monitoring instrument and not as a control by itself.

## HEAT STRESS ASSESSMENT IN ALUMINIUM SMELTING: MAKING IT WORK IN A CHALLENGING AND CHANGING CLIMATE

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### ABSTRACT

Workers in occupational settings are often exposed to high levels of heat which can be compounded by process generated heat and the climatic region in which the industry is located.

This paper outlines the process that was undertaken to characterise the thermal environment within the Reduction Line of an aluminium smelter, determine the potential for heat strain and evaluate the status of a group of employees working in this environment using a modern approach to physiological measurement.

The data collected as a part of this study enabled us to identify gaps in our standards, determine the best methods for collecting data in our challenging work environment and identify those tasks and roles at risk.

Planned follow up work will entail a complete review of our heat stress monitoring policy and standards and the introduction of practical and sustainable controls on the work front to eliminate and or reduce the risk of heat strain for employees working in high risk areas.

The potential for processes within this industry to change further as the industry is challenged moving forward is without question. These changes must be managed whilst operating an aluminium smelter in the current economic climate.

## MANAGING WORK RELATED HEALTH RISKS IN THE CANTERBURY REBUILD PROGRAMME

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### What happened?

At 4.35am on 4th September 2010 a 7.1 magnitude earthquake hit Darfield, near Christchurch New Zealand. At 12:59pm on February 22, 2011 a 6.3 magnitude earthquake hit Christchurch. This resulted in 185 fatalities and thousands of injuries.

Close to 30,000 aftershocks have occurred since including a 6.4 magnitude earthquake on 13 June 2011 and a magnitude 6.0 on 23 December 2011.

On Friday 19 November 2010, at 3:45pm, three and a half hours drive from Christchurch, and almost at the midpoint between both earthquakes timewise, the Pike River Coal Mine exploded. Twenty-nine men underground died from the blast or from the toxic atmosphere. Two men in the stone drift, some distance from the mine workings, managed to escape.



Figure 1 and 2: Christchurch city post-earthquake 2011

### The scale of the rebuild

A significant challenge faced Christchurch. The city needed to be rebuilt. The cost of the earthquakes is estimated to be \$40 billion. The February earthquake was deemed to be the third costliest earthquake worldwide in terms of destruction to an established urban city. The losses covered by insurance were estimated to be 80%, the largest percentage of a globally significant earthquake. The next largest was less than 40% according to the Swiss Reinsurance Company Ltd.

Nearly 18,000 homes were destroyed or rendered uninhabitable; 155,000 homes required repair or rebuild; 1400 CBD buildings were demolished by the quake (70% of CBD).

There was an estimated \$1.8 billion in damage to civic buildings including churches, schools, hospitals, libraries, rugby stadium, town hall, convention centres. Many were severely damaged and in need of demolition.

Infrastructure challenges were extensive with 1,320,375m<sup>2</sup> of road pavement damaged, 659 kilometres of wastewater pipe damaged, and 125 bridges required repairs. \$2.64 billion was needed just to fix roads and underground services.

It was estimated that an extra 20,000 workers would be required, mainly in construction.

### Pike River highlighted New Zealand's poor Health and Safety Performance and changes were made

The Royal Commission of Enquiry into the Pike River explosion and the resulting 29 deaths identified that New Zealand had a poor health and safety record. The changes recommended by the Royal Commission rested firmly on the principle that health and safety in New Zealand could only be improved by the combined efforts of government, employers and workers.

The subsequent Independent Taskforce on Workplace Health and Safety) found that New Zealand's current health and safety system was not fit for purpose. The Taskforce believed that there was no single critical factor behind New Zealand's poor health and safety record. Rather, New Zealand's workplace health and safety system had a number of significant weaknesses that need to be addressed if we were to achieve a major step-change in workplace health and safety performance. The Taskforce recommended practical strategies for reducing the high rate of workplace fatalities and serious injuries by 2020.

One key result was that WorkSafe NZ was established as a stand-alone crown agency in December 2014 with a mandate to improve health and safety regulation. A commitment was made to make a demonstrable change in occupational health by 2016. New legislation came into effect on April 4 2016, The Health and Safety at Work Act (2015).

**In particular, Canterbury Construction had a poor track record.**

Canterbury construction had a history of poor performance when compared to New Zealand's overall health and safety performance. Estimates showed that if nothing was done, and based on the record to date and the workload in the rebuild, there could be 1-2 fatalities each year of the rebuild, 600,000 working days lost and \$80 million in ACC entitlements claims.

**The immediate safety challenges to rebuilding [Covering our response 2010-2012]**

The immediate response to the earthquake included the need for a multi-agency emergency approach; many of these agencies weren't used to working together and had their own way of doing things. People needed to see progress being made and things not being tied up by red tape. The cost of compliance was seen as a potential issue and ignorance and short cuts being taken were a risk. Contractor management was a challenge for many agencies and companies. The availability and applicability of legislation and industry guidance was an issue. The then current asbestos regulations were identified as needing updating. A pragmatic approach was needed in certain situations.

The size and scale of asbestos-related work was identified early. Some buildings were unsafe to enter therefore it was not possible to undertake asbestos identification. Many buildings had no asbestos survey information available and demolition was undertaken without prior removal of asbestos. Issues arose with dust suppression, the lack of PPE, appropriate transportation and disposal of asbestos waste.

**The Rebuild opportunities**

As a result of the earthquakes in Christchurch a number of opportunities presented. There was strong emotional commitment and engagement; people involved in the rebuild were dedicated to getting through without any further harm to people; there was a sense that the time was right to make a difference and emerging local and national leaders with passion.

In 2013 \$10.78m of Government funding was allocated to WorkSafe for a four year Canterbury Rebuild Health and Safety Programme.

**There are five key focus areas in Canterbury Rebuild Health and Safety Programme:**

1. Working with industry
2. Operating an effective and visible inspectorate
3. Targeting key harms and high-risk areas
4. Occupational health
5. At risk/vulnerable workers

Our approach has demonstrated modern health and safety regulatory practice. We have taken a high engagement, education and enforcement approach. We have not focused on one instead of the other.

**Working with industry**

A key focus for our engagement with industry has been our work with the Canterbury Rebuild Safety Charter. The Charter was developed in 2013 as a way of making sure everyone who works in construction in Canterbury comes home safe and healthy

every night. It's an agreement on health and safety between more than 300 organisations – from small companies to large construction firms and from government organisations to NGOs. The Charter is made up of a vision, 10 aspirational commitments and concrete actions under those commitments. The Charter's vision is:

*By demonstrating leadership and working together, we will rebuild Canterbury safely and create a legacy to be proud of. The earthquakes reminded us that the most important thing is people. The Canterbury Rebuild Safety Charter puts people first. It is our commitment to do all we can to ensure the rebuild is safe. It's up to all of us to watch out for each other. Together, we will rebuild Canterbury safely.*

Signing the Charter means those organisations will meet or work towards the Charter's ten commitments and detailed actions. Benefits of being a Charter signatory include:

- Access to Charter events including key speakers on topical health and safety issues.
- Guidance notes, factsheets, toolbox talks and shared industry information
- Access to the online Charter tools including an organisational assessment tool, an organisational performance plan and personal leadership assessment tools
- Support from the Charter support officer including Charter orientations and other site engagements with workers.

WorkSafe provides the Canterbury Rebuild Safety Charter with a secretariat and communications support, funding, and membership on the Charter's Steering and Working Groups.

#### **Operating an effective and visible inspectorate**

It was identified early on that there was a lack of resources available in Christchurch, particularly inspectors experienced in construction work. A commitment was made to ensure the operation of an effective and visible inspectorate.

During the early years of the rebuild, we saw a significant increase in inspectorate activity with worksite assessments increasing from 399 in 2012 to 2881 in 2014/15 and enforcement notices from 122 in 2012 to 1926 in 2014/15.

The New South Wales inspectorate provided a senior inspector on a rotating secondment over a two year period. This helped significantly with building the capability of our inspectors, setting expectations for industry and increasing the number assessments undertaken. As part of our initial response, inspectors from throughout New Zealand came to Canterbury and supported our work. However, as we got further away from the earthquakes themselves and with a significant restructuring in the build up to WorkSafe's establishment, it was more difficult to attract the inspectors needed. We worked with inspectors to develop their capability in work-related health issues and to assist with assessments and investigations as required.

#### **Targeting key harms and high-risk areas**

We have run a conference, seminars, forums, briefings and trade breakfasts featuring international speakers. Work-related health topics include asbestos, contaminated soil, fatigue, critical risks, dust and noise, Hazardous Activities and Industries List (HAIL)<sup>1</sup> sites, health and safety in manufacturing, occupational health for smaller construction businesses, and alcohol and other drugs. Other topics include working at heights, mobile plant, demolitions, vehicle accidents, hot works, electricity and traffic management

Factsheets and toolbox talks have been developed with industry. Inspectors focus on these areas as part of their assessment work.

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<sup>1</sup> A compilation of activities and industries that are considered likely to cause land contamination resulting from hazardous substance use, storage or disposal.

## Work-related Health

### *Government direction*

The Cabinet Paper that established WorkSafe identified the need for an increased focus and resources for the Canterbury Rebuild. This included an *“increased and enhanced focus on occupational health hazards, the need to identify and target occupational health issues at a workplace level; and to target specific health initiatives at high risk rebuild worker populations including new workers, young workers, immigrants and workers with poor literacy.”*

### *Dedicated resource focused on Occupational Health*

We have a dedicated occupational health specialist in the four-strong Canterbury programme team who works with industry and the inspectorate teams. Her role includes engaging, educating and enforcing. She develops and manages a number of work-related health projects as part of the programme.

### *Research*

To better understand the risks posed, we commissioned Massey University to carry out research which identified the leading work-related health risks in the construction sector as carcinogens (including asbestos, silica, cement dust, asphalt fumes, wood dust, diesel fumes and solar radiation), dermatological disorders, psychosocial issues (including fatigue and stress), impairment, musculo-skeletal disorders, noise, vibration, solvents, and carbon monoxide. This work was useful in determining our focus areas.

### *Projects to date*

#### **1. Early focus on Asbestos**

In 2011 public concerns were raised about the levels of asbestos dust in Christchurch. We carried out a survey. Results found that there was a large variance in Dust Trak results with peaks up to 25,000µg/m<sup>3</sup>. All averages were within workplace exposure standards (WES) limit (3000µg/m<sup>3</sup>) and no asbestos was found in any of the samples analysed. Work practices varied, with most sites were using some form of dust suppression during demolition.

Overall results confirmed that the advice given on dust management was appropriate; however, improvements could be made to further reduce the likelihood of harm. These included:

- more effective dust suppression on demolition sites
- cab doors and windows must be closed at all times when demolition is in progress
- air filters in cabs must be serviced and details recorded
- a no smoking policy when operating machinery or working on site
- respiratory protection of P2 or P3 to be provided along with training in their use and a ‘Clean Shaven’ policy should be implemented thus ensuring a good fit.

The Department of Labour (a predecessor agency to WorkSafe) then developed, provided and made available information on these recommendations.

The Canterbury Rebuild Team developed an initiative to engage, educate and enforce against regulatory expectations of asbestos management. This included engagement with key stakeholders such as the Canterbury Earthquake Recovery Authority (CERA), The Stronger Christchurch Infrastructure Rebuild Team (SCIRT) and the Earthquake Commission (EQC) to mutually recognise systems and methods of controlling the asbestos hazard. Education of contractors in asbestos awareness was necessary. Inspectors carried out assessments of demolition and asbestos contractors’ systems of managing restricted work involving asbestos. This required an up-skilling our own inspectorate capability. An improved approval process was put in place for Certificates of Competency to undertake restricted work involving asbestos.



An Asbestos Awareness Campaign set out to improve the level of small-medium enterprises' (SMEs) and homeowners' understanding of:

- asbestos identification
- the numbers of competent asbestos removal contractors available
- the competency of supervision and monitoring required and
- the content and availability of adequate asbestos information and guidance.

We developed and launched the Asbestos Aware website, working with the Combined Health and Environmental Risks Programme Control Group (CHER) which includes greater Christchurch local and regional councils, Canterbury District Health Board, Ministry for the Environment and Ngai Tahu (the principal [Māori iwi](#) (tribe) of the southern region of New Zealand, with its tribal authority. They own or invest in many [businesses](#) throughout the country).

## 2. Silica dust pilot project

The pilot project was commissioned in 2014 due to concerns raised that worker exposure to respirable crystalline silica (RCS) may have been high during the post-earthquake rebuild of Christchurch. The findings were used to educate and engage industry and guide local assessment work.

Findings (Douwes, J. et al. 2015) showed that 12 out of 39 personal dust samples (i.e. 31%) exceeded the NZ workplace exposure standard (WES) of 3 mg/m<sup>3</sup> for respirable dust. The majority of samples exceeding these limits were collected from concrete polishers and grinders with average respirable dust concentrations of 15.2 mg/m<sup>3</sup> and 13.8 mg/m<sup>3</sup> respectively. Drilling and Linea board cutting were also associated with higher dust levels with one in four samples exceeding NZ (and international) standards.

In total:

- 14 out of 39 personal RCS samples (i.e. 36%) exceeded the NZ WES of 200 µg/m<sup>3</sup>
- 16 (41%) exceeded the UK Health and Safety Executive workplace exposure limit (HSE WEL) of 100 µg/m<sup>3</sup> and
- 22 (56%) exceeded the American Conference of Industrial Hygienists threshold limit value (ACGIH TLV) of 25 µg/m<sup>3</sup>.

The highest levels were observed in concrete polishers and grinders with average concentrations of 306 µg/m<sup>3</sup> and 657µg/m<sup>3</sup> respectively. Although exposure levels associated with other tasks (bobcat and digger driving, jackhammering, cutting concrete, drilling, labouring, crushing, and cutting Linea board) were lower, they still regularly exceeded the ACGIH TLV of 25 µg/m<sup>3</sup>. None of the nine static RCS samples exceeded the NZ and Health and Safety Executive standards, but two of the four samples collected close to Linea board cutting exceeded the ACGIH TLV.

This pilot study showed that workers performing selected 'at risk' tasks in the construction industry in New Zealand were being exposed to levels of respirable dust and RCS exceeding national and international standards. Preliminary data suggested that control measures currently applied may not be adequate to protect workers from adverse respiratory effects. The results of this study together with extensive data from international studies, therefore suggested that action was required to reduce silica exposure in the New Zealand construction industry.

We released the results of the report at an industry trade breakfast. An industry meeting was then set up with the aim of industry taking ownership of the need to manage silica dust. Industry focused on education with the development of toolbox talks to support a factsheet WorkSafe had developed. We increased inspectorate activity in this area. This included education on the controls required with a focus on wet cutting and on tool extraction plus respiratory protective equipment, which included the need for fit testing.

We have seen a significant improvement in the management of silica dust, and construction dust in general, on sites. An increase in health monitoring has also occurred with increasing awareness of the work-related health risks in construction. Industry carries

out worker exposure assessments as the need arises - for example to determine if controls are effective. Our work has aligned with the WorkSafe National Clean Air Programme that was implemented in 2015. The focus of this programme is on airborne contaminants, in particular silica, solvents, wood dust, welding fumes and carbon monoxide.

### 3. Impairment

Charter members have continually indicated fatigue is an area where they need further assistance. Results from the Charter Assessment tool have consistently indicated further assistance is being sought in 7 of the top 10 questions relating to Charter performance. We designed a Beat Fatigue Campaign where we delivered branded water bottles to work sites and gave toolbox talks on preventing and managing fatigue. The key messages delivered were eating fruit and vegetables each day, taking regular rest breaks, getting adequate sleep and drinking plenty of water throughout the day. We have run this project twice in the summertime. In one three week period we delivered 2000 water bottles to 150 work sites.

Factsheets, toolbox talks and posters have been developed for industry. We are currently considering an online fatigue management plan tool.

Alcohol and drug use is an issue in Christchurch. A guide to developing an alcohol and drug policy has been developed, with a supporting toolbox talk. A further impairment campaign is planned for the coming summer with water bottles being branded with the messages 'No drugs and alcohol here', 'I'm fit and ready for work' and 'We look out for each other'. Fatigue-branded water bottles will also be delivered as part of this campaign.

Industry has been very supportive of this work and the water bottles can be seen on site throughout the year. Awareness of fatigue related issues and how to manage these has risen.

### 4. Occupational health van

We contracted a mobile van and two occupational health nurses to visit over 80 work sites and 1500 workers to raise awareness and provide information about work-related health issues. In 2015 we carried out a pilot project offering health checks and education to workers. Of the 272 construction workers who underwent a health check, 16% were advised to seek further evaluation from a doctor. We offer toolbox talks and the work provides an opportunity to talk to site foreman and workers one-to-one and as a group. We have found this also provides an opportunity to engage with the large number of migrant workers in the sector.

Again industry has been very supportive of this work and we have received enquiries from throughout the country as to when the van can visit their workplace. This has assisted in raising the profile of work-related health risks.

The various projects provide an opportunity for inspectors to engage with workers, site managers and employers about a variety of topics. It has also enabled industry and workers to see the WorkSafe inspectorate as more than simply enforcers of legislation.

## 5. Health monitoring data project

We are currently undertaking a health monitoring data project analysing spirometry testing data from 200 construction companies from the last 5 years.

## 6. Our 2016/17 programme is likely to feature the following work:

Focus Area	What we will do.
1. Silica Dust (Construction dust)	Carry out dust monitoring project to follow up Silica Pilot Project findings from 2015 & incl. behavioural questions. Target in construction assessment work
2. Impairment Fatigue Alcohol and Other Drugs	Carry out an impairment water bottle campaign in Summer 2016. Develop an online fatigue mgmt. plan. OH Van – educate/engage re this topic (March 2017). Develop Safety Charter Tool Box talk.
3. Body Stressing (Musculoskeletal Disorders)	Run a tidy worksite campaign with Charter – using radio, media etc., and prizes. Could run at same time as we next do OH Van. (March 2017). Develop a Safety Charter factsheet and Tool Box talk aimed at this sector. Trade Breakfast with this topic.
4. Dermatological disorders	Develop a Safety Charter factsheet and Tool Box talk aimed at this sector. OH Van – educate/engage re this topic (March 2017). Trade Breakfast with this topic. Link with the use of hazardous substances/solvents.
5. Solvents	Target in construction assessment work. Develop a Safety Charter factsheet and Tool Box talk aimed at this sector. OH Van – educate/engage re this topic (March 2017). Trade Breakfast with this topic.

### *WorkSafe NZ's Work-Related Health Strategic Plan 2016 to 2026*

WorkSafe's Strategic Plan for Work-related Health "Healthy Work" outlines our plan for a New Zealand where, ultimately, fewer people experience work-related ill-health. The plan explains the high-level direction and approach we will take, our activities and the outcomes needed by 2026 to achieve our vision that everyone who goes to work comes home healthy and safe. The Canterbury work-related health programme aligns with this plan.

### **At risk/vulnerable workers**

Since our programme started, Immigration, Labour Inspectorate and health and safety officials have had concerns regarding potential 'at-risk' workers. We have all recognised that poor performance by an employer in one area is a likely indicator of poor performance in another. We have worked together to identify employers of potential concern and have undertaken joint audits

as appropriate. There has been a focus on employers hiring migrant labour, particularly labour on hire firms. A factsheet was also developed for migrant workers helping them to understand their H&S rights.

### Evaluation of the programme

Our programme is currently being evaluated and results will be published in late 2016. The funding for the four year programme will end in June 2017.

### Resources

A range of Canterbury Rebuild health and safety resources is available on:

<http://www.business.govt.nz/worksafe/information-guidance/guidance-by-industry/construction/canterbury-re-build>

<http://safetycharter.org.nz/>

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## “RESPIRATORY PROTECTION: ARE OUR STANDARDS PROTECTING WORKER HEALTH?”

### A CASE STUDY WITH REFERENCE TO DIESEL PARTICULATE MATTER.

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#### ABSTRACT

##### Aim:

Ultrafine diesel engine emissions are known to cause adverse health impacts including lung cancer, cardiovascular and irritant effects (World Health Organisation 2012). Respiratory protective devices are commonly used to mitigate worker exposure to many hazardous contaminants. Current standards to evaluate penetration through respirator filter media may not consider ultrafine particles due to the diameter of the challenge aerosol and the detection limit of the instrument. Nor do they test penetration at flow rates representative of moderate to heavy work rates.

##### Methods:

Emissions from a Detroit D706 LTE diesel engine were fed into a purpose built experimental chamber. Penetration was determined by particle count at diameters ranging from 5.6 – 560nm, using an Engine Emissions Particle Sizer (EEPS). Penetration was also measured by mass of Elemental Carbon, using NIOSH 5040. Flow rates ranged from light to heavy, as designated in AS/NZS 1716 (Standards Australia International Ltd & Standards New Zealand 2012) and ISO DIS 16975 – 1.2 Work Rates 2 and 3 (ISO 2015).

##### Results and Conclusions:

A method has been developed and validated. Initial findings indicate penetration exceeded standards specified limits for filtering efficiency for a number of filters less than 25 - 30nm, when measured as a function of particle count. Penetration was found to increase as flow rate increases. These results were compared to the penetration by mass of elemental carbon through the respirator filters. This research is relevant as it has been postulated that the ultrafine particles may contribute to adverse cardiovascular mortality and morbidity associated with diesel engine emissions (Martinelli, Olivieri & Girelli 2013).

## A CASE STUDY OF APPLYING A PROGRAM APPROACH TO OCCUPATIONAL HYGIENE ON AUSTRALIA'S LONGEST UNDERGROUND RAIL TUNNELS: THE SYDNEY METRO NORTHWEST RAIL LINK

*Kate Cole MAIOH, COH*

Ventia

### Executive Summary

An occupational health and hygiene program was implemented on Tunnels and Station Civil (TSC) Contract as part of the delivery of the Sydney Metro Northwest project. The targeted program aimed to control exposures to respirable dust and respirable crystalline silica (RCS) with the aim of reducing the incidence of illness and disease to workers on this project.

A multi-faceted strategy was applied to exposure control, which commenced with the design of the tunnel ventilation systems, purpose-designed plant, numerous methods of dust suppression, procedural controls, medical surveillance, respiratory protection, and most importantly, workforce engagement and ongoing communication.

A centralised risk-based occupational hygiene program was developed based on a comprehensive review of previous projects, current literature, the work scope, and the facilities available to support such a project. The program was overseen by a Certified Occupational Hygienist (COH)<sup>®</sup> with a focus on both qualitative observations and quantitative personal exposure assessments.

At the commencement of the program, qualitative risk assessment was performed to identify work groups that were at a high risk of exposure, which then placed them on a prioritised control and monitoring regime. This was supplemented through further qualitative and quantitative assessments to identify if additional controls were needed and if so, where their implementation would be most effective. As time progressed and exposures were further reduced over time, the focus continued towards controlling and assessing exposure to other priority work groups.

As tunnelling progressed through a range of different host rock, exposures to RCS also varied. The program focussed on controlling the amount of respirable dust generated, which in turn would reduce RCS exposures. During each round of assessment, further controls were recommended and subsequently implemented resulting in low exposures of respirable dust to all TBM work crews.

The proportion of RCS to respirable dust was highly variable and measured to be as high as 72%. Average RCS exposures were measured to be below the workplace exposure standard (WES) for most TBM work crews, with the exception of ring builders and grouters. While the data demonstrates that the continued use of respiratory protection in this environment is essential, the amount of reliance on respiratory protection to control exposure was reduced through the adoption of a multi-faceted control strategy.

Notwithstanding the challenges faced through delivering a project of this magnitude, respirable dust and RCS exposures were controlled to levels that were as low as reasonably practicable. Implementing a structured process involving ongoing risk assessment and adaptive management has resulted in an improved work environment during the construction of Australia's largest underground rail tunnels, which has been a step-change in minimising workers' exposure to harmful substances.

### Project Overview

The \$8.3 billion Sydney Metro Northwest is currently under construction and a priority infrastructure investment for the NSW Government. The \$1.15 billion Tunnels and Station Civil (TSC) contract was awarded to a Joint Venture between CPB Contractors, John Holland, and Dragados (CPBJHD) in June 2013, to design and construct the 15 kilometre twin tunnels. It also included civil works for five new stations, two services facilities and an onsite precast facility to manufacture the tunnel segments used to line the tunnels.

The TSC works involved the construction of the longest rail tunnels in Australia with the mainline tunnels excavated with four purpose-built tunnel boring machines (TBMs). Excavation and tunnelling occurred through various strata including sandstone

containing over 75% quartz. Controlling exposures to respirable RCS which can cause an incurable lung disease known as silicosis, was a focal part of developing an effective occupational health and hygiene program.

### **Context and Key Drivers**

Silica is present in almost all types of sand, shales, gravel and rock. Due to the high proportion of quartz in the host rock and the nature of the work environment, it was anticipated that RCS would be generated in significant concentrations from various tunnelling activities. Over exposure to RCS can result in the development of silicosis, which is an irreversible and progressive condition and causes damage resulting in an increase of fibrotic (scar) tissue. The International Agency for Research on Cancer (IARC) has classified crystalline silica in the form of quartz as a Group 1 carcinogen to humans (IARC, 2012). Therefore it was paramount that a strategy was developed to lower this health risk to as low as reasonably practicable.

### **Controlling RCS exposure**

The control of exposure was considered across different stages of the TSC works. At each stage, risks were identified and appropriate controls determined. Risks that could not be eliminated during design were carried through to the planning and procurement phases. This process was integral to investigating and selecting the most effective suite of control measures. Control measures that provided the highest level of protection and reliability were prioritised when CPBJHD considered approaches to reduce exposure.

A significant number of engineering controls were implemented to reduce exposure to RCS. During the design and planning stage, the target for in-tunnel airflow in the tunnels was set to well beyond the minimum 0.5 m/s in the underground environment to reduce airborne contaminants, such as RCS. For example, a ventilation rate of 0.75 m/s was adopted for the longest six-kilometre Cherrybrook to Epping tunnel drive (TJHD, 2013). This created more air to remove and filter the contaminants away from the work area, even though this increased both plant and running costs.

CPBJHD researched the latest procurement options for key items of heavy machinery early in the planning and design phase. There was a strong focus on reducing worker exposure in line with their Workplace Health and Safety Policy (TJHD 2014). This resulted in excavation methods using comprehensive dust extraction and suppression systems.

To reduce the amount of airborne particles generated during cutting, the TBM was designed to enable foam to be directly injected into the cutterhead during TBM excavation operations. The foam was specifically designed for hard rock TBMs and while its primary purpose was to reducing abrasive wear on cutting tools, it had the added benefit of providing dust suppression during excavation. Spoil that was excavated by the TBM was transported out of the tunnel through a series of overhead conveyors. Sprinklers were designed and installed on these conveyors, which functioned to keep tunnel spoil wet to reduce the release of dust (TJHD, 2013).

Transporting people in and out of the tunnels was a necessary part of daily operations, however the process of driving through the tunnels could liberate dusts if spoil was present on the floor of the tunnel. An engineering control was implemented on the man-rider (the plant used to transport workers in and out of the TBM tunnels) where an exhaust deflector was engineered and fitted to prevent the air from the man-rider exhaust system drying out the tunnel floor and liberating dust over time. It was also important that where workers were performing activities inside heavy plant that good quality seals were installed on doors and windows so that when shut, dust exposure would reduce (Ventia, 2016).

A number of adjoining activities occurred in the TBM tunnels that had the potential to liberate dusts such as the excavation of the cross passages. Brokk excavators dug out cross passages through the constructed tunnel. To reduce the amount of dusts generated at the source, water was delivered via a nozzle system through the housing of the hammer as the main element for dust suppression. In addition, dust extraction scrubber systems were designed and installed at each cross passage to capture and filter airborne particles, which controlled airborne dusts to an isolated area (TJHD, 2013).

Numerous administrative controls were also used to ensure airborne emissions and associated health risks were reduced to as low as practicable. These included keeping windows and doors shut on heavy plant and inside underground crib rooms; using

wet cloths to wipe down the inside of heavy plant, rather than using brooms or dry brushes to prevent silica-containing dusts from being liberated; and shortening the duration of TBM crew shifts to be 8-hours per shift (Ventia, 2016).

A comprehensive tunnel wash-down program was implemented that involved allocating dedicated plant and personnel to washing down and cleaning the TBM tunnels on an ongoing basis. This prevented spoils from drying out which could then lead to airborne dusts including silica (Ventia, 2016).

To ensure that control methods were effective on an ongoing basis, routine testing and inspections were performed on the ventilation systems, conveyor belts, heavy plant and ambient conditions inside the tunnel (Ventia, 2016).

To prevent non-occupational exposures, work clothes were laundered on-site so that silica dusts were not taken back to the workers home. The laundry was equipped with ventilation and was cleaned regularly using wet methods to prevent exposure to laundry personnel (ie: the “peggy”) (TJHD, 2013).

Underground workers completed a pre-employment medical to ensure they were fit for assigned duties. They also received comprehensive training as part of the underground induction on RCS, including measures to reduce exposure. The key messages in training included the toxic nature of RCS, the importance of the numerous control measures to reduce exposure on an ongoing basis, including situations when respiratory protective equipment was needed and how to fit and use it correctly (TJHD, 2014a). In addition, awareness signage explaining the presence and hazard of RCS was installed at the entry to the tunnels and stations (Ventia, 2016).

All workers in the TBM tunnels were required to wear P2 respiratory protection when working in-by of the TBM operators cabin at a minimum. In addition, P2 respiratory protection was required when performing specific activities and/or if visible dust was observed. Further upgrades to higher-level respiratory protection such as powered air purifying respirators and full face air purifying respirators were made when specific activities were performed (Ventia, 2016).

CPBJHD had a clean shaven policy, which mandated that if workers were required to wear respiratory protection that relied on facial fit, such as a P2 respirator, then they must come to work clean shaven so that the respirator provided the required level of protection. A quantitative respirator fit testing program was implemented for all workers who needed to wear such respirators, with testing performed by occupational hygienists (Ventia, 2016).

#### **How is this different?**

Controlling exposure to RCS is always a point of focus on tunnelling projects. However on previous tunnel projects, issues had been encountered surrounding the accuracy of measurements when monitoring exposures to RCS. Difficulties were also encountered when using that information to determine whether or not exposures were acceptable as required under work health and safety legislation (Willie & Howes, 2014).

There are multiple different sampling devices and analytical methods that can be used to measure exposure to RCS, while still collecting these samples in accordance with Australian Standard 2985 (SAI Global, 2009). To minimise errors and differences of opinion regarding the actual risk of exposure to the CPBJHD workforce, a comprehensive review was performed encompassing current literature; reviewing geological information along the proposed underground footprint; and the current facilities available to support such a project (Thiess Services, 2014).

There are very few studies that have been published which specifically focus on assessing and controlling exposures to workers in tunnelling. Historically the focus has been to collect stationary samples at set-points to monitor the concentrations of RCS in general along the tunnel alignment. The disadvantages of this approach are many, including not knowing what workers are being exposed to as they move to various locations in the tunnels.

Another recurrent issue, was determining what to do if RCS was measured at high concentrations in certain areas. Using technicians to put out and pick up sampling devices with no relation to the work being performed, meant that it would have been difficult to determine appropriate control measures to put in place to lower the concentrations over time.



The strategy developed for the TSC Project involved the development of a centralised occupational hygiene management program overseen by a COH where technical and consistent requirements were documented for independent parties who measured and assessed worker exposure to crystalline silica. A strong emphasis was placed on the use of qualitative observations by occupational hygienists, rather than technicians. The focus of the program was on the workers, where occupational hygienists (classified as provisional or full members of the Australian Institute of Occupational Hygienists) remained onsite during sampling and observed the tasks the workers performed. Having a better understanding of the process meant that practical control measures were able to be implemented in consultation with the workforce and management. The focus of the program was on personal sampling, where occupational hygienists were responsible for sample collection from the workers, rather than static locations across the tunnels (Ventia, 2016).

### **Exposure monitoring and adaptive management**

The occupational health and hygiene program was designed as a structured process that used both historic and current information to effectively manage and control the risk of exposure to RCS throughout the life of the TSC Project. In the early stages of the project, all workers were grouped into Similar Exposed Groups (SEGs) which represented groups of workers who were expected to have the same general level of exposure to RCS due to the nature of the work that they would perform and the location where they would work. A significant amount of time and focus was put towards understanding workers job function, processes, tasks, control equipment, and materials they would use as part of this process. That information, together with historic data from previous tunnelling projects, was used to identify higher-risk SEGs that were then placed on a prioritised control and monitoring regime to verify if the controls in place were effective at reducing RCS exposure.

Site walkthroughs and exposure assessments were performed by independent occupational hygienists who also collected personal exposure measurements for RCS on a campaign basis. These assessments were used to identify additional control measures in consultation with project teams. As time progressed and exposures were further reduced to certain SEGs, the focus continued towards controlling and assessing exposure to higher-risk SEGs. It is this process of ongoing assessment and adaptive management that has resulted in a step-change in minimising workers' exposure to harmful substances.

A key strategy that was implemented during design, was to ensure that persons who conducted these exposure measurements were competent experienced professionals, given the high-risk nature of the substance being assessed. The program also specified sample collection methods and tools as well as the NATA-accredited laboratory used to analyse the samples collected to minimise areas of uncertainty.

The sampling and analysis for respirable dust and RCS were performed in accordance with Australian Standard (AS2985-2009) using portable sampling pumps fitted with Simpeds cyclones. All samples were analysed by NATA accredited NSW WorkCover TestSafe Laboratory using gravimetric analysis and X-ray diffractometry (XRD).

### **Results and Discussion**

As the TBMs tunnelled through a range of different host rocks ranging from Ashfield Shale through to Hawkesbury Sandstone, the concentrations of RCS also varied. The proportion of RCS measured from respirable dust samples across the four TBM work crews was measured to be as high as 72% quartz. The amount of RCS in relation to respirable dust was not under the control of project teams, given that the alignment of the tunnels was fixed by the Client, so a strong focus was placed on controlling the amount of respirable dust generated as part of performing the works, which would in turn reduce the amount of RCS exposure.

During each round of monitoring, controls were recommended and subsequently implemented to further reduce exposures, which meant that exposures to respirable dust began to reduce even further over time (Figure 1). Implementing the numerous control measures previously described resulted in low exposures of respirable dust to all TBM work crews on the Project to well below industry standards.

Currently no respirable dust WES is regulated in NSW outside of the coal mining industry (SWA, 2011a). As such, personal exposure data was compared to a trigger value of 1 mg/m<sup>3</sup> (8-hour time weighted average) as recommended by the Australian Institute of Occupational Hygienists (AIOH, 2014) which is lower than the level recommended by the Department of Primary Industries for use in a mining environment (NSW, 2007).

While respirable dust exposures were below recommended guidelines, the aim was to reduce exposures lower than industry standards. Unfortunately, there are limited published studies in tunnelling environments can be referenced for comparison

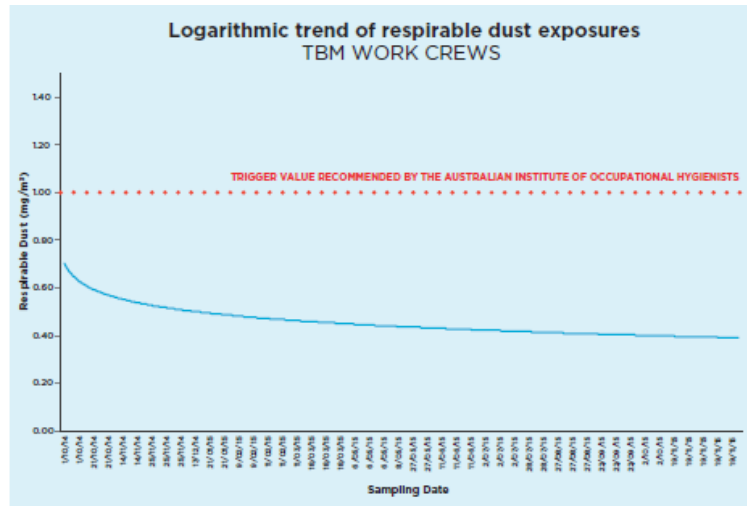


Figure 1: Trend of respirable dust exposure over time

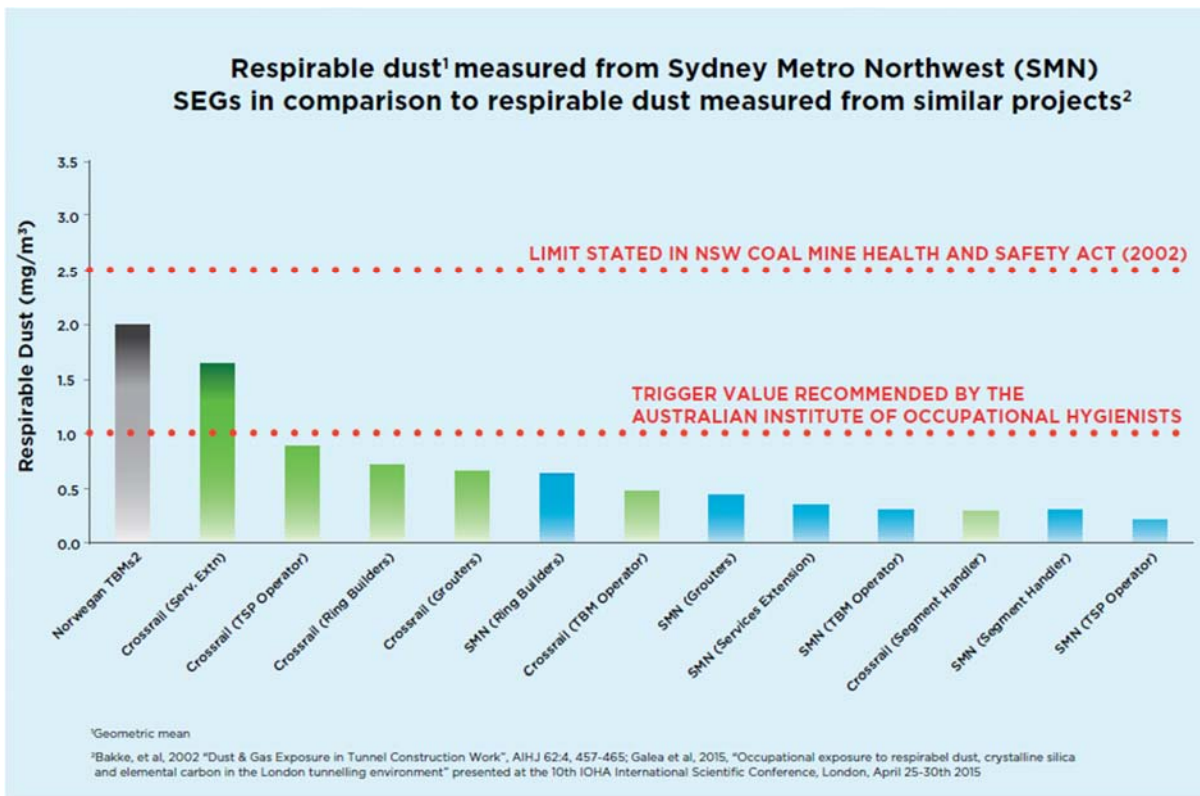


Figure 2: Average exposure concentrations measured from TBM crews on the TSC project in comparison to Industry standards.

purposes, with the exception of data representing a series of Norwegian tunnelling projects (Bakke et al, 2002) and London's recent Crossrail tunnelling project (Galea et al 2015). When comparing exposure results to such similar scale projects, the average respirable dust exposure concentrations measured on TSC TBM crews were lower and continues to demonstrate the value of implementing a targeted exposure reduction program.

Taking an industry best practice approach to controlling dust exposures has resulted in respirable dust being well controlled. However, a significant proportion of respirable dust was measured as RCS due to the high amount of quartz that was present in the host rock being tunnelled. Predicting concentrations of RCS relative to the percentage of quartz comprising the host rock at any one point in time however was challenging as numerous other factors impacted on this estimate. Therefore a conservative approach was maintained, where the continued use of P2 respiratory protection was required to be used regardless of the location of the TBM within the tunnels. As RCS is invisible to the naked eye, P2 respiratory protection also continued to be required in cases where visible dust was not observed.

The current regulated WES for RCS is 0.1 mg/m<sup>3</sup> (SWA, 2011a). If measured within 50 percent of that value, additional control measures were put in place to further reduce exposure. This included increased ventilation and filtration, dust suppression, and the use of PPE. The effectiveness of those control measures were then assessed through follow-up testing. It is this process of ongoing adaptive management that ultimately saw RCS concentrations reduce over time.

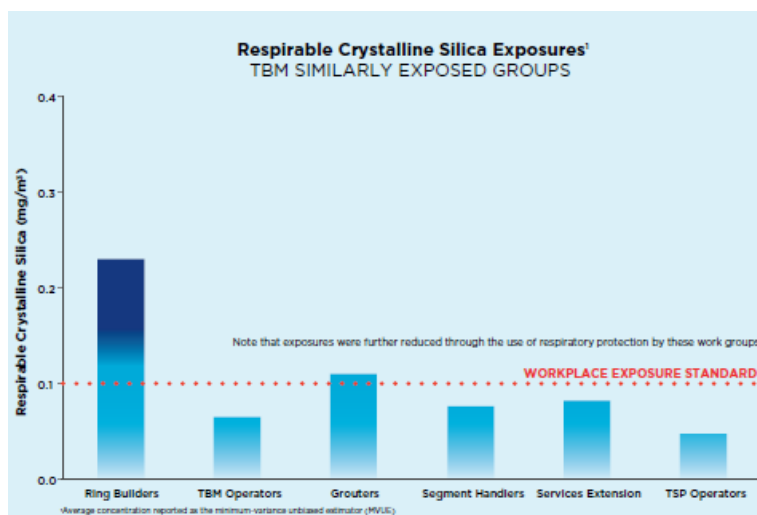


Figure 3 demonstrates how essential this proactive approach was at reducing exposure. While mean TWA exposures to RCS were measured below the WES for most TBM work crews, mean exposures to TBM ring builders and grouters were above the WES.

The correct use of P2 respiratory protection, reduces exposure to one-tenth of the concentrations measured, which means that the level of RCS potentially breathed in by TBM workers was well below this standard however, at levels where the risk of the incidence of silicosis is reduced.

### Lessons Learnt and Achievements

Over the period of the TSC project, regular exposure monitoring coupled with the implementation of targeted control measures, resulted in reduced exposures over time. Although the presence of respirable dust and RCS is widespread in tunnelling, exposure data demonstrated that the risk of exposure to respirable dust was low in comparison to both regulatory and industry standards. High and varied concentrations of quartz in the rock being tunnelled, presented ongoing challenges for exposure control to RCS and will likely continue to do so in future tunnelling projects in Sydney. Notwithstanding these challenges, RCS exposures were controlled which resulted in an improved work environment during the construction of Australia's largest underground rail tunnels.

The risk-based occupational health and hygiene program enabled project teams to understand the risk of exposure across their workforce and enabled targeted application of controls to where they were most effective at reducing exposure. While dusts may no longer be visible in the tunnelling environment, respiratory protection such as P2 dust masks continue to be needed to further reduce RCS exposure to underground workers as an ongoing control measure to prevent silicosis.

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## DOES PERCEPTION EQUAL PROTECTION? OCCUPATIONAL NOISE EXPOSURE & HEARING PROTECTIVE DEVICE UTILISATION FOR ENGINEERING TRADES

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### ABSTRACT

The study examined exposure trends amongst a specific cohort of workers (n=55), loosely defined as “engineering trade” employees, but essentially comprising fitter and boilermaker trade disciplines at a variety of workplaces (n =6). Workers’ perceptions of their noise exposure was surveyed, and factors likely to influence positive or negative HPD use behaviours. The goal being to identify determinants of Hearing Protective Device (HPD) use behaviour and potentially apply targeted interventions to increase the efficacy of a workplace’s Hearing Conservation Program (HCP).

Exposures for the study cohort were characterised utilising a combination of shift-long personal noise dosimetry and short term area (at-ear) measurements of specific tasks and activities. Risk perception and HPD use factors were examined utilising a questionnaire administered to study participants.

Two distinct Similar Exposure Groups (SEGs) were confirmed, reflective of both fitting and boilermaker trade disciplines; both of which exhibited mean exposure confidence ranges wholly above the  $L_{Aeq8hr}$  85dB(A) regulatory limit. Workers at the five workplaces where mandatory HPD use policies were implemented reported strong positive HPD use behaviours, and conversely at the sixth (and only) workplace where a mandatory HPD use policy was not implemented, negative HPD use behaviours were reported. On regression analysis this factor (mandatory HPD use policy) proved one of only 2 significant factors determining HPD use ( $p < 0.01$ ).

The research concludes that a mandatory HPD use policy is an essential element in predicting positive HPD use behaviours to ensure exposure control.

### INTRODUCTION & BACKGROUND

A comprehensive review of Occupational Noise-Induced Hearing Loss (ONIHL) by Safe Work Australia (2010) concluded that very few wide ranging studies on the extent and distribution of noise exposures within Australia have actually been conducted. The agency notes that the former Australian Safety & Compensation Council (ASCC) concluded during 2001-2 that approximately 10.5-12% of the Australian working population was exposed to excessive noise (i.e. >85dB(A))  $L_{Aeq8hr}$ .

Safe Work Australia (2014) occupational disease indicators show a recent increase in compensable ONIHL claims in Australia. After remaining steady around the 400 claims per million employees rate for the first half of the decade claims had increased markedly to more than 500 claims per million employees for the 2008-11 period.

Anecdotal evidence about noise control programs has long framed a certain bias towards a “HPD first” approach to exposure control. A study by Daniell et al (2006) of 76 US workplaces indicated that since the inception of OSHA noise regulations 20 years prior, most workplaces reported little if any implementation of source or transmission noise controls, with a strong bias towards the use of HPD’s as a “first and only” control. Of those workplaces surveyed HPD utilisation rates were reported at only 38% for confirmed excessive noise environments.

Neither the ready availability of HPDs, nor the instruction for their use, are absolute guarantees that workers will use them. Studies by numerous researchers (Lusk et al 1994, Lusk et al 1998, Edelson et al 2009, Oisaeng et al 2011, and Arezes & Miguel 2006) have examined levels of hearing protector use in various occupational cohorts, as well as factors that may be significant determinants and predictors of HPD use.

A majority of the aforementioned studies that address factors likely to influence HPD utilisation are based on Pender’s (2006) Health Promotion Model (HPM) originally proposed in 1982, and revised in 2006 (see Figure 1). The model proposes that a health

promoting behaviour (such as the adoption of HPD) is the result of a series of defined factors acting in concert or competition to yield that behaviour.

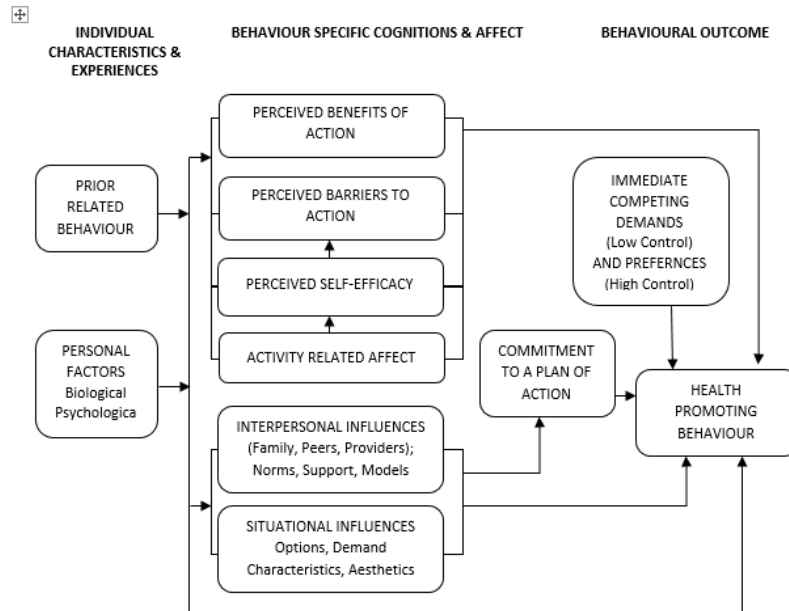


Figure 1 – Health Promotion Model (as revised). Source: Pender et al (2006)

## RESEARCH OBJECTIVE

The aim of the study was to examine noise exposure within a particular occupational group, namely engineering workshop employees from fitting and boilermaker trade disciplines; to establish the following;

- The likelihood of worker noise exposures typically exceeding acceptable noise exposures, as defined by regulation, with the potential to result in ONIHL;
- The extent to which workers can correctly predict their exposure risk as “acceptable” or “unacceptable”;
- HPD utilisation behaviours and factors that may typically influence or predict the likelihood of correct behaviours occurring.

## EXPOSURE CRITERIA

All participating workplaces were based in Queensland and subject to regulatory  $L_{Aeq8hr}$  requirements pertaining to occupational exposures to noise mandated by either *Work Health & Safety Regulation 2011* (Qld) or *Coal Mining Safety & Health Regulation 2001* (Qld).

Both of the aforementioned regulatory instruments prescribe that workers’ exposure to noise is kept to an acceptable level and the worker is not exposed to noise levels exceeding the levels stated in the *Safe Work Australia National Standard for Occupational Noise* [NOHSC: 1007]. Excessive noise as defined by the Standard is a level of noise above an 8 hour equivalent continuous A-weighted sound pressure level ( $L_{Aeq8hr}$ ) of 85dB(A) and a C-weighted peak sound pressure level exceeding 140 dB(C). Adjustments to normalized 8hr noise exposure level for extended work-shifts were made for participating workplaces/employees working shifts of  $\geq 10$  hours duration as required by AS/NSZ 1269.1.

Principal consideration has been given to  $L_{Aeq8hr}$  exposures for the purposes of the current project as the principal exposure measure in relationship to the potential development of an ONIHL for an engineering trade worker over the working life of that tradesperson from chronic exposure.

## METHODS

The study was conducted utilising a mixture of quantitative, semi-quantitative, and qualitative data collection techniques aimed at characterising noise exposure within the sample group, and understanding HPD utilisation rates and potential determinants within a sample group (n=55). Workers participating in the project were from separate workplace sample groups (n=6), and from one of two distinctly categorised “engineering trade” disciplines – (i) boilermakers (n=33), and (ii) fitters (n=22). All participants were fully trade qualified personnel (no apprentices).

### QUANTITATIVE EXPOSURE EVALUATION TECHNIQUES & EXPOSURE CHARACTERISATION

Occupational noise exposure assessments were performed with reference to measurement principles outlined in Australian Standard AS/NZS 1269.1 - *Occupational Noise Management - Part 1: Measurement and assessment of noise immission and exposure*. Noise dosimeters were used to monitor noise exposures for selected study participants. Noise dosimetry was performed over representative monitoring periods (exceeding 90% of total shift duration in all instances).

The following equipment was used to conduct the survey:

- 10 x Casella 35X Personal Exposure Noise Dosimeters – Type 2 Devices. (SN:2039003 - 2039012);
- Svantek SV-30A Type 1 Acoustic Calibrator – (S/N: 19472).

Personal exposure meters used conform to those meters referenced for operation in AS/NZS 1269.1. The acoustic calibrators in use was within a current NATA calibration periods at the time of assessments. All personal exposure meters were within their initial 2 year Casella Original Equipment Manufacturer (OEM) factory calibration period at the time of assessments. All devices were field checked against the NATA certified field calibrator for accuracy prior to and immediately after measurement. Deviations of more than  $\pm 0.5\text{dB}$  were not observed during field calibration and checking.

Results of personal noise dosimetry ( $L_{Aeq8hr}$ ) were inputted the American Industrial Hygiene Association (AIHA) IHSTAT+ Similar Exposure Group (SEG) spreadsheet package (as linear pascal inputs) to confirm sample distribution trends and the likely presence of one or more SEGs. A further ANOVA was performed to confirm the statistically significant variance ( $p < 0.01$ ) between two identified SEGs groups – fitters and boilermakers.

### HPD UTILISATION QUESTIONNAIRE

A HPD Utilisation Questionnaire was constructed with the aim of assessing the rate of HPD utilisation within the sample group and establishing potential significant predictors of HPD utilisation behaviour. The questionnaire also sought to assess workers’ perceived risk of noise exposure against their actual noise exposure, and the accuracy of this judgement.

The questionnaire was largely structured upon the Pender (2006) Health Promotion Model (HPM) as depicted in Figure 1. Previous researchers (Lusk et al. 1998; Oisaeng et al. 2011) had constructed study questionnaires based on the HPM, however none of the actual questionnaire instruments were published. In lieu of access to a previously utilised or validated questionnaire researchers set out to construct a questionnaire based on HPM factors and other selected factors as possible independent variables influencing the dependent variable (HPD use behaviour). These factors are detailed following;

Individual Characteristics				
Age	Trade	Years Trade Experience	Perceived Hearing Acuity	Perceived Risk
Behaviour-Specific Cognitions & Affect – HPM Factors				
Interpersonal Influence	Situational Influence	Perceived Benefits of HPD Use	Perceived Barriers to HPD Use	Perceived Self-Efficacy of HPD Use

Behavioural Outcomes relating to HPD usage were assessed utilising 4 questionnaire items. Variables were also based on a 5-point Likert psychometric scale (ordinal) assessing the worker's self-reported incidence of a HPD use behaviour from "Never" to "Always".

HPD Questionnaire results were manually collated and entered into the IBM SPSS Statistics v. 20.0.0 program for coding and analysis. Statistical analysis techniques applied included dimension reduction (through exploratory and confirmatory factor analysis), and multiple regression analysis.

Factor analysis techniques were chosen to attempt to firstly confirm the efficacy of the questionnaire design in relation specifically to Pender's (1996) HPM model factors, and further examine the potential significance of factors on HPD use behaviours (behavioural outcomes). A single behavioural outcome was confirmed and subjected to regression analysis utilising independent variable factors derived from both HPM model factors, and individual characteristics factors previously identified. Further regression analysis was also performed for HPM factors only in isolation.

## RESULTS

### *Exposure Measurement*

A SEGs data summary including current assessment data for fitters, boilermakers, and all workers combined is detailed in the following Table 1. Highlighted cells indicate excessive values as compared against the  $L_{Aeq8hr}$  regulatory limit. To further verify the presence of proposed SEGs a one-tailed ANOVA test was performed, which confirmed the between groups mean exposure difference (fitters vs. boilermakers) to be very significant ( $p < 0.01$ ).

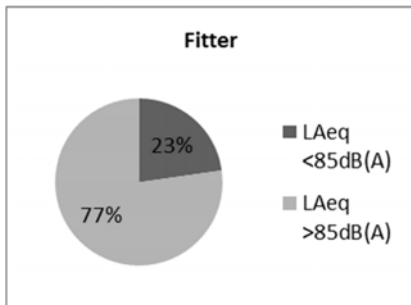
**Table 1: Summary Results - Comparative SEGs Analysis**

DESCRIPTIVE STATISTICS	Fitters	Boilermakers	All Workers
Number of samples (n)	22	33	55
Maximum (max)	92.3	105.5	105.5
Minimum (min)	79.3	85.7	79.3
Percent above OEL (%>OEL)	77.3	100.0	90.9
Mean	87.3	95.3	92.9
Median	87.0	94.5	90.9
TEST FOR DISTRIBUTION FIT			
Normal ( $\alpha = 0.05$ )?	Yes	Yes	No
NORMAL PARAMETRIC STATISTICS			
$LCL_{1,95\%}$ - t statistics	86.2	93.7	91.4
$UCL_{1,95\%}$ - t statistics	88.2	96.8	94.3
95th Percentile - Z	91.0	101.3	99.8
UTL95%,95%	92.2	102.6	101.0

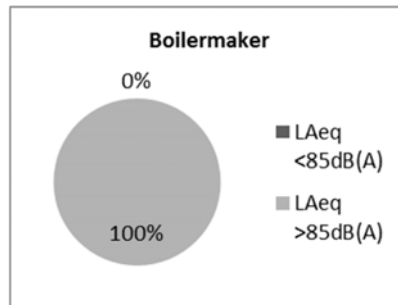
Further descriptive results are presented subsequently. Figures 2.1-2.3 indicated the total proportion of the "all workers" sample group reported an excessive (>85dB(A)) exposure by dosimetry for all samples was 92%. All (100%) sampled boilermakers recorded  $L_{Aeq8hr}$  exposures >85dB(A) compared to 77% of fitters sampled.



**Figure 2.1 - % Fitters exposed to excess noise**



**Figure 2.2 - % Boilermakers exposed to excess noise**



**Figure 2.3 - % Total Workers exposed to excess noise**

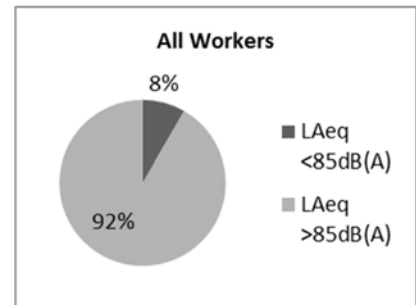
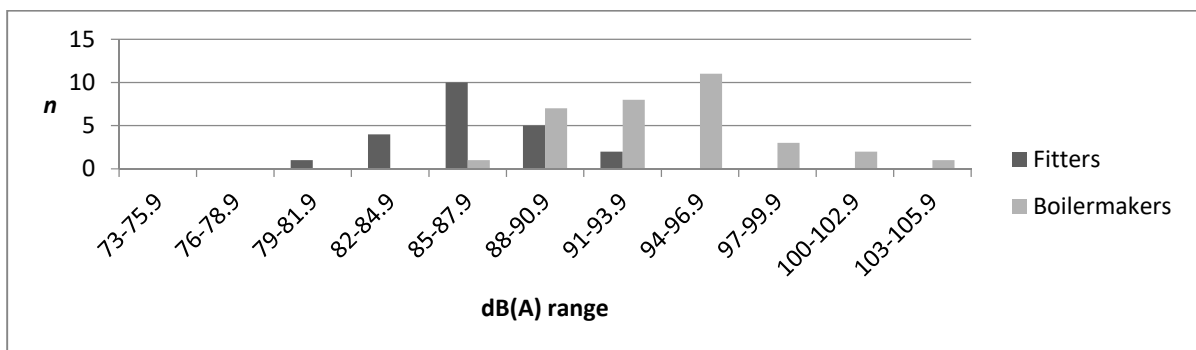


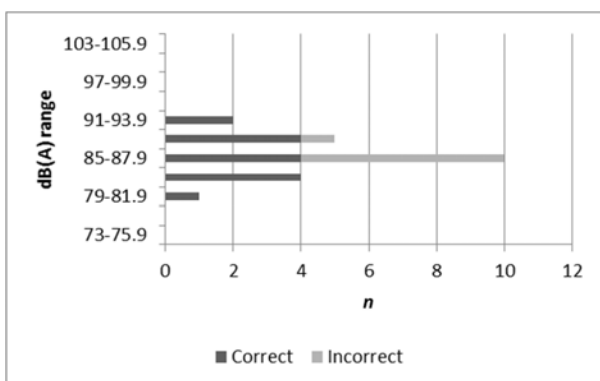
Figure 3 represents exposure frequency distribution for both boilermaker and fitter sample groups. The distribution has been modelled at  $\pm 3\text{dB}$  about the  $85\text{dB(A)}$  regulatory exposure limit to reflect the  $3\text{dB}$  exchange rate assumption (i.e. noise dose is doubled in  $3\text{dB(A)}$  increments). The distribution appears to depict a binomial structure (which shall be discussed subsequently in SEGs analysis). Boilermakers appear to generally exhibit greater average noise exposures than their fitter counterparts.

**Figure 3 – Distribution of  $L_{Aeq8hr}$  noise exposure by trade discipline**

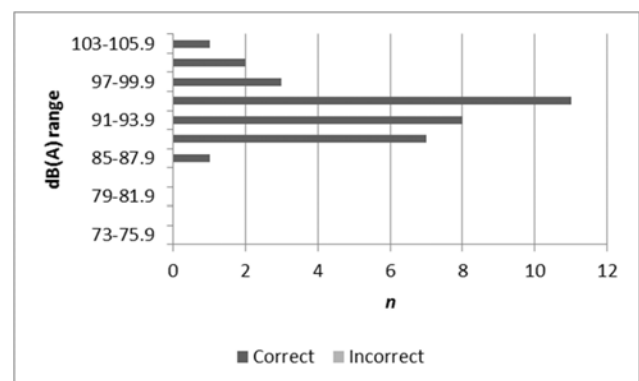


Figures 4.1 and 4.2 depict distribution of correct to incorrect exposure predictions (i.e. risk perception) as reported by workers at the end of their dosimetry periods. All (100%) of boilermakers were able to correctly predict their overexposure. Fitters were less able to accurately predict their overexposure, with more than half (6/10 sample cases) in the  $85-87.9\text{dB(A)}$  exposure range able to correctly predict their overexposure.

**Figure 4.1 - Fitters – Correct vs Incorrect Noise Exposure Prediction**



**Figure 4.2 - Boilermakers – Correct vs Incorrect Noise Exposure Prediction**



### HPD Utilisation Questionnaire

All 55 administered questionnaires were returned. Missing data/items were not reported and all questionnaires were incorporated for study analysis. Confirmatory Factor Analysis (CFA) was performed on questionnaire data for results comparison against Pender's HPM Behaviour-Specific Cognitions & Affect factors. Most HPM factors were confirmed during CFA (albeit with KMO <0.6 indicating reduced sampling adequacy), however two factors performed poorly and were restructured prior to input into regression analysis.

Results of multiple regression analysis performed for all study factors is detailed in Tables 2 & 3 below. Initial analysis incorporating essentially all study factors (Table 2) found Hearing Protection Policy ( $p < 0.01$ ) and Years Trade Experience ( $p = 0.02$ ) to be significant predictors of the combined HPD use behavioural outcome factor.

**Table 2 – Multiple Regression Analysis –HPM & Individual Characteristic Factors Coefficients<sup>a</sup>**

Model (Factor)	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	-3.039	.989		-3.074	.004
Interpersonal Influences Factor 1	.156	.120	.156	1.297	.202
Situational Influences Factor 1	.092	.088	.092	1.047	.301
Situational Influences Factor 2	-.015	.083	-.015	-.184	.855
Perceived Benefits Factor 1	.132	.090	.132	1.472	.148
Perceived Barriers Factor 1	.099	.106	.099	.930	.358
1 Perceived Self Efficacy 1	.021	.089	.021	.230	.820
Mandatory HPD Policy	1.845	.409	.656	4.514	.000
Actual_Exposed	-.166	.342	-.048	-.485	.630
Exposure_Perception	.194	.259	.081	.751	.457
Age	.060	.031	.497	1.953	.057
Years Experience	-.065	.027	-.526	-2.404	.021
Perceived Hearing Acuity	.130	.298	.051	.436	.665

a. Dependent Variable: BehavFac1 (i.e. Reported Use of HPD)

Analysis incorporating Pender's (2006) HPM factors only (Table 3) did not yield any significant predictors of the combined HPD use behavioural outcome factor. However, the interpersonal influences factor did emerge as the best predictive factor ( $p = 0.096$ ) amongst all HPM factors by a considerable margin.

**Table 3 – Multiple Regression Analysis –HPM Factors Only**
**Coefficients<sup>a</sup>**

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.261	.091		2.881	.006
Interpersonal Influences Factor 1	.208	.122	.274	1.704	.096
Situational Influences Factor 1	.048	.085	.089	.570	.572
1 Situational Influences Factor 2	.045	.094	.075	.484	.631
Perceived Benefits Factor 1	.057	.089	.101	.635	.529
Perceived Barriers Factor 1	.036	.116	.051	.312	.756
Perceived Self Efficacy 1	.100	.085	.191	1.173	.248

a. Dependent Variable: BehavFac1 (i.e. Reported Use of HPD)

**DISCUSSION**
***Exposure Characterisation***

Mixed results were found regarding the initial research objective of establishing the overall likelihood of an “engineering trades” cohort being exposed to excessive. Sample groups of both boilermaker and fitter trade disciplines typically manifested  $L_{Aeq8hr}$  exposures that exceeded the 85dB(A) regulatory exposure limit. There was, however, a clear binomial distribution trend in reported exposure data, confirmed through SEGs analysis and ANOVA, indicating the initial characterisation of an overall “engineering trades” SEG by the researchers is likely incorrect and that the sample group is best defined as comprising 2 separate SEGs based on fitter and boilermaker trade disciplines.

Despite the apparent exposure intensity differences between boilermaker and fitter trade disciplines, and the failure to establish a homogenous SEG, the results of dosimetry sampling, observations made during (and the results of area sampling), do indicate there is a likelihood of  $L_{Aeq8hr}$  exposures exceeding the 85dB(A) regulatory exposure limit during typically representative work activities for all sample group workers. Based on such characterisations, there is an evident requirement to implement exposure controls to ensure otherwise unprotected workers are not at risk of ONIHL through chronic exposure to noise over their working lifetimes.

***Noise Exposure – Accuracy of Risk Perception***

Results for the questionnaire item asking workers to nominate post-shift “*whether or not they believed they were exposed to excessive noise*” indicated that fitters, in particular, within an 85-88dB(A) exposure range were poor predictors of their excess exposure. This range also happens to reflect the expected mean and 95% confidence range determined for fitter SEG noise exposure in the sample group. In contrast, boilermakers were much better predictors of their excessive noise exposure with 100% of sampled workers correctly reporting a perceived excessive exposure. As previously mentioned the boilermaker sample groups reported a much higher mean and 95% confidence range, approximately 94-97dB(A).

It is contended by the researchers that there are two key reasons as to why fitters predicted their overexposure in the 85-88dB(A) range poorly. Firstly, as previously mentioned, as many as six fitters required extended shift adjustments that took their exposure from sub-85dB(A)  $L_{Aeqt}$  levels to final exposures in the 85-88dB(A) range. The AS1269.1 adjustment method is contrived on

principles that on face value bear little relation to human perception of noise. Initially, normalisation of noise exposure essentially involves the “compaction and repackaging” of a 12 hour sound pressure level into an 8 hour equivalent. Furthermore, the addition of a +1dB adjustment to cater for reduced hearing mechanism recovery time does not reflect an actual “experienced” acoustic energy. To this end, workers are perhaps at a -2.8dB(A) perceptual disadvantage (based on a 12 hour shift normalisation and adjustment) before the next proposed reason is accounted for – loudness.

The loudness of sound is the key input with regards to how an individual experiences and hears noise as processed by the hearing mechanism. Yet research has shown an individual’s subjective response to changes in sound pressure level does not precisely align. Lamancusa (2000) relates that an increase of 3dB to sound is only barely noticeable to the listener, and that change is not typically clearly noticeable to the listener until an approximate 5dB increase has occurred. In terms of the decibel scale and an assumed 3dB exchange rate, at 5dB noise exposure has more than doubled in terms of acoustic energy.

In total, based on the aforementioned two reasons, a worker on a 12 hour work shift could be at a perceptual disadvantage somewhere in the 7-8dB(A) range from the likely measured and adjusted noise exposure, making it somewhat difficult for workers to correctly predict their excessive noise exposure around the 85dB(A) regulatory criterion limit. Whereas, for boilermakers with much higher average exposures, the increased and perceivably high loudness of their exposure makes their judgement of excessive noise more well-defined.

Other factors are also suspected as potential determinants of fitter’s poor predictive abilities as compared to their boilermaker counterparts. Background noise measurements were not obtained for all workshop settings, but for the two monitored fabrication workshops where 80-85dB(A) background noise measurements were recorded there were a number of indirect noise sources present within the workshop (e.g. grinding, needle gunning, hammering) at any given time. The lower recorded background noise for workshop six is seemingly the result of less indirect noise contribution. Indeed, in this instance between the performance of more isolated noise tasks (e.g. torquing up bolts with an air wrench, hammering a pinion) there was much less background noise, in fact the workshop was perceivably quiet.

It is postulated that where, for fitting tasks, background noise levels are lower, and task duration with noisy tooling lower, than those recorded for boilermaker workshops, there is perhaps greater potential to discount the cumulative exposure effects of utilising noisy tooling by the operator. As this study did not collect specific and accurate task duration times it is not however possible to quantify the potential predictive power of these variables.

#### ***HPD Utilisation***

The institution of a mandatory hearing protection policy ( $p < 0.01$ ) was determined to be the most significant positive predictor of self-reported HPD use by study workers. Workers at workplaces with mandatory hearing policies almost universally reported positive HPD use behaviours, whilst such behaviours at the one study workplace with an elective HPD use policy (workplace six) were mixed to negative.

Years trade experience was a negative predictor ( $p = 0.02$ ) of reported HPD use. This effect may have been exacerbated or pronounced by a number of workers at workplace six having long term trade experience reporting no HPD use, as face examination of trade experience vs HPD use data for remaining workplaces shows no discernible relationship. Removal of workplace six data from regression analysis resulted in the elimination of this effect ( $p = 0.28$ ).

Incorporation of Pender’s (1996) HPM factors only for regression analysis failed to yield any significant predictors of HPD use behaviour, however the strongest predictor by some margin were interpersonal factors ( $p = 0.096$ ). Items comprising this factor addressed how workers perceived HPD use by other worker colleagues, supervisors and management as either positive or negative. So results may tend to indicate a degree of “modelling behaviour” influence in the decision of workers as to whether or not to use HPDs.

Despite potential construct validity issues with the survey instrument researchers were curious as to why all but essentially one of Pender's (1996) nominated modifying factors (i.e. interpersonal factors) had reasonably weak predictive value whilst other researchers had managed to establish stronger, significant and more numerous HPM predictive factors.

It is noted that many of the previously research studies, such as Oisaeng et al (2011) and Lusk et al (1998), incorporated study cohorts such as firefighters and construction workers from multiple work locations. The mandated requirement to wear hearing protection is not explicitly referenced by these studies and it is possible that HPD use for many of these participants was based on an elective basis. If this was the case, then with reference to the HPM, the researchers suggest that the effect of modifying factors (e.g. perceived benefits, barriers, self-efficacy) is likely to be more pronounced.

With reference to the current study, the majority of sampled workers were at workplaces where a mandatory hearing protection policy was instituted. In the HPM this could be considered an "immediate demand" as an external rule has been placed on the individual – i.e. they must wear hearing protection. As previously mentioned, a very significant ( $p < 0.01$ ) predictive relationship was established for HPD use based on hearing protection policy (i.e. mandatory or not mandatory).

The researchers contend that it is highly likely in the absence of the previously referenced "immediate demand" of a mandatory hearing policy, HPD utilisation rates may drop significantly as workers elect to exercise their own decision making power and execute their own intended "plan of action" – i.e. not to utilise HPDs.

In summary, it is asserted that whilst a number of individual characteristics and behavioural and cognitive factors affect workers' likelihood of engaging in HPD use, this is mitigated by an external mandatory requirement to wear HPD (where instituted). The researchers assert this further underscores the responsibility of the employer at any given workplace to establish whether or not excessive exposures are likely through formal exposure assessment (i.e. occupational noise survey), and should exposure reduction be achieved by no other means than HPDs, that the use of those HPDs is formally mandated and supported by a well implemented HCP including selection and availability of appropriate HPDs, and training, instruction and enforcement of HPD use.

## Limitations & Conclusion

### General Study Limitations

A likely sizeable degree of selection bias is suspected by the researchers. As previously mentioned, five of six participating workplaces were assessed not only for the purposes of research, but as part of a commercial consulting arrangement. In essence, these participating workplaces "self-selected" their participation as convenience sample groups. Also, on this basis these workplaces demonstrated a degree of hazard/risk awareness at the workplace by actually seeking out and engaging a consultant to conduct a noise assessment and evaluate/recommend controls to ensure their legislative compliance. These workplaces were also larger workplaces employing more than 50 employees. The exception to the aforementioned considerations was workplace six, which was a smaller workshop (<15 employees), that the researchers actively sought out for study participation.

The researchers believe that workplace size may be a significant predictor of both overall control implementation, and also HPD utilisation rates. Given the likely large number of small engineering enterprises across Australia employing less than 50 workers, the current study would probably under-represent these workers in the cohort overall, and potentially positively bias HPD utilisation rates.

Future and better resourced research should perhaps seek to incorporate a greater proportion of smaller workplaces to better reflect workplace size distribution for the study cohort.

### Exposure Characterisation Limitations

Personal dosimetry was conducted for only one shift period at each participating workplace (except for 1 workplace). Hence, there is no basis for comparison to determine whether exposures fall within historical mean exposure ranges for the workplace. Instead exposures can only be considered representative of the actual conditions and work activities conducted on the monitoring day.

The researchers did anticipate a high degree of noise exposure variability for workers due to the nature of the noise environments in engineering workplaces which are not typically subject to steady state noise sources from fixed plant. Rather engineering workshops are typically characterised by intermittent high intensity noise from portable plant, where the overall reported daily exposure to noise may vary markedly dependent on the duration and repetition of plant use.

### HPD Use Determination Limitations

A degree of self-reporting bias is assumed, in particular with regards to HPD questionnaire items relating to HPD use behaviours. Despite the questionnaire being confidential, the researchers believe that many workers may still be likely to report positive/compliant HPD use behaviours – especially for sites where a mandatory HPD use policy is enforced. The desire to “say the right thing” may outweigh the compulsion to report negative/non-compliant behaviour. The researchers had no means to individually verify the accuracy of worker’s responses through direct and continuous observation of HPD use in most cases due to simultaneous dosimeter deployment across workshops and project sites.

With greater time allowance and resources, the researchers could have spent more time refining the HPD questionnaire. As previously indicated, a standard and previously validated questionnaire based on Pender’s (2006) HPM model was not available. Some questionnaire items statements such as “I like wearing hearing protection” (for the perceived benefits of HPD use factor) did not align well to other questionnaire item statements for the factor, when subjected to Confirmatory Factor Analysis (CFA).

The limited number of sample cases (n=55) and limited number of questionnaire items detailed for each factor also had implications for HPM factor validation in the questionnaire. Indeed, initial exploratory factor analysis of independent question variables was only able to yield 2 factors in total before maximum iterations for the factor analysis function was exceeded, an implicit indication of the requirement for a larger study sample group.

### Conclusion

Research findings confirm the likelihood of excessive exposure, above the  $L_{Aeq8hr}$  regulatory criterion limit of 85dB(A), for the sample group, but in the form of two distinct SEGs aligning to boilermaker and fitter trade disciplines. Fitters exposed to  $L_{Aeq8hr}$  exposures in an 85-88dB(A) range were shown to be particularly poor predictors of their overexposure.

Engagement in positive HPD use behaviours was significantly aligned to the presence or otherwise of a mandatory hearing protection policy. Of Pender’s (2006) suggested Health Promotion Model (HPM) factors, interpersonal influences (i.e the modelling and perceived use of HPD by other workers, supervisors, and management) at the workplace proved the strongest, yet not significant HPD use predictive factor.

Future research could improve on the deficits in research design encountered during the current study, such as improvement of the construct validity of the HPD utilisation questionnaire and increasing the total sample size and number of participating workplaces to account for the greater exposure variations and levels of HCP implementation anticipated across wider industry.

The researchers wishes to acknowledge and thank the workers and workplaces that have participated in the current study, and their demonstrated commitment to understand and protect workers from harmful exposures to noise at work.

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## AUSTRALIAN BAT LYSSAVIRUS

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### Introduction

This paper discusses an audit program conducted by Workplace Health and Safety Queensland into risk management practices at workplaces where people have contact with bats and are exposed to the risk of Australian bat lyssavirus.

### Australian bat lyssavirus

Australian bat lyssavirus (ABLV) is an emerging zoonotic disease that was first identified in 1996. It belongs to the family *Rhabdoviridae*, genus *Lyssavirus*. It is closely related to the rabies virus and causes a neurological illness that is indistinguishable from classical rabies. ABLV poses health and safety risks for people who have contact with bats at workplaces.

ABLV has been found in all species of flying foxes (also known as fruit bats) in mainland Australia: the grey-headed flying fox (*Pteropus poliocephalus*), the little red flying fox (*Pteropus scapulatus*), the spectacled flying fox (*Pteropus conspicillatus*) and the black flying fox (*Pteropus alecto*). It has also been found in the yellow-bellied sheath-tail bat (*Saccolaimus flaviventris*), a species of insectivorous microbat (McCull et al. 2002). Both adult and juvenile bats are susceptible to infection (Field, McCall & Barrett 1999; NSW Government 2016).

ABLV causes neurological illness in bats, however clinical status alone is not a reliable predictor of infection. Clinical signs include weakness, paralysis, seizures, aggression, depression, being unable to fly and being in unusual locations (e.g. on the ground or low in the branches of a tree). ABLV is present in the saliva and neural tissues (brain and spinal cord) of infected bats, and excretion in saliva may precede the onset of illness (McCull et al. 2002). ABLV survives on the external surface of an infected bat's carcass for a few hours only (Queensland Government 2015), but persists in neural tissues.

The prevalence of ABLV in healthy wild or captive bats is very low (<1%), however the prevalence is higher in sick, injured and orphaned bats (5-10%), in sick bats showing neurological illness (up to 30%) and in the yellow-bellied sheath-tail bat (up to 62.5%) (Australian Government 2007; McCall et al. 2000). All bats should be considered potentially infectious, regardless of species, age or health status.

Human exposure to ABLV occurs when a non-immune person is bitten or scratched by an infected bat. Exposure may also occur if saliva or neural tissue from an infected bat comes into contact with a person's non-intact skin (e.g. cuts and abrasions) or mucous membranes (e.g. the eyes, nose and mouth). There is no evidence that transmission occurs through contact with bat urine, faeces or blood. Following exposure, the virus migrates to the central nervous system where it causes encephalitis with an invariably fatal outcome. The incubation period is usually 3-8 weeks but very rarely is as short as a few days or as long as several years (Hanna et al. 2000).

ABLV has the potential to infect other animal species. Two horses at a property in south-east Queensland developed fatal ABLV infection in 2013, presumably following contact with a microbat (Annand & Reid 2014). This was the first confirmed case of ABLV in animals other than bats and humans.

### ABLV risk management

ABLV is a low frequency, high consequence hazard. Although the likelihood of human infection is low because of the low prevalence of ABLV in bat populations, the consequences of infection are catastrophic because clinical disease is invariably fatal. To date three known cases of ABLV infection have occurred, all with fatal outcomes. These have included a bat handler who was scratched and possibly bitten by a microbat, a member of the public who was bitten by a flying fox and a child who had a presumed scratch from a flying fox (Moore et al. 2010, Hanna et al. 2000, Francis et al. 2014).



Occupational groups at-risk of exposure to ABLV from contact with bats include wildlife conservation, rescue, rehabilitation and care workers, wildlife veterinarians and veterinary nurses, wildlife demonstrators, zoological gardens and wildlife sanctuary workers, bat scientists and fauna spotter-catchers. Other occupational groups may be at risk from indirect or incidental contact with bats such as local government workers, waste industry workers and electrical workers who collect and dispose of bat carcasses.

ABLV risks at workplaces can be managed by implementing a suite of control measures to eliminate or minimise the risk. These include ensuring that bats are handled only by persons who have current rabies vaccination, are trained in the safe handling of bats and are wearing suitable personal protective equipment (PPE), as well as ensuring that bat bites, scratches and other potential exposures are properly managed.

Workers who handle bats should complete a course of three doses of the rabies vaccine (known as pre-exposure prophylaxis or PrEP). They should not handle bats until two weeks after the third dose of rabies vaccine is administered (Queensland Health 2015). Although data on the effectiveness of the rabies vaccine as prophylaxis against other lyssaviruses are limited, the available animal data and clinical experience supports its use (Australian Government 2013).

Vaccinated workers who have ongoing contact with bats should maintain their rabies immunity by undergoing a second yearly blood test to measure their rabies antibody titre level (a measurement of rabies immunity) and having a booster dose of rabies vaccine if titre is reported as inadequate (<0.5 IU/mL). Alternatively, they may have a booster dose of rabies vaccine every two years without determining the antibody titre. Persons who work with live lyssaviruses in research laboratories should undergo six monthly rabies antibody titre measurements and have a booster dose if the titre is reported as inadequate (Australian Government 2013).

Procedures should be developed for the safe handling of bats, and workers should be instructed and supervised in safe work methods to minimise the risk of bat bites, scratches and other potential exposures.

Workers should wear PPE when handling bats. This should include a long sleeved shirt and long pants, puncture resistant gloves and gauntlets and enclosed footwear. In addition, safety eyewear or a face shield should be worn where there is a risk of exposure to the face and mucous membranes via bat bites, scratches, bat saliva or neural tissues, for example when working with bats at eye level. Gloves should be carefully selected to ensure that they are compatible with the species and age of the bat (e.g. microbat, juvenile bat), its demeanour (e.g. aggressive or defensive behaviour) and the performance requirements of the task (e.g. dexterity and puncture resistance), as inappropriate selection of gloves may fail to adequately protect the worker or may harm the bat. The puncture resistance rating of gloves ranges from one to four (Standards Australia 2005), however the level of dexterity generally decreases as the puncture resistance rating increases. Some brands of disposable gloves (e.g. some nitrile gloves) have a puncture resistance rating, although this is usually of a lower order. Such gloves may be suitable for tasks requiring a high level of dexterity (e.g. veterinary procedures) and may be worn double-gloved. They may also be worn under non-disposable puncture resistant gloves to provide an additional level of protection. Puncture resistant gauntlets protect the forearm and partially protect the hands from bites and scratches. They provide a safe surface for captive bats to hang from during handling, especially where puncture resistant gloves do not provide protection over the entire glove surface.

A protocol should be developed for managing bat bites, scratches and other potential exposures. This includes washing the wound thoroughly with soap and water for at least five minutes and then applying an iodine or alcohol containing antiseptic (e.g. povidone iodine). If the exposure involves the eyes, nose or mouth, the area should be flushed thoroughly with water for several minutes. Following any exposure, the person should be referred for immediate medical attention to assess their post-exposure prophylaxis (PEP) requirements. PEP for a person who has previously completed a course of rabies vaccination consists of a further two doses of rabies vaccine (day 0 and 3). If the person has not previously been vaccinated, the person requires rabies immunoglobulin injected into the wound; this product is made from blood donated by people who have been vaccinated against rabies. The person also requires four doses of rabies vaccine (day 0, 3, 7, 14). An additional fifth dose and follow-up blood test is required if the person is immunocompromised (Commonwealth of Australia 2013). Tetanus vaccination may also be required.

If the bat is available it can be euthanased and tested for ABLV infection. People who have regular contact with bats should not forego pre-exposure prophylaxis on the basis that post-exposure prophylaxis is available. This is because undetected exposures may occur during day-to-day contact with bats, for example from superficial scratches.

Additional industry specific control measures may further reduce ABLV risks, for example by installing standoff barriers and warning signage at wildlife exhibits to protect members of the public, installing wildlife friendly fencing and netting to prevent wildlife entanglements at properties, and using implements such as tongs and spades to handle bat carcasses.

### **ABLV audit program**

During 2013-2014, Workplace Health and Safety Queensland conducted a small, statewide audit program of workplaces where persons conducting a business or undertaking (PCBU), workers and other persons were exposed to ABLV risks from contact with bats. The program included consultation with key stakeholders, development and dissemination of industry resources to support compliance, development of audit tools and inspector training and workplace visits. An audit report was developed on completion of the program and feedback was provided to stakeholders.

Nineteen workplaces were chosen from a cross section of at-risk industries. Workplaces were identified using web-based industry information sources and regional inspectorate knowledge of local businesses. These included nine businesses that provided wildlife conservation, rescue, care, rehabilitation and/or veterinary services, three businesses that exhibited wildlife or provided wildlife demonstrations, five businesses that provided animal carcass disposal services and two businesses that provided other bat related tourism activities.

Inspectors visited the nominated workplaces between November 2013 and June 2014. At each workplace inspectors conducted a desktop audit of ABLV risk management systems and a walk through inspection. Following each inspection, the PCBU was provided with information and resources to further improve ABLV risk management practices. Non-compliance issues were rectified promptly and cooperatively and no notices were required to be issued.

### **Findings**

Workers were reported to have direct contact with bats at 15 of the audited workplaces and to have indirect or incidental contact with bats at the remaining 4 workplaces.

Of the 15 workplaces where workers had direct contact with bats, all workers were required to complete a course of rabies vaccination. Documented staff immunisation records were available at 11 of these workplaces. The due date for blood tests to measure rabies antibody titre levels and/or for booster doses of rabies vaccine was documented at 7 of these workplaces.

Information, training and instruction on ABLV and safe bat handling was provided at all of the workplaces, with the exception of one workplace where workers had received training outside of work in their capacity as volunteer wildlife carers. Documented training records were available at 11 of the workplaces.

Some level of PPE for handling bats were provided at all of the workplaces, however the following PPE issues were common to many of the workplaces:

- a limited range of gloves, for example the provision of suitable gloves for handling adult flying foxes but not for handling juvenile flying foxes or microbats
- a limited range of PPE other than gloves, for example not providing gauntlets to protect the forearms
- inconsistent use of PPE, for example using PPE for rescuing bats but not for the ongoing care and rehabilitation of bats or for handling juvenile flying foxes and microbats.

Non-immune workers and others (e.g. members of the public) were restricted from contact with bats at all of the workplaces. This was achieved by using a range of control measures including the provision of suitable enclosures for exhibiting, housing and transporting bats, installing stand-off barriers to restrict public access to bat enclosures, installing warning signage, and allocating non-immune workers to non-contact tasks such as preparing food for the bats. At two workplaces where bats were exhibited

there was the potential for members of the public to gain access to the outside of the bat enclosure because of inherent design features of the stand-off barrier. This was promptly rectified when brought to the attention of the PCBU.

A protocol for managing bat bites, scratches and other potential exposures was implemented at all of the workplaces and was documented at 10 of the workplaces. First aid facilities for managing bat bites, scratches and other potential exposures were provided at all of the workplaces. At 14 of the workplaces the first aid kit contained an iodine or alcohol containing antiseptic. At 17 of the workplaces there was a system to record incidents of bat bites, scratches and other potential exposures.

### **Challenges to ABLV risk management**

A number of challenges to effective ABLV risk management were identified through industry consultation and discussions at the audited workplaces. These included the following issues:

- the time required to implement and document policies and procedures, training records and immunisation records. This was particularly challenging for wildlife organisations during times of intense activity when large numbers of bats come into care, such as during extreme weather events and the tick paralysis season
- costs, particularly for not-for-profit and/or volunteer organisations
- PPE design features, in particular the need for gloves that provide suitable levels of both puncture resistance and dexterity
- discomfort associated with wearing PPE, particularly when working in hot and humid conditions
- a high turnover of workers, particularly among volunteers
- industry culture.

Cultural barriers to effective ABLV risk management included the following issues:

- risk assessments being made based on the likelihood of infection but without also considering the consequences of infection
- self-protection being accorded a lower priority when faced with the immediate welfare needs of an injured, sick or orphaned bat
- bat bites and scratches being considered as 'part of the job'
- bat scratches, minor nips and exposures involving juvenile bats and captive bats being considered very low risk
- vaccination being considered as negating the need for other control measures such as PPE
- bat handling practices of the past which have often not incorporated PPE.

Despite the challenges, some positive changes were observed at some workplaces such as the recent introduction of enhanced PPE and trials of different types of PPE to better inform selection. Industry consultation also provided evidence of industry leadership and commitment for safer bat handling practices.

### **Discussion and recommendations**

The audit program provided evidence of knowledge and implementation of ABLV risk management practices at the audited workplaces. Importantly, all persons who had direct contact with bats were reported as having completed a course of rabies vaccination. Almost all of the workplaces reported providing training to their workers on ABLV and safe bat handling and all of the workplaces reported having a protocol for managing bat bites, scratches and other potential exposures.

The audit program identified issues with the provision and use of PPE. Although rabies vaccination provides a high level of protection against ABLV, no vaccine is considered to be 100% effective and vaccine-induced immunity can wane over time. Moreover, vaccination only provides protection following exposure to ABLV. The routine use of PPE when handling bats can

prevent a person from being exposed to ABLV in the first instance, with vaccination providing a critical safety net in the event of accidental exposures such as may occur as a result of PPE failure.

The audit program identified that documentation was a challenge, including the documentation of safe systems of work for handling bats, staff vaccination records, staff training records and protocols for managing bat bites, scratches and other potential exposures. Documentation of health and safety activities is important as a means to provide information to workers, to monitor and review health and safety performance and to meet health and safety duties.

The audit program also identified that industry culture has the potential to contribute to unsafe bat handling practices. This is consistent with other studies that have found that wildlife carers do not perceive bat viruses as a potential risk to their health (Sánchez & Baker 2016). This is despite wildlife carers handling sick, injured and orphaned bats that are known to have a higher prevalence of lyssavirus infection. Given the seriousness of ABLV and the potential for undetected exposure, it is important that safe bat handling practices are always adopted regardless of the species, age or health status of the bat.

A number of opportunities for enhanced risk management were identified from the audit program. These include the following:

- ensuring that gloves with varying levels of puncture resistance and dexterity are made available at workplaces so that workers can be properly protected when handling different species and ages of bats and when performing bat handling tasks that involve varying levels of dexterity and puncture resistance
- where disposable gloves are required to be worn, providing disposable gloves that have a puncture resistance rating
- providing training to workers on how to select suitable PPE to achieve the best fit between the safety and welfare needs of the bat and the puncture resistance and dexterity needs of the task
- routinely wearing PPE for all bat handling activities. This should include puncture resistant gloves, gauntlets to protect the forearms, long sleeved shirts and long pants to protect exposed skin on the arms and legs, enclosed footwear to protect the feet, and risk-based safety eyewear or face shield where there is a risk of exposure involving the face, eyes, nose and mouth
- ensuring that policies, procedures and protocols for ABLV risk management are properly documented and readily available
- ensuring that staff training records are kept and maintained
- ensuring that staff immunisation records are kept and maintained. These should clearly identify the due date for ongoing blood tests to measure rabies immunity and/or booster doses of rabies vaccine
- ensuring that first aid kits contain an iodine or alcohol containing antiseptic for managing potential ABLV exposures
- ensuring that the design of bat enclosures and stand-off barriers at workplaces where wildlife are exhibited are effective in restricting public access.

### Limitations

The limitations of these findings include the small sample size and the potential for bias created by self-reported health and safety practices especially in the absence of supporting documentation.

## Conclusion

The proper management of ABLV risks at workplaces is important to protect against potential exposure to ABLV and to meet health and safety duties. It is also important to ensure the safety and welfare of bats so that avoidable euthanasia of bats following potential ABLV exposures is prevented.

This study found evidence of ABLV risk management at all of the audited workplaces, especially for rabies vaccination. However it identified areas for improvement, particularly in relation to the use of PPE, wound management and record keeping. It also identified barriers to effective risk management including industry culture and perceptions of risk.

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## WHOLE ROOM DISINFECTION" TEST TUBE VS. REAL WORLD: A CASE STUDY ON ADVANCED DISINFECTION ATOMIZATION TECHNOLOGY

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### Abstract

New innovative approaches to the remediation of contaminated atmospheres, surfaces and solutions by pathogenic materials are important for protection of human health and the environment. For example the safe containment of outbreaks of *C. difficile*, *L. monocytogenes* or *B. cereus* in the environment is an extremely challenging undertaking. Outlining individual case studies in the whole room disinfection arena we report on a combined approach for delivering environmentally friendly biocides, with state of the art atomization technology, to remediate infrastructure contaminated with biological agents. Dual fluid atomization technology generates supersonic gas flow into which disinfection media can be delivered producing extremely small droplets. Rapidly projecting these droplets in the form of a dense and turbulent mist the reported technology is capable of delivering solid, liquid and polymeric based decontaminants to all non-line of sight surfaces. Typically we can disinfect an average size room of 40-60m<sup>3</sup> with a visually dense mist in less than half an hour, using little more than one litre of decontaminant. Not only that, but compared to the more traditional systems available, the reported atomisation Technology will mean that, on a typical undertaking, only 5-10% of a disinfection/decontamination agent will be required. The atomisation technology is chemically agnostic and compatible with a wide range of off-the-shelf chemistries, allowing true multi-decontaminant capability to be realised. Drastically reducing both the chemical footprint and time required for effective disinfection. This combination affords minimization of decontaminant mass per unit of application whilst maintaining an efficient surface and airborne decontamination capability.

### 1. Introduction

New innovative approaches to the remediation of contaminated atmospheres, surfaces and solutions by pathogenic materials are important for protection of human health and the environment. For instance Health Care-Associated Infections (HCAIs) are illnesses that patients acquire while receiving treatment for medical or surgical conditions and are the most frequent adverse event during care delivery.<sup>2</sup> HCAI is a major problem for patient safety and its impact can result in prolonged hospital stay, long-term disability, increased resistance of microorganisms to antimicrobial agents, a massive additional financial burden for the health system, high costs for patients and their families, and even excess deaths.<sup>3,4</sup> The risk to acquire HCAI is universal and pervades every health-care facility and system worldwide, but the true burden remains unknown in many nations, particularly in developing countries. In Europe, HCAIs cause 16 million extra-days of hospital stay, 37 000 attributable deaths, and contribute to an additional 110 000 every year.<sup>5</sup> Annual financial losses are estimated at approximately € 7 billion, including direct costs only<sup>6</sup>. In the USA, approximately 99 000 deaths were attributed to HCAI in 2002 and the annual economic impact was estimated at

<sup>2</sup> Bates DW et al. Global priorities for patient safety research. *British Medical Journal*, 2009, 338:b1775.

<sup>3</sup> Burke JP. Infection control - a problem for patient safety. *New England Journal of Medicine*, 2003, 348:651-656.

<sup>4</sup> Allegranzi B et al. Burden of endemic health care-associated infection in developing countries: systematic review and meta-analysis. *Lancet*, 2011, 377:228-241.

<sup>5</sup> World Health Organization, *Report on the burden of endemic health care-associated infection worldwide 2011*.

approximately US\$ 6.5 billion in 2004.<sup>4</sup> Infection control in the industrial sector shows similar traits in rising demand from the food and beverage industry, driven by stringent regulations guiding food safety, and increased adoption in water disinfection and aquaculture applications. According to a new report from Global Industry Analysts, Inc. (GIA), the global market for disinfectants is projected to reach \$2.9 billion by 2017, primarily driven by increased focus on hygiene and growing concerns over spread of infectious diseases in both residential and commercial/industrial “Whole room disinfection” spaces.<sup>7</sup>

“Whole room disinfection” is a means of controlling persistent micro-organisms in critical working areas and to that end a plethora of commercial biocides are now available with which to treat and disinfect surfaces from infectious materials. Commercial biocides of this nature have to be registered under the relevant national guidelines such as Australian Register of Therapeutic Goods (ARTG), OSHA in the United States or under the Biocidal Product Regulations (BPR)<sup>8</sup> in Europe.

Traditionally such certifications rely heavily upon testing regimes that utilize suspension tests (e.g. EN13704, 1275/1276 etc.) as their main procedure for ascertaining the biocidal efficacy of the chemical being evaluated. When addressing the concept of “*whole room disinfection*” we must therefore ask how representative is this suspension test methodology when considering the actual disinfection requirements in the working environment. As the activity of biocides against microorganisms depends on a number of factors, some of which are intrinsic qualities of the organism, others of which are the disinfectant, the delivery mechanism and/or the external physical environment? For example, despite still being the biocide of choice for “*High Level*” disinfection, Formaldehyde has an optimal performance at temperatures above 10°C and relative humidity’s within 65-85%. At temperatures and relative humidity outside of this operating range the effectiveness of formaldehyde tends to zero.<sup>9</sup> Therefore the efficacy observed within a controlled laboratory suspension test may not always represent how the disinfectant will behave in the real environment it is required to operate in.

Furthermore comparison of the efficacy of disinfectants on challenge samples placed at differing heights and orientations within a “*whole room*” scenario can also be used to demonstrate if the disinfectants are being delivered to all surfaces or not. Experiments of this nature can be used to confirm how important the biocide delivery mechanism is to the overall disinfection process. For example figure 1 demonstrates the differences in non-line of sight efficacy for an equivalent volume of 0.5% Peracetic Acid (PAA) delivered from a single smooth bore cavity nozzle and dual fluid atomization nozzle respectively against a *Bacillus cereus* challenge.

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<sup>7</sup> See <http://www.infectioncontroltoday.com/news/2011/11/global-disinfectants-market-to-reach-29-billion-by-2017.aspx>

<sup>8</sup> See <http://www.hse.gov.uk/biocides/index.htm>

<sup>9</sup> U. Theilen, F.J. Wilsberg, R. Böhm and D. Strauch, Zentralsbl. Bakteriologie Mikrobiologie Hygiene 1987 Jun 184(3-4) p229-252.



Log Reduction

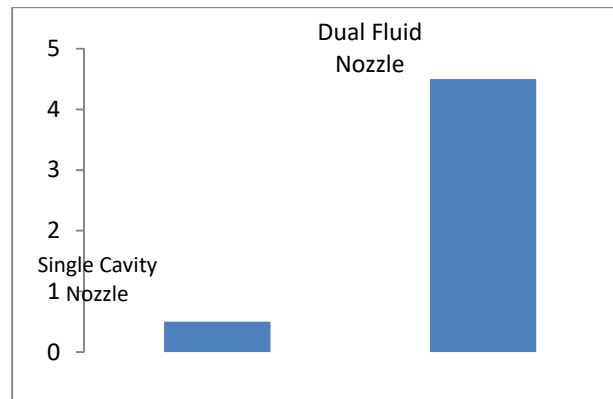


Figure 1: Non Line of Sight Efficacy of 0.5% PAA against *Bacillus cereus* (NCTC11145) using two different types of disinfection system.<sup>10</sup>

As Figure 1 clearly demonstrates, the biocidal delivery mechanism can have a dramatic effect on the overall disinfection process of hard to reach/ dead space areas, if the chemistry is not delivered correctly. Previous work in the hygiene management field supports the above conjecture in highlighting that inadequate application devices, which supply insufficient chemical biocide and possibly non-uniformly, result in deposition of the biocide that is mainly due to sedimentation which means that vertical surfaces and, in particular, upward-facing surfaces do not receive as much deposit as downward facing surfaces.<sup>11</sup>

Indeed these and several other physical and chemical factors also influence disinfectant procedures: namely temperature, pH, relative humidity, and water hardness. For example, the activity of most disinfectants increases as the temperature increases, but some exceptions exist (e.g. hypochlorites)<sup>12</sup>. Furthermore, too great an increase in temperature can cause the disinfectant to degrade and weakens its biocidal activity and thus might produce a potential health hazard. An increase in pH improves the antimicrobial activity of some disinfectants (e.g., glutaraldehyde, quaternary ammonium compounds) but decreases the antimicrobial activity of others (e.g., phenols, hypochlorites, and iodine). The pH influences the antimicrobial activity by altering the disinfectant molecule or the cell surface. Relative humidity is the single most important factor influencing the activity of gaseous disinfectants/sterilants, such as EtO, chlorine dioxide, and formaldehyde. Water hardness (i.e., high concentration of divalent cations) reduces the rate of kill of certain disinfectants because divalent cations (e.g., magnesium, calcium) in the hard water interact with the disinfectant to form insoluble precipitates.

Therefore having the ability to deliver a range of disinfectants from a single system is pivotal if the above effects are to be minimized in the working environment and timely disinfection is to be achieved. As the validation process<sup>13</sup> in any disinfection regime should always consider the following

- Disinfectant choice
- Challenge Organism
- Delivery mechanism

<sup>10</sup> Campden BRI Test Report (MB/REP/125271/1) Replicate experiments were conducted in an aerobiology laboratory (350cm wide x 404cm long x 300cm high: Volume 43m<sup>3</sup>). Inoculated stainless steel discs (10<sup>6</sup> cfu/ml) were positioned in line of sight and non-line of sight orientations e.g. horizontally, vertically and on the underside of a shelf. 3 discs per challenge organism were left untreated as controls and processed at the same time as the test samples.

<sup>11</sup> D.Burfoot, K. Hall, K. Brown and Y. Xu, *Trends in Food Science & Technology* 10 (1999) 205±210

<sup>12</sup> White's Handbook of Chlorination and Alternative Disinfectants: 5<sup>th</sup> Edition, Black & Veatch Corporation, Wiley 2010.

<sup>13</sup> Disinfection and Decontamination: Principles, Applications and Related Issues; Edited by G Manivannan, CRC Press 2008.

We will now consider each of the above elements in more detail.

The choice of disinfectant and challenge organism are generally interlinked as the choice of disinfectant will generally depend upon the Virus, Yeast / Mold, Bacteria, or Spore etc encountered. Each organism represented above is generally more difficult to disinfect than the last and therefore requiring a more potent biocide to treat. Common examples are gaseous or vapour phase disinfectants and reactive liquids or foam treatments.

Gaseous or vapour phase disinfectants such as, Chlorine dioxide, Methyl Bromide, Ethylene Oxide, or Vapour Phase Hydrogen Peroxide (VHP) are ideally suited to accessing cracks, fissures and other non-line of sight structures. Yet despite these these chemicals are generally toxic in nature and can only be used in enclosed spaces, with correspondingly slow diffusion rates and requiring high humidity to afford optimal activity e.g. formaldehyde.

Reactive liquid/ foam treatments, such as Liquid Hydrogen peroxide, Hypochlorous acid / hypochlorite solutions or Glutaraldehyde, Guandines etc, on the other hand can be applied locally enabling personnel to undertake targeted disinfection of hot spots at concentrations higher than those that can be safely achieved by a vapour. Although in general such treatments are not well suited for horizontal surfaces and provide an increased logistical load to the user in requiring larger quantities of chemistry and increased occupational exposures. This latter observation is of key importance in the workplace as we should always consider the health risk of a chemical exposure including the duration, intensity (i.e., how much chemical is involved), and route (e.g., skin, mucous membranes, and inhalation) of exposure during any disinfection process.

With such a wider range of disinfectants now available we are better placed to meet the evolving nature of biological pathogens in the workplace, however any successful disinfection regime is still dependent upon the aforementioned disinfectant being delivered to the right place at the right time. This as we have seen is still challenging for hard to reach/ dead space areas. The choice of delivery system largely depends upon the biocide of choice unless you have a system that is capable of delivering a range of chemistries. Selection should take into consideration the size of infected area? Type of microorganism encountered? and the unit availability (e.g. individual cost, and number required)? The range of delivery techniques designed for whole room disinfection is increasing, but those that are commercially available include: - chemical fogging - hydrogen peroxide vapour - ozone - chlorine dioxide - ultraviolet light - titanium dioxide coating and ultraviolet light – ionisation. The latter systems are generally larger more expensive fixed type installations and therefore not amenable to mobile disinfection applications. By comparison most fogging technology currently available utilizes vaporization as a means of mist generation rather than atomization. Both thermal and electrostatic vaporization are slower and less efficient processes in terms of chemical degradation and time than other techniques such dual fluid atomization. The former techniques also offer a more limited chemical capability in that they can only really effectively deliver chemicals of a volatile nature such as hydrogen peroxide etc.

One alternative technology that can provide true multi-chemical delivery is that of “*dual fluid*” atomization. Dual fluid atomization systems, which use a propellant gas such as nitrogen or compressed air to atomize a liquid, powder or viscous material, are the only successful systems for producing large dense cloud of very small droplets. Capable of disinfecting large volumes up to 2000m<sup>3</sup> in a single application, the technology rapidly fills a problem space, and the turbulence of this gas-like vapour keeps the droplets suspended in the air longer and ensures a consistent and even coverage. Capable of reaching all complex non-line-of-sight surfaces, and with no-moving parts, dual fluid systems can deliver a diverse range of biocides making them suitable for treating the entire biological spectrum from molds & fungi to endospores and viruses. The single system, with its improved deposition rates further reduces the effluent footprint by providing efficient neutralization of any pathogenic materials. Table 1 compares and contrasts the advantages and disadvantages of dual fluid systems over more traditional systems




Disinfection Delivery Technologies	Competitive Advantages: For Dual Fluid Atomizers	Competitive Disadvantage For Dual Fluid Atomizers
Thermal Foggers 	<ul style="list-style-type: none"> <li>• Higher delivery output</li> <li>• Simple mixing of air and liquids (no heating, no damage)</li> <li>• Very fine mist (reaches non-line of sight surfaces)</li> <li>• High efficacy (15 minutes)</li> <li>• Less liquid consumption and also less wetting</li> </ul>	<ul style="list-style-type: none"> <li>• Energy consumption through air stream (air cylinder for portable systems)</li> <li>• Overpressuring of smaller contained environments (Clean-rooms)</li> </ul>
Ultrasonic Foggers 		
Spraying devices 		

Table 1: Competitive Advantages and Disadvantages for Dual Fluid Atomization Systems

Effective against both airborne and surface threats (figure 2), “dual fluid” systems such as the Light Decontamination System (LDS) (Figure 3) typically use 5-10% of the decontaminant required by existing systems to afford effective disinfection. Capable of knocking down particulate hazards such as biological spores and the isolation and destruction of highly virulent species such as virus’, through the delivery of the appropriate biocide or antimicrobial coatings, this robust system can easily be reconfigured for other disinfection applications with minimal effort via a simple change in disinfectant.

For example the LDS is capable of delivering traditional biocidal liquids such as hydrogen peroxide, peracetic acid, formaldehyde, hypochlorous acid, potassium peroxydisulfate “Ozone” and quaternary ammonium compounds, as well as more exotic species such as enzymes and polymeric supported materials e.g. stimuli responsive hydrogels (e.g. NIPAM). This multi payload feature further reduces logistical burden and offers a truly comprehensive capability in a single system. Such system integration, combining the advantages of tailor made and versatile disinfectants, with the versatility of “dual fluid” nozzle based systems will allow the occupational hygienists of the future to affect timely disinfection in any global theatre against most pathogens encountered.



Figure 2: Dual Fluid Atomization System



Figure 3 Light Decontamination System (LDS)

The true versatility of “dual fluid” atomization systems such as the LDS can be illustrated through “whole room” disinfection testing, where the technology has shown exceptional efficiency against virus, vegetative bacteria and endospores alike. We will now illustrate three individual case studies in the *Health Care-Associated Infections (HCAIs)*, *Food & Beverage spoilage* and *Public Safety & Resilience* arenas to demonstrate the validity of using dual fluid technology in disinfection regimes.

#### **Health Care-Associated Infections (HCAIs)**

Hygiene management in health-care settings is of paramount importance if cross-infection is to be prevented amongst staff and patients. However, typical architectures encountered in hospital settings such as enclosed spaces, equipped with sensitive apparatus is not conducive to effective disinfection using current methodology and therefore represents an arduous challenge.

In this case study the product testing considered two biocidal chemicals, namely peracetic acid - PAA (0.5%) and hypochlorous acid – HOCl (0.5%), and a range of healthcare related microbiological challenges, as well as various contact times across which product efficacy was assessed. The emphasis of the testing was not only on the efficacy of the two chosen disinfectants, but also on the performance of the delivery system itself. “Whole-room” disinfection experiments were therefore conducted under adapted CEN13697 conditions with challenge samples placed in 8 positions and 3 orientations in each experiment (total 64 plates for each run). Replicating conditions typically found in a hospital room, with mock furniture used to house challenge samples in various vertical and horizontal orientations, each experiment consisted of a rapid one litre delivery over 60 seconds, the biocide being delivered into a typical 40-50m<sup>3</sup> working area. In all experiments each challenge organism was treated with the two disinfectants over three replicate runs respectively, with samples removed at agreed time points such as 1,5,10,15,30 and 60 minutes. Typical challenge conditions for each experiment comprised of an approximate concentration on each plate: 10<sup>3</sup>-10<sup>8</sup> cfu/pfu /ml (LOD 10 cfu) depending upon organism used. Organisms were dried at room temperature in clean environment for about 3 hours prior to use.

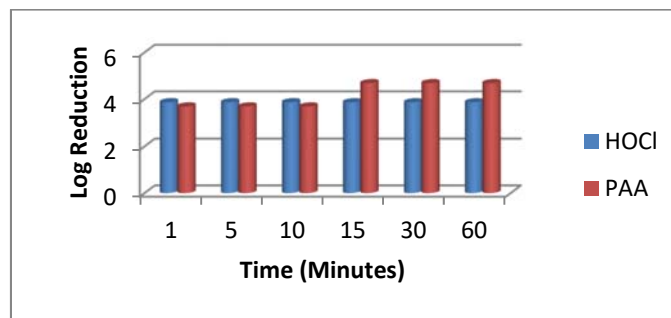


Figure 4: Average Microbial Reductions with time for *M. terrae* tested against biocides delivered via dual fluid atomizer.

Comparison of the efficacy of the disinfectants on samples placed at differing heights and orientations clearly demonstrate that disinfectant is being delivered to all samples, including those not within the line of sight of the system (Table 2). Furthermore the timed extraction samples confirm a rapid disinfection process with peak microbial reduction never taking longer than 15 minutes following delivery. Figure 4 illustrates a representative example in the averaged (e.g. incorporates line of sight and non-line of sight results) log reduction by sample extraction time, for each disinfectant against *M. Terrae*. Table 2 confirms this conjecture and highlights excellent average microbial reductions for a range of organisms when the biocide is delivered independently from a “dual fluid” system.

Challenge Organism	Biocide	Volume Delivered	Average Log <sub>kill</sub> (15Mins)*
<i>S. Aureus (MRSA)</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	5.97 (99.9999%)
<i>M. Terrae</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	4.68 (99.99%)
<i>Vaccinia Virus</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	2.98 (100%)
<i>MS2 Bacteriophage</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	5.98 (100%)
<i>C. Difficile.</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	5.80 (99.9999%)

Table 2: Average Microbial Reductions for a range of HCAI challenge organisms tested against biocides delivered via dual fluid atomizer.

The collective findings of this HCAI case study show that PAA or HOCl, when delivered via “dual fluid” is an inexpensive and highly effective biocidal chemical capable of killing a wide range of microbiological challenges, including spores.

## Food and Beverage Spoilage

Disinfection in the food and beverage industry is of paramount importance as not only can microbial spoilage affect the look and quality of a company' offerings, but it can also severely affect the commercial reputation of a manufacturer as well. For example costs for medical treatment & lost productivity due to food poisoning in the US is estimated at \$7-\$37 Billion (USD) per annum with ~76 Million (314 Million Population) Foodborne illnesses recorded in the US alone (US:CDC) in 2014. This latter figure included 325,000 Hospitalizations with 5000 deaths.<sup>14</sup>

As we have seen previously effective disinfection in such industrial settings is often difficult due to the complex nature of the equipment and machinery encountered in such environments e.g. pipework, vessels and other complex structures. As germs and bacteria in industrial food processing, beverage handling and food storage areas have a wealth of cracks, fissures and other non-line of sight structures with which to conceal themselves and grow in. Under conditions typically found in these environments "dual fluid" atomization systems are found to excel in delivering effective disinfection against a range of spoilage organisms. Table 3 highlights typical average microbial reductions for a range of organisms when tested against two biocides delivered independently from a "dual fluid" system. These "Whole-room" experiments were again conducted under adapted CEN13697 conditions with challenge samples placed in 8 positions and 3 orientations in each experiment (total 64 plates for each run). Comprising of a rapid one litre application over 60 seconds, the biocide was delivered into a typical 40-50m<sup>3</sup> working area. Typical challenge conditions for each experiment comprised of an approximate concentration on each plate: 10<sup>6</sup>-10<sup>8</sup> cfu /ml (LOD 10 cfu) depending upon organism used. Organisms were dried at room temperature in clean environment for about 3 hours prior to use.

Challenge Organism	Biocide	Volume Delivered	Average Log <sub>kill</sub> (15Mins)*
<i>C. albicans</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	5.97 (99.9999%)
<i>L. brevis</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	5.00 (99.999%)
<i>L. acidophilus</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	5.90 (99.9999%)
<i>S. cerevisiae</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	4.3 (99.99%)
<i>B. subtilis</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	7.64 (99.99999%)
<i>E. Coli (Shiga)</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	6.75 (99.9999%)
<i>L. monocytogenes</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	7.02 (99.99999%)
<i>C. Difficile.</i>	0.5% PAA or HOCl	1000ml (40m <sup>3</sup> )	5.80 (99.9999%)

Table 3: Average Microbial Reductions for a range of challenge organisms tested against biocides delivered via dual fluid atomizer.

Although a 60 minute contact time was used in all experiments, as with the HAcI test case, timed experiments confirmed that peak microbial reduction was achieved in 15 minutes following delivery in all cases. As table 3 confirms the special combination of rapid intervention with effective biocidal delivery removes the need for complex and time consuming cleaning processes, e.g. scrubbing and sensitive drying.

<sup>14</sup> CDC Estimates of Foodborne Illness in the United States <http://www.cdc.gov/foodborneburden/index.html>

## Public Health & Resilience

Public Health and Biosecurity measures are practical steps designed to minimize the risk of introducing or spreading pests and diseases. The threat to our nations has never been greater. Increased global trade and the movement of goods between respective nations means an increased risk of spreading pests and diseases, which may travel hidden in plant products, packaging and shipping crates. As it is not always possible to see pests and diseases, as they can be transmitted accidentally by people moving between different regions, rapid disinfection and intervention is of paramount importance if we are to protect of populace.

Naturally occurring *Bacillus anthracis* e.g. *Anthrax* is endemic in several regions around the world with sporadic occurrence elsewhere, notably the developed world, tending tend to grab the headlines. People normally acquire the disease from infected animals or occupational exposure to contaminated animal products.<sup>15</sup> The outbreak in Northern Russia in August this year was attributed to climate change where unseasonably warm weather was purported to have thawed the ground, thereby releasing spores from infected reindeer carcasses shallow-buried in frozen ground decades ago. One person died while more than 40 were admitted to hospital. In 2007 and 2009 in the United Kingdom there were high profile fatal cases where infected drum hides led to pulmonary anthrax, while in 2009/10 there were 47 cases in Scotland with 14 deaths mainly attributed to sub-cutaneous self-administration of infected heroin. Biosecurity has often been associated with the prevention of zoonotic diseases, but increasingly it has become synonymous with response measures, containment and eradication. When looking to test the Light Decontamination System as a response mechanism, we decided on *Bacillus anthracis* as the most appropriate challenge, not just due to the longevity and robustness of its spores, but also its effects in the agricultural domain, transfer to humans and the security concerns associated with its deliberate release in aerosolised form.<sup>14</sup>

Over a six week period, a rigorous and wholly independent testing regime was established with the United Kingdom government's Health and Safety Laboratory at Buxton, Derbyshire. Tests confirmed the efficacy of the supersonic plume of turbulent and penetrative atomised decontaminant; specifically its ability to reach both line of sight and non-line of sight surfaces and to 'rapid-fill' an enclosed interior of approximately 50-110m<sup>3</sup> depending upon challenge organism.

Challenge Organism	Biocide	Average Time PMR	Volume Delivered	Average Log <sub>kill</sub> (15Mins)*
<i>B. thuringiensis</i> (HD-1 Cry-)	2.0% PAA	15 minutes	2000ml (55m <sup>3</sup> )	6.99 (99.99999%)
<i>B. cereus</i>	2.0% PAA	15 Minutes	2000ml (55m <sup>3</sup> )	8.01 (99.999999%)
<i>B. anthracis</i>	2% PAA	5 minutes	2000 (100m <sup>3</sup> )	8.18 (99.999999%)

Table 4: Average Microbial Reductions for a range of bio-security challenge organisms tested against biocides delivered via dual fluid atomizers

For each test, coupons were attached to a variety of complex surfaces at different angles and heights. Non line of sight coupons contaminated with challenge organisms were disinfected with simple Peracetic Acid (2%) and achieved extremely efficacious

<sup>15</sup> De Vos V, Turnbull PC. Anthrax. In: Coetzer JA, Thomson GR, Tustin RC, editors. Infectious diseases of livestock, with special reference to Southern Africa, 2nd ed. Vol. 3. Cape Town (South Africa): Oxford University Press Southern Africa; 2004. p. 1788–818.

results; that is, an typically 7-8 log reduction in 5-15 minutes (Table 4). *Bacillus* surrogates<sup>16</sup> (*B. cereus* and *B. thuringiensis*) were used for the tests conducted in the smaller aerobiological facility (55m<sup>3</sup>) and live agent testing was undertaken with *B. anthracis*, within the confines of HSL's CL3 laboratory (100m<sup>3</sup>), providing a comparison with the data obtained from these *Bacillus* surrogates (Table 4). The decontamination and indeed disinfection process has application right across government departments from Homeland Security, to Defence, Health, Agriculture and the Environment and across into the Industrial Sector.

## Conclusions

This paper has highlighted the current challenges faced by hygienists in developing effective disinfection protocols. In that traditionally disinfectant certifications rely heavily upon testing regimes that utilize suspension tests as their main procedure for ascertaining the biocidal efficacy. We have demonstrated that this methodology can be inaccurate as the activity of biocides against microorganisms depends on a number of other factors, some of which are intrinsic qualities of the organism, others of which are the disinfectant, the delivery mechanism and/or the external physical environment? One alternative delivery technology that can provide true multi-chemical delivery is that of "dual fluid" atomization. Dual fluid atomization systems, which use a propellant gas such as nitrogen or compressed air to atomize a liquid, powder or viscous material, are the only successful systems for producing large dense cloud of very small droplets. Capable of disinfecting large volumes up to 2000m<sup>3</sup>, the technology rapidly fills a problem space, and the turbulence of this gas-like vapour keeps the droplets suspended in the air longer and ensures a consistent and even coverage. Capable of reaching all complex non-line-of-sight surfaces, and with no-moving parts, dual fluid systems can deliver a diverse range of biocides making them suitable for treating the entire biological spectrum from molds & fungi to endospores and viruses. The single system, with its improved deposition rates further reduces the effluent footprint by providing efficient neutralization of any pathogenic materials. Experiments of this nature can be used to confirm how important the biocide delivery mechanism is to the overall disinfection process.

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<sup>16</sup> Bishop, AH and Robinson, CV. (2014), *Bacillus thuringiensis* HD-1 Cry: development of a safe, non-insecticidal simulant for *Bacillus anthracis*. *J Appl Microbiol*, **117**; 654-662. Also at; <http://onlinelibrary.wiley.com/doi/10.1111/jam.12560/abstract>.



## 1-BROMOPROPANE, AN ENVIRONMENTALLY FRIENDLY NEUROTOXIN

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### ABSTRACT

*The use of 1-Bromopropane (1-BP) has increased during the last 20 years as a safety solvent in cleaning, particularly in electrical component cleaning and in non-flammable applications. It has increasingly been established in the literature as a neurotoxin in situations of overexposure. The previous ACGIH TLV of 10 ppm has now been lowered to 0.1 ppm, based predominantly on its CNS effects. SafeWork Australia lists no exposure standard for 1-BP. In an underground mining incident in 2009, a significant quantity of 1-BP was applied as a cleaner to a hot gearbox cover in a restricted space resulting in suspected, acute exposure of at least one worker to 1-BP vapour resulting in long lasting, apparent debilitating neurological effects to his well-being. However, assessing the likely magnitude of any such exposure could not be replicated in-situ, and modelling proved unconvincing. A program to replicate the circumstances of this event using extensive engineering and hygiene monitoring services identified, in a series of tests with a solvent containing 1-BP, that the concentration of 1-BP at the operator's work position could rise to as high as 1200 ppm. This paper, which principally reports the procedures that were undertaken to estimate the extent of this exposure, adds evidence that single acute, very high exposures to 1-BP (at several thousand times the ACGIH's present TLV) may be responsible for significant neurological effects. Use of this product, particularly in confined spaces, should be strictly controlled. The project also demonstrates that difficulty, complexity and costs of hygiene investigations should not deter the pursuit of empirical data which is crucial to our understanding of actual exposures and their proper control.*

### Introduction

Over recent decades there has been a growing focus on the environmental impacts of industrial processes and the pursuit for alternatives to "environmentally unfriendly" products which has resulted in the introduction of a range of new chemicals into the industrial landscape. In 2007 the Significant New Alternatives Policy (SNAP) program of the US Environmental Protection Agency subsequently listed 1-bromopropane (1-BP) as an acceptable substitute compound to chlorofluorocarbons (CFCs) and over the last decade the use of 1-BP has dramatically increased (EPA, 2007). Its chemical and physical properties make it an effective cleaning solvent, spraying adhesive and precision dry cleaning agent. Of importance, its non-flammable properties and moderate volatility makes it an ideal cleaning solvent for use in underground coal mines.

Exposure to 1-BP can cause irritation to the eyes, upper airways and skin. Chronically exposed workers have shown to display neurological effects including headaches, dizziness, slurred speech, difficulty in walking, muscle twitching and loss of feeling in extremities (ICHIHARA et al., 2002; LI et al. 2010). In recent years a number of regulatory agencies nationally and abroad have issued health hazard alerts in response to specific workplace incidents and exposure case studies involving exposure to 1-BP (NIOSH, 2013; DNRM, 2009).

Currently Safe Work Australia does not list a workplace exposure standard for 1-BP, however the American Conference of Governmental Industrial Hygienists (ACGIH) had recommended a Threshold Limit Value (TLV) of 10ppm which was significantly lowered down to 0.1ppm in 2014 (ACGIH, 2016). The basis for this 100 fold reduction is due to mounting evidence from human and animal studies linking exposure to 1BP with central nervous system (CNS) impairment, peripheral neuropathy, hepatotoxicity, reproductive and development toxicity (ICHIHARA et al, 2002; LI et al., 2010; MAJERSIK, CARAVATI and STEFFENS, 2007; ICHIHARA et al., 2012).

In 2014 the International Agency for Research on Cancer (IARC) classified 1-BP as a Group 2B substance – *Possibly carcinogenic to humans* and recommended it for high priority IARC Monograph evaluation during the period 2015 – 2019 (WHO, 2014).

### Incident

Two coal mine workers were setting up a shuttle car for routine maintenance in an underground coal mine. An electrician was preparing to perform work on the electrical box in between the shuttle car wheels and an operator was sitting in the driving seat of the shuttle car. A fitter approached the shuttle car to take a scheduled oil sample from the conveyor gear box which was located directly behind the shuttle car operator's seated position and on the outbye (up wind) side of the ventilation. The temperature of the conveyor gear box was not known, however it was described by witnesses as warm to touch.

The fitter poured a quantity of industrial solvent containing (98% 1-BP) over the filler plug on the gearbox. Witnesses report seeing a puddle "1 foot in diameter" of the solvent on the ground directly under the conveyor gear box and residual solvent "fuming" off the gear box. Both coal mine workers inbye (downwind) experienced immediate health effects including acute upper respiratory irritation, vomiting and loss of coordination. The operator positioned in the shuttle car was unable to retreat to a position of fresh air. Subsequently his symptoms progressed after being taken to the surface of the mine and after admission into hospital. After release from hospital the operator's condition continued to deteriorate. Ten weeks after the initial exposure the operator's symptoms included loss of taste, numbness in feet from tip of toes to sock line, leg pain, extreme fatigue, persistent headaches, difficulty concentrating and mood swings.

The ongoing health effects experienced by the shuttle car operator are consistent with reported cases implicating 1-BP causing both central and peripheral nervous system effects in chronically exposed workers. However on this occasion, the operator's exposure profile was not chronic but apparently massively acute, and some mathematical modelling that had been undertaken to estimate the likely concentration of exposure appeared to be grossly conservative.

It was hypothesised by the investigating inspectors that the shuttle car operator may have been exposed to an extremely high concentration of 1-BP resulting in a single dose, perhaps some orders of magnitude above the ACGIH TLV excursion limit.

The subsequent occupational hygiene experiments were aimed to identify the possible magnitude of peak exposure to 1-BP in this specific incident. If greatly excessive, this may help explain any adverse neurological symptoms observed.

### **Methodology**

The reported CNS impairment and peripheral neuropathy caused by 1-BP and the post exposure responses exhibited by one of the exposed workers indicated considerable caution should be observed in any procedure to recreate similar exposure conditions to those of the incident. SafeWork Australia did not list an exposure standard for 1-BP in 2009. Best guidance was sought using the ACGIH TLV of 10 ppm, but with the caveat that the ACGIH had signalled an intended change to 0.1 ppm at least as early as 2011 when this work was being planned. The more stringent TLV would not have been relevant in 2009.

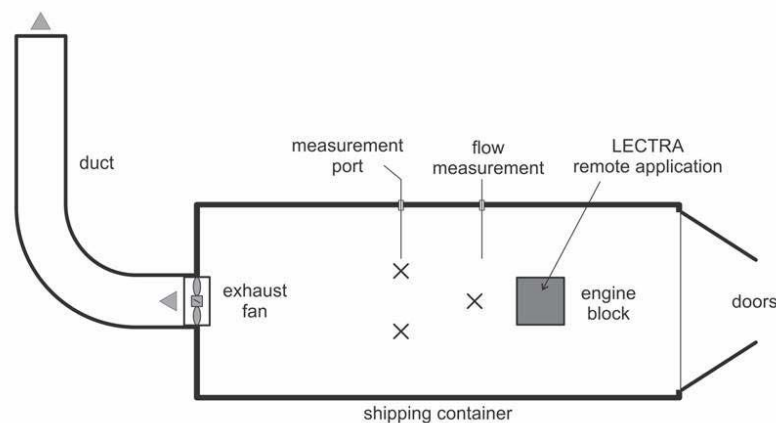
The offending material had been analysed to determine the major components (Flynn, 2009). Gas chromatography mass spectrometry (GC/MS) confirmed the product involved consisted of >98% 1-BP, together with smaller amounts of stabilizers. A small amount of acidic HBr was detected, believed to be present from reaction of 1-BP and alcohols catalysed by metal in the can. Product age and exposure to heat are believed to aid this breakdown.

For ethical reasons and practical limitations related to instrument intrinsic safety, recreating an in-situ underground scenario was impractical. The initial approach to gauge the possible concentration to which the shuttle car operator was subjected, was made through theoretical modelling based on, among other factors, solvent evaporation from a heated block, diffusion of 1-BP at different air temperatures, bulk air movement and surface area of evaporation. Though relevant in a laboratory setting, this approach was considered less suited to the dynamic and complex situation of an underground coal mine where there was no surety on the amount of solvent used as the degreaser, the actual temperature of the gearbox and the characteristics of the airflow between the point of vapour generation and the exposed worker. The modelling approach, though, did identify a significant exposure to one of the equipment operators, up to 6 times the then existing ACGIH TLV of 10ppm. However, the modelling fails to reveal the possibility and extent of any peak exposures which might occur. That requires experimentation. One reason to question the accuracy of the modelling approach is that it does not account for the contribution of around 3.5L of the heavy, near-saturated vapour which pours from the up-ended can as solvent is poured out, and which subsequently contaminates the air stream, and which required some inclusion and perhaps, quantification.

## Experimental set-up

The underground situation involving the hot gearbox cover of a large coal mining shuttle car was simulated in a 6m shipping container in which both the air flow conditions (0.2 – 0.4 m/s) and source temperature (30°C – 50°C) of a simulated gearbox cover could be controlled. The similarly proportioned machined metal plate was orientated directionally in the air stream to match the actual incident situation. Measurements were made 1.2 m inbye of the gearbox cover to match the operator's workstation, and then a further 1.2m inbye. A remote control device was arranged to dispense the approximately 0.5L 1-BP containing solvent from a can of similar proportions (4L) onto the heated block in a series of 6 tests at different temperatures and air flows. This aliquot was likely to be smaller than that in the actual event (estimated about 1L), but much of which fell directly to the floor in both events from where it evaporated more slowly. The simulated gearbox cover was treated with oil and coal dust to replicate original circumstances as far as possible. Air flow measurements were made using a calibrated TSI Model 8545-M-GB VelociCalc hot wire anemometer. Gearbox cover temperature was controlled externally.

**Figure 1** Plan view of experimental set-up



## Necessary precautions

Forced, rapid, repeated evaporation of around 1L aliquots of the neurotoxin 1-BP in a relatively confined space created an environment to which experimentalists should not be exposed. The conduct of the experiments, all monitoring and the final discharge of the solvent vapour were all conducted distant from all other activities with mandatory remote or isolated monitoring. The planning for experimentation, engineering design and construction of the facility, all to be conducted at Simtars site at Redbank, Queensland, was subject to meticulous planning with design and safety approvals and precautions no less comprehensive than those needed for conducting coal dust and gas mixture explosions. Because normal respiratory protective equipment provides inadequate protection at the expected concentrations, all handling of 1-BP was conducted by Queensland Fire and Rescue Services officers using breathing sets for hazardous environments. In all tests, risk to personnel handling 1-BP was further minimised by using limited aliquots of approximately 500 mL of a new batch of 1-BP rather than the 1L suspected of being involved in the incident.

## Calibration of ppbRAE Photo-ionisation meter

This instrument was calibrated against the proprietary solvent containing 1-BP by Queensland Workplace Health and Safety. The ppbRAE does not come with a proprietary in-built calibration for 1-BP in its internal library. An atmosphere containing 300 ppm 1-BP was generated in a Tedlar sample bag containing 4L fresh air against which the instrument was calibrated using the manufacturer's instructions. The calibration range chosen was 0 to 300 ppm, but with the instrument's wide dynamic auto-ranging, it is accurate for higher concentrations. This allowed the instrument to provide reliable measurements well above 300 ppm if the situation arose. Because 1-BP lacks any aromaticity or other readily photo-ionised bonds, it was necessary to determine if any of the stabilisers or additives in the product were biasing the instrument response. A safety data sheet (SDS)

for the product did not specify, for confidentiality reasons, the exact concentration of all the components, but merely stated > 60% 1-BP and <10% isopropyl alcohol. Addition of a small amount of isopropyl alcohol during the calibration routine showed that it did not alter instrument 1-BP response significantly.

### **MIRAN calibrations**

Two MIRANs were used in this program, one was a Foxboro Model 1A and the other a Model 205B SapphIRe instrument. The 1A instrument can be relatively easily calibrated using the standard closed loop calibration system (CLCS) system at its maximum absorbance wavelength of 8.2  $\mu\text{m}$ . This instrument was used to monitor at 2.4 m from the spill event, the position of a second operator. Resulting absorbance figures were read visually, hand recorded and 1-BP concentrations were read from a manually constructed calibration graph.

The Model 205B SapphIRe MIRAN has no inbuilt 1-BP calibration in its internal 120 component library, and because it is computer controlled, the wavelength cannot simply be manually controlled for a CLCS calibration. Calibration required a full infra-red spectrum of the 1-BP using a 300 ppm CLCS test concentration, downloading the test result into a Thermo-match program to determine a unique "finger-print" to choose the wavelength of maximum absorption of IR energy. This was 8.3  $\mu\text{m}$ . This wavelength can then be programmed into the instrument and a series of measurements (ranges 0-600 and 0-3000 ppm were selected) obtained to construct a calibration graph. The MIRAN requires a quadratic term in its calculation of this graph. These quadratic terms were then calculated using an Excel<sup>®</sup> spreadsheet and entered into the instrument computer. After calibration, the accuracy of the instrument was verified against known concentrations by syringe injection using the CLCS.

Again, because the 1-BP solvent contains isopropyl alcohol, spectral interference, if any, had to be accounted for. The isopropyl alcohol has a maximum absorbance at 8.825  $\mu\text{m}$ . This was sufficiently remote not to interfere with the 1-BP measurements.

### **Field measurement of vapour concentrations**

Measurements were made using two different instruments. At 1.2 m from the spill area, corresponding to the operating position of the principal worker, a ppbRAE-plus photoionisation detector with fast response was used to monitor for any relatively short lived but very high concentrations, and a MIRAN miniature infrared analyser (Foxboro Model SapphIRe 205B) for more averaged measurement of concentrations. Because the MIRAN had to be operated outside the container for safety reasons, the delay in sending atmosphere to the instrument, an increased dead space of the sample tubing and machine internal volume all contributed to unavoidable smoothing of MIRAN measured peak concentrations of 1-BP. The second MIRAN was used to obtain some peak measurements 2.4 m from the proposed spill events corresponding to the position of the second exposed operator. All measurements at the 1.2 m position were data logged with both instruments for subsequent downloading and plotting.

A second photo-ionisation monitor was used outside the test chamber where the experimenters were located to spot check their working environment, and to monitor the exhaust discharge.

### **Test results at 1.2 m downstream of the pouring incident**

Logged results from the photo-ionisation detector and the SapphIRe MIRAN were plotted separately to examine the sequential concentrations for the major events following each pour as recorded by each instrument using an IHSTAT<sup>™</sup> (AIHA) plotting procedure. Figures 2 to 13 in the Appendix contain the details of the concentrations of 1-BP vapour from the cleaning solvent measured at 1.2 m from the solvent application for both instruments for the six different runs. In the majority of cases, each pouring event was followed by a cloud of vapour created by pouring and evaporation from the heated block surface which lasted not much longer than 3 minutes 20 seconds (200 seconds).

In each of the measurement runs, the ppbRAE photo-ionisation detector had a very rapid response, and was able to follow the peak profile second by second. In contrast, the SapphIRe MIRAN took several seconds to respond and smoothed out the peak profiles. This can be observed by examining concentration curves for each instrument in the paired readings.

**Table 1** presents the main peak front concentrations and some 3 minute averaged values recorded by both instruments for all of the six different test runs at the shuttle car operators seated position. Comparison can be made with the modelling predictions in the right hand column.

**Table 1** Peak concentrations and 3 minute averages of 1-BP measured at 1.2 m for 6 Test Runs

Run Number	Temp (°C)	Air Flow Rate(m /s)	Photo- ionisation maximum peak concentration ppm	MIRAN maximum peak concentration ppm	Photo-ionisation average concentration ppm		MIRAN average concentration ppm		Predicted concentration from by modelling
					Leading peaks	3:20 sec	Leading peaks	3:20 sec	
Run 1	30	0.2	175	95	50	38	43	34	
Run 2	30	0.4	1180	591	422	82	276	84	4.4 (at 25°C)
Run 3	40	0.3	242	99	62	35	54	31	
Run 4	40	0.4	228	99	57	33	44	35	26
Run 5	40	0.2	278	150	-	70	-	58	
Run 6	50	0.4	406	206	-	82	-	61	36.8

The modelling approach clearly misses the potential for the massive peak concentrations which are revealed in the plotted curves.

There are three aspects to the results of these tests. The first is that large peaks were observed in all tests. The second is that the vapour concentration observed at the 1.2 m measuring point does not always rise and fall in an ordered manner. The third is that concentration observed at the 1.2 m point appears to be the result of a combination of different generating processes, directional disturbances in air flow between the point of generation and the target area and the effect of increased rate of evaporation caused by the heat of the evaporating surface. Both Test Runs 5 and 6 which were conducted at 50°C demonstrate behaviour not consistent with the lower temperature tests. Overall, the behaviour is not fully predictable.

To determine a likely mean and to gain some idea of upper confidence of the mean which these peak readings might yield, the peak values for the ppbRAE and the MIRAN were each separately tested for lognormality using the IHSTAT program. In each case, the spread in values of the respective peaks indicate that the peak exposure profiles can be reasonably approximated by a log normal distribution (see Figures 14 and 15). This allows us to predict with some certainty the mean and the upper confidence limit (UCL) for the mean value of concentration for both instruments. In the case of ppbRAE readings, the mean of the peaks is 418 ppm and its UCL is approximately 1100 ppm. For the SapphIRe MIRAN measurements, the mean is 207 and its UCL is 567 ppm. The true average cannot be precisely predicted, only that it will fall in a range, because these results represent probability distributions based on only a small number of tests.

The most consistent results from this series of tests are (i) that the concentration of the vapour 1-BP measured at the 1.2 m point is not uniform; (ii) that all test runs produced peak concentrations which were high to very high; (iii) these peak profiles typically lasted no more than 3 minutes, during which multiple peaks were observed. A worker located 1.2 m downwind from the point of generation and unaware of the approaching cloud of vapour could be enveloped by it within 10 to about 60 seconds. The maximum concentration observed during Test Run 2 was a peak of 1180 ppm (equivalent to 5900 mg/m<sup>3</sup>). This concentration observed in simulated Test Run 2 is around 30 times higher than the maximum predicted by modelling for evaporation at 60°C, 120 times higher than the existing TLV and approximately 12,000 times higher than the proposed ACGIH 8-hour TLV.

The peak concentration observed of 1180 ppm of 1-BP in Test Run 2 is also well above the maximum excursion level (of 5 times TLV = 50 ppm) recommended by the ACGIH.

#### **Which has the predominating effects, temperature or other factors?**

Maximum concentrations generally are observed well before cold solvent has had any time to come fully to the temperature of the heated block. The concentration profiles in all tests show that concentration starts to rise within a few seconds of the solvent being dispensed. It takes about 3 seconds for air moving at 0.4 m/sec to travel from the point of application to the first measurement point. The period at which the peak concentration passes the 1.2 m test point is variable. However, it is predictable that the main peak should appear earlier in those tests conducted at 0.4 m/sec, than those conducted at 0.2 m/sec and this is observed. While in two cases (30° and 50°C) the maximum peak value also is greater at the higher (0.4m/sec) ventilation rate, this may not be significant.

The effect of increasing temperature, if any, is slight between 30°C and 40°C. The averaged concentrations, whether measured by ppbRAE photo-ionisation detector or SapphIRe MIRAN, are not greatly different (see Table 1, columns 5 and 7). A slight increase in peak concentrations is observable (excluding the apparent disproportionate, but real, response for Test Run 2) across the tested temperature range. At 50°C, the pattern of vapour concentration produced at the 1.2 metre test point changes from the earlier tests, with some late phase vapour production evident. It is thought to be the result of solvent being trapped in machining holes or absorbed on the test surface and evaporated after the first wave of vapour created in dispensing the solvent has passed. Solvent heated to a higher temperature as it contacts the block might subsequently evaporate more readily after falling to the floor, but the mechanisms are not fully explained. Overall, temperature does not appear to be the influencing variable below 50°C, but would become important had the temperature of the gearbox cover been between 50°C and 60°C (or even hotter and nearer the boiling point of the solvent (71°C)).

A separate (un-logged) measurement was made by SapphIRe MIRAN of the concentration of 1-BP vapour at the 1.2m displacement point during the filling of the dispensing can with 500 mL of the solvent. Although no solvent was poured onto the heated metal plate, the concentration of 1-BP measured more than 100 ppm. This indicates that there is a significant contribution of vapour arising, as predicted earlier, just from pouring the solvent. This single event, though short lasting, contributed a peak vapour concentration around three (3x) times any maximum concentration predicted by modelling.

#### **Test results at 2.4 m downstream of pouring incident**

Measurements were made to follow the approximate concentration profile of the 1-BP vapour 2.4 m downwind (approximate initial position of a second exposed person) using a calibrated MIRAN 1A. Peak values only are reported here in Table2.

**Table 2** Peak concentrations of 1-BP measured at 2.4 m for 6 Test Runs

Test Run Number	Temp (°C)	Air Flow Rate (m/s)	Maximum concentration in ppm of 1-BP
1	30	0.2	70
2	30	0.4	200
3	40	0.3	70
4	40	0.4	70
5	40	0.2	70
6	50	0.4	45

The peak concentrations of 1-BP at the 2.4 m measuring point were found to be considerably lower than those found at the 1.2 m point in all Test Runs. This was expected as the vapour plume will be progressively mixed and diluted as it streams away from the source. Its concentration will be an inverse function of the distance from source to point of detection.

#### **Limitations to the test results**

There are acknowledged limitations in this simulation. The air flow rate could not always be set exactly to a chosen value, either 0.2 or 0.4 m/sec. This is believed to have resulted from slight fluctuations in the power control to the extraction fan run from a portable power generator, and the unavoidable perturbations to air flow in both quantity and in the direction of air flow (non-laminar) past a forward pointing hot wire anemometer. However, these kinds of flow variations would be observed in practice in monitoring the air flow in any workplace. Ambient temperature also increased several degrees over the four hour period of the test procedure during which the 40 and 50°C tests were conducted. However, this temperature increase was still significantly smaller than the incremental increases in test temperatures of the heated block at both 40° and 50°C. The amount of saturated vapour in the test can would never have been at its maximum after the first pouring as insufficient time could be allocated to allow the vapour to come to equilibrium each time the can was refilled.

#### **Conclusions**

- Testing has revealed that the process of dispensing a constant quantity (500 mL) of the cleaning solvent onto a machined and mildly heated metal plate which is surface contaminated with oil and coal dust can create very large unexpected peaks in the concentration of 1-BP in a travelling airstream of 0.2m/s and 0.4 m/s at a point 1.2 m downstream from the point of dispensing.
- Multiple large peaks in concentration of 1-BP were observed in most tests.
- These peaks (175 – 1180 ppm) ranged from 17 to more than 100 times the nominal value of the then ACGIH Threshold Limit Value of 10 ppm, and up to 20 times the maximum excursion value (which is 5 times the TLV); now it could be in excess of 2,000 times any excursion value.
- Neither the existence of nor the magnitude of such peaks had been adequately predicted using theoretical concepts employed in modelling.
- The process of dispensing solvent and local disturbances in air flow caused by the spill target (eg. a machined block or a gearbox/shuttle car) appear more significant in influencing the downstream concentrations than is temperature at 40°C or lower.

- The time of arrival of individual vapour peaks at a 1.2 m distance is unpredictable, other than that most have passed within about 3 minutes.
- Some vapour in the front vapour peaks is likely to be derived from saturated vapour released in the dispensing/dispersing event.
- A worker stationed 1.2 m downstream (in by) in such an incident dispensing cleaning solvent has a high probability of having a massive short term exposure to 1-BP.
- There is evidence that large serial exposures can occur.

The 3 min 20 second averaged concentration of 1-BP vapour observed at the 1.2 m downwind test point following a dispensing event ranged for the series of Test Runs between 31 and 82/84 ppm (using both instruments), or just over the then recommended excursion value of 5 times the 8-hour TLV. However, there is no evidence that the actual period of exposure of the principal exposed worker is likely to have been much longer than three minutes, unless the worker was temporarily incapacitated by the exposure. During the first few minutes, the worker is likely to have been exposed to several large peaks of exposure.

Interestingly though, the initial modelling approach provided a result which, if integrated over the time it takes to evaporate around 1L of 1-BP, was not greatly different in its total exposure from the results obtained in experimentation.

Though the experimentation was complex, time consuming and costly to plan and conduct, it is only through this type of empirical reconstruction, and not through modelling, that the extreme nature of the likely short term exposure has been able to be observed. Because of the significant toxic nature of 1-BP, and the acute, severe and disabling effects exhibited by the exposed miner, it was imperative in this case that occupational hygiene investigation looked for unexpected events in the exposure episode which might otherwise have been missed. This is an important consideration to carry into routine hygiene practice. It also might indicate that the process currently being considered of using only theoretical approaches to determine derived no effect limits (DNELs) may suffer fatal flaws for some substances.

**Acknowledgement:** *Acknowledgement is made to the Directors of Simtars and Queensland Workplace Health and Safety for permission to prepare and present this paper, and to the Coal Mines Inspectorate for use of de-identified information relating to the initial investigation.*

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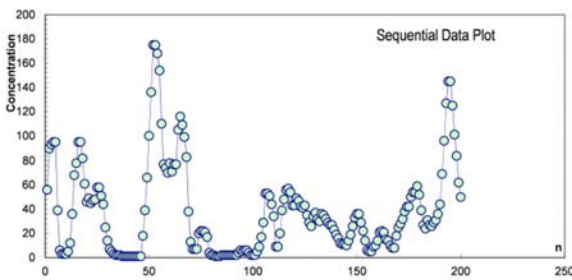
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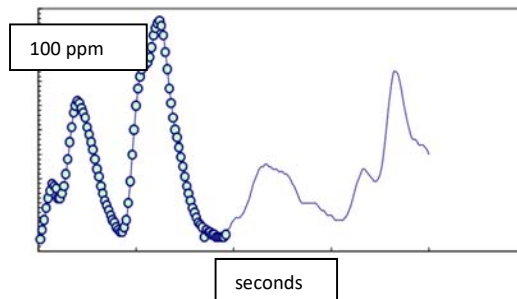
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**APPENDIX Supporting Figures showing the sequential concentrations of 1-BP in each paired Test Runs as measured by ppbRAE and SaphiRe MIRAN respectively.**

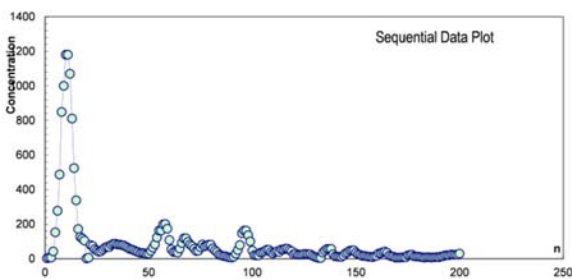
In all following Figures F 2-13, the Y axis is the concentration of 1-BP expressed in parts per million (ppm) of the atmosphere. The X axis is in seconds.



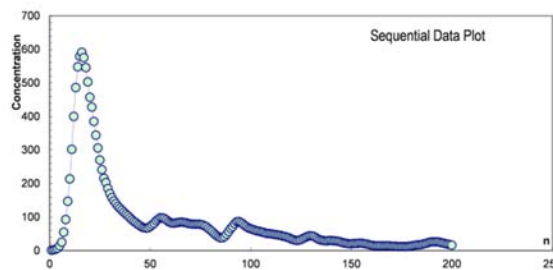
F 2. PID detector 30°C and 0.2 m/s airflow



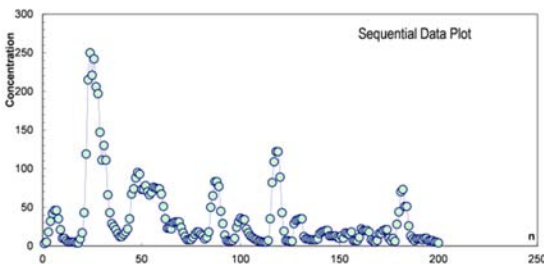
F 3 MIRAN detector 30°C and 0.2 m/s airflow



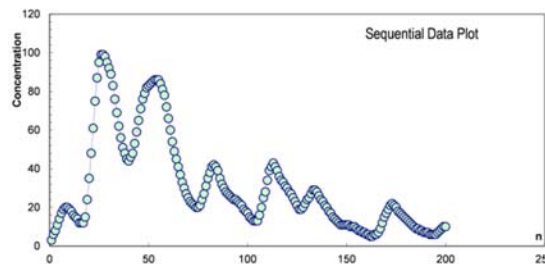
F 4. PID detector 30°C and 0.4 m/s airflow



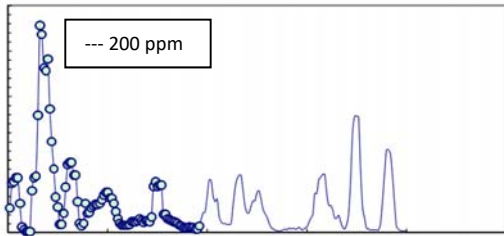
F 5. MIRAN detector 30°C and 0.4 m/s airflow



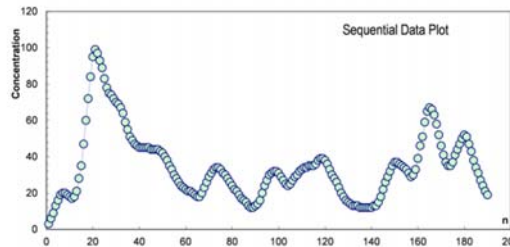
F 6. PID detector 40°C and 0.3 m/s airflow



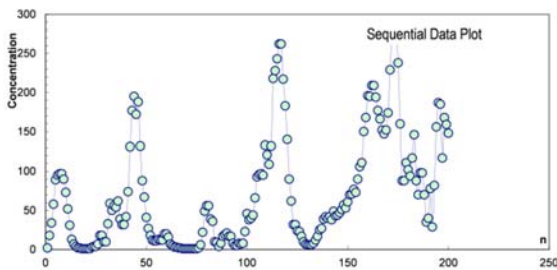
F 7. MIRAN detector 40°C and 0.3 m/s airflow



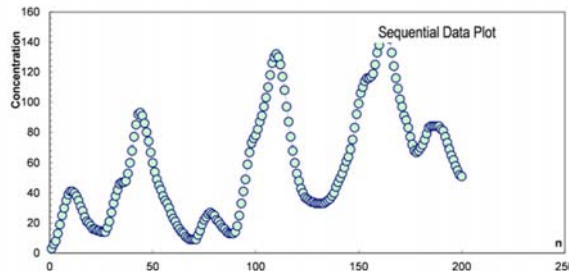
F 8 PID detector 40°C and 0.4 m/s airflow



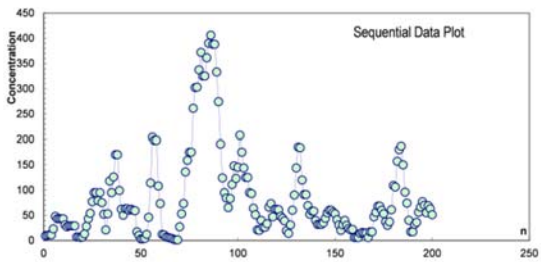
F 9 MIRAN detector 40°C and 0.4 m/s airflow



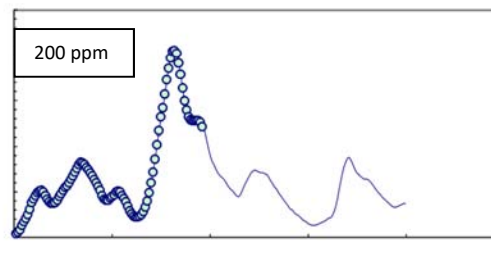
F 10 PID detector 40°C and 0.2 m/s airflow



F 11 MIRAN detector 50°C and 0.2 m/s airflow

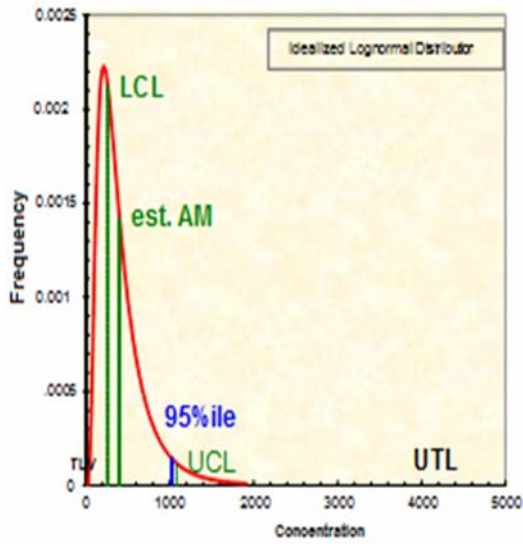


F 12 PID detector 50°C and 0.4 m/sec

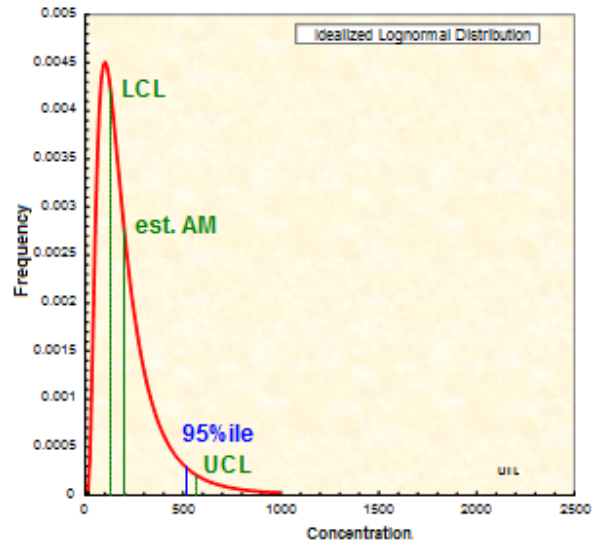


F 13 MIRAN detector 50°C and 0.4 m/s airflow

The major peak values in each run for both instruments were examined using a lognormal plot to estimate the likely 95% percentile for 1-BP using both instruments. For fast acting measurements made using the ppbRAE, photoionisation detector, the 95%ile was about 1000 ppm. For measurements made using the SapphIRe MIRAN, the 95%ile was just over 500ppm.



**Figure 14** Probability distribution of peak values of 1-BP by ppBRAE. Concentration units are parts per million (ppm)



**Figure 15** Probability distribution of peak values of 1-BP by MIRAN. Concentration units are parts per million (ppm).

## WORKPLACE RPD STUDY AT MIM: REAL-TIME FLOW RATES AND METABOLIC RATES

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### ABSTRACT

The aim of the study was twofold, to generate workplace data on breathing rates and metabolic rates and compare measured work rates with those determined using ISO 16975(draft) RPDs – Selection, Use and Maintenance. RPD used for the study were Sundstrom- SR100 half face and SR200 Full-face respirators with ABE1- P3 filters. A pocket sized pressure data logger (purposed design PCB with pressure transducer with a capability of logging 50 samples/seconds for a full shift was used) with exhalation valve adaptor and characterised filters was used to collect real-time data. Since each filter has its unique constant, their values and exhalation value constants were loaded to the software. Breathing patterns were displayed and minute volume were calculated. Metabolic rate according to ISO 16976-1: 2007 were calculated and compared with the ISO work rate as discussed in ISO 17420-2(draft). Some of the realtime workplace metabolic rates were much higher than recommended in the ISO 17420-2 draft document. It was observed that the pressure data logger is a potential tool that can be used to measure actual work rate and breathing rate under real work conditions. WOB was measured. The highest exposure may be at the highest work rate. Specific work tasks at different work rates were discussed. Additional information to also consider include ambient temperature, humidity and radiant heat while doing pressure testing. More data is still being collected to fully characterise different tasks to understand required metabolic rates and flow-rates.

## HYDRATION THAT WORKS

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### ABSTRACT

Staying hydrated while working in hot environments has been emphasized time and again to prevent heat related illness. However there is little evidence of a consistent guideline for what constitutes a “hydration management plan” that really works. This study examined several factors highlighted in published research that contribute to getting the worker to stay hydrated. These include education, training, programmed drinking, ‘buddy’ system for working in hot environments, subjective and objective symptoms of dehydration, hydration status testing and biological monitoring. In addition to these factors, correlation studies were undertaken at an open cut metalliferous mine in NSW to ascertain the association between hydration status and core body temperature, heart rate and body mass index. The result was that pre-shift hydration status was the primary determinant of a worker’s ability to stay hydrated throughout the shift. A hydration management plan comprised of several components was trialled which resulted in an 87% increase in the number of workers who came to work hydrated.

## IMPLEMENTING EMISSIONS BASED MAINTENANCE TO REDUCE EMPLOYEE EXPOSURE TO DIESEL EXHAUST AND DECREASE FUEL CONSUMPTION

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### ABSTRACT

Emissions based maintenance (EBM) of diesel engines is not a new phenomenon, however it is a considerably under-utilised control. There are a number of incentives to implementing a comprehensive EBM programme, that span across various departments within an organisation.

It has previously been proven that reducing emissions at their source by improving engine operability, worker exposures to diesel exhaust can be reduced by up to 50% (Davies 2004; McGinn 2000). Further incentive is also available with the anticipated outcome of a 5 to 23% reduction in fuel consumption resulting in a significant cost saving to a business.

Newer engines with reduced emissions are now on the market satisfying the US and Euro emission standards, however, the upgrade of vehicle fleets will take many years, and in some instances these engine packages are not suitable for the work environment for instance in Australian underground coal mines. For businesses where upgrades to diesel fleets are pending, alternative controls must be explored as proposals for exposure guidelines to be reduced to protect the health of the worker are encouraged, and lowering commodity prices in a high cost environment cause the bottom line to be examined (MacCalman, Cherrie & Searl 2015). Alternative controls are available, however none with a return on investment that is expected with EBM.

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## PERFORMANCE OF PVC GLOVES: EFFECTS OF TEMPERATURE, ULTRAVIOLET (UV) AND ABRASION ON PERMEATION OF ORGANOPHOSPHORUS PESTICIDES (OPS)

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### ABSTRACT

The use of elbow length PVC gloves is often recommended for hand protection against organophosphorus pesticides (OP). However, most agricultural activities are conducted outdoors at high temperature, and the gloves may have degraded performance from UV exposure and abrasion. As literature addressing the effects of these variables on glove performance is scarce, OP permeation was investigated in reasonable worst case scenarios (Lee et al. 2009).

Glove permeation tests were conducted with 1-inch ASTM cells on two PVC glove brands (thickness 1.05 to 1.28mm) at 23(±2) and 45°C for up to 8 hours. Two OPs listed as Chemicals of Security Concern, dichlorvos and diazinon were utilised at full and application strengths. Tests were conducted on new gloves, gloves exposed to simulated UV light (UV-A and B), and abraded gloves (5% reduction in total thickness). Chemical analysis was via HPLC-UV.

According to the standard flux criterion of 1 µg/cm<sup>2</sup>/min, breakthrough of diazinon was not reached, except for full strength at 45°C (120 mins, average cumulative permeation 54.6 (±4.0) mg. (maximum flux 30 and 56 µg/cm<sup>2</sup>/min). Dichlorvos permeated more rapidly than diazinon, recording greater permeation with the temperature increase, especially for full strengths. UV-exposed and abraded gloves indicated reduced performance, with approximately doubled maximum flux for dichlorvos but insignificant for diazinon.

Greater permeation was observed for both OPs at elevated temperatures. The results also indicated that performance of UV-exposed and abraded gloves was degraded against concentrated OPs. Therefore, extra precautions should be taken when handling concentrated OP at high temperature, or when using gloves with extended UV-exposure and abrasion.

## WHAT IS THE BLUE-LIGHT HAZARD? A REVIEW OF RECENT DEVELOPMENTS

*Martin Jennings*

### ABSTRACT

Blue light is becoming increasingly more intrusive into modern day life with the use of screen-based equipment, light emitting diode (LED) lighting and high definition televisions, smartphones and computers. This paper will review the hazards of blue light and discuss evaluation and control of the risk associated with the so-called “blue light hazard” (BLH).

In this paper, blue light is defined as light within the wavelength range of 400-500 nm. Within this range, there is evidence of three separate action spectra, each with different biological effects.

Light wavelengths in the range of 400-480 nm account for 88% of the risk of photo-oxidative damage to the retina, with the blue light hazard peaking at 440 nm. BLH effects on human health are mainly linked to photoretinopathy, a photochemical injury of the retina, in which photochemical decomposition occurs in the pigments in photoreceptor cells. The photopigment fragments thus created act as free radicals, leading to the death of the photoreceptor cells. Australia has more recently regulated this with the introduction of AS/NZS IEC 62471:2011.

The range peaking at approximately 480 nm helps regulate human circadian day/night rhythms. Inadequate or inappropriate exposure to blue light can disrupt the circadian biological clock and the sleep/wake cycle. The resultant neuroendocrine impacts can have significant long-term consequences.

Wavelengths between 415-455 nm generate the greatest risk for retinal pigment epithelial cells, which are critical to the long-term health of the macula. This is coming under suspicion of contributing to age-related macular degeneration, a leading cause of legal blindness among people over age 65.

### Optical radiation hazards

Sliney (1994) considered that there were at least five separate types of hazards to the eye and skin from optical sources:

- a Ultraviolet photochemical injury to the skin (erythema and carcinogenic effects), and to the cornea (photokeratitis) and lens (cataract) of the eye (180 nm to 400 nanometers (nm))
- b Thermal injury to the retina of the eye (400 nm to 1400 nm)
- c Blue-light photochemical injury to the retina of the eye (principally 400 nm to 550 nm, and with the lens removed, 310 to 550 nm)
- d Near-infrared thermal hazards to the lens (approximately 800 nm to 3000 nm)
- e Thermal injury (burns) of the skin (approximately 400 nm to 1 mm) and of the cornea of the eye (approximately 1400 nm to 1 mm).

This paper will focus on the effects described at c, with the intent to raise awareness among occupational hygienists of the current status of knowledge on the nature of the blue light hazard. It is also intended to discuss new and emerging information on other potential hazards that could be associated with light in this region of the spectrum.

### What is blue light?

The visible spectrum is the portion of the electromagnetic spectrum that is visible to the human eye. A typical human eye will respond to wavelengths from about 390 to 700 nm and frequencies in the vicinity of 430–770 THz. Blue light falls within this region, primarily between 400 and 500 nm. This portion of the spectrum is also known as high-energy visible (HEV) light because of the high photon energy associated with these shorter wavelengths.



Blue light damage occurs when a photosensitizer absorbs photon energy of a specific wavelength, setting in motion a series of intracellular chemical reactions. Rods, cones and retinal pigment epithelial (RPE) cells of the outer retina—the cells responsible for photon absorption and visual transduction—are rich in photopigments and therefore susceptible to photochemical damage.

The principal retinal hazard resulting from viewing bright light sources is photoretinitis, e.g. solar retinitis with an accompanying scotoma results from staring at the sun. Solar retinitis was once referred to as "eclipse blindness" and associated "retinal burn." Only in recent years has it become clear that photoretinitis results from a photochemical injury mechanism following exposure of the retina to shorter wavelengths in the visible spectrum, i.e. violet and blue light. Photoretinitis is a photochemical injury of the retina in which photochemical decomposition occurs in the pigments in photoreceptor cells. The photopigment fragments thus created act as free radicals, leading to the death of the photoreceptor cells. Light wavelengths in the range of 400-480 nm account for 88% of the risk of photo-oxidative damage to the retina. The blue light hazard peaks at 440 nm and falls to 80% of peak at 460 and 415 nm.

The retinal toxicity of blue light has been known for many years. Ham et al (1976) found that with exposures of up to 1000 seconds in monkeys, the action spectrum strongly peaked in the blue part of the spectrum, and with the lens removed, in the UV. This photic damage was referred to as the 'blue light hazard'. Prior to conclusive animal experiments at that time (Ham 1976); it was thought to be a thermal injury mechanism.

However, it has been shown conclusively that an intense exposure to short-wavelength light (hereafter referred to as "blue light") can cause photochemical retinal injury (Sloney, 1994).

### **Standards for the blue light hazard**

The ACGIH TLV for visible light is intended to protect against retinal photochemical injury from chronic blue light ( $305 < \lambda < 700$  nm) exposure. As the spectrum for the blue light hazard peaks at around 440 nm, the ACGIH TLV for the photochemical hazard applies a weighting factor  $B(\lambda)$ , with a maximal weighting of 1.0 at 435 – 440 nm. However the TLV for visible light does not confer protection against chronic neuro-endocrine effects from exposure to light.

*AS/NZS IEC 62471:2011 Photobiological safety of lamps and lamp systems* provides guidance for evaluating photobiological safety of lamp and lamp systems including luminaires. This standard is essentially identical to the ACGIH TLV for visible light (ACGIH, 2008). *AS/NZS IEC 62471:2011* now has the status of legislative authority or guidance in that the exposure limits from this standard are called up in Schedule 1 of the *Australian Radiation Protection and Nuclear Safety Regulations 1999*. However, as with all exposure standards it is important to read the supporting documentation to understand what protection this standard is designed to confer.

### **Blue light and maculopathy**

The effects of ultra-violet radiation (UVR) and infra-red radiation are well known in welding, with the former causing keratitis, an inflammation of the cornea, sometimes known as 'welder's flash' or 'arc-eye'. Less well documented are effects from visible light and, in particular, blue light. This is not widely recognized although several authors have described retinal lesions from welding as far back as 1902.

As an example of how poorly understood the condition is, Magnavita, (2002) describes how an Italian welder had a compensation claim rejected, as the compensation authority asserted that there was no cause and effect relationship between retinal lesions and arc welding. This was despite an earlier paper by Brittain, (1988) in which he describes two cases of retinal lesions caused by MIG welding, exacerbated by failure to use eye protection correctly. In a later paper Kim and co-workers (2007) also describe a case study of macular degeneration in a MIG arc welder, noting the potential for confusing this with age-related macular degeneration (AMD).

There appears to have been very little work done to characterize the blue light hazard associated with welding. Okuno, (1986) measured the blue-light effective radiance of a range of welding processes and compared the results against the ACGIH TLVs. In 2010, Okuno published a further study in which the objective was to quantify the blue-light hazard from CO<sub>2</sub> arc welding of mild

steel over a range of conditions, viz. solid and flux-cored wires at welding currents of 120–480 A. He found that the effective blue-light radiance ranged from 22.9 to 213.1  $\text{Wcm}^{-2}\text{sr}^{-1}$ . The corresponding maximum acceptable exposure duration was only 0.47–4.36 seconds, meaning that the total daily exposure to the welding arc without eye protection should not exceed this duration.

Notwithstanding the above, it is now encouraging to note that this is recognized by some major suppliers of welding equipment. For example, BOC Industrial Gases (BOC) advise on their website that high intensities of blue light, 400 to 500 nm, have been shown to cause photochemical lesions on the retina.

The mechanism of the light-induced retinal injury associated with arc welding is not thermal because the temperature rise in the retina is estimated to be insufficient to cause a burn; therefore, the injury mechanism is considered to be photochemical (Okuno, (2010) citing Naidoff and Sliney, 1974).

### History of artificial light

Humans developed artificial light as a means of brightening their darkness and one may speculate, to better observe potential threats. In so doing, they also extended the length of their daytime activities. No doubt, the earliest artificial light was created accidentally by fire, although early man soon found this could be controlled and even created. Early civilisations used oil to create lamps and maybe later, tallow for candles. This gave man the option of having a light source that was both portable and could be replicated in several locations simultaneously. Much later, the gas lamp was developed with the advantage of increased levels of illumination. At approximately the same time, kerosene was used for lamps, and these two materials indicated a move away from animal based products, and hence, much greater availability of artificial light.

Towards the end of the nineteenth century, the incandescent light bulb was developed by Swann and then commercialised by Edison. A feature of this technology was that it was not dependent on a naked flame to generate light, making it much safer. This factor, together with the convenience and the versatility of electric lighting, led to its rapid acceptance in urban environments. In the mid twentieth century, the fluorescent electric lamp was developed. This provided a cost effective and efficient source of light that was so readily accepted that it was estimated that by 1951, fluorescent lamps had overtaken incandescent lamps as the most popular source of lighting.

The advent of fluorescent lighting also introduced a new consideration, in that all previous light sources had been based upon heat; this was inefficient, as most of the energy was dissipated as heat rather than light. Moreover, the spectral distribution of the light was at the red end of the spectrum and therefore longer wavelengths. However, by careful selection of phosphors, which produced differing spectral distributions, lamp manufacturers could produce lights, which were designated 'warm white' or 'cool white'. This was driven in part by the market demand for lighting to provide different colour rendering properties for different applications.

Although it was not appreciated at the time, the widespread use of fluorescent lighting meant that there had been a very significant change in the lit environment. For thousands of years, human's exposure to light at night had been predominantly from the red end of the spectrum. This exposure was now shifted to light of a very different spectral frequency distribution.

More recently, other artificial light sources have become commonplace, such as quartz-halogen lighting, and in the last decade or so, light emitting diodes. In addition, humans are now spending a significant portion of their time staring into light emitting devices, such as computer screens, i-Pads and i-Phones or televisions. The light emitted by these sources is mainly at the blue end of the spectrum.

### Health impact of artificial light

Until the advent of artificial lighting, the sun was the major source of lighting, and people spent their evenings in (relative) darkness. Now, in much of the world, night-time hours are illuminated and light at night (LAN) is considered the norm. The consequence for humans exposed to LAN is that light desynchronises the body's circadian rhythm. This adversely affects sleep and a significant body of research shows that it may contribute to the causation of cancer, diabetes, heart disease, and obesity.

In 1998, it was discovered that there was a relationship between the colour of light and the secretion of melatonin by the pineal gland. It was observed by Thapan et.al. (2001) that melatonin secretion could be suppressed by exposure to blue light and stimulated by exposure to red light. The action spectrum associated with the suppression of melatonin secretion had a peak sensitivity of around 459 nm. This suggested a mechanism for synchronising the day/night circadian rhythm of melatonin secretion, which was known to peak in the dark hours and fall to a minimum during the hours of daylight. In other words, light was exhibiting circadian synchroniser (zeitgeber) properties.

In a seminal paper, Berson and co-workers, (2002) conclusively confirmed the existence of a third type of non-visual photoreceptor, in addition to the well-known rods and cones. These are referred to as intrinsically photosensitive Retinal Ganglion cells (ipRGCs). Whereas our cones and rods have spectral responsivities defined by the functions for photopic and scotopic vision, ipRGCs have a different spectral responsivity. The action spectrum of ipRGCs is referred to as melanopic in that it follows the action spectrum for the optical pigment melanopsin, with a peak of 481 nm (Peirson, 2006).

The spectral responsivity of ipRGCs is of particular interest to lighting designers. Since the discovery of the ipRGC, the lighting industry has responded by producing design guidelines for creating melanopic lighting environments. Until recently, lighting designers had no real idea of how to design lighting schemes that would not only provide effective lighting to support visual tasks but also provide non-visual biologically effective illumination. The first steps are now underway. In Germany, the *DIN SPEC 67600 (2013-04) Biologically Effective Illumination - Design Guidelines* are now available (Ritter 2013).

Similarly, a number of lighting manufacturers are currently looking at ways of optimizing the spectral power distributions of their products to produce biologically-effective white light; that is, white light with an abundance of blue light centered on the melanopic peak wavelength (Ashdown, 2015).

Less formal advice has been provided by other workers, such as Roos (cited by Ashdown, 2015) who stated “Expose normal populations to high-levels of blue-rich light near 460 nm in the morning through early afternoon, and eliminate these shorter wavelengths and reduce light levels in the late-afternoon. After 10 p.m., total darkness is ideal – or if this is not practical – very low levels of warmer red-rich light. Even an incandescent lamp can disrupt the circadian cycle if it is too bright.”

### **Age related macular degeneration (AMD)**

AMD is the name given to a group of chronic, degenerative retinal eye diseases that cause progressive loss of central vision, leaving the peripheral or side vision intact. Macular degeneration is progressive and painless and although it can lead to legal blindness, it does not result in total or ‘black’ blindness. It is usually related to ageing and most frequently affects people over 50 years of age. However, it is not a normal or inevitable consequence of ageing. Certain forms of the disease can also affect younger people. Other risk factors are family history and smoking (MD Foundation, 2013).

However, there is recent evidence that environmental and occupational exposure to blue light may also contribute to MD. In an extensive review, Algerve (2006) suggested that blue light might contribute to AMD, although this was only based on animal and cellular observations.

Blue light exposure, owing to its impact on lipofuscin accumulation and N-retinylidene-N-retinylethanolamine (A2E) mediated phototoxic effects, has come to be considered a potential risk factor. With maximum absorption around  $435 \pm 20$  nm, A2E is excited by blue light. Blue light can induce formation of toxic reactive oxygen species that cause photochemical damage, leading to the death by apoptosis first of critical retinal pigment epithelial (RPE) cells and then photoreceptors. This slow process, in which damage accumulates over a lifetime, has been implicated in the pathogenesis of retinal degenerative diseases such as AMD (Smick, 2013).

### **LEDs and electronic devices and implications for Occupational Health**

In 2013, the US Department of Energy (DoE) stated that, in relation to the risk of retinitis from the blue light hazard of LEDs, these products were no more hazardous than other lighting technologies that have the same colour correlated temperatures (DoE, 2013).

Given that iPhones, tablets, computers and other devices that are backlit with LED lights are concentrated blue rays, there has been concern expressed about their widespread usage. O'Hagan & colleagues (2016) assessed a range of lamps (CFL and LED), computer screens, tablet computers, laptops and smartphones for comparison with the blue light hazard exposure limit. All devices examined were found to be well within the limit for the blue light hazard, but the impact of the blue light from the studied sources on circadian rhythm and sleep quality was outside of the scope of this study.

The impact of blue light on circadian rhythm and sleep quality has attracted media interest; for example, the ABC reported that users of small handheld electronic devices were experiencing sleep disorders, which was exacerbated by the habits of users, who hold them close to their faces and use them often late at night (ABC, 2013).

Subsequent to their 2013 fact sheet, the DoE published another fact sheet that recognized the wide-ranging, non-image forming response to light including circadian, neuroendocrine, pupillary, behavioral, and other physiological effects. These are the effects mediated by melanopsin. It noted that LEDs have the potential to be engineered so as to be carefully tuned to meet the diversifying demands placed on lighting systems (DoE, 2014). In this regard, it is interesting to note that there are now commercial enterprises, such as Lumitech in Austria, and, Biological Innovation and Optimization Systems (BIOS), providing biological lighting systems and developing LED-lighting systems to reflect melanopic lighting technology.

This creates the possibility of producing lighting products capable of delivering a melanopic lighting regime of the type described by Roos earlier. As noted by authors such as Davis et.al., (2001), there is evidence of a linkage between light at night and breast cancer in female shift workers. It is quite possible that the implementation of such lighting technology in hospitals and similar workplaces could deliver a lit environment where the colour correlated temperature can be adjusted yet still provide a constant level of illumination, so as to ensure optimal visual requirements for work efficiency, comfort, aesthetics and safety, but where the spectral distribution shifts with time so as to be acceptable from a health perspective.

## Conclusion

There is a significant risk to ocular health from the blue light hazard, although this is not widely appreciated even in the occupational health community. The risk of photoretinitis has been addressed by the development of appropriate legislated exposure standards and guidelines.

With regard to the hazards from light at night, the disruption to the circadian rhythm and related other health effects are recognized and standards are being developed. There is also growing evidence that the lighting industry is responding to the challenge by developing melanopic lighting technology to counter the chrono-disruptive effects of LAN.

The evidence for other long-term health effects associated with blue light, such as AMD, is less substantial and further work needs to be done to determine whether this is an issue for concern.

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## ANIMAL HOUSE WORKERS EXPOSURE TO AIRBORNE MOUSE URINARY PROTEIN (MUP)

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### ABSTRACT

A risk-based control approach to animal allergens, which keeps airborne allergens as low as reasonable practical, but accepts a small pre-defined risk of allergic sensitization in some individuals, is used at University of Queensland. Individuals at risk are identified by initial and ongoing health surveillance and managed to stop sensitisation and occupational disease occurring.

The control of MUP relies on engineering controls such as internally ventilated cages for rodent storage and local exhaust ventilation (LEV) for changing rodents between cages and cage bedding knockout. Determination of airborne allergen levels is valuable in determining the efficacy of control measures, it has poor utility for compliance monitoring due to the lack of an evidence based exposure standard, multiple allergens contributing to worker sensitisation, and other technical and cost limitations.

MUP1 measurements were completed at three (3) research institute animal houses located at The University of Queensland (UQ) St Lucia campus. The facilities were deliberately chosen for their differences in building age, design and implementation of higher order controls, layout of the facilities, and the entry and exit requirements (facility cleanliness). The samples were analysed using an enzyme-linked immunosorbent assay (ELISA) technique. The results were compared to similar studies from animal house facilities in USA and Sweden.

Airborne levels of MUP1 at UQ were found to be similar to overseas facilities, showing that IVC and LEV controls at UQ facilities were effective. Airborne MUP1 levels varied greatly for identical tasks, with large variations observed with the same operator, processing different batches of cages. Workers process cages from mice of different breeds, age and sex, which affects the excretion of MUP1, likely contributing to the differences in airborne MUP1 between batches.

## A HEAT STRESS PHONE APP FOR THE HEALTH AND SAFETY PROFESSIONAL

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### ABSTRACT

Rational heat stress indices have been shown to provide a more accurate assessment of heat stress scenarios than many of the simpler and more commonly used empirical indices such as Effective Temperature and Wet Bulb Globe Temperature (WBGT). A key advantage is that the rational indices also provide an avenue for the health professional to evaluate potential controls. Despite this they have not been as readily accepted and utilised. One of the barriers has been their complexity and the numerous calculations associated with their use.

In order to address this issue, a project has been undertaken at The University of Queensland to develop and evaluate a mobile phone application based on the ISO standard 7933 Predicted Heat Strain. This freely available application allows investigators to input a number of parameters associated with the environment, task and individual to evaluate the work scenario's potential risks and controls without requiring access to a computer. Based on the input data, the app uses a number of algorithms to produce predicted core body temperature and water loss graphs and reports. It is envisaged that the app will become a useful tool for the practising occupational health and safety professional in the investigation and control of heat stress in the field.

### Introduction

The best approach to the monitoring and assessment of heat stress has long been a conundrum for the occupational health and safety professional in the field. To this end, many health and safety practitioners have turned to the application of one of many heat stress indices currently available in the literature. To date, the selection of the index used has been limited by the complexity of the index and the accessibility of the user to technology in the field. The growing utilisation of mobile phone applications (apps) in the assessment of working environments has opened up a new area that can be utilised for this purpose. This paper details a recent project, which marries these two areas to produce a heat stress index phone app for the analysis of the working environment.

### Background

One of the earliest applications of the heat stress index concept was by Haldane in 1905 where he proposed the use of the wet bulb temperature as an index in the Cornish tin mines (Haldane, 1905). Some years later saw the development of the Effective Temperature (ET) in the early 1920s by Houghton and Yagloglou (Houghton and Yagloglou, 1924), one of the earliest of the empirical indices. It was primarily designed as an aid to determine the effects of temperature and humidity on comfort (Parsons, 2003). It was later modified by the addition/ variation of parameters resulting in Basic Effective Temperature, (BET) and Corrected Effective Temperature (CET). These empirical indices were based on equations developed from a series of trials utilising controlled variation of climatic conditions. The physiological responses of human subjects were recorded and assessed resulting in data that enabled the development of psychometric charts (Parsons, 2003).

A better known and more recent adaptation is the Wet Bulb Globe Temperature (WBGT) index which was developed by Yaglou and Minard (1957) as a response to the growing number of heat stress casualties in military training exercises. WBGT limitations, particularly in relation to its response to humidity and air movement, have been well documented over the years (Budd, 2008, Bethea and Parsons, 2002, Rastogi et al., 1992, Ramsey and Chai, 1983), despite this its ease of use has led it to be one of the most used indices around the world (Di Corleto et al., 2014)(Di Corleto et al 2014).

A more recent evolution of the heat stress index has been the rational index which is based on the heat balance equation. These include, but are not limited to:

- Heat Stress Index (HSI) (Belding and Hatch, 1955)



- Thermal Work Limit (TWL) (Brake and Bates, 2002)
- Predicted Heat Strain (PHS) (ISO 7933, 2004)

These indices utilise the concept of thermal equilibrium, such that to avoid illness or injury, a thermal balance must be maintained. This heat balance equation is given by:

$$H = M \pm C \pm R \pm K - E$$

Where:

H = net heat accumulation by the body

M = metabolic heat output

C = convective heat input or loss (can be positive or negative)

R = radiant heat input or loss (can be positive or negative)

K = conductive input or loss (can be positive or negative)

E = evaporative cooling by sweating (can only be negative).

The rational indices readily provide the opportunity to assess the different contributors to the heat balance equation both environmentally and task specific. As a result, they have proven to be a valuable tool in the assessment of the impact of a broad range of environmental parameters and more importantly greater granularity in the assessment of the impact of controls.

However, this greater flexibility has come with a cost. In order to achieve this level of granularity there are numerous often complex equations that are required to be analysed. This has dissuaded health and safety practitioners who would often revert to the simpler indices.

The introduction of personal computers has alleviated the situation to some extent. This has also been assisted by the publication of computer script in Annex E of *ISO 7933:2004 Ergonomics of the thermal environment -- Analytical determination and interpretation of heat stress using calculation of the predicted heat strain (ISO: 7933:2004)*, to enable the use of the predicted heat strain model. Unfortunately, not all are fluent with the application of computer programming and limited programs have become available and usually associated with the purchase of monitoring equipment.

The proliferation and acceptance of mobile phone applications has introduced another potential avenue to further improve this situation. The feasibility of using a phone app in the management of heat stress has already been demonstrated with apps such as "Thermal Risk" presented at the 2014 AIOH conference (Gopaldasani et al., 2014). The challenge to produce a phone app that would enable the use of a rational index in the field by health and safety personnel was hence taken up by a project team at the University of Queensland.

### Overview of the Application

The index chosen to create the app was the predicted heat strain (PHS) index based on ISO 7933:2004. In addition to the justification provided above for the use of a rational heat strain index, a key reason for choosing the PHS index was the availability of the computer program script in Annex E, which could be used as a starting point for the development of the app. The formula comprises of several complex algorithms and component calculations, hence the advantage of the PHS app in simplifying the evaluation process.

The PHS app provides the following interpretive data:

- Predicted heat strain summaries for specified parameters/ scenarios
- Predicted heat strain graphs for specified parameters/ scenarios

- One, two and/ or three work phase analyses
- Predicted water loss values
- Custom reports based on summary information and graphs (which can be emailed)

As stated, PHS was primarily developed to increase the ability of occupational health and safety personnel to critically assess and analyse factors contributing to thermal strain and risk. Through modelling predicted heat strain in work environments and tasks, users are able to alter various parameters (e.g. air velocity, air temperature, rest cycles, etc.) to determine the resulting effect on employee thermal strain.

Rather than simply classifying a work task or environment as 'unsuitable' due to air temperature or other factors, personnel are encouraged to determine how. By utilising control measures influencing parameters of PHS (e.g. fans, air conditioning, radiant heat shielding, frequency of rest breaks, etc), contributors to heat strain may be reduced or controlled. This will enable steps to reduce risk to as low as reasonably practicable and work may continue through the application of practical solutions.

In addition to PHS, the application provides predictive information regarding water loss. Within summary information and graphs, values for predicted water loss over time are provided. These values provide information that may assist in reducing the risk of dehydration as employees can be provided with task-specific fluid intake guidance and values may indicate when the use of electrolyte supplements or re-hydrating products is required.

Note: that predicted water loss values are still under review and as such should not be used as definitive dehydration risk criteria.

Prior to utilising PHS, users require a thorough understanding of the task being analysed (e.g. duration, level of physical exertion, frequency of breaks etc.) and the thermal parameters of the environment the task is performed in (e.g. air and globe temperature, air velocity, humidity etc.).

Employee input should be sought to provide accurate knowledge of task details. Accurate monitoring data should be used to determine environmental parameters.

### **App Design and Build**

The app was designed and built by an American based computer software company - Stellar Science Ltd. Co. (<http://www.stellarscience.com/>). The app has been developed for Apple's iOS operating system as a first stage and is available for free download from the Apple App Store. It operates on both iPhones and iPads. There are plans to develop the app for use on other smart phone operating systems, including Android OS and Windows Phone OS. The Apple iOS system was selected for development first as the authors used Apple smart phones and the app could be tested on these devices.

Once the initial version of the app was developed by Stellar Science, the authors undertook a testing process using the Apple Xcode application for the design and testing of iOS applications and their own Apple iPhones. Testing aimed to examine the useability and accurate functioning of the application ensuring the output produced was correct based on the formulae provided in Annex E of ISO 7933:2004. Modifications were made to the application based on the testing process.

The app is currently available on the Apple App Store and the project is now moving into a user evaluation stage, which is planned for summer 2016/ 2017. The evaluation process will involve a number of organisations with personnel working in hot environments. End users, including on-site occupational health and safety personnel, will trial the use of the application and complete a user evaluation questionnaire.

### **App Appearance and Functioning**

The design of the user interface has been kept simple to ensure ease of use (refer to screen shots below). Feedback will be sought during the end user field trials planned for summer 2016/ 2017.

The app allows for the analysis of between one and three work phases (i.e. between one and three separate tasks and/or rest breaks undertaken by an individual or SEG during a work period). Each phase represents a change in task or environment. For example, a worker in phase one may spend 30 minutes working in 30°C, phase two rest for 10 minutes in 20°C and phase three working again in 30°C for 20 minutes.

The 'Phase View' and 'Model Variable' screens (see screen shots below) allow the user to enter data required to perform the PHS calculations. Values are entered in each phase (depending on the number of phases analysed, 1-3). Model variables (individual characteristics of height and weight) are pre-set to 1.8 metre height and 75kg weight. These parameters were used to validate the application against Annex F in ISO 7933:2004.

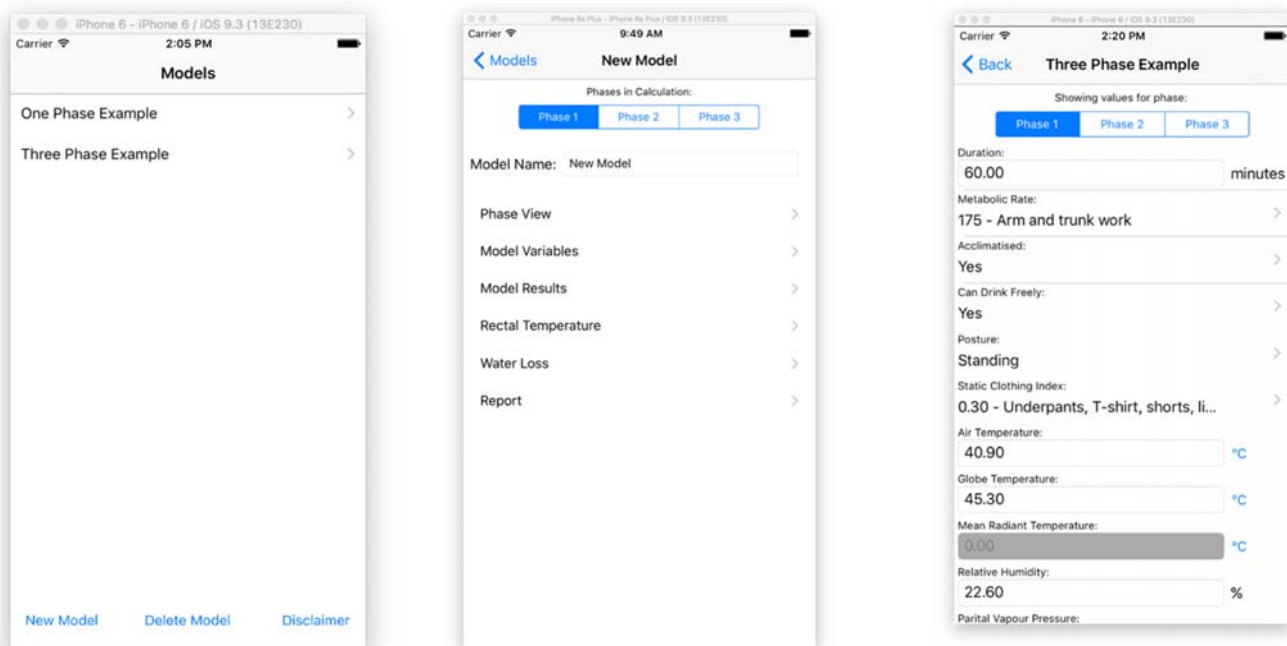
Each parameter field has defined value limits therefore data outside the ranges are automatically identified by the application. Users are notified when entered values lie outside the acceptable range but the application will still provide a calculation. Although the toggle fields are pre-populated with values, it is possible to type in site specific data for a calculation into the "New Value" box.

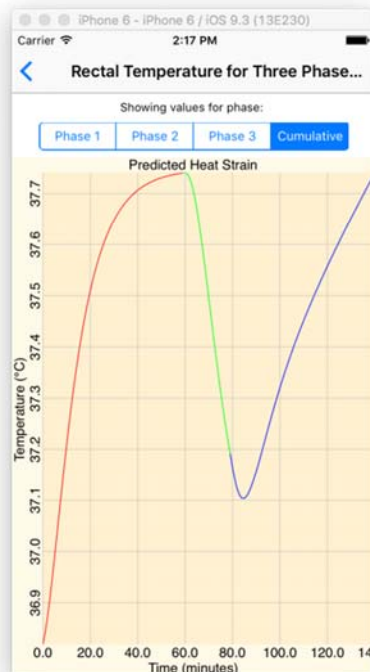
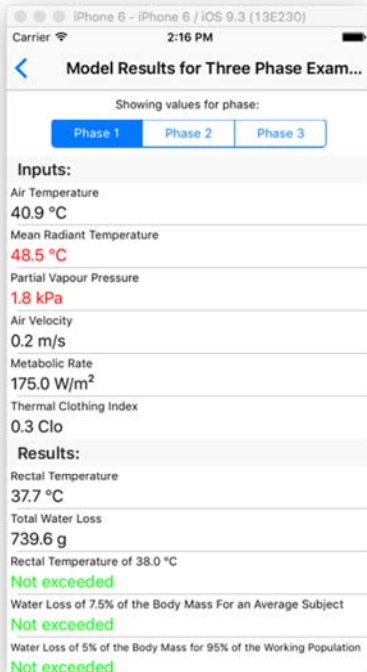
The Output screens (see screen shots below) provide four options for displaying calculated information, including;

- 'Model Results' screen– characteristics of the individual and environment used in the analysis and results of end temperature, water loss and time to exceed 38°C (for phase selected).
- 'Rectal Temperature' screen – graphical display of temperature increase for number of phases analysed.
- 'Water Loss' screen – graphical display of water loss over time for number of phases analysed.
- 'Report' screen – provides user ability to email a copy of the summary results information and graphs of predicted heat strain and water loss for analysed phases, individually or combined.

A user guide has been developed with step by step instructions on the use of the application and interpretation of the results and is available from the following website: <http://www.thethermalenvironment.com/the-predicted-heat-strain-mobile-application/>

### App Screen Shots:





## Conclusion

It is hoped that the PHS app provides field-based occupational health and safety practitioners and others with responsibility for managing workers in hot environments with a useful tool for the evaluation and management of heat stress risks. The app has only recently been completed and released and the authors would encourage interested professionals to download the app and trial its use. The authors look forward to any feedback on its useability and practical functionality and will be completing a formal evaluation of the use of the app in the field in summer 2016/ 2017. Any organisations interested in being involved in the user trials are encouraged to contact the authors.

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## CHARACTERIZING BLUE LIGHT EXPOSURE: METHODOLOGICAL CONSIDERATIONS AND PRELIMINARY RESULTS

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### ABSTRACT

Blue light is emitted from a variety of light sources and can damage the retinal photoreceptor cells, potentially exacerbating age-related macular degeneration. A widening array of bright energy-efficient sources are available, particularly white LED lamps. However, few systematic occupational health studies of blue light exposure and effects have been carried out. Assessment of blue light exposure in the occupational visual field (OVF) is complex and most hygienists are unfamiliar with the methodological issues. This exploratory study briefly examines published work on occupational blue light exposure and describes a methodology for a workplace case scenario.

A narrative literature review was undertaken using a hazard/exposure/control framework. Worker and public exposure to blue light in a nail salon setting were explored, in order to understand the various exposure factors, including directionality. Worst case and typical situations were considered. Integrated effective spectral radiances from the nail resin curing lamp in the occupational visual field were recorded with a spectroradiometer, modified with a customised imaging attachment.

This preliminary review indicates that most previous exposure studies have been screening in nature, based on source characteristics and simple task assessment. What is required now is the gathering of robust exposure data that will support future epidemiology and risk communication. A key consideration is the initial determination of the OVF, and whether or not blue light is present in a significant region of the field, for how long and at what radiance.

### 1. Introduction

Blue light is emitted from a variety of light sources and can damage retinal photoreceptor cells. This potentially exacerbates age-related macular degeneration (AMD) which is an increasing public health problem due to an ageing population. With an ageing workforce, AMD and blue light accelerated AMD may be an emerging issue in the workplace. A number of reviews have been published on the complex phototoxicity of blue light (Glickman, 2002; Algreve et al, 2006, Essilor, 2013). Photochemical damage to the retina and, in particular, within the macula, from non-coherent blue light sources is the outcome of interest for this paper. The investigation is set in the context of a widening availability and distribution of bright energy-efficient light sources particularly white LED lamps, and public concern about the possible health and ecological impacts.

The macula has the highest concentration of the sensory cells needed for visual acuity, and the movement of the eyeballs together with accommodation, naturally focuses the image of the object on this part of the retina for both eyes.

The damage is energy-related, and is similar in many ways to the effect of noise on the sensorineural hair cells. Microstructural damage to both the visual cones in the macula and auditory hair cells in the cochlea is evident at high levels of exposure. The threshold for irreversible damage from blue light is thought to be  $100 \text{ J/cm}^2$  or  $10^6 \text{ J/m}^2$ , based on animal experiments, with the most convincing evidence coming from experiments with monkeys trained to "read" Landolt ring charts (Moon et al, 1978). The figure of  $10^6 \text{ J/m}^2$  roughly approximates to looking directly at the sun for one minute, and interestingly would correspond to a noise level of 160 dB for 100 seconds.

More recent in vitro studies with isolated cells demonstrate cellular injury at total delivered energies as low as  $10^4 \text{ J/m}^2$  (Naknishi-Ueda et al, 2013; Zhang et al, 2015).

Since the energy delivered is actually the product of power by time, and there have been various such combinations in the photobiology studies to date, it is still unclear whether there is true reciprocity. i.e. short durations at high levels of blue light produces the same effect as long durations at low levels. The International Commission on Non-Ionizing Radiation Protection (2013) has promulgated guidelines on exposure limits on the assumption that the effects are cumulative. However, there have

been no exposure studies on animals for periods longer than a few months (Harwerth and Sperling, 1971). The only human epidemiology relates to fishermen, with crude estimates of sunlight and blue light exposure. In the Chesapeake Bay study, Taylor et al (1992) found an elevated risk of macular degeneration in the most exposed group.

Thus, according to current knowledge, the retinal photochemical injury may result from both short term exposure or long term exposure.

The ACGIH TLV for blue light exposure to normal eyes (non-aphakic) is based on ICNIRP guidelines (ACGIH, 2016; ICNIRP, 2013) summarised below.

$$L_B = \sum_{300}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda$$

$L_B$  : Effective radiance of blue light ( $W/m^2 \cdot sr$ )

$$D_B (L^{EL}_B) = L_B \cdot t = \sum_{300}^{700} L_\lambda \cdot t \cdot B(\lambda) \cdot \Delta\lambda$$

$D_B$  : Effective blue light radiance dose ( $J/m^2 \cdot sr$ )

$L_\lambda$  : Spectral radiance ( $W/m^2 \cdot sr \cdot nm$ )

$B(\lambda)$  : Blue light hazard function

$$L^{EL}_B = 100 W/m^2 \cdot sr$$

$\Delta\lambda$  : wavelength interval (nm)

$t$  : seconds

For viewing durations up to 10,000 seconds (2.8h) the effective radiance dose must not exceed  $10^6 J/m^2$ , and for periods greater than 10,000 seconds, the radiance limit is  $100 W/m^2 \cdot sr$ .

There are nuances in these limits, and aspects of practical measurement that are not immediately obvious for those seeking to assess workplace risk according to the guidelines.

For one thing, measurements should be conducted in the occupational visual field (Piccoli et al, 2004), with special consideration of the averaging angle of acceptance. According to ICNIRP, the acceptance averaging angle is time dependent (from 0.01 to 0.1 radians; 0.6 to 6 degrees). However, depending on the actual task and behaviour, a larger averaging angle can be used, provided that any spot on the retina is not exposed beyond the radiance dose limit. In terms of macular degeneration and maintenance of visual acuity, the key requirement is that this spot is the macula. Damage to the peripheral retina makes relatively little difference to visual function, as evidence by laser treatment for diabetic retinopathy. This means that the risk should be assessed on any blue light source in the visual field that may be imaged on the macula. The product of this particular radiance and the viewing time is what delimits risk for short exposures up to 2.8h, and this would apply to most real life exposure scenarios. If it were certain that the worker was constantly exposed to a blue light source within the acceptance angle for more than 2.8h, the radiance limit would apply.

In any case, the averaging is *assumed* to be an arithmetic mean.

The assessment of the blue light hazard requires the use of a radiometer, or preferably a spectroradiometer, rather than a photometer (lux or luminance meter). There is no simple or reliable conversion factor between photometric and radiometric quantities.

Given all of the abovementioned guidance, have there been any published exposure studies in a workplace setting?

This paper (1) reviews the literature on blue light exposure studies, (2) describes the application of the guidelines for a simple LED spot source, and (3) explores the exposure methodology for two commercially available nail curing lamps used in beauty salons. The aim is to highlight practical issues for hygienists.

## 2. Narrative literature review

The literature review was construed as a narrative review with systematic search.

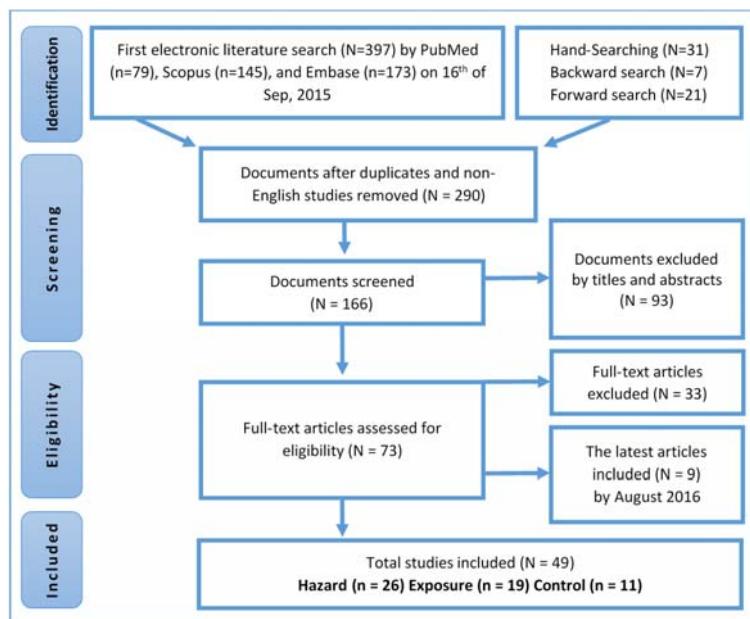
The literature, which is scattered, inter alia, in ophthalmology, health physics, occupational hygiene and medicine was narrated according to the themes of *hazard*, *exposure* and *control*. Only the theme of exposure is presented in this paper.

Search strategy: Three different bibliographic databases (PubMed, Scopus, and Embase) were used, and supplemented with forwards, backwards and hand-searching, including with the authors' names. The search was conducted from September 2015 to August 2016. The major search terms were "blue light", "retina", "light emitting diode", "metal halide" and "work". The initial logic grid is given in Table 1 below.

**Table 1.** Initial Logic Grid - PubMed, Scopus, and Embase

		Hazard	Exposure	Workplace
<b>PubMed</b>	Key Words	Retina	Blue Light, LED, Metal-halide	Occupations[MESH] Health Occupations[MESH] Occupational Groups[MESH] Work[MESH] Employment[MESH]
	First search	((retina*) AND ((blue light) AND (((LED) OR "light emitting diode") OR "metal halide")))) Results: <b>60</b> articles		
	Second search	(((retina*) AND blue light) AND (((Occupations[MESH] OR Health Occupations[MESH] OR Occupational Groups[MESH] OR Work[MESH] OR Employment[MESH]) Result: <b>19</b> articles		
<b>Scopus</b>	Key Words	Retina	Blue Light, LED, Metal-halide	Occupation* Work* Employ* Job*
	First search	(((retina*) AND ((blue light) AND (((led) OR "light emitting diode") OR "metal halide")))) Results: <b>126</b> articles		
	Second search	(((retina*) AND ((blue light) AND (((led) OR "light emitting diode") OR "metal halide")))) AND (TITLE-ABS-KEY(work* OR occupation* OR employ* OR job*)) Result: <b>19</b> articles		
<b>Embase</b>	Key Words	Retina	Blue Light, LED, Metal-halide	Occupation* Work* Employ* Job*
	First search	(((retina*) AND ((blue light) AND (((LED) OR "light emitting diode") OR "metal halide")))) Results: <b>86</b> articles		
	Second search	occupation* OR work* OR employ* OR job* AND retina* AND 'blue light' Result: <b>87</b> articles		

The yield is summarised in the PRISMA 2009 flow diagram - Figure 1 (Moher et al., 2010).



**Figure 1.** PRISMA Flow diagram relating to literature on blue light



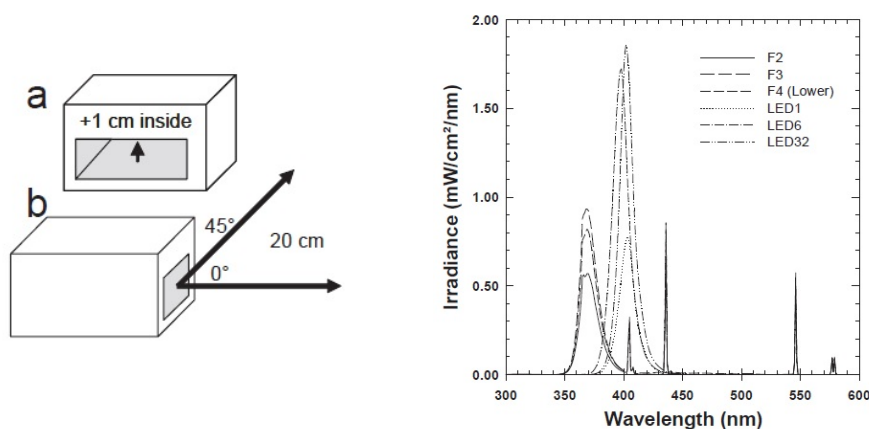
A literature table relating to the 19 exposure studies is given in the Appendix. The literature is presented in a ranked order of empirical relevance according to the following: Workplace exposure study, experimental simulation, or review paper (non-empirical). More than half of the studies were published in the last six years, showing its relatively new emergence as an issue. The leading research groups in the area are principally from the United States, Japan and Europe.

Workplace exposure studies should involve measurements of light sources in actual workplaces, taking note of worker, tasks, time and other important exposure factors relevant to blue light (e.g. directionality). As there is no commercially available personal exposure monitor for blue light in the visual field, such measurements in micro-environments of blue light are currently tedious, and there is a very limited literature.

Experimental simulations are more common and typically measure spectral radiance and/or irradiances of light sources under simulated workplace environments. These studies appear to be the majority of research in this area (12/19 articles), and only measure different light sources and report spectral radiance/irradiance with little interpretation for workplace and worker scenarios. They can be described as screening studies.

The types of light sources characterised for blue light emissions were mostly blue/white LEDs, compact fluorescent lights, metal-halide lights and welding arcs. The workplace scenarios included nail shops, dental clinics, medical fields, welding, and so on.

With regard to nail curing lamps, to be examined later, Dowdy and Sayre (2013) measured a number of commercial lamps at 20cm distances and at angles of 0°(direct) and 45°. The retinal risk of the nail curing lamps was deemed to be low, but it is evident that LED sources in these devices had emissions two times higher than fluorescent sources. (Figure 2)



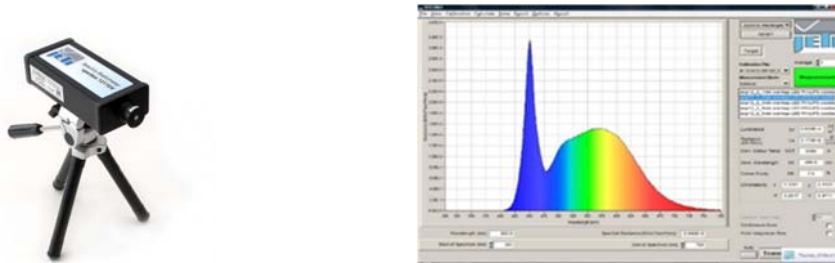
**Figure 2.** Measurement parameters and irradiance spectra of nail lamps by Dowdy and Sayre (2013)

### 3. Blue light radiance experiments

#### 3.1 Methods

##### 3.1.1 Instrumentation

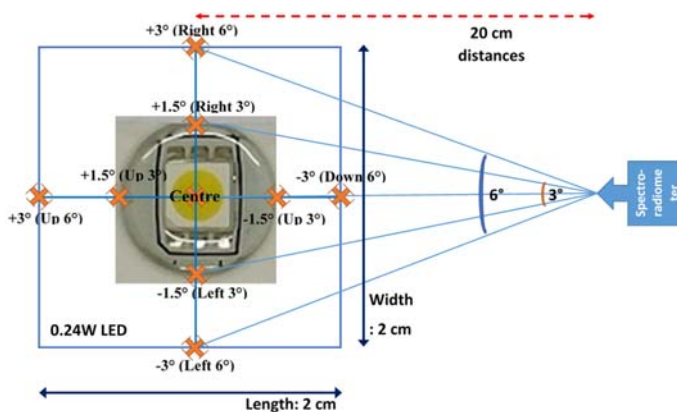
A spectroradiometer (Specbos 1211 UV, JETI Germany) was used in the experiments. (Figure 3)



**Figure 3.** The spectroradiometer used for experiments and an example power spectrum of a LED light source

### 3.1.2 Procedure for the assessment of point sources of blue light

Lights from commercially available LED strips were used (Jaycar Electronics). Single 0.24W spot sources were isolated from cool white and warm white LED strips. Measurements were conducted at several points across a 0.1 radian acceptance angle vertically and horizontally, as per ICNIRP guidance (Figure 4). A total of four experiments were conducted and the data were calculated by averaging values of each targets. The 20 cm distance is considered the worst case viewing distance by ICNIRP.



**Figure 4.** Measurement of radiances from an approximate point source across a 0.1 radian acceptance angle

### 3.1.3 Assessment of nail curing lamps

The nail salon curing lamps have UV sources for curing nail gel but also have significant blue light emission, as in Figure 1. A 36W LED professional nail curing lamp (Gelish 18G) and an 18W LED training lamp (Gelish 5-45) were used. The former had 18 x 2W LED in an array and the latter had an 18 x 1W LED array. See Figure 5.

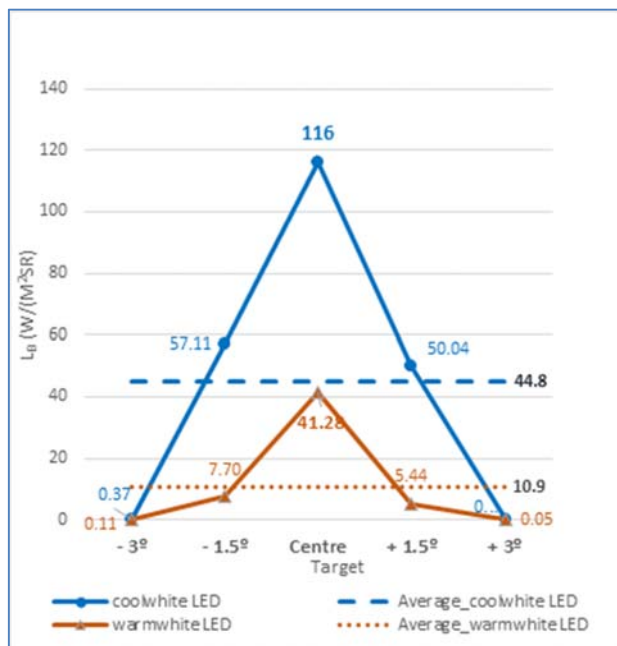


**Figure 5.** Nail curing lamps and experimental setup. Left to right (a) 36W UV curing lamp; (b) 18 W UV curing lamp and (c) example measurement setup.

### 3.2 Results

#### 3.2.1 Spot source assessment

Figure 6 shows the variation in effective blue light radiance. The highest radiance was the centre of the LED spot ( $L_b$  116  $W/m^2sr$  and 41  $W/m^2sr$ ). The radiance at the centre of the cool white LED exceeds the  $100W/m^2sr$  limit (>2.8 hr), but the average across 0.1 radians is 44.8. The maximum and average radiances of the warm white LED are within the limits.



**Figure 6.** The effective spectral radiance of two 0.24W LEDs at 20cm distance. One dimension only.

#### 3.2.2 Assessment of nail curing light exposure

Before the simulation study, observations were conducted to find out actual blue light exposure duration, distances and directionality from a nail lamp for nail technicians and customers in a series of nail salons. A total of seven nail salons located in Adelaide (4 salons on weekend, the busiest time, 1 salon in the daytime, and 2 salons in the afternoon) were visited by one or two researchers from April to July 2016. Each salon was observed for information on average numbers of customers, curing time or environmental conditions for around 30 min to 1.5 hr. Most salons were using LED nail curing lamps with only one place using a fluorescent type lamp. Through the observations, the average nail curing time was 30 to 45 sec per one nail top coat by a LED nail lamp and the fluorescent lamp was used for over 120 sec. On average, customers have had 4 or 5 top coats per one hand and it took 20 to 30 min for a nail curing service. Therefore, the average typical curing times were around 300 to 800 sec. (Table 2)

For pedicure services, it takes for around 1 hour and it is longer than nail services. However, they used essentially the same method as with the manicure (e.g. same frequency for top coats of the manicure).

**Table 2.** General information from the observations in seven nail salons

ID. #	Observation	Number of Customers	Curing time(s)/Nail lamp	Top Coat Frequency	Average typical curing time* (s)	Type of Nail lamp
Nail salon 1	Daytime	4	45s	4	360	LED
Nail salon 2	After 5pm	7	40s	4	320	LED
Nail salon 3	After 5pm	6	30s	5	300	LED
Nail salon 4	Weekend	Over 15	40s	5	400	LED
Nail salon 5	Weekend	Over 15	Over 120s	4	800	Fluorescent
Nail salon 6	Weekend	Over 10	45s	4	360	LED
Nail salon 7	Weekend	Over 20	40s	4	320	LED

\* Average typical nail curing time (s) × top coat frequency × 2 hands

There were two types of nail care services in the shops. Generally, customers come in for a manicure or pedicure, get 4 to 5 top coats per one hand or foot. Some customers also have special nail art services. In some cases, the customers may be exposed to a nail lamp for a much longer time than a typical case. Similarly, a nail technician may make fancy hand-made false nails for customers and the technician is likely to be exposed to a nail lamp for extended periods.

Table 3 summarised the observational in the nail salons. The estimated exposure durations for a customer and a nail technician are typically 72 sec and 360 sec and as the worst estimates are 900 s for a customer and 2,700 s for a technician.

**Table 3.** Estimated direct blue light viewing times for customers and technicians

		Customer	Nail technician
Typical case	Total duration	72 seconds	360 seconds
Worst case	Total duration	900 seconds	2700 seconds

According to the field observations, the actual distance between a nail lamp and a customer/technician in a nail shop was about 30 to 40 cm. There were no significant blue light sources in the salon other than the nail lamps.

Table 4 presents the outcomes from the simulations with the two types of LED nail lamps. Radiances, at 45 degrees, were measured at various points along the base – the zone of normal eye fixation, rather than at any individual LED light source.

The data from Table 4 show that the radiances and radiance doses are well below the current limits, even in the worst case. That is, for viewing durations up to 10,000 seconds (2.8h) the effective radiance dose must not exceed  $10^6$  J/m<sup>2</sup>, and for periods greater than 10,000 seconds, the radiance limit is 100 W/m<sup>2</sup>sr.

**Table 4.** The effective radiances ( $L_B$ ) and the daily estimated effective radiance dose ( $D_B$ ) for nail technicians

Nail lamp	Target	$L_B$ (W/m <sup>2</sup> sr)	$D_B$ (J/m <sup>2</sup> sr)	
			Typical case	Worst case
36W LED nail lamp (2W×18LEDs)	Centre	9.17		
	Right corner	2.26	2174	16308
	Left corner	6.68		
	Average	<b>6.04</b>		
18W LED nail lamp (1W×18LEDs)	Centre	0.23		
	Right corner	1.96	1062	7965
	Left corner	6.65		
	Average	<b>2.95</b>		

#### 4. Conclusions and recommendations

The literature review indicates that most previous exposure studies have been screening in nature, based on source characteristics and simplistic worst case task assessment. What is required now is the gathering of more fine grained and extensive exposure data that will support future epidemiology and risk communication. A key consideration is the initial determination of the OVF, and then whether or not blue light is present, for how long and at what radiance.

Noise and blue light are similar hazards with respect sensorineural degradation, and so it could be argued that intense blue light sources in the visual field should be treated in the same way as loud noise.

Owing to the potential variability of viewing times and radiances, and the uncertainties associated with thresholds, longitudinal epidemiological studies on populations exposed to significant blue light sources in the visual field should be conducted. Finally, moving away from blue-rich commercial lighting to warmer lighting may be an appropriate precaution.

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**Appendix. Literature Table – Studies of Exposure to Blue Light**

Study type	Citation	Study design	Main findings
Workplace Exposure Studies	PINTO, I., BOGI, A., PICCIOLO, F., STACCHINI, N., BUONOCORE, G. & BELLINI, C. V. 2015. Blue Light and Ultraviolet Radiation Exposure from Infant Phototherapy Equipment. <i>J Occup Environ Hyg</i> , 12, 603-10.	<ul style="list-style-type: none"> <li>• Light sources: 12 different phototherapy equipment items</li> <li>• Work-related: Medical personnel</li> <li>• Standard: ICNIRP</li> </ul>	The potential risk from UV or blue light of phototherapy equipment depends on the types of lamps. Some light sources from the equipment exceeded the exposure limitation.
	Price RB, Labrie D, Bruzell EM, Sliney DH, Strassler HE. The dental curing light: A potential health risk. <i>Journal of occupational and environmental hygiene</i> . 2016; 13(8):639-46. Epub 2016/03/24.	<ul style="list-style-type: none"> <li>• Five magnification loupes</li> <li>• Light sources: Blue-light emitting curing unit (LCU)</li> <li>• Work-related: Dental clinician</li> <li>• Standard: ACGIH</li> </ul>	Dental clinicians without loupes are at a greater risk for ocular damage from blue LCU exposure than those with loupes. However loupes increase the amount of irradiance due to magnification of the light on the retina.
	BRIGGS, T. P., PARKER, C., MILLER, R. A., PHILLIPS, P. M., DEAN, F. M. & DAVEY, C. C. 1992. Blue light emission from urological equipment. Can it damage the eyes? <i>British Journal of Urology</i> , 70, 492-495.	<ul style="list-style-type: none"> <li>• Light sources: Quartz halogen, metal halide, xenon light and cables</li> <li>• Measuring device: Spectrometer</li> <li>• Work-related: Urologist</li> <li>• Standard: ACGIH</li> </ul>	Long term exposure to blue light equipment for therapy may be harmful to the urologists' eye and protective filters for equipment are recommended.
Experimental Simulations	O'HAGAN, J. B., KHAZOVA, M. & PRICE, L. L. 2016. Low-energy light bulbs, computers, tablets and the blue light hazard. <i>Eye (Lond)</i> , 30, 230-3.	<ul style="list-style-type: none"> <li>• Light sources: CFL, LED, computer screens, tablet computers, laptops, and smartphones</li> <li>• Work-related: Public</li> <li>• Standard: ICNIRP</li> </ul>	There was no risk on the eyes from low-energy light bulbs exposure.
	NECZ, P. P. & BAKOS, J. 2014. Photobiological safety of the recently introduced energy efficient household lamps. <i>Int J Occup Med Environ Health</i> , 27, 1036-42.	<ul style="list-style-type: none"> <li>• Light sources: 19 CFLs, 11 Halogens, 4 LEDs</li> <li>• Measuring device: Spectrometer</li> <li>• Work-related: Public</li> <li>• Standard: ICNIRP</li> </ul>	The typical household artificial light sources did not exceed the threshold limit values.
	SLINEY, D. H., STACK, C., SCHNUELLE, D. & PARKINSON, J. 2014. Optical safety of comparative theater projectors. <i>Health Phys</i> , 106, 353-64.	<ul style="list-style-type: none"> <li>• Light sources: Arc projector and Digital laser-based projector</li> <li>• Work-related: Audience in a movie theatre</li> <li>• Standard: ICNIRP/ACGIH</li> </ul>	Not significant unless audiences look at the projector directly.
	DOWDY, J. C. & SAYRE, R. M. 2013. Photobiological safety evaluation of UV nail lamps. <i>Photochem Photobiol</i> , 89, 961-7.	<ul style="list-style-type: none"> <li>• Light sources: 6 UV nail lamps</li> <li>• Measuring the exposure limit</li> <li>• Work-related: Nail lamp user</li> <li>• Standard: ANSI/IESNA RP-27.1-05 &amp; 27.3-07</li> </ul>	The hazard level on skin and eye from nail lamps was evaluated with a spectroradiometer. The retinal photochemical blue light hazard was not significant.
	MOU, T. & PENG, Z. Measurement and standardization of eye safety for optical radiation of LED products. <i>Proceedings of SPIE - The International Society for Optical Engineering</i> , 2013.	<ul style="list-style-type: none"> <li>• Light sources: LED with illumination of 500lx</li> <li>• Measuring device: Spectrometer</li> <li>• Work-related: Non work</li> <li>• Standard: IEC 60825/ IEC 62471</li> </ul>	The optical radiation safety assessment from various light sources can be measured by the retina radiance meter.

	<p>OKUNO, T., OJIMA, J. &amp; SAITO, H. 2010. Blue-light hazard from CO2 arc welding of mild steel. <i>Ann Occup Hyg</i>, 54, 293-8.</p>	<ul style="list-style-type: none"> <li>• Light sources: welding torch (CO2 arc welding)</li> <li>• Measuring device: welding robot</li> <li>• Duration of exposure: 120A to 480A at intervals 40A</li> <li>• Work-related: Welder</li> <li>• Standard: ACGIH</li> </ul>	<p>Every welders and welding related workers can have serious retinal damage and the protective eye equipment is significantly suggested.</p>
	<p>OKUNO, T., SAITO, H. &amp; OJIMA, J. 2002. Evaluation of blue-light hazards from various light sources. <i>Developments in Ophthalmology</i>, 35, 104-112.</p>	<ul style="list-style-type: none"> <li>• Light sources: various light sources</li> <li>• Measuring device: Spectrometer</li> <li>• Duration of exposure: 8-120 min exposure to blue and red light</li> <li>• Work-related: Welder</li> <li>• Standard: ACGIH</li> </ul>	<p>Evaluation of blue light hazards and measurement of permissible exposure time per day. High-intensity light sources can cause greater retinal damage than low-intensity sources.</p>
	<p>HIETANEN, M. T. K. &amp; HOIKKALA, M. J. 1990. Ultraviolet radiation and blue light from photofloods in television studios and theaters. <i>Health Physics</i>, 59, 193-198.</p>	<ul style="list-style-type: none"> <li>• Light sources: 11 photofloods(Metal halide &amp; Halogen)</li> <li>• Work-related: Photographer/Audience</li> <li>• Standard: ACGIH</li> </ul>	<p>Photofloods can be damaged to the retina in TV studios and theatres and direct exposure of the light should be limited to a few minutes per day to avoid potential retinal hazards.</p>
<b>Experimental Simulation</b>	<p>FOSTER, C. D., SATROM, K. D. &amp; MORRIS, M. A. 1988. Potential retinal hazards of dental visible-light resin curing units. <i>Biomedical Sciences Instrumentation</i>, 24, 251-257.</p>	<ul style="list-style-type: none"> <li>• Light sources: 11 visible-light resin curing units</li> <li>• Work-related: Dental clinician</li> <li>• Standard: ACGIH</li> </ul>	<p>The study was conducted to measure the permissible exposure for the potential retinal hazards from dental composite resin curing units and the maximum permissible exposure time values(<math>t_{MAX}</math>) was ranged from 2.4 to 16.4 min daily.</p>
	<p>MOSELEY, H., STRANG, R. &amp; MACDONALD, I. 1987. Evaluation of the risk associated with the use of blue light polymerizing sources. <i>Journal of Dentistry</i>, 15, 12-15.</p>	<ul style="list-style-type: none"> <li>• Light sources: 4 blue light curing units</li> <li>• Measuring exposure time by ACGIH formula Data measurement time: between 12 and 30 min</li> <li>• Work-related: Dental clinician</li> <li>• Standard: ACGIH</li> </ul>	<p>The study was conducted to measure the permissible exposure for the potential retinal hazards from dental composite resin curing units and <math>t_{MAX}</math> ranged from 40 to 100 min daily. Protective eyewear was recommended.</p>
	<p>SATROM, K. D., MORRIS, M. A. &amp; CRIGGER, L. P. 1987. Potential Retinal Hazards of Visible-light Photopolymerization Units. <i>Journal of Dental Research</i>, 66, 731-736.</p>	<ul style="list-style-type: none"> <li>• Light sources: 11 visible-light photopolymerization units (370-730nm)</li> <li>• Standard: ACGIH</li> </ul>	<p>Maximum permissible exposure for the blue light hazards was assessed by ACGIH criteria.</p>
	<p>OKUNO, T. 1986. Measurement of blue-light effective radiance of welding arcs. <i>Industrial Health</i>, 24, 213-226.</p>	<ul style="list-style-type: none"> <li>• Light sources: 14 different welding conditions</li> <li>• Measuring exposure: 6 seconds</li> <li>• Work-related: Welder</li> <li>• Standard: ACGIH</li> </ul>	<p>This study was conducted to determine the permissible exposure to blue light for protecting welders' retina hazards by the ACGIH's standard</p>
<b>Other empirical studies</b>	<p>COLEMAN, A., FEDELE, F., KHAZOVA, M., FREEMAN, P. &amp; SARKANY, R. 2010. A survey of the optical hazards associated with hospital light sources with reference to the Control of Artificial Optical Radiation at Work Regulations 2010. <i>Journal of Radiological Protection</i>, 30, 469-489.</p>	<ul style="list-style-type: none"> <li>• Light sources: hospital light sources</li> <li>• Work-related: Medical personnel</li> <li>• Standard: ICNIRP</li> </ul>	<p>The survey covered examples of office lighting, operating theatre lighting, examination lamps, and sources for ultraviolet phototherapy and visible phototherapies, including photodynamic therapy and neonatal blue-light therapy.</p>
	<p>CHRISTENSEN, T. 2005. Protection against ultraviolet and visible radiation use in medical therapy. <i>Perinatology</i>, 7, 43-48.</p>	<ul style="list-style-type: none"> <li>• Light sources: UV and Visible radiation sources</li> <li>• Work-related: Medical personnel</li> <li>• Standard:</li> </ul>	<p>The survey was compared to the previous hospitals' survey of the medical technical equipment regarding artificial light sources. The values of irradiance from the sources are increasing more than in previous years.</p>



<b>Review Paper</b>	<p>LANG, D. Blue enhanced light sources: Opportunities and risks. Proceedings of SPIE - The International Society for Optical Engineering, 2012.</p>	<ul style="list-style-type: none"> <li>• Review paper</li> <li>• Light sources: various artificial light sources</li> <li>• Work-related: Public</li> </ul>	<p>It shows beneficial effects as well as potential hazards of blue light as a health risk factor. Even though the high blue light sources can be damaged in the retina, blue light hazards can be reduced by indirect lighting.</p>
	<p>COWAN JR, C. L. 1992. Light hazards in the operating room. Journal of the National Medical Association, 84, 425-429.</p>	<ul style="list-style-type: none"> <li>• Review paper</li> <li>• Various devices in the operating room</li> <li>• Work-related: Medical personnel</li> </ul>	<p>Exposures to devices emitting intense light such as operating microscopes, the indirect ophthalmoscopes, and endoilluminators should be limited.</p>

## NOISE RISKS – THE CASE FOR NOISE CONTROL BEYOND HEARING CONSERVTION

*Stephen Lloyd*

WoodGroupKenny

### ABSTRACT

The impact on employees of working in high noise, in terms of the risk of noise induced hearing loss, is well understood, with prescribed limits applied in many countries around the world. However, what is less well understood is the additional impact that noise has on employee fatigue, safety, productivity and even long-term health. These effects not only present additional risks to business, but also represent a potentially significant, if unquantified, cost burden. Both new and established research shows a clear link between noise and these effects, thus providing a previously unconsidered rationale for noise mitigation in the workplace.

As businesses are driven to improve return on investment, presenting the case for noise control can be difficult if the justification is limited to hearing conservation. However, a much more compelling case can be made when considering the often overlooked costs of noise in relation to safety, productivity and health.

## ASSESSMENT OF THE EFFECTS OF VARIOUS PERSONAL PROTECTIVE EQUIPMENT (PPE) AND APPAREL IN THE PERFORMANCE OF EARMUFFS

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### ABSTRACT

Hearing protectors have been used extensively to mitigate the risk of occupational noise-induced hearing loss (ONHL) but the rate of workers compensation claims for noise-induced hearing loss in Australia has remained relatively stable in the period of 2006 to 2010. One factor which may be related to this unchanged rate of ONHL is that workers may not be receiving the expected level of protection from their hearing protectors.

Earmuffs are frequently selected as the preferred hearing protector due to their robustness and ease of use. However, earmuffs are often worn with other PPE, where compatibility issues between PPE are commonly reported.

The study investigated the effects of a range of PPE and apparel on the level of protection achieved by headband earmuffs (3M™ Peltor™ X4A and X5A). It also evaluated the influence of different models of industrial safety helmets in the performance of helmet mounted earmuffs (3M X4P3 and X5P3). Measurements of Personal Attenuation Rating (PAR) were taken for 28 test subjects with the use of field microphone-in-real-ear (F-MIRE) system. Each person was tested with combinations of headband earmuffs and various PPE including safety glasses, goggles, reusable respirator, nonwoven hood, hairnet, fleece beanie, golf style cap and three models of industrial helmets.

The paired t-test revealed a reduction in PAR of up to 7 dB when safety glasses were worn with headband earmuffs. The straps and buckles of the reusable respirator also affected the PAR by up to 8 dB. The use of a fleece beanie under the headband earmuff resulted in a reduction of 12 dB of attenuation. The PARs achieved for the helmet mounted earmuffs were not affected by the differences between the models of industrial safety helmets. Understanding the significance of the effects of other PPE in the level of protection provided by earmuffs can assist end users and occupational health and safety professionals in the selection of the most appropriate hearing protector.

### INTRODUCTION

Assessing the level of protection provided by hearing protection devices (HPDs) has historically been done by measurement of the attenuation provided by a specific HPD using the real ear attenuation at threshold (REAT) methodology as the “gold standard.” This process uses a panel of test subjects and measures the occluded and unoccluded noise levels detected by each member of the panel across a range of frequencies. The pooled data are then used to calculate a representative value for the overall attenuation provided by the device. In the case of AS/NZS 1270, the value is called the Sound Level Conversion 80 or SLC<sub>80</sub> – a calculated value indicating the attenuation expected to be achieved by at least ~80% of the test population wearing the tested HPD in the same manner as did the test subjects. All of this testing has taken place in specialised acoustic rooms with appropriate noise emission and measurement equipment.

There are many studies that show that this lab-acquired REAT data often gives an inadequate prediction of real-world attenuation for groups of users. Even though AS/NZS 1270 test method provides a somewhat better group indication, it still doesn't give a good indication for the individual attenuation with potential variations of 20dB or more (Gauger & Berger 2004).

Recent advances in miniature microphones and computer software are now allowing various methods to be used in the field, without the expense, size and bulk of the physical room and equipment needed for traditional REAT testing. Variants of this method such as use of circumaural earphones and loudness balancing are now possible in the field. Another approach is called field microphone-in-real-ear (F-MIRE), and this methodology is used by the 3M™ E-A-Rfit™ system. This objective method uses small dual-element microphones with associated proprietary technology and probed earplugs or ear muffs to measure the

Personal Attenuation Rating (PAR) of the individual test subject using the HPD, all in a very short timeframe (<10 sec per measurement).

The PAR for specific ear muffs can thus be quickly determined on an individual in this way. In the real world, however, use of ear muffs is often associated with simultaneous use of other personal protective equipment or apparel that can have a degrading effect on the PAR achieved. Equipment like safety glasses, goggles, hair nets, caps and beanies can all interfere to some degree with the seal of the ear muffs on the head of the wearer. Helmet-mounted ear muffs are another case, with the size of the helmet and the quality of the seal of the ear muff cushions on an individual's head both potentially having an effect on the PAR achieved.

This study looks at the effect of several different types of PPE and apparel on the PAR achieved by a panel of test subjects when wearing either the 3M™ Peltor™ X4A or the X5A ear muffs with a headband configuration. The PAR was also measured when using the 3M™ Peltor™ X4P3E and X5P3E helmet mounted ear muffs fitted to three different industrial safety helmets to investigate the effect on the PAR between individuals and with different helmets.

## METHOD

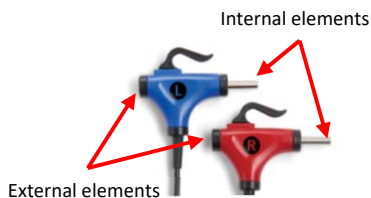
A total of 28 adults, including 12 female and 16 males, were tested with a set of PPE and apparel as shown in Table 1. The test subjects were given brief verbal and visual instructions on how to properly fit and adjust the earmuffs prior to the beginning of the tests but they were not assisted by the testers during the actual tests. All subjects were office-based employees and most of them had little or no previous experience with the use of earmuffs. Each subject was tested with four models of earmuffs starting with the headband models X4A and X5A, followed by the helmet-mounted models X4P3 and X5P3. The headband earmuffs X4A and X5A were tested with the same set of PPE or apparel and the helmet-mounted earmuffs X4P3 and X5P3 were tested with three different brands of industrial safety helmets.

**Table 1: Combinations of 3M Earmuffs and PPE/Apparel**

Category	Devices description	Earmuffs	
Respirator	3M™ 7500 half face piece	X4A	X5A
Eyewear	3M™ SecureFit™ (thin frame)	X4A	X5A
	3M™ SX 2000™ (medium frame)	X4A	X5A
	3M™ Virtua™ (thick frame)	X4A	X5A
	3M™ Lexa™ (thick adjustable frame)	X4A	X5A
	3M™ Fahrenheit™ goggles (thick straps)	X4A	X5A
Apparel	Nonwoven hood (white)	X4A	X5A
	Hairnet (blue)	X4A	X5A
	Golf style cap	X4A	X5A
	Fleece Beanie	X4A	X5A
Combinations	7500 + SecureFit™ + hairnet	X4A	X5A
	7500 + SecureFit™	X4A	X5A
	7500 + Fahrenheit™	X4A	X5A
Industrial Safety Helmets	3M™ G2000 (P3K attachment)	X4P3	X5P3
	MSA V-Guard (P3E attachment)	X4P3	X5P3
	Protector HC600 (P3G attachment)	X4P3	X5P3

The test method utilised for the assessment of the earmuffs is F-MIRE, as mentioned above. F-MIRE is also referred as objective fit test method as it doesn't rely on measuring the person's hearing thresholds. The 3M™ EARfit™ Dual Ear Validation system used in this study is one example of a commercially available F-MIRE system. It comprises a pair of dual-element microphones illustrated in **Error! Reference source not found..** The external microphones measure the test noise emitted by a standard speaker while the internal microphone measures the noise underneath the earmuffs. The dual-element microphones were connected to ear cushion probes that were specifically designed to fit the 3M X-Series earmuffs as illustrated in **Error!**

**Reference source not found.** and Figure 3. Measurements of the PARs were taken using EARfit™ software v5.1.14.0 in a laboratory environment with no particular attention to the background noise.



**Figure 1: 3M™ EARfit™ Dual-Element microphones**



**Figure 2: 3M™ Peltor™ X-Series earmuffs test probes**



**Figure 3: Dual-element microphone attached to the earmuff test probe**

The F-MIRE results for all earmuffs were compared with their respective AS/NZS 1270 REAT results. Paired t-tests were used to analyse the changes in PARs when the earmuffs were worn with other PPE and apparel. Finally, analysis of variance (ANOVA) was utilised to determine whether the differences in the design of the industrial safety helmets assessed in this study have any significant influence in the performance of the X4P3 and X5P3 earmuffs.

## RESULTS AND DISCUSSIONS

### *Comparison between AS/NZS 1270 REAT and F-MIRE*

The F-MIRE results were compared with existing AS/NZS 1270 test reports provided by Michael & Associates Inc., an independent laboratory accredited by the American Association for Laboratory Accreditation (A2LA) to conduct attenuation tests according to AS/NZS 1270. This test method requires the selection of test subjects inexperienced in the use of hearing protectors and does not allow them to receive any assistance for the correct fitting of hearing protectors apart from what is provided on the packaging instructions.

Considerations should be made when comparing REAT  $SLC_{80}$  and F-MIRE PAR as they have their own variabilities and computational differences. The uncertainty of the PAR value is a result of three factors: variation within subject fitting, differences between REAT and F-MIRE test methods and noise spectrum uncertainty. However, PAR has been developed to estimate individual attenuation ratings and thus it doesn't take into account variations between subjects as  $SLC_{80}$  does. Having said that, one standard deviation was subtracted from the  $PAR_{50}$  to encompass the variability between subjects and compare  $PAR_{84}$  with  $SLC_{80}$ . The  $PAR_{84}$  values for the assessed earmuffs is listed in the middle column of Table 2.

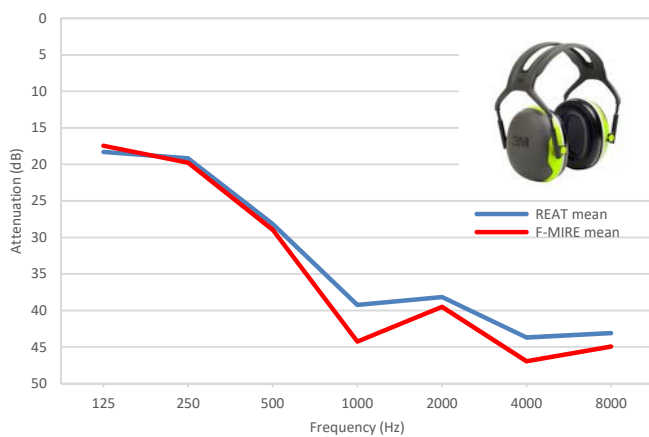
$SLC_{80}$  and PAR values are also derived from different noise spectra and weightings. Whilst PAR values are derived from the NIOSH 100 noise spectra and can be directly subtracted from A-weighted sound levels,  $SLC_{80}$  is derived from the South Australia 615 noise spectra and is intended for subtraction from C-weighted sound levels. The median C-A value for industrial noises is about 2.5 dB, so that much should be subtracted from the  $SLC_{80}$  when it is used with dBA (Waugh R, 1976 and 1984). The  $SLC_{80}$  (dBA) values are listed in the right column of Table 2.

The differences observed between  $PAR_{84}$  and  $SLC_{80}$  values varied between 1-5 dB. This is a reasonable range of variation considering the differences in the REAT and F-MIRE subject test panels. The PAR values could also have been affected by the learning factor. Some test subjects might have improved their fitting techniques over the tests sequence, achieving higher PAR results. The learning factor could have affected X5A and X5P3 more noticeably as these earmuffs were tested after X4 and X4P3, respectively.

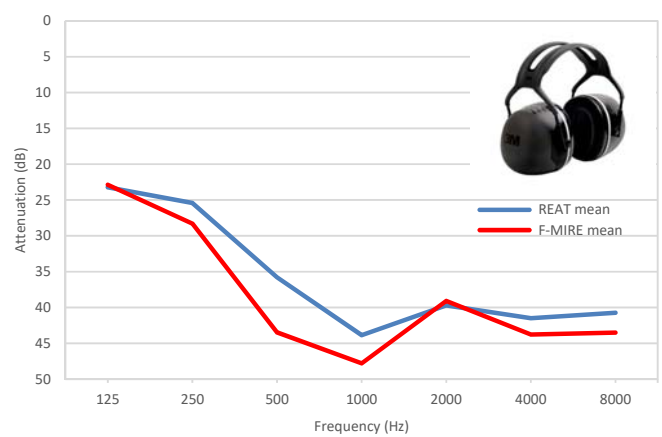
**Table 2: Comparison between REAT SLC<sub>80</sub> and F-MIRE PAR<sub>84</sub> ratings**

Earmuff model	F-MIRE PAR <sub>84</sub> (dB)	REAT SLC <sub>80</sub> (dBA)
X4A headband	30	29
X5A headband	36	31
X4P3 helmet mounted	24	25
X5P3 helmet mounted	34	29

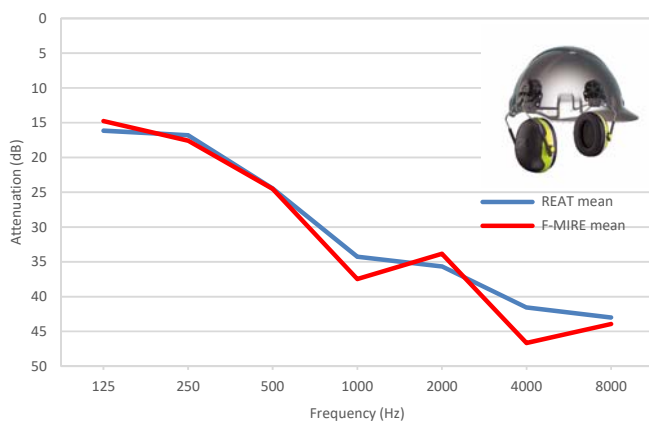
Figure 4 to Figure 7 show the overall one-third octave-band (OB) data presented at OB centre frequencies for REAT and F-MIRE for the earmuffs without any interfering PPE. In these charts, mean values were used for each frequency in order to establish a direct comparison between the average OB data from both test methods. The charts in Figure 4 to Figure 7, showed similar trends for REAT and F-MIRE for all earmuffs with the largest discrepancies being 10 dB at 4000 Hz for X5P3, 8 dB at 500 Hz for X5A, 6 dB at 4000Hz for X4P3 and 5 dB at 1000 Hz for X4A. Having said that, the individual frequency variations observed in the OB analysis did not affect the calculation of the overall PAR and the ability of F-MIRE to predict REAT values.



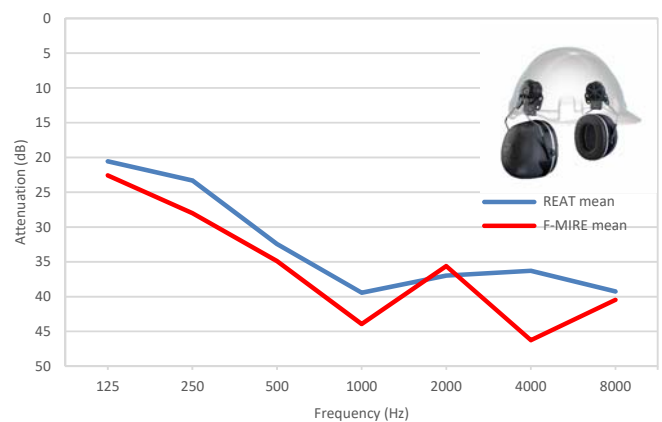
**Figure 4: Comparison between REAT and F-MIRE for X4A earmuff**



**Figure 5: Comparison between REAT and F-MIRE for X5A earmuff**



**Figure 6: Comparison between REAT and F-MIRE for X4P3 earmuff**



**Figure 7: Comparison between REAT and F-MIRE for X5P3 earmuff**

In addition to the OB analysis, REAT and F-MIRE individual attenuation data were plotted against each other as showed in Figure 8 in order to evaluate the equivalency of these two test methods. Each model of earmuff was tested by 16 subjects totalising 64 data points in the chart. The bold line crossing the centre of the chart represents a perfect relationship between REAT and F-MIRE where the difference between them is zero, whilst the dashed lines at  $\pm 10$  dB indicate the limits where the F-MIRE would be divergent from REAT by more than 10 dB. When all data were analysed together, the cluster was slightly off set above the  $x=y$  line which could be associated on differences between the subject test panels utilised for REAT and F-MIRE. Further investigation would be necessary for a more definitive explanation for this slight under prediction trend. Having said that, 94% of the values fell within the specified range of  $\pm 10$  dB, demonstrating consistency with Berger et al, (2011), where the authors obtained 97%-98% of a total of 80 data for earplugs within the same specified range.

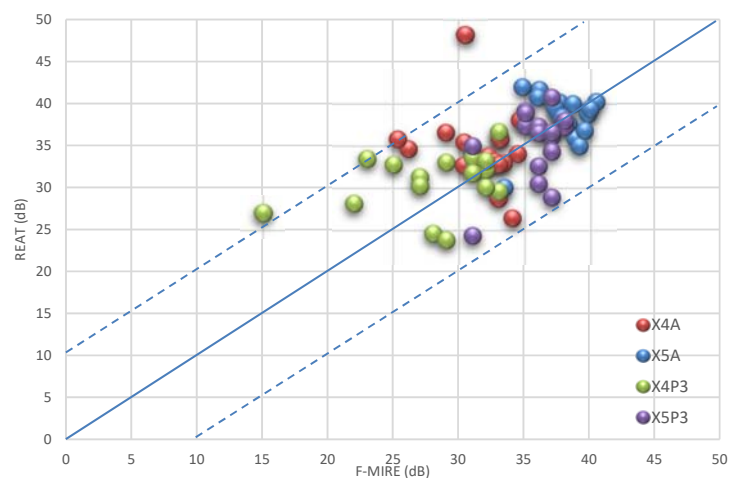


Figure 8: Scatter Plot chart for F-MIRE versus REAT for four models of earmuff

### Effects of Eyewear

It is well known that the use of safety glasses and goggles are likely to affect the noise attenuation when worn with earmuff. Previous investigation have been conducted by Lemstad and Kluge (2004) utilised F-MIRE and reported significant increase (5-8 dB) in the attenuation provided by the earmuffs when the workers were asked to remove their safety glasses. Brueck L (2009) utilised microphone in real ear (MIRE) to measure SNR on four subjects wearing safety glasses with earmuffs. Brueck found differences between 3.5-8.5 dB for safety glasses and as much as 10 dB of reduction for large goggles. More recently, Wells et al. (2013) used REAT on ten subjects and reported loss in the NRR between 2-11 dB depending on the thickness of the temple frames and the model of the earmuff.

The charts on Figure 9 and Figure 10 shows the degraded PAR values for four models of safety glasses and one goggles. The thickness of the safety glasses frame have a clear influence in the reduction of the PAR. 3M SecureFit has the slimmest design of all and showed the least impact in the PAR (3 dB) for both X4A and X5A earmuffs. On the other hand, 3M Lexa, with a thick adjustable frame, presented reductions of 7 dB and 6dB for X4A and X5A respectively. The effects observed for 3M Fahrenheit goggles were 6 dB and 5 dB for X4A and X5A which was no different from other safety glasses with thick frames.

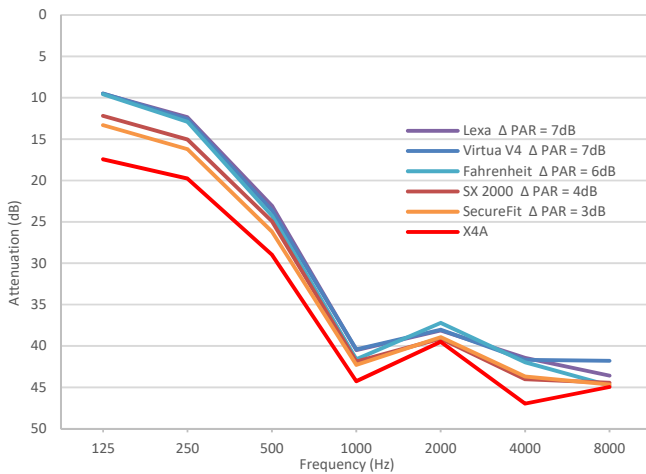


Figure 9: Effects of safety glasses and goggles when worn with X4A earmuff

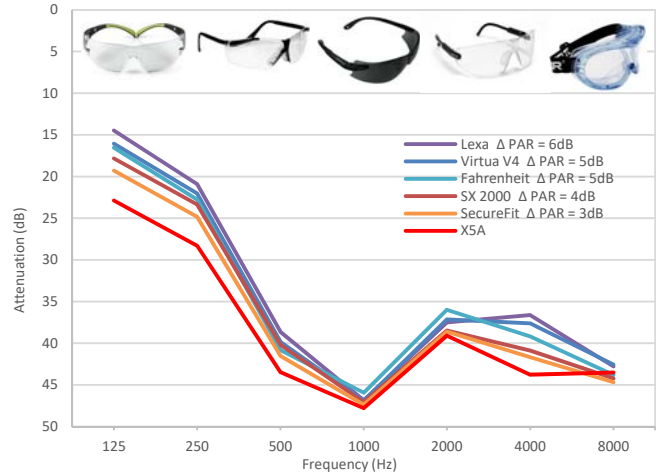


Figure 10: Effects of safety glasses and goggles when worn with X5A earmuff

Effects of apparel

Figure 11 and Figure 12 show the reduction of the PAR provided by different types of apparel. The white nonwoven hood had minimal influence in the PAR (1 dB). However, all the other apparels had significant effects on the PAR when worn underneath the earmuffs. Even the thin translucent hairnet provided a reduction of 4 dB for both X4A and X5A. Some subjects used the hairnet above the ears and others preferred to have them covering the ears. Since these two set ups are commonly found in the food and health care industries, the testers did not influence the subjects' preferences in order to have a more realistic approach. Wells et al. (2013) reported a loss of 7 dB as a result of the use of a similar hairnet under the Model 1000 earmuff. Golf style caps and fleece beanies are commonly used in several workplaces especially in outdoor environments where workers are subject to hot or cold climates but in some cases it may be part of the worker's uniform (e.g. military and law enforcement). Examples of industries where caps and beanies can be easily found are manufacturing, warehouses, food industries (chill rooms), transportation, airports, construction sites, etc. Cap reduced the PAR by 9 dB when worn underneath X4A and 6dB when worn with X5A. The fleece beanie was used folded over the ears and provided the most drastic reduction in the PARs, 13 dB for X4A and 12dB for X5A.

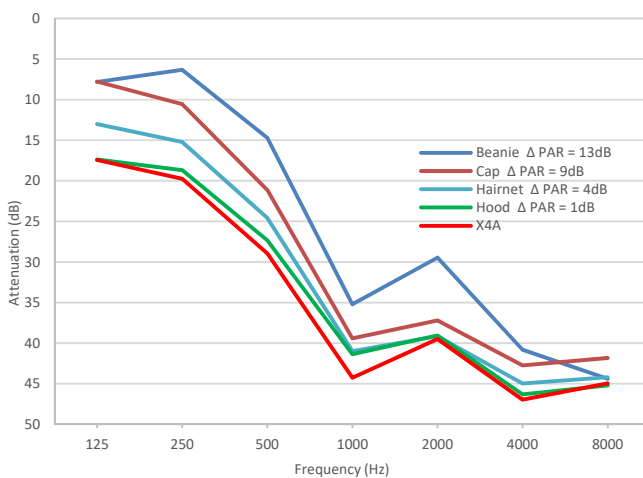


Figure 11: Effects of different types of apparel when worn under the X4A earmuff

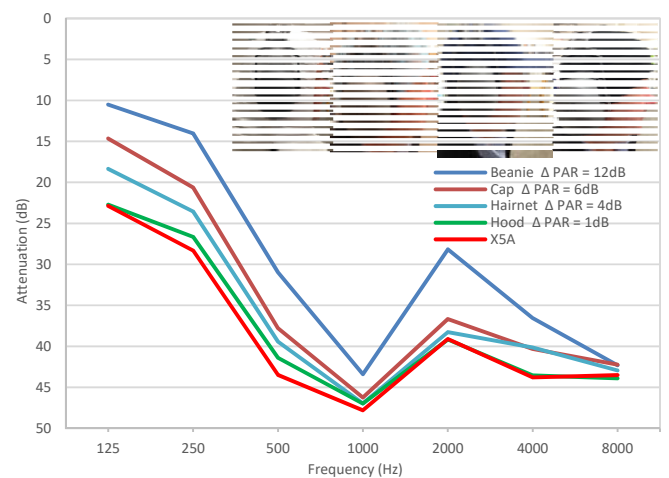


Figure 12: Effects of different types of apparel when worn under the X5A earmuff



### Effects of the 3M 7500 half face piece respirator

Respiratory protection is commonly used in combination with earmuffs and other hearing protectors in several industries including mining, smelter, oil and gas, construction, food industry and work tasks such as grinding, welding, blasting and spraying. There is a wide range of styles of respirators in the market but for the purpose of this study, 3M 7500 reusable half face respirator was selected due to its likelihood to interfere in the attenuation provided by earmuffs. The 7500 respirator has adjustable straps which allow the wearers to adjust the height of the face piece and achieve appropriate face fitting. However, when the respirator is in use, plastic buckles are positioned right above the wearer's ears. As a result of that, the buckles and folded straps interfered in the seal of the earmuff cushions reducing the attenuation of X4A and X5A earmuffs in 8 dB and 5 dB respectively. Figure 13 and Figure 14 shows the degraded attenuation of X4A and X5A caused by the 7500 respirators across the frequencies spectrum.

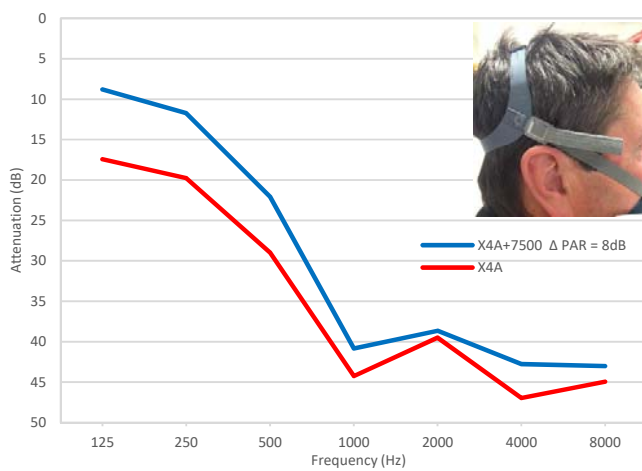


Figure 13: Effects of 7500 respirator when worn with X4A earmuff

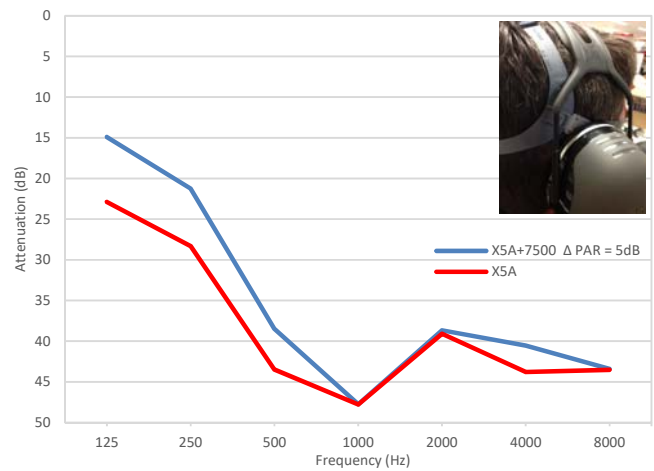


Figure 14: Effects of 7500 respirator when worn with X5A earmuff

### Effects of the different combinations of respirator, goggles, safety glasses and hairnet

Some workplaces and work tasks require the use of respiratory protection combined with eye and hearing protection. Therefore, the combination of 7500 respirator with SecureFit safety glasses and one Fahrenheit goggles were included in the scope of this study. Both combinations provided approximately 10 dB of reduction in the PAR for X4A and X5A earmuffs. The inclusion of the blue hairnet with 7500 and safety glasses did not show any further loss in the attenuation.

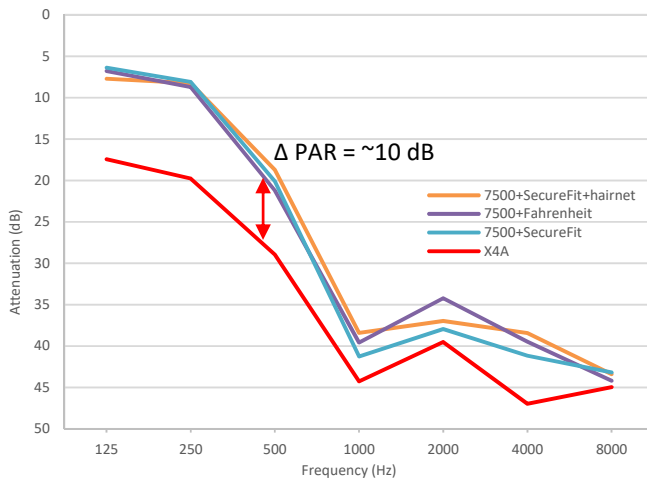


Figure 15: Effects of 7500 respirator, safety glasses, goggles and hairnet when worn with X4A earmuff

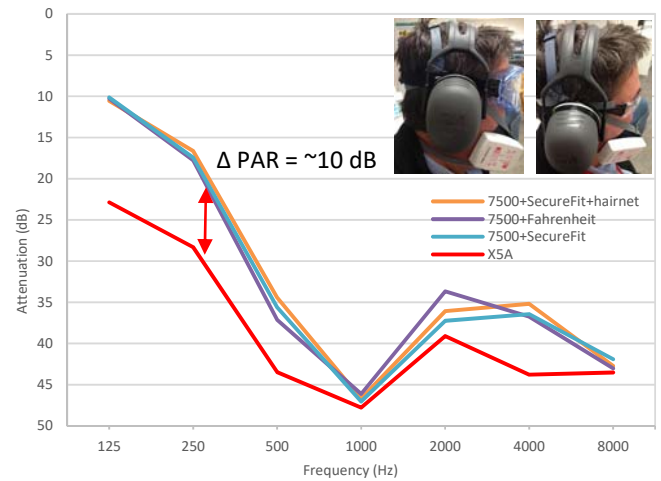


Figure 16: Effects of 7500 respirator, safety glasses, goggles and hairnet when worn with X5A earmuff

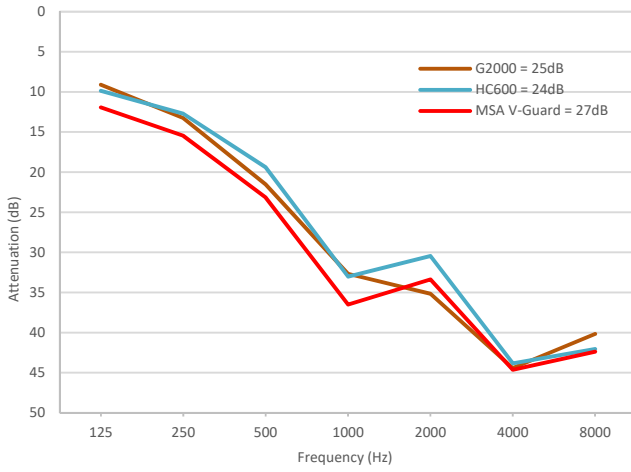
### Significance of industrial safety helmets

Helmet mounted earmuffs can be designed to fit a wide variety of industrial safety helmets. However, due to the costs and practicalities associated with the AS/NZS 1270 testing, they are usually tested with one or two models of safety helmets that should be indicated on the product packaging with following statement from the standard: "These earmuffs were tested in combination with the following industrial safety helmets and may give different levels of protection if fitted to different helmets: (list helmets)."

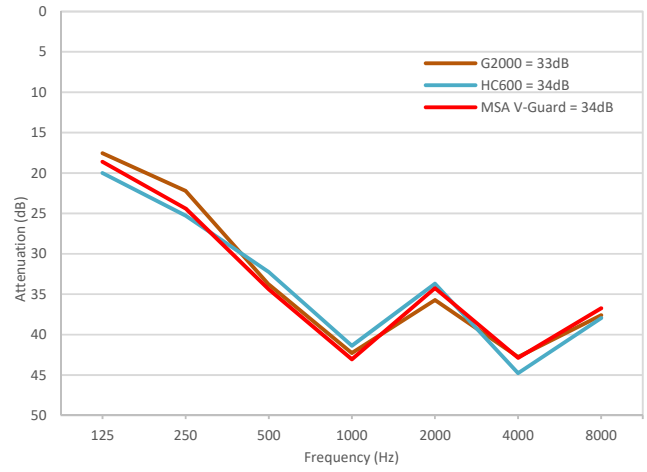
In Europe, the EN 352.3:2002 established specific requirements for the headband force of supplementary combinations based on the headband force measured for a basic combination. If the headband force of supplementary combination cannot meet requirements of this standard, then it should be submitted for a new attenuation testing.

In order to assess the influence of industrial safety helmets in the performance of earmuffs, three models of helmets commonly found in the Australian market were tested in combination with X4P3 and X5P3 earmuffs.

The charts in Figure 17 and Figure 18 shows the OB results for X4P3 and X5P3 respectively. The OB analysis indicated a maximum variation of 3 dB at 1000Hz for X4P3 and 3 dB at 500Hz for X5P3 suggesting that the model of the safety helmet does not have a significant influence on the OB results. The ANOVA conducted for the three models of safety helmets provided  $p$ -values  $>0.05$  for both X4P3 and X5P3 confirming that the differences associated with the helmets were not statistically significant for the overall PAR values with 95% confidence.



**Figure 17: F-MIRE Octave Band results for X4P3 earmuff attached on industrial safety helmets**



**Figure 18: F-MIRE Octave Band results for X5P3 earmuff attached on industrial safety helmets**

## CONCLUSIONS

### *Suitability of the F-MIRE to predict REAT ratings*

The comparison of  $PAR_{84}$  and  $SLC_{80}$  was reasonable, within 1 to 5 dB. The fitting of the F-MIRE test subjects versus the REAT laboratory subjects certainly had an influence in this result.

When the PAR values were compared to the AS/NZS 1270 individual data, 94% out of 64 values fell within an interval of  $\pm 10$  dB. This result indicates that there is a good fit or equivalency between F-MIRE and REAT. The overall results suggested that F-MIRE has a trend to slightly lower than REAT results. However, this trend could be associated with the fact that the comparison was based in different subject test panels. Further investigation would be necessary to reach a more definitive explanation for this observation.

### *Performance of earmuffs when worn with other PPE and apparel*

Earmuffs are often selected as the preferred type of hearing protector due to ease-of-use and durability. On the other hand, earmuffs are more susceptible than earplugs to the interference and compatibility issues provided by other PPE when worn with earmuffs.

This study provided quantitative information about the degradation of attenuation caused by a range of PPE and apparel. This information is relevant to wearers and occupational health and safety professionals involved in the selection of hearing protectors as part of the control measures for noise exposure.

The reduction of the PAR caused by the use of safety glasses worn underneath the ear cushions varied between 3 dB to 7 dB depending on the thickness of the safety glasses temple frames. The degraded attenuations may still be sufficient to maintain the noise exposures within what is considered safe levels (below 85 dB for an 8-hr shift). However, wearers and professionals involved in the specification of PPE should be aware about the potential effects of eyewear on the performance of the earmuffs and take into consideration characteristics of the design of these PPE (e.g. thickness of temple frames, width of straps or presence of buckles) in the selection of the most appropriate combination of eyewear and earmuff.

Respirators are also commonly worn underneath earmuffs and similarly to eyewear, the harness design, the thickness of straps and the positioning of buckles can affect the attenuation of the earmuffs. The 3M 7500 half face respirator reduced the attenuation of X4A and X5A in 8 dB and 5 dB respectively. The reduction of attenuation can be aggravated by another 3-5 dB when 7500 respirator is worn in combination with eyewear.

When hairnet, cap and beanie were worn with earmuffs, they reduced the attenuation in 4 dB (hairnet), 6-9 dB (golf style cap) and 12-13 dB (fleece beanie). Once again, wearers and professionals involved in the selection of PPE should consider these effects in their risk assessment in order to determine whether earmuffs are suitable to maintain the workers exposure at safe levels or if additional controls or other styles of hearing protectors are necessary.

Some helmet mounted earmuffs can be attached to a wide range of industrial safety helmet models although it is unreasonable to test all possible combinations of earmuffs and helmets to AS/NZS 1270. In this study, three models of industrial safety helmets were assessed with the intention to verify the influence of these safety helmets on the attenuation of the X4P3 and X5P3 earmuffs. The PAR differences amongst the models of safety helmet were not statistically significant, suggesting that the design of these helmets have no significant influence in the level of protection provided by the earmuffs.

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## CASE STUDIES - CHARACTERISATION OF PARTICLE EMISSIONS FROM NANOTECHNOLOGY AND NON-NANOTECHNOLOGY PROCESSES UTILISING A MULTI-METRIC APPROACH

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### ABSTRACT

This paper presents the results of a three-tiered assessment process that was used to:

1. Identify points of particle emission, temporal and spatial particle size and number concentration, and
2. Validate engineering controls in relation to selected nanotechnology processes and operation of laser printers.

The particle size of an aerosol typically spans many orders of magnitude from the ultrafine to supermicrometre. Traditionally, characterisation of exposure to airborne particles in occupational and non-occupational environments has focused on measurement of mass concentration. There is now growing consensus in the literature that particle mass on its own is not an adequate metric for evaluating exposure to ultrafine particles (UFPs).

The Tier 1 assessment included a walk-through survey of each process area to gather information on aspects of the processes such as likely emission sources and controls already in use. Tier 2 & 3 assessment measurements were designed around a multi-metric approach employing differing suites of instruments based upon degree of portability.

Tier 2 used a P-Trak, Optical Particle Counter (OPC), and DustTrak, all co-located on a tray to enhance portability and temporal location of the aerosol inlets. Tier 3 used multiple condensation particle counters (CPCs), OPC, DustTrak, Nanoparticle Surface Area Monitor (NSAM), plus equipment for collection of particles for off-line analysis, including electron microscopy, Energy-Dispersive X-ray (EDX) Spectroscopy and Thermal Optical Analysis of Elemental Carbon.

Because of differences in the operating principles of real-time instruments and differences in particle properties, correlation of measurement data cannot be assumed. Therefore, the Spearman rank correlations between time-series airborne particle number concentration (PNC), particle mass (PM) concentration (< 2.5 µm [PM<sub>2.5</sub>]) and alveolar lung-deposited surface area of particles were also calculated in order to understand the strength of the relationships between the particle data measured/calculated by these real-time instruments.

### INTRODUCTION

Workers are exposed to airborne particles both within and outside the workplace from a diverse range of sources, including nearby vehicular traffic, nanotechnology processes, combustion processes such as welding and smelting [1], and office equipment such as laser printers [2].

Although airborne particulate matter is comprised of particles ranging from a few nanometers to hundreds of micrometres [3], most of particles in urban environments are in the submicrometre size and their predominant source is combustion [3]. In contrast, particles arising from mechanical processes such as grinding and milling are likely to have a particle size mode dominated by larger supermicrometre particles [4]. The ultrafine particle fraction (<100 nm, UFP) and the lower end of the accumulation mode (100 to 1000 nm) account for most of the PNC and surface area of an aerosol, whilst the upper end of the accumulation mode and the coarse particle mode (2.5 µm to < 10 µm) account for a substantial part of the PM [4-6]. Concern has been expressed that the small size and a large surface area of UFPs impart unique toxicological properties independent of larger particles [7-13].

Elevated exposure to ambient PM<sub>2.5</sub>, and in particular urban air pollution, has been reported to be associated with cardiovascular [3, 14-17], and respiratory [16, 18-23] morbidity, including morbidity in already compromised or susceptible fraction of the population and increased respiratory hospitalisations [19, 21, 24].

Traditionally, characterisation of exposure to airborne particles in occupational and non-occupational environments has focused on measurement of mass concentration [9]. There is now growing consensus in the literature [9, 25, 26] that particle mass on its own is not an adequate metric for evaluating exposure to UFPs. Properties of UFPs including surface area and

redox activity [9, 25, 27, 28], particle number concentration [9, 27], or fibre aspect ratio and length [27], are considered to be better exposure metrics than mass.

Restricting analysis to a particle size range of less than 100 nm is simplistic and arbitrary when discussing health effects or emission characteristics of aerosols because particle size within an aerosol is rarely homogenous [29], unless they are purposely generated as such. Regardless, airborne UFPs may not remain at their primary size when released into the air and will agglomerate into larger particles and exposure is likely to both sub- and supermicrometre particle size modes [30-37].

Therefore, airborne particles need to be characterised using multiple instruments and methods that respond over a particle size range spanning many orders of magnitude, when assessing particle emissions and exposures. A range of portable, handheld and relatively easy to use real-time instrumentation is available for airborne particle measurement, and the use of such instrumentation is widely reported in literature, for example [30, 32, 33, 36-42]. A time-series plot of this data is commonly used to identify trends and peaks [43, 44].

The utility of time-series data in providing information on peak exposure and patterns of exposure to airborne particles, including UFPs, is well established [9, 27, 32, 33, 43-46]. Very useful information on particle exposure and emission, including temporal changes over short-periods of time, can be obtained from time-series data by qualitatively analysing peak particle concentrations [43]. A tiered measurement strategy has been recommended by a number of authors [43, 47-52].

However, there are gaps in knowledge regarding the strength of correlation between these instruments' responses to aerosols, which has implications regarding the efficacy of the recommendations above. This means there is uncertainty as to which instruments are best suited for assessing sub- and supermicrometre particle emission and exposure within workplace environments. This paper aims to provide further information on this topic which is essential for assessment of particle exposure in general, including within the rapidly expanding nanotechnology industry.

## METHODS

Four sets of particle data (Figure 1) were collected from laser printers located within office locations serviced by a ducted air-conditioning system. The aerosol inlets were located within ~0.5 m of paper exit tray of each printer. Print episodes included in the study were only those initiated by the office occupants in order to incorporate the typical use of the printers. The location of the instrument aerosol inlets was informed following the release of artificial smoke which allowed visualization of the direction of airflow within the room.

Five sets of airborne particle data (Figure 1) from different nanotechnology processes were collected and are described to reflect the dominant material used in the process: TiO<sub>2</sub>, Clay, Poly/Clay, multi-walled carbon nanotubes (MWCNT) and single-walled carbon nanotubes (SWCNT).

The aerosol inlets of the instruments were co-located and sampled simultaneously, with the sampling interval set as short as possible for each instrument while attempting to ensure equivalent sampling frequencies. The duration of particle measurement was governed by the aim to characterize both representative background particle concentration and particle concentration associated with each process, and the time is tabulated on the x-axis of Figure 1.

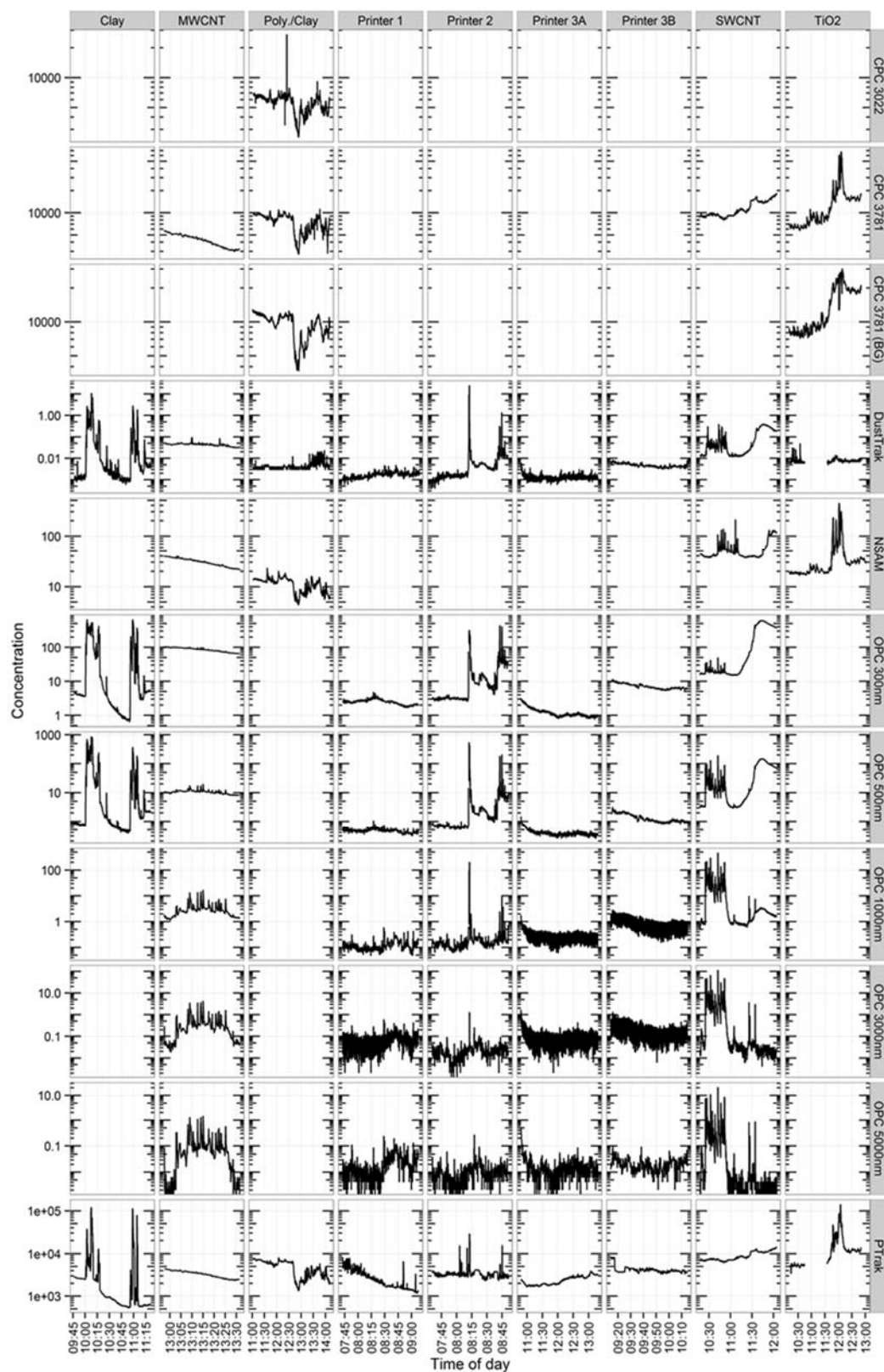


FIGURE 1: Time-series particle concentration displayed as PNC ( $\text{p cm}^{-3}$ ) for all CPC, P-Trak and OPC data,  $\text{mg m}^{-3}$  for DustTrak data, and  $\mu\text{m}^2/\text{cm}^3$  for NSAM. BG = background signifying this CPC operated concurrently but approximately 7 m from the particle source.



Not all instruments were used for all aerosols because of portability factors. The experiments were designed around two suites of instruments based upon degree of portability. The first suite of instruments were a P-Trak, OPC and DustTrak, all co-located on a tray that enhanced portability and temporal location of the aerosol inlets. The second suite of instruments included multiple CPCs, OPC, DustTrak, NSAM, plus collection of particles for off-line analysis. This approach allowed conclusions to be made in the context of instrumentation recommended for Tier 1, 2 and 3 assessments [33, 40, 47-49, 52].

A list of the real-time instrumentation, associated particle metric, measurement range and principle of operation of each instrument used in the study is provided in Table I.

*Insert Table 1 here (find Table 1 at end of manuscript)*

In all cases, the aerosol inlets of the instrumentation were co-located between 0.2 and 7.0 m of the various aerosol emission sources, with the final distance governed by factors such as dimensions of the process equipment, local safety rules and whether the intent was to collect temporal or spatial particle data. Particle number and mass concentration, and surface area equivalent alveolar dose were measured before, during, and after process operation.

The investigation of airborne particles associated with the operation of both the *TiO<sub>2</sub>* and *Poly/Clay processes* utilised a P-Trak, OPC, DustTrak, CPC3022A, CPC3781 and a NSAM which were co-located on a trolley, and black conductive rubber tubing was used to connect the aerosol inlets of each instrument to approximately 0.2 m of the particle source. In addition, a CPC3781 was located approximately 7 m away to characterise spatial variation in PNC.

For the *Clay process* a P-Trak, OPC, and DustTrak which were co-located on a tray and used as portable instruments at varying locations within one meter of the Jet Milling machine, including at approximately 0.2 m of the machine, and at the breathing zone position of the machine operator.

For the *MWCNT and SWCNT processes*, a P-Trak, OPC, DustTrak, CPC3781 and a NSAM were co-located on a trolley and black conductive rubber tubing was used to connect the aerosol inlets of each instrument to approximately 0.2 m from particle source inside a chamber. Aliquots of SWCNT and MWCNT were introduced into the chamber. In addition, to verify the response of the real-time instrumentation was to airborne CNTs and not to other particles, the aerosol inside the chamber was concurrently sampled through collection of the aerosol onto open-face sampling cassettes containing mixed cellulose ester (MCE) and polytetrafluoroethylene (PTFE) filter membranes, which were connected via tubing to sampling pumps. The MCE and PTFE filters were examined using an FEI Quanta 200 Environmental SEM operated in high vacuum mode and analysed for elemental composition using an EDX microanalysis system.

Aerosol from the inside of the CNT experimental chamber was also sampled onto quartz fibre filters using sampling pumps at a flow rate of 3.6 LPM. The organic, elemental, and total carbon mass of each filter was analysed using Evolved Gas Analysis by a Thermal-Optical analyser in accordance with the *NIOSH Method 5040* [71] and the elemental carbon (EC) concentration in  $\mu\text{g m}^{-3}$  was calculated.

### Data Analysis

As listed in Table 1, the CPCs, OPC and DustTrak measure particle concentrations. However, the NSAM recalculates the particle concentration data into lung deposition of particles using criteria from the International Commission on Radiological Protection (ICRP) lung deposition model [53, 54]. In addition, the instrument data were averaged, using RStudio statistical software, to the longest sampling time interval for the group of instruments being compared, to allow comparison of the time-series plots.

Spearman rank order coefficients ( $r_s$ ), a non-parametric measure of correlation [55] were then calculated for each pair of co-located instruments within each experiment. Spearman correlation was chosen over Pearson correlation to relax the assumption that the relationship between the time series is linear, replacing it with an assumption that the relationship is monotonic (either always increasing or always decreasing).

### RESULTS

Figure 1 presents the time-series plots, for nine sampling episodes, of particle number and mass concentration and surface area equivalent alveolar dose. Dependent upon whether suite 1 or 2 instruments were used, some plots are blank indicating the data was not recorded for that particle metric, or in the case of the Clay Process, the OPC data for the particle bin sizes 1000 to 5000 nm was inadvertently deleted before it could be analysed. The plotted measurement values reflect both the particle background and particle concentrations associated with discrete events associated with each process. Each particle bin size of the OPC has been plotted separately to enhance the comparison of particle data with other instrumentation.

Figure 1 highlights the variability in particle concentration associated with each process and associated aerosol, and shows that there is a trend in instrument response, in terms of point of time and magnitude of change in particle concentration, between the instruments measuring the same particle source. The time-series highlights the frequent and substantial elevation of particle concentration relative to background for some processes.

For the TiO<sub>2</sub> process, increases in particle concentration of one or more orders of magnitude during process operation were recorded concurrently by all CPCs and the NSAM. Similarly for the Poly/Clay process, all CPCs and the NSAM recorded a concurrent reduction of at least an order of magnitude at 13:45 hours coinciding with commencement of extraction ventilation above the process extruder.

For the SWCNT process, each of the peaks greater than the background particle concentration for the OPC, DustTrak and NSAM, between 10:00 and 10:30 hours, is associated with the introduction of each aliquot of SWCNTs to the chamber. While the time-series plots for the CPCs do not indicate an obvious increase in PNC associated with each aliquot, the other instrumentation does, with greater than one order of magnitude increases in PNC for OPC bin sizes > 500nm and weaker increase for bin sizes 300 nm. In contrast, at approximately 11:30 hours all instruments recorded an increase in particle concentration, indicating an aerosol with both substantial sub and supermicrometre sized particles. At this time CNTs were not being introduced to the chamber but rather nearby welding associated with building construction was occurring.

Similarly, for the MWCNT process, each of the peaks greater than the background particle concentration for the OPC bin sizes  $\geq 1000$  nm and the DustTrak between 10:30 and 13:30 hours is associated with the introduction of each aliquot of MWCNTs into the chamber. However, no significant peaks in particle concentration were visible on the plots for the NSAM, CPCs, or OPC particle bin sizes of 300 and 500 nm, indicating the predominant instrument response is to supermicrometre particles.

For the Clay process, the Jet Milling of the clay particles occurred in two distinct time periods of 10:00 to 10:15 hours and 11:00 to 11:15 hours. During these time-periods almost identical peaks greater than the background particle concentration are visible on the plots for the OPC particle bin sizes 300 and 500 nm, the DustTrak and the P-Trak.

For Printers 1 and 3 there did not appear to be a marked increase in particle concentration over background, associated with printing of pages, possibly due to variation in background particle concentration occluding peaks associated with printer episodes. However, for Printer 2 several large peaks in PNC associated with print episodes were recorded by the P-Trak between 08:02 and 08:09 hours, and large peaks in particle number and mass concentration of greater than an order of magnitude were recorded by all instruments at approximately 08:11 hours and 08:38 hours, and is a result of the release of artificial smoke. Particle emission varied considerably from one print episode to the next.

Peaks in particle concentration associated with the time of print episodes were evident for Printer 1 and Printer 2, and only detected by the P-Trak. Fluctuations in PNC recorded by the OPC are not associated with print episodes but rather with background particles. Apart from times when artificial smoke was released, the variations in PM<sub>2.5</sub> recorded by the DustTrak are not markedly above background variation. In addition, increases in PNC were registered by the P-Trak and the OPC in bin sizes 300 and 500 nm at the time of smoke release. Increases in particle number or mass concentration, above background variation, corresponding to print episodes for Printers 3A and 3B, were not registered by any of the instrumentation, greater than background.

Examination of the PTFE and MCE filters for the MWCNT samples revealed the airborne particles consisted of both small clusters of particles in the size range of 0.5 – 2 $\mu$ m and larger clusters in excess of 10  $\mu$ m in length. The clusters consisted of both carbon based spherical particles and nanotubes. The SWCNT samples collected on the MCE and PTFE filters showed a greater concentration of clusters than was observed with the MWCNT samples. These clusters comprised mainly carbon

particles with aggregates of nanotubes within the clusters. The cluster sizes varied extensively from below 1  $\mu\text{m}$  to above 10  $\mu\text{m}$ . Figures 2 and 3 provide SEM images of the particles sampled during the MWCNT and SWCNTs experiments, respectively. The predominantly supermicrometre dimensions of both the SWCNTs and MWCNTs is consistent with the plots in Figure 1.

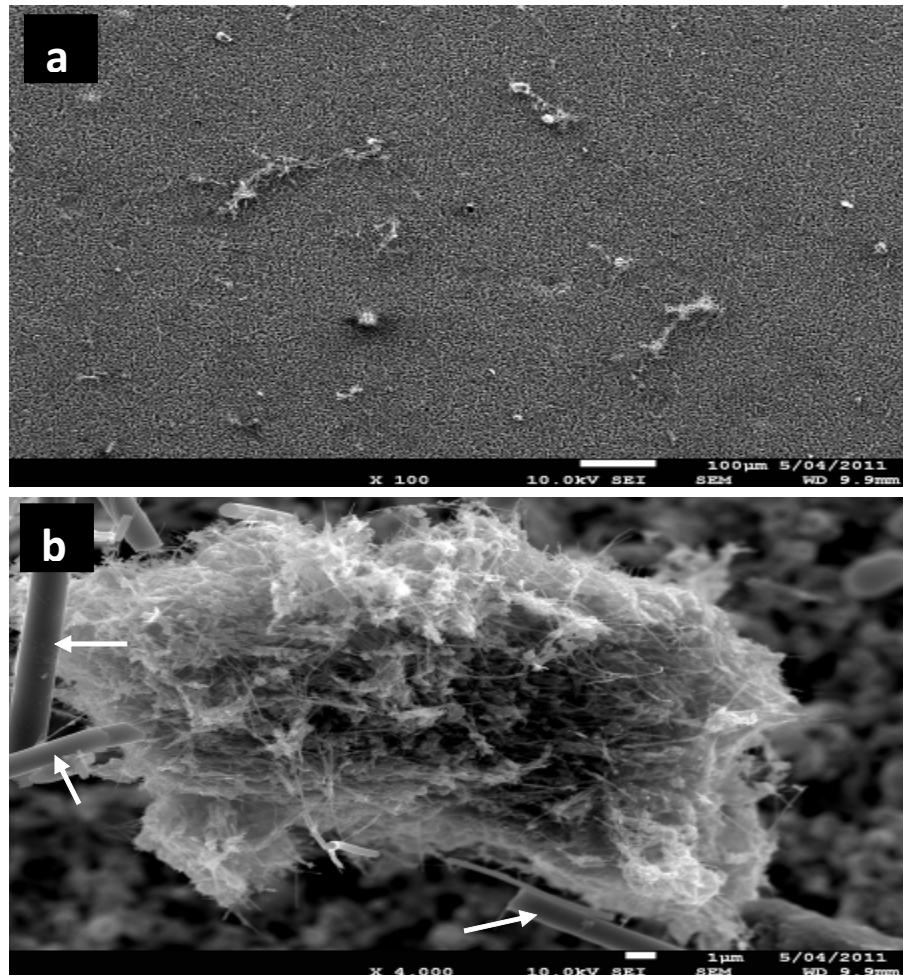
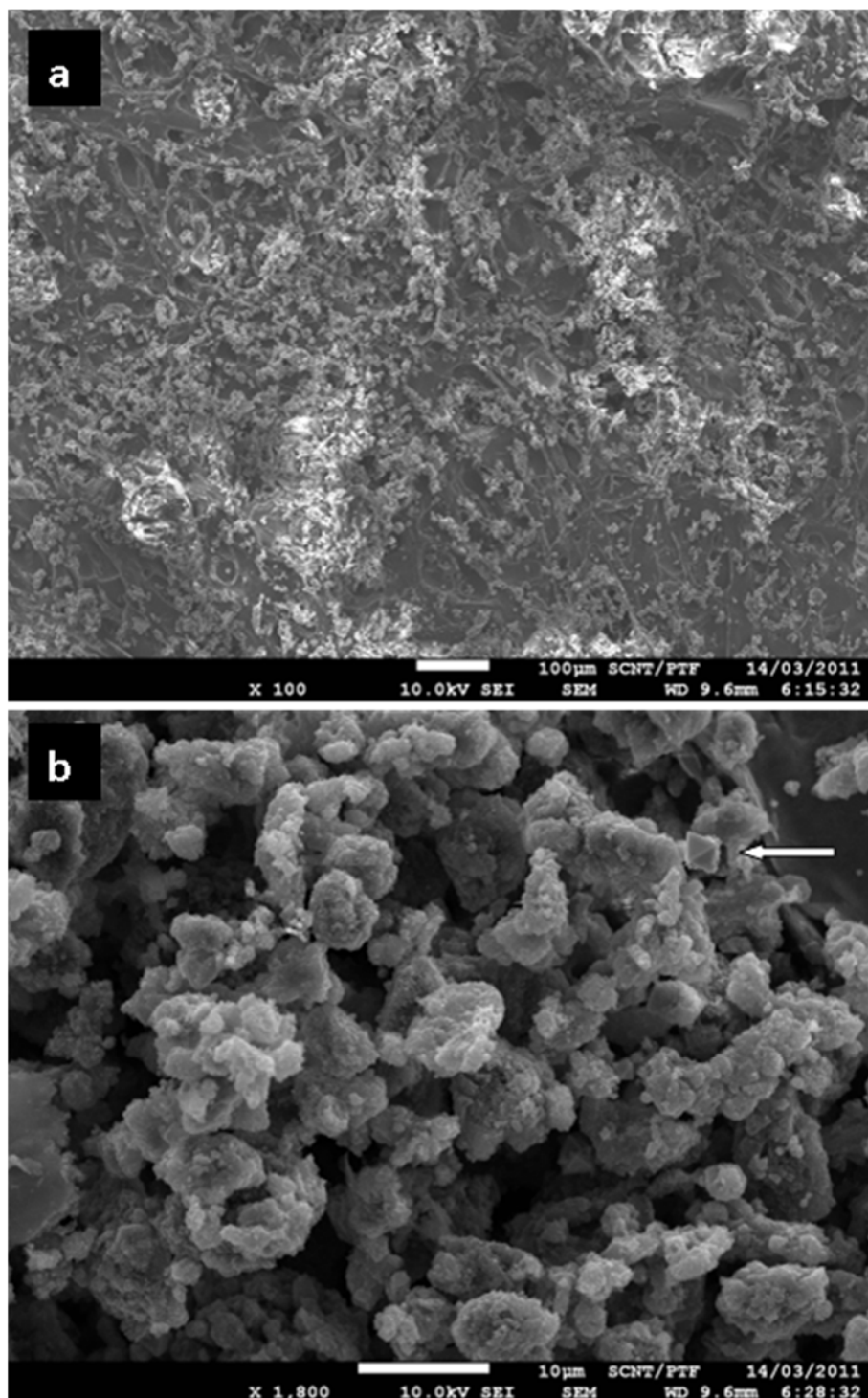


FIGURE 2: MWCNT sample on MCE filter; (a) scattered clusters of nanotubes and amorphous material, (b) a cluster of amorphous carbon and nanotubes, together with some fibreglass fibres (arrows).

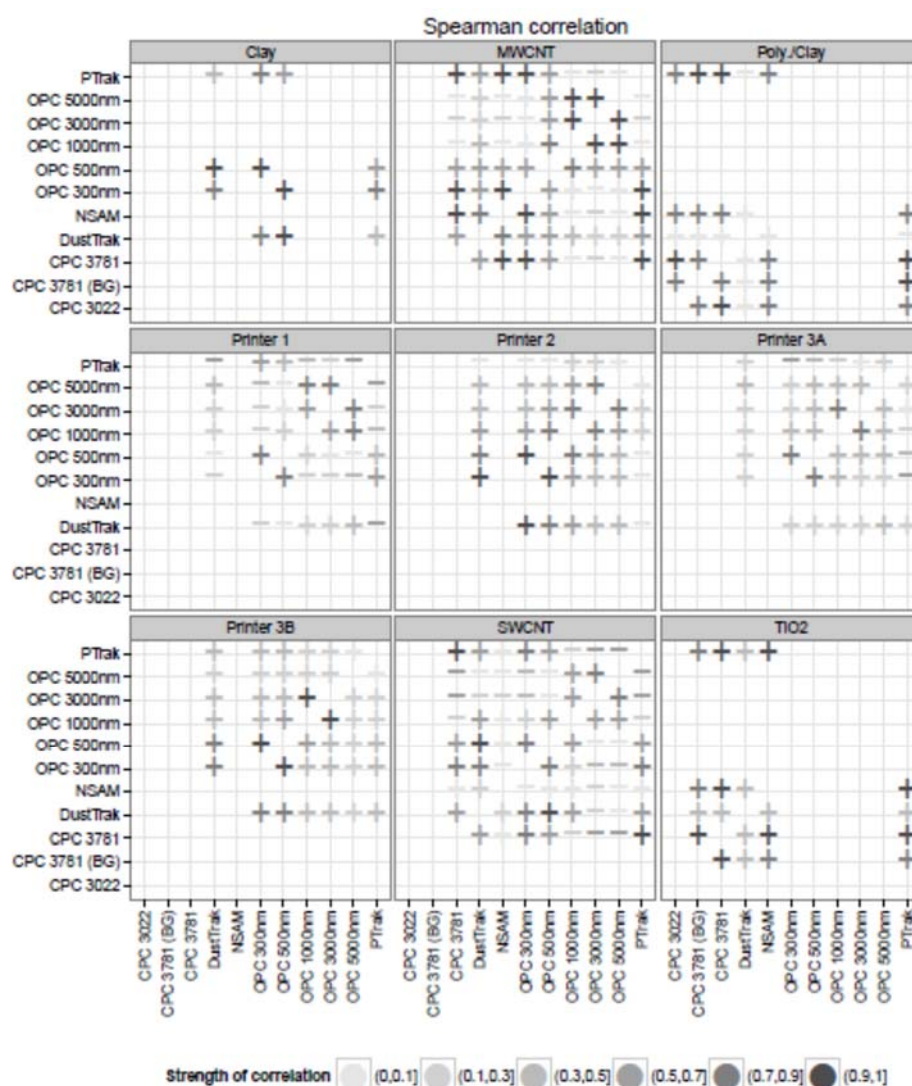


**Figure 3: SWCNT sample on PTFE; (a) dense coating of clusters on the filter; (b) details of a large cluster showing smaller aggregates; the arrow indicates a Mo crystal**

The analysis of elemental carbon (EC) mass concentration collected during the CNT experiments indicated the airborne concentration of MWCNTs was significantly less than that of SWCNTs,  $< 2 \mu\text{g m}^{-3}$  and  $1474 \mu\text{g m}^{-3}$ , respectively. This is consistent with the lower magnitude of particle concentration recorded by the real-time instrumentation for the MWCNTs compared to the SWCNTs, as plotted in Figure 1.

Figure 4 presents the Spearman's ranked coefficients for the pairing of all instruments particle concentration data recorded for each experiment. Blank values indicate the data from that instrument was not recorded for that process (related to which

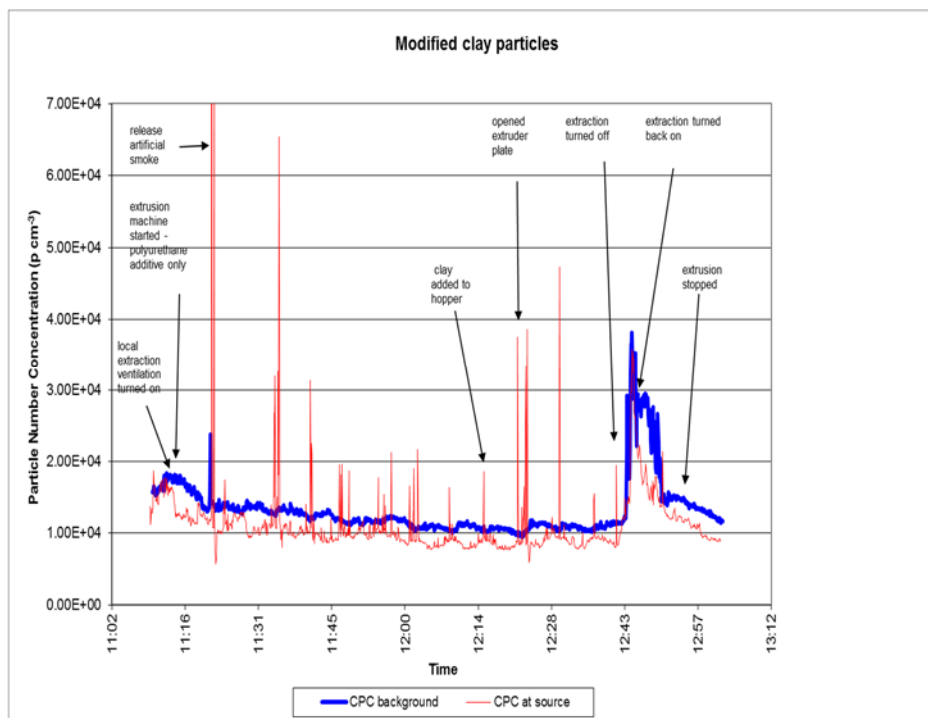
suite of instrumentation was used) and for the Clay Process, the inadvertent deletion of the OPC data for the particle bin sizes 1000 to 5000 nm.



**FIGURE 4. Spearman's  $r_s$ . (BG) = background measurement with instrument position approximately 7 m away from particle source to characterise spatial particle concentration.**

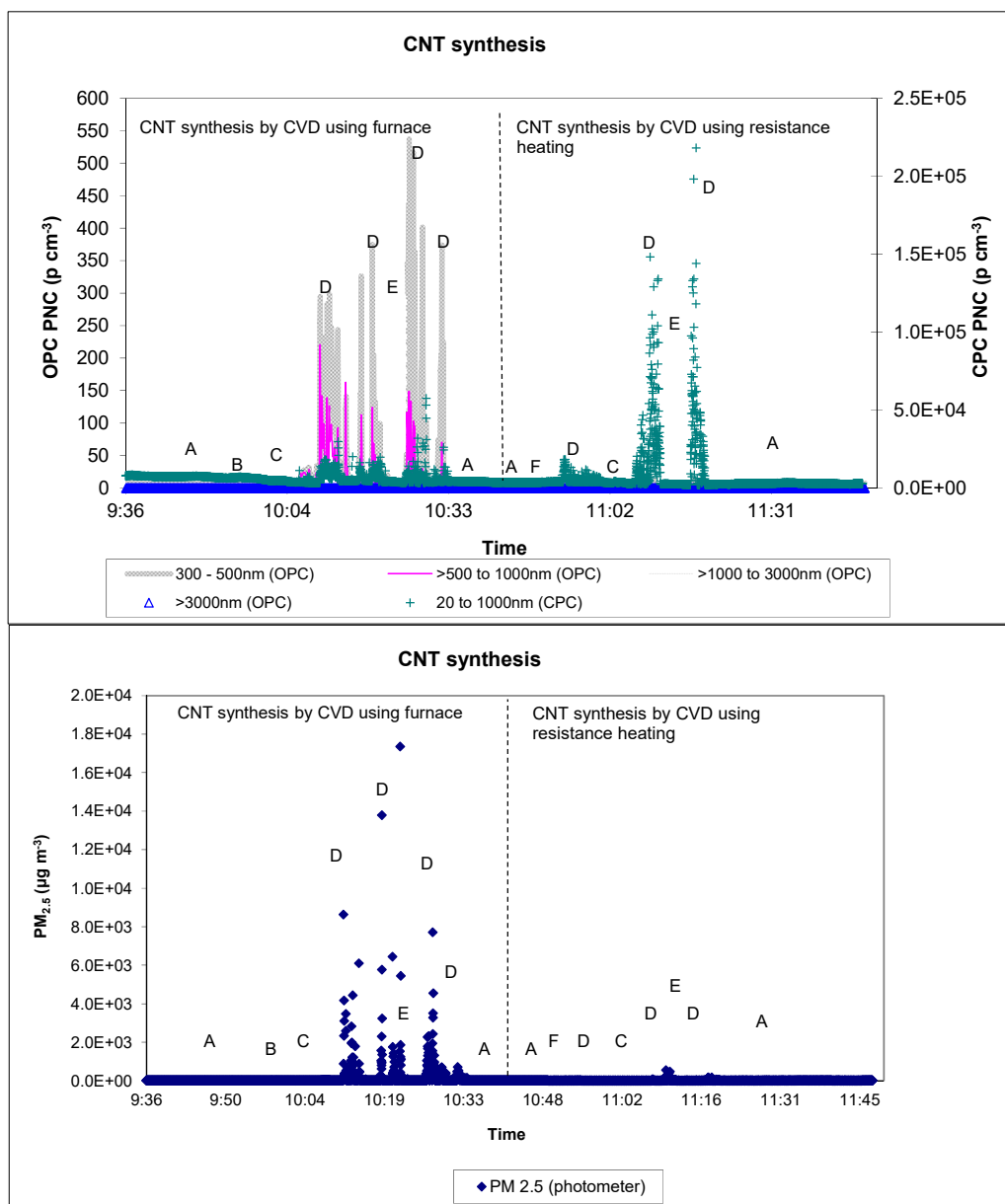
Generally, all CPC values were strongly positively correlated, values for P-Trak and DustTrak, P-Trak and OPC bin sizes 300 and 500 nm, NSAM and CPCs, NSAM and OPC bin sizes 300 and 500 nm were strongly positively correlated for most aerosols. Negative correlations were associated with a CPC not recording a change in PNC while the non-CPC instruments recorded an increase in particle concentration.

The influence of local extraction ventilation (LEV) in capturing particle emission from the Clay/Poly process can clearly be seen in Figure 5 when the LEV is switched off and on at 12:43 hours.



**FIGURE 5: Spatial and temporal PNC associated with operation of the extruder machine during the Clay/Poly process. The circled area on the plot signifies the effect on PNC of turning off the local extraction ventilation.**

From Figure 6 is the time-series plot of particle number and mass concentration associated with during two different condensation vapour deposition CNT synthesis processes. It can be seen that the particle emission is different between both condensation vapour deposition (CVD) processes with the PNC for the resistance heating process concentrated in the size range 20 to 1000nm, whilst for the furnace process the dominant PNC response is in the 300 to 500 nm size range. It can also be seen that: (i) airborne particles are produced as part of the CVD process; (ii) the P-Trak, OPC and DustTrak are capable of characterising such particles; (iii) there is a temporal relationship in particle concentrations measured by the OPC and DustTrak during the furnace process, (iv) the enclosures for both CVD processes prevent particle leakage to the laboratory atmosphere; (v) the fume cabinet is capable of containing the particles exhausted from the processes.



**FIGURE 6: Plots of spatial particle concentration obtained during the assessment of the effectiveness of local extraction ventilation and process enclosure to contain particle emission. Particle number and mass concentration measured at various locations during two different condensation vapour deposition CNT synthesis processes. Measurement locations, marked A to F in the figure, were as follows: A = Background ambient PNC at various locations around the room; B = commencement of first CNT synthesis; C = entire outer surface of furnace; D = end of furnace extraction tube inside fume cabinet; E = outside and along sash opening to fume cabinet; F = commencement of second CNT synthesis.**

## CONCLUSIONS

Overall, the  $r_s$  values indicated a strong positive correlation between a portable CPC (P-Trak), DustTrak, and OPC bin sizes from 300 and 500 nm, the DustTrak and the OPC bin sizes from 300 to 3000 nm, and CPC-P-Trak/CPC 3781/CPC3022A, when the airborne particles were within the measurement range of all instruments.

Because strong positive correlations between instrument data were only evident when the particle size was within the measurement range of the instrument, it is recommended to concurrently utilise a second instrument, with a similar particle size measurement range. This increases the chance that important peaks will be captured regardless of their source and the variability in response of instruments caused by different aerosol sources. A portable CPC such as a P-Trak should always be

utilised, however the strong correlation between the DustTrak and the OPC indicates either of these instruments can be utilised as the second instrument. In addition, all three instruments can be readily used as portability of these three instruments is easily facilitated by using a tray to co-locate the aerosol inlets. Although the NSAM calculated peaks in surface area concentrations *relative* to background concentration and these calculations were strongly correlated with PNC measured by the CPCs, its selection in the first instance is not recommended due to its relatively non-portability and the limitations regarding particles > 400 nm in diameter.

Our finding of strong correlation provides confidence regarding the validity of these real-time instruments, when used concurrently, to identify significant peaks in *relative* particle concentration compared to background, and supports recommendations from earlier studies [39, 40] that a P-Trak, OPC, and a DustTrak represent a valid and portable means for reliably characterising particle emissions from a process, relative to background particle concentration. These findings are fundamental to Tier 2 evaluation that aims to identify potential sources of particle emission that may require more comprehensive Tier 3 exposure assessment. This is of particular relevance to both nanotechnology and non-nanotechnology sources of particles at workplaces where the relative strength of the emission concentration is variable compared to background sources of particles.



**TABLE I: Instrumentation associated particle metric and measurement size and concentration range utilised for this study**

Instrument	Particle metric	Particle size range	Particle concentration range	Measurement principle
<b>TSI Model 3781 CPC</b>	PNC	0.006 - 3 $\mu\text{m}$	0 to $5 \times 10^5$ p. $\text{cm}^{-3}$	A vapour from the instrument's working fluid is condensed onto particles to "grow" them to a size that can be detected with optical methods. Water, Isopropanol, and Butanol is the working fluid for the model 3781, 8525 and 3022A, respectively [56].
<b>TSI Model 8525 P-Trak CPC</b>		0.02 - 1 $\mu\text{m}$	0 to $5 \times 10^5$ p. $\text{cm}^{-3}$	
<b>TSI Model 3022A CPC</b>		0.006 - 3 $\mu\text{m}$	0 to $9.99 \times 10^6$ p. $\text{cm}^{-3}$	
<b>TSI Model AeroTrak 9306 OPC</b>	PNC	Six particle size distribution channels between 0.3 $\mu\text{m}$ to 10 $\mu\text{m}$	0 to $2.1 \times 10^4$ p. $\text{cm}^{-3}$	Particles enter an optics chamber via isokinetic probe and a light source counts particles according to light scattering [57]. The OPC logs particle counts in six channels (particle bin sizes [PBS]): 0.3 to < 0.5 $\mu\text{m}$ , 0.5 to < 1.0 $\mu\text{m}$ , 1.0 to < 3.0 $\mu\text{m}$ , 3.0 to < 5.0 $\mu\text{m}$ , 5.0 to 10.0 $\mu\text{m}$ , and > 10 $\mu\text{m}$ , and as the PNC recorded for each channel is that of the lowest particle size cut for the channel, the data has been labelled as OPC <sub>300nm</sub> , OPC <sub>500nm</sub> , OPC <sub>1000nm</sub> , OPC <sub>3000nm</sub> and OPC <sub>5000nm</sub> . Data was not recorded for the bin size > 10.0 $\mu\text{m}$ , i.e. OPC <sub>10000nm</sub> because all PNC were less than 2 particle $\text{cm}^{-3}$ and the upper particle size for this bin is not defined.
<b>TSI Model 8520 DustTrak Aerosol Monitor</b>	PM <sub>2.5</sub>	0.1 to 2.5 $\mu\text{m}$ (using a 2.5 $\mu\text{m}$ impactor at the aerosol inlet)	0.001-100 mg. $\text{m}^{-3}$	Particles enter a optics chamber via a sample inlet conditioner nozzle that is particle size specific, and mass per volume is calculated using data of the amount of laser light scattered by the particles [58].

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<b>TSI 3550 NSAM</b>	Lung surface area equivalent dose of inhaled particles $\mu\text{m}^2/\text{cm}^3$	0.01 $\mu\text{m}$ to 1.0 $\mu\text{m}$	Particles enter the instrument through a cyclone inlet with a 1 $\mu\text{m}$ cut point, particles are conditioned by diffusion charging and charge measured using an electrometer [54]. Lung deposition of particles is calculated using criteria from the International Commission on Radiological Protection (ICRP) lung deposition model [53] [54]. Only lung-deposited surface area concentrations of aerosols with no significant surface contribution above 400nm can be accurately measured using these devices [59, 60].
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## URINARY LEVELS OF MALONDIALDEHYDE AND 8-DEOXYGUANOSINE AS BIOMARKERS OF OXIDATIVE DNA DAMAGE INDUCED BY EXPOSURE TO NICKEL AND COBALT IN METAL REFINERY WORKERS

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### ABSTRACT

Metal mining and refinery workers have the potential to be occupationally exposed to quantities of heavy metals that may be associated with health impacts affecting major organ and immune systems (Li, et al., 2014). To ensure the safety of personnel in such occupations regulatory and internal company policies and guidelines require regular monitoring of occupational exposures of employees through a combination of air borne sampling as well as biological monitoring for heavy metals.

Toxic levels of heavy metals accumulated in the body have been shown to elicit inflammatory responses linked to exacerbated health effects impacting the respiratory, cardiovascular and nervous systems (Tchounwou, et al., 2012). There are many studies that have established a significant link between heavy metal exposure and increased oxidative stress (Aflanie, et al., 2015; Ghasemi, Rostampour, Ranjbar, 2014; Pizzino, et al., 2014; Valko, Morris, and Cronin, 2005; Sørensen, et al., 2005). In light of these observations, this study investigated urinary levels of Nickel (Ni) and Cobalt (Co) and oxidative stress markers of cellular and DNA damage, Malondialdehyde (MDA) and 8-deoxyguanosine (8-OHdG) respectively among Ni and Co refinery workers.

The traditional methods of assessing workers exposure using airborne dust concentrations do not consider variations in individual susceptibility. The results of this study showed a positive correlation between urinary Ni and Co exposure and oxidative stress markers, MDA and 8-OHdG, among refinery workers. This finding has implications for occupational health management as individual responses to exposures can now be identified providing an accurate estimate of potential long term health impacts.

### INTRODUCTION

In Australia, minerals extraction has been an integral part of the country's culture and development since Europeans first colonised the continent. The first metals mined in Australia were silver and lead at Glen Osmond in South Australia in 1841 (ABS, 2001). Australia has since become one of the world's leading mineral resources nations with the mineral industry being one of the biggest contributors to Australia's export trade.

The location of current Western Australia nickel-cobalt laterites at remote locations dictates the need for metal refineries to also be located remotely (Elias, 2013). The issue is further complicated by the extended shifts and longer work days that workers spend on site, as well as the fact that the accommodation facilities are also located in close proximity to the work site and workers return to the mine village in their work uniforms thus potentially transporting contaminated dust to their sleeping accommodation.

As, Cu, Cd, Se, Hg, Pb, V, Zn, Fe and Ni are often present in particulate matter, and it is common for them to undergo speciation to form reactive oxygen species when present in excess (Shah, et al., 2008). Chronic levels of exposure in metal refinery workers may therefore be associated with the high prevalence of the metals in the inhalable particulate matter. There is accumulating evidence in experimental and epidemiological studies indicating that atmospheric pollution based toxic metal exposures can contribute to the induction and alteration of epigenetic markers through cellular oxidative stress (Numan, et al., 2015). To protect its workforce, these industries adhere to strict guidelines to ensure that their personnel do not suffer from metal toxicity. In Western Australia, metal mining and refining practices are monitored strictly by the Department of Mines and Petroleum (DMP) with up to date regulations in order to maintain a safe and efficient work place for their workforce (DMP, n.d).

### Heavy Metal Toxicity

Heavy metal poisoning occurs when toxic amounts of the metals accumulate within the tissues of the body and the usual mechanisms of elimination are impaired resulting in subsequent health effects (National Organization for Rare Disorders,

[NORD], 2006). Through establishing and maintaining epigenetic chromatin states, environmental metals may exert their effects on gene expression (Martinez-Zamudio & Ha, 2011).

Different toxic metals produce varying symptoms which may lead to serious damage, in both people and animals exposed to them in concentrations sufficient to cause poisoning. From an occupational health perspective, work force heavy metal exposures have been investigated extensively Nelson, et al., (2010), particularly because of their association with health effects affecting the lungs, kidney, liver, heart and nervous systems and are known to evoke an immune response in individuals exposed to significant quantities (Rouse, et al., 2008, Lynes, et al., 2007).

Heavy metals have been shown to elicit inflammatory responses in the respiratory system, as well as impact cardiovascular and nervous systems when present at toxic levels (Aflanie, et al., 2015). Their propensity to exacerbate health effects have linked them with a significant amount of respiratory and cardiovascular health burden associated with particulate matter exposures (WHO, 2013, Nelson, et al., 2010, Huang, et al., 2009, Zota, et al., 2009, Shah, et al., 2008).

The tendency for such systemic toxicants to induce multiple organ damage even at chronic low levels of exposure have led to their classification as known or probable human carcinogens by the U.S. Environmental Protection Agency (EPA) and the International Agency for Research on Cancer (IARC), and part of Australia's National Pollution Inventory (NPI) Air Toxic program as they are most commonly associated with poisoning of humans.

#### **Nickel Toxicity**

Nickel is an essential trace metal required for various biochemical and physiological functions (Tchounwou, et al., 2012). However, in excess, it may also produce cellular and tissue damage which may lead to a variety of adverse effects and human diseases and has been deemed a toxic and carcinogenic metal of environmental concern (Martinez-Zamudio & Ha, 2011; Das, et al., 2008). Dose, duration and route of exposure to essential metals such as Cu, Zn, Ni, Fe and Co, can permit these metals to reach levels that are also toxic in individuals, eliciting very similar health effects on cellular targets within these organ systems (Lynes, et al., 2007). The inhalation of nickel particles represents another major route of human exposure, where nickel has been suggested to exert its toxic effects through non-genotoxic mechanisms such as DNA methylation (Martinez-Zamudio & Ha, 2011).

Nickel transformation has been shown to suppress the DNA repair gene, O6-methylguanine DNA methyltransferase (MGMT) expression in lung cancer cells (Martinez-Zamudio & Ha, 2011). As a potential immunomodulatory and immunotoxic agent in humans, nickel compounds, except for metallic nickel, have been classified as human carcinogens by the International Agency for Research on Cancer (IARC) and the U.S. Department of Health and Human Services (DHHS, National Institute of Environmental Health Sciences; 1994, IARC; 1990).

#### **Cobalt Toxicity**

Cobalt is an element that occurs naturally in many different chemical forms throughout our environment (Lisbon et al., 2001). The inhalation of Co alone can cause asthma with toxic effects in higher concentrations affecting mainly the lungs, leading to pneumonia, wheezing and pulmonary oedema (Barceloux, 1999). Other health effects linked to overdosing on cobalt (>5 mg/day) include broad and unspecific effects such as, abnormal thyroid functions, polycythemia and overproduction of red blood cells (erythropoiesis), with increased production of the hormone erythropoietin which may lead to peripheral vascular thrombosis and optic nerve atrophy (Hengstler, et al., 2003).

Cobalt is therefore a potent inducer of oxidative stress causing free radical generation, which in turn induces DNA damage, inhibits DNA repair mechanisms and the exchange of DNA between sister-chromatids and aneuploidy contributing to its toxicity and carcinogenicity (Galanis et al., 2009). Recent experimental studies confirm its interference with DNA repair processes, and its direct induction of DNA damage, DNA-protein crosslinking, and sister-chromatid exchange (Jomova and Volko, 2011). As such, the IARC also classified cobalt as "possibly carcinogenic to humans" (IARC, 2006).

#### **Proposed mechanism of heavy metal toxicity**

The accumulation of heavy metals to a toxic level has been shown to occur when metallothioneins that normally neutralise these metals are insufficient to restrict their interference with cellular mechanisms (Mohamed, et al., 2014, Wei, et al., 2010).



It is proposed that, when in excess, one of the main reasons heavy metals can interfere with cellular processes is because, they share similar valencies with essential metals normally utilised by the body for co-factors in important enzymatic functions or the construction of cellular structures (Choudhary, et al., 2007). Studies have shown that the toxic accumulation of metals within the organism not only produce reactive radicals that compromise normal biological processes, but also result in DNA damage, lipid peroxidation, depletion of protein sulfhydryls and other effects (Shah, et al., 2008, Valko, et al., 2005).

At a molecular level, the main factor that defines the toxicity or carcinogenicity of a metal is its ability to generate reactive oxygen and nitrogen species (Ghasemi, Rostampour, Ranjbar, 2013; Das, et al., 2008; Valko, et al., 2005). These free radicals then activate redox sensitive signalling pathways of transcription factors, resulting in a number of modifications to DNA bases, lipid peroxidation, and altering the calcium and sulphhydryl homeostasis (Rahman, 2007; Valko, et al., 2005).

### **Malondialdehyde (MDA)**

Malondialdehyde is an example of a reactive aldehyde resulting from lipid peroxidation of polyunsaturated fatty acids. As a major bioactive electrophile species, malondialdehyde causes toxic stress in cells by reacting with deoxyadenosine and deoxyguanosine in DNA, forming DNA adducts, which are mutagenic. The production of this aldehyde is used as a biomarker to measure the level of oxidative stress in an organism. In human nutrition and biology, advanced glycation end products, known as AGEs, are substances that can be a factor in the development or worsening of many degenerative diseases, such as diabetes, atherosclerosis, chronic renal failure, and Alzheimer's disease (Ghasemi, Rostampour, Ranjbar, 2013; Das, et al., 2008; Valko, et al., 2005).

Malondialdehyde is an advanced lipoxidation end-products (ALE), and is also believed to play a causative role in the blood-vessel complications of diabetes mellitus. AGEs are seen as speeding up oxidative damage to cells and in altering their normal behaviour (Jomova, K., Valko, M., 2011; Rahman, 2007; Valko, et al., 2005).

### **8-hydroxy-deoxyguanosine**

8-hydroxy-2' -deoxyguanosine has been widely accepted as an indicator for oxidative stress and carcinogenesis with extensive studies showing urinary 8-OHdG to be a good biomarker for risk assessment of various cancers, cardiopulmonary events and degenerative diseases as it is not influenced directly by either diet or cell turnover (Ściskalska, et al., 2014; Ren, et al., 2011; Lagadu, et al., 2010). Although the presence of 8-OHdG alone is insufficient for the formation of tumours, 8-OHdG is considered to be a potential intermediate marker of disease end-point and is likely to play a role in many pathological conditions where it has been shown to be elevated (Cooke, et al., 2003). Studies have established a significant relationship between the formation of 8-hydroxy-2' -deoxyguanosine (8-OHdG) as a predominant form of free radical-induced oxidative lesions in nuclear and mitochondrial DNA and heavy metal toxicity (Ściskalska, et al., 2014; Valavanidis, Vlachogianni, Fiotakis, 2009). Occupational health studies have therefore utilised the significant and consistent linear associations between urinary heavy metals and 8-OHdG as a measure of oxidative stress from heavy metal exposure (Wang, et al., 2015).

MDA and 8-OHdG were therefore deemed to be appropriate biomarkers that would potentially be correlated with levels of nickel and cobalt in urine.

## **MATERIALS AND METHODS**

### **Study Population**

This cross-sectional study sought to assess the oxidative stress levels of Ni and Co refinery workers (n=77) by measuring urinary Ni and CO as well as MDA and 8-OHdG concentrations. Personnel were recruited from all sectors of the refinery. Participants were informed of the study via a company information session and through the dissemination of an information brochure. Interested volunteers were briefed on the study procedures and any risks, and subsequently given the option to sign an informed consent form (Appendix G) to participate. Recruited participants completed a questionnaire providing demographic information on their age, weight, sex, smoking status and frequency, alcohol consumption, dietary habits, as well as information on their work profile, such as hours worked outdoors in the refinery and tasks performed. Participants were then required to provide urine samples for analysis. All participant consent forms, accompanying questionnaires and urine samples were de-identified.

The study was approved by the Edith Cowan University Human Research Ethics Committee as well as management of the refinery.

## **Data Collection**

### **Questionnaire**

All participants were asked to complete a self-administered questionnaire at the end of their work shift which was adapted from an instrument used by Van Wijnen, Slob, Jongman-Liedekerken, van de Weerdt, and Woudenberg, (1996), to more accurately address the occupational exposures of workers in a refinery setting. The questionnaire was designed to collect data on demographics, a brief medical history and environmental exposures, including consumption of fruit and vegetables. Questionnaires were completed after urine sample collection.

### **Urine Samples**

Participants were issued with 120ml sterile screw cap cryostorage containers to provide post shift urine samples which were then sealed in biohazard bags and refrigerated before being transported by air to Perth in cold storage on the same day of collection. Samples were subsequently stored at Edith Cowan University at -80 C prior to analysis of Creatinine, Ni, Co, MDA and 8-OHdG.

### **Urinalysis**

#### **Ni and Co urinalysis**

For the measurement of Cobalt and Nickel, the total urine volume was recorded and approximately 5 mL of each sample was treated with 4% HNO<sub>3</sub>(aq), and digested in a microwave oven. Urine samples were analysed for Ni and Co, using an Agilent 7700 ICP-MS instrument equipped with a quartz spray chamber, glass ICP torch, and a micro mist nebulizer and X-len ion lens.

#### **Urine MDA and 8-OHdG urinalysis**

Urinary MDA and 8-OHdG concentrations were determined using an Acquity ultra performance water chromatography system (UPLC) coupled to a Xevo TQ-S triple quadrupole mass spectrometer (Waters, Milford, MA, USA). UPLC separation was conducted with an Acquity HSST3 column (2.1 mm×100 mm; 1.8 µm; (Waters), and the mobile phase was ACN and 0.1% formic acid water (0.1% FA), with the flow rate set at 0.3 mL/min and the injection volume at 5 µL. Extraction was performed on a Positive Pressure-96 Processor (Solid Phase Extraction Manifold, Waters, Milford, MA, USA).

### **Statistical Analysis**

Statistical analysis was performed using STATGRAPHICS – Centurion, V.1.10, 2015. The association of urinary MDA and 8-OHdG concentrations with the following variables: urinary metals (Ni and Co), self-reported age, weight, sex, smoking status and frequency, dietary habits, hours outdoors, tasks during working hours were investigated. An analysis of variance (ANOVA) was performed between MDA and 8-OHdG urinary concentrations (dependent variables), and Ni and Co urinary concentrations, smoking status and frequency, age, weight, to determine the significance of the relationship between MDA and 8-OHdG and each respective independent variable listed.

A simple regression was then subsequently used to investigate the strength of the linear relationship between each oxidative stress marker and each urinary metal and covariates.

Multiple variable analysis, was used to investigate the bivariate and multivariate relationships between the urine metals (Ni and Co) and oxidative stress markers (MDA and 8-OHdG) in the urine samples. A multiple regression analysis was also performed to construct a statistical model to best describe the impact of the independent variables and the covariates on the dependent variables. Formal statistical significance was defined at the conventional 5% level.

## RESULTS

### Participant Characteristics

Table 6.1 summarises the basic characteristics of the recruited participants from the refinery workforce. In total, 77 refinery workers volunteered to take part in this study. The percentage of participants that indicated that they were smokers was approximately 18%. The range of average hours worked outdoors was broad (1 – 12 hrs).

Table 6.1 Subject Demographics of Refinery Workers, Western Australia

Age (Median and Range)	55 , 35-71
Current Smokers	18%
Daily Frequency of Smoking	Daily
Range of Indv. average hours outdoors during the day over the working week.	1 - 12

The primary focus of this study was to investigate the relationship between personal exposure to Ni and Co and oxidative stress markers in urine, indicative of systemic oxidative stress. To determine the significance of association, a bivariate analysis was performed for urine Ni and Co concentrations separately in relation to concentrations of MDA and 8-OHdG (Figure.6.1). For all four associations, the Pearson product-moments showed P values of < 0.05, indicating that there was a significant relationship between oxidative stress markers (MDA and 8-OHdG) and urine metals (Ni and Co) concentrations in the analysed urine samples. Although elevated concentrations of both MDA and 8-OHdG were also apparent at lower levels of both urinary Ni and Co concentrations in participating refinery personnel, these points were statistically insignificant.

#### Urinary Oxidative biomarkers and Metal Concentrations

Scatterplots of bivariate analysis between Oxidative Stress marker concentrations (MDA and 8-OHdG) and Ni and Co concentrations in urine samples.

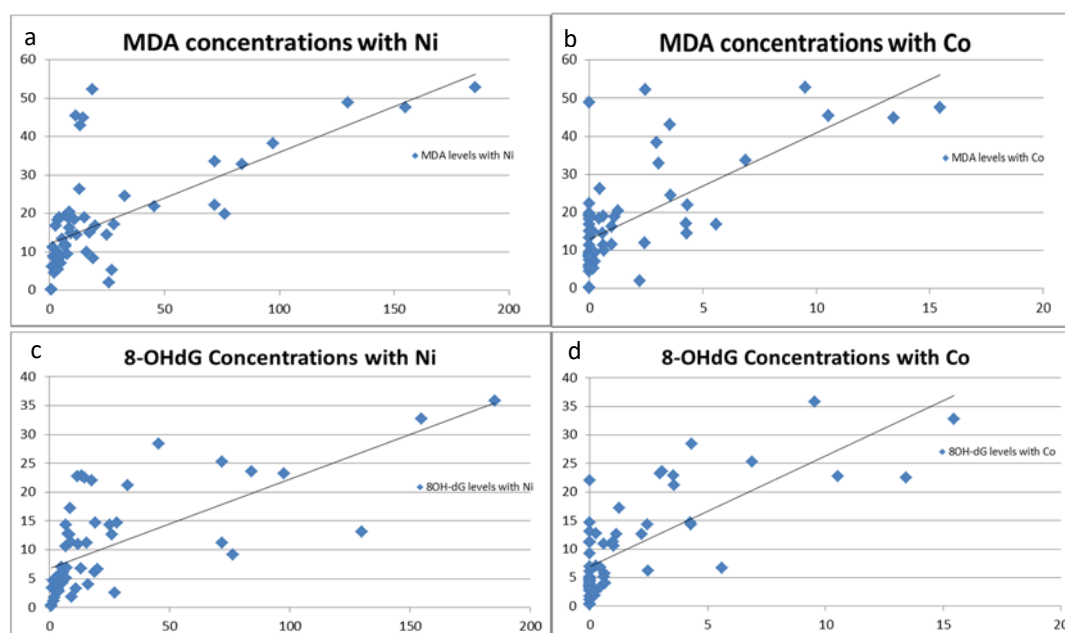


Figure 6.1. Shows the scatterplots of the bivariate analysis between urine MDA and urine Ni (a) and Co (b) concentrations, as well as 8-OHdG concentrations and urine Ni (c) and Co (d) concentrations, from all study participants.

Simple regression linear models illustrating the relationship between the concentrations of oxidative stress markers and Ni and Co concentrations in urine samples.

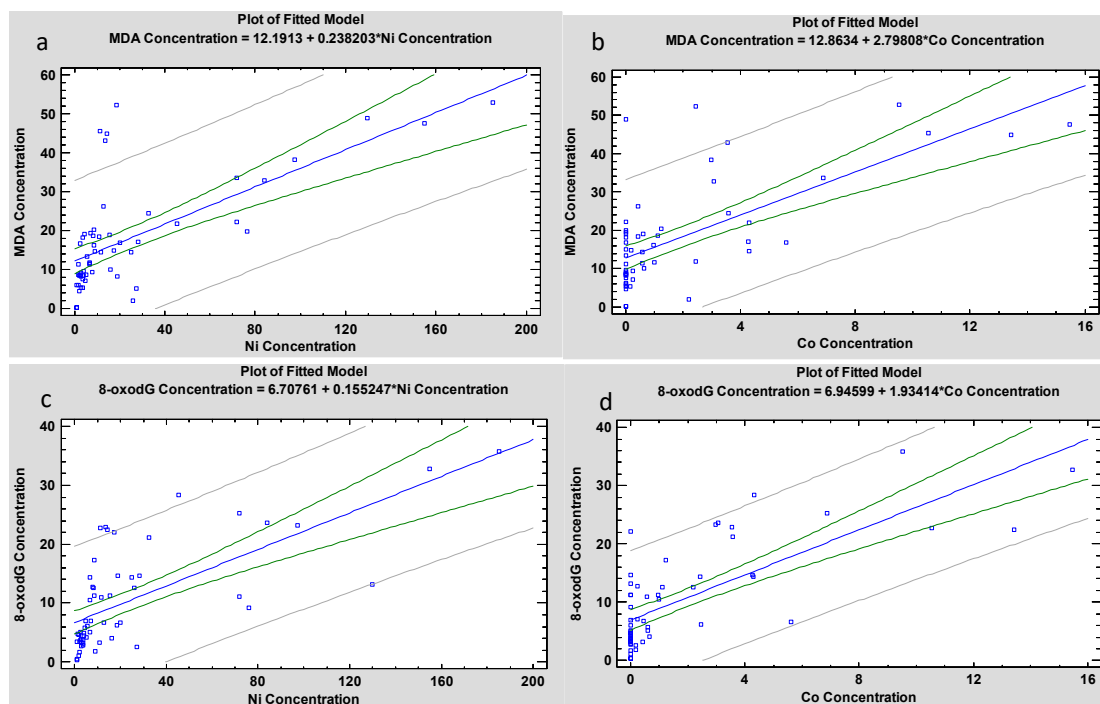


Figure 6.2. Shows the respective results of fitting a linear model to describe the relationship between urine MDA and Ni (a), MDA and Co (b), 8-OHdG and Ni (c) and finally 8-OHdG and Co (d). All four correlations showed patterns with slopes presenting a significant relationship at the 95.0% confidence level.

To determine the strength of these correlations, a simple regression analysis was conducted on both urine MDA and 8-OHdG concentrations in relation to Ni and Co concentrations in urine separately (Figure. 6.2). All four models showed a linear regression pattern with slopes for all cases presenting a significant association between the oxidative markers (MDA and 8-OHdG) and metal concentrations.

P-values in their ANOVAs were all less than 0.05, indicating statistically significant relationships for all simple regressions constructed, at the 95.0% confidence level (Figure 6.2a, 6.2b, 6.2c & 6.2d). All four models presented coefficients ranging from 0.67 to 0.75, indicating moderately strong relationships, accounting for approximately 50% of the variability in urine MDA and 8-OHdG concentrations (R-squared values ranged from 45.4 to 55.9).

MDA concentrations were significantly correlated with Ni as well as Co concentrations in the urine samples (Fig. 6.1a, 6.1b and 6.2a, 6.2b;  $P < 0.005$ ,  $R^2 = 45.4 - 47.2$ ). Similarly, 8-OHdG concentrations were also significantly correlated with Ni as well as Co concentrations in the urine samples. (Fig. 6.1c, 6.1d and 6.2c, 6.2d;  $P < 0.005$ ,  $R^2 = 47.8 - 55.9$ ).

This study also considered the significance of the relationships between other independent variables and MDA and 8-OHdG to determine if there were any confounding factors such as smoking status or age affecting these results.

An analysis of variance performed on urine MDA concentrations and smoking status, as well as participant age, both provided P-values greater than 0.05. This indicated that there were no statistically significant differences in urine MDA concentrations based on smoking status, or participant age at the 95% confidence level.

This was also confirmed through simple regression performed separately for smoking status, and participant age, with urine MDA concentrations which indicated that both variables only explained 0.55% and 0.29% of the variability in MDA concentrations respectively and were therefore not statistically significant.

Similarly, an analysis of variance performed on urine 8-OHdG concentrations and smoking, as well as participant age both also provided P-values greater than 0.05. This also indicated that there were no statistically significant differences in urine 8-OHdG concentrations based on smoking status, or participant age at the 95% confidence level.

Through simple regression performed separately for smoking status and participant age, with urine 8-OHdG concentrations, it was indicated that their association only explained 0.06 % and 0.13 % of the variability in 8-OHdG concentrations respectively and were therefore not statistically significant.

However, an analysis of variance performed on urine MDA concentrations and average hours outdoors in a day provided a P-value less than 0.05, indicating a statistically significant relationship between mean urinary MDA concentrations and average hours working outdoors in a day during their shift at the 95% confidence level.

Simple regression on urinary MDA concentrations and average hours outdoors in a day indicated that there was a moderately strong relationship between the variables which explained 63.8% of the variability in MDA concentration observed.

An analysis of variance performed between mean 8-OHdG concentrations and average hours outdoors in a day also showed a statistically significant relationship at the 95% confidence level, with simple regression on urinary 8-OHdG concentrations and average hours outdoors in a day also indicating a moderately strong relationship between the variables explaining 39.3% of the variability in 8-OHdG concentrations observed in the refinery personnel.

This finding reflected the exposure profile of workers, as those that spent most of their time in a control room had lower exposures than those who worked on maintenance tasks in the actual refinery. Other variables such as, smoking frequency and diet were also not shown to contribute significantly to the variation in urine MDA and 8-OHdG concentrations.

Taking into consideration the significant relationship with hours worked outdoors, a multiple regression analysis was performed to analyse the combined effects of Ni and Co exposure, measured from their concentrations in the urine samples, and the average hours participants worked outdoors during their shifts, on urine MDA and 8-OHdG concentrations.

The equation of the fitted model assumed the equation;

**MDA Concentration = 1.79495 + 0.0720098\*Ni Concentration + 1.21732\*Co Concentration + 2.09334\*Average hours outside in a day.**

For this model, the P-value in the ANOVA showed a value < 0.05, indicating a statistically significant relationship between the variables at the 95% confidence level. The R-squared statistic also indicated that the model as fitted explains approximately 75% of the variability in MDA concentrations in the urine samples.

Although this attributes approximately 25% of the MDA concentration variability to other factors not included in the model, a Lag 1 residual autocorrelation value that was close to zero (-0.08) indicated no significant variable was not accounted for in the model. In addition, a Durbin-Watson statistic of 2.14, and a P-value greater than 0.05, also indicated that residuals tested had no indication of serial autocorrelation at a 95% confidence level.

Similarly a multiple regression analysis was subsequently performed on urine 8-OHdG concentrations in relation to Ni and Co concentrations in the urine samples, as well as the average hours participants worked outdoors during their shifts, smoking frequency and their age, to analyse the significance of their combined effects on the variation of 8-OHdG concentrations in the urine samples.

The result indicated that only Ni and Co concentrations showed statistically significant associations at the 95% confidence level between both independent variables and the variations observed in urine 8-OHdG concentrations as indicated by P-values in the ANOVA (< 0.05).

Variables such as average hours outside during their shift, smoking frequency and age were shown not to be associated significantly with urine 8-OHdG concentrations and therefore were excluded from the analysis without any consequence to the multiple linear regression model describing their relationship.

From the fitted model the R-squared statistic also indicated that the model as fitted explains approximately 70% of the variability in 8-OHdG concentrations in the urine samples, leaving approximately 30% of the 8-OHdG concentration variability to other factors not included in the model. However, a Lag 1 residual autocorrelation value that was close to 0 (-0.08) indicated no significant structure not accounted for in the model. In addition, a Durbin-Watson statistic of 1.77, and a P-value greater than 0.05, also indicates that residuals tested had no indication of serial autocorrelation at a 95% confidence level.

Potential confounders for this study include smoking and diet. Self-reported questionnaire data indicated that smoking prevalence was low at 18%.

Personnel in the refinery participating in this study had very similar food consumption patterns. This could be expected as all personnel at this remote site during their shift are residential and they all ate food provided from the same mess hall. From this perspective diet can be excluded as a confounder and this assumption was confirmed by participant responses to the dietary questions in the survey.

## DISCUSSION

The currently employed method of exposure assessment for occupational cohorts is to determine a time weighted average (TWA) concentration of a contaminant that workers are exposed to over the length of a shift. The sampling method utilises a pump to collect the total particulate matter exposure across the shift giving an average result. Therefore, in cases where the exposure profile is not homogenous peak exposures are not identified. The complexity and cost of TWA exposure assessments are also limiting factors that make it unlikely that monitoring will be conducted more than once or twice per year for a particular exposure cohort and so the likelihood of missing high exposures is relatively high. Exposure standards for TWA's are generally based on toxicological data obtained from animal experimentation or epidemiological studies. The standards are designed to protect the "average" workers from harmful effects, and so do not compensate for variations in individual susceptibility, this is a fundamental flaw of the TWA exposure assessment method (ACGIH, 2015; Safe Work Australia, 2016).

In some cases health monitoring or health surveillance is also prescribed by the regulators as an additional check on workers exposures (Safe Work Australia, 2013; DMP, 2010). In the case of nickel and cobalt, exposure is assessed as total metal concentration in urine. However, these traditional measurements also do not account for the specific effects of exposure and do not consider other risk factors such as individual susceptibility and lifestyle factors that could also contribute to personal susceptibility.

The nickel and cobalt refinery plant offered a unique opportunity to investigate the impact of heavy metal exposure on individuals under chronic occupational exposure conditions. In this study the relationship between oxidative stress markers MDA and 8-OHdG and biomarkers of metal exposure were investigated in workers exposed to Ni and Co. Occupational exposure to both metals can be attributed to the inhalation of heavy metal residue in a number of pollutants transported by dust through the air, by hand to mouth contact, or by the consumption of contaminated drinking water and food.

This study has shown that the refinery workers demonstrated varied concentrations of Ni and Co exposure during their workweek, as indicated by their post-shift urine samples. Corresponding to these urine metal concentrations are concentrations of MDA and 8-OHdG detected in the respective urine samples that are significantly correlated. It was evident from the study that personnel with higher concentrations of Ni and Co also presented higher concentrations of MDA and 8-OHdG in their urine.

Another variable that was shown to affect the MDA and 8-OHdG concentrations in the urine samples was the average number of hours personnel spent outdoors in the refinery as opposed to working in the control rooms in-doors. Multiple regression analysis reinforced this association showing that as workers were occupationally exposed to Ni and Co for longer periods, metal levels in their urine were invariably higher, resulting in associated increases in oxidative stress as evidenced by elevated MDA and 8-OHdG levels.

Urinary Ni and Co concentrations have been reported in other occupational cohorts as being predictive of urinary MDA and 8-OHdG with associated DNA damage (Mukherjee, et al., 2004; Hengstler, et al., 2003). This study therefore provides further evidence to support the correlation between urinary metals, Ni and Co, and urinary MDA and 8-OHdG without being influenced by confounding variables such as smoking, alcohol, or age.

This study has shown that the potential exists to develop a simple and non-invasive screening tool to ascertain the physiological response of workers to a range of workplace contaminants and to work towards developing a new health surveillance regime that is personalised and tailored to suit individuals rather than relying on TWA and metal concentrations in urine as an indicator of potential for adverse health effects. Research should be directed at ascertaining what levels of 8-OHdG and MDA biomarkers are associated with DNA damage and workers should be screened regularly in order to ensure

they remain working within acceptable parameters. Post shift levels of 8-OHdG and MDA should also be analysed over time in order to determine how long workers require to recover from their period of time on-site as this could help determine the ideal FIFO swing period that will allow recover and repair after a swing on-site.

### Limitations

The workplace questionnaire only focused on the on-site activities and did not take into consideration other the lifestyle activities (with the exception of smoking) of the workers particularly during their rest and recreation time away from the refinery. These life style (confounding) factors may well have accounted for the elevated oxidative stress markers (MDA and 8-OHdG) seen in figure 6.1 where the oxidative stress markers were elevated even at low levels of urinary Ni and Co.

The role of oxidative stress markers such as MDA and 8-OHdG require further research. While more post shift urine samples of refinery workers from a larger sample size, and over longer work periods will help build confidence in the predictive value of oxidative stress biomarkers through epidemiological studies; it is recommended that in-vitro cell culture techniques could be utilised to help establish the predictive value of oxidative stress biomarkers for specific pollutants which will provide a model for occupational disease surveillance/ screening. It may be possible then to predict occupational exposure standards based on an in vitro model rather than waiting for the onset of symptoms due to exposure to heavy metals.

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## HEARING PROTECTION AND HAIRNETS

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### ABSTRACT

Ear muffs have been observed being worn over hairnets in a number of workplaces in Queensland in the food industry. The practice appears to be widespread and may indicate that food safety is considered to the exclusion of hearing protection.

This behaviour has also been noted in England by the Health and Safety Laboratory, with the practice of inserting earplugs with the hairnet in place also observed; and by 3M in the US where a reduction of 6dB was found with a single measurement.

Experiments were conducted to determine the effect of hairnets, safety glasses and hair on ear muff performance and the combined effect of these elements.

For quality muffs, which felt more comfortable than a cheaper pair, the hairnet was shown to decrease performance by about 4-6 dB. The addition of safety glasses and hair further degraded performance by 2-4 dB. While the degradation in performance was repeatable with replicated trials which included moving the hairnet, safety glasses or simulated hair, the expected step increases in degradation of earmuff performance with each additional element was not observed.

Quantifying the effect of insertion of earplugs after donning a hairnet did not produce the expected reduction of protection, perhaps because the bored "ear hole" was not as smooth as a human one.

It was also found that usage increased the performance of quality ear muffs by 8dB in the laboratory. This was attributed to the seal warming and flexing and producing a better seal. This may not be an issue in the real-world, where the occluded ear would warm the muff.

### INTRODUCTION

In most workplaces, there is a greater focus on occupational safety than occupational health. In the food industry the extra dimension of food safety also trumps occupational health matters.

One area where this is apparent is the common practice of wearing earmuffs over hairnets and even inserting earplugs into the ear canal with a hairnet in place (Brueck, 2009)



**Figure 19 Ear muff and hairnet with beard guard, safety glasses and hair; laboratory test rig**

The practice of wearing hairnets under earmuffs has been observed (RM) to be widespread in the food industry in Queensland.

There is limited data on how hairnets affect the protection afforded by hearing protection, but a study by 3M (Wells et al., 2013) indicated that losses in the order of 7 dB could be expected. This is equivalent to wearing hearing protection for less than two hours in an eight hour shift.

One of us (DB) built a rig for use in university teaching to demonstrate the losses produced by spectacle frames (about 6 dB) breaking the seal on muffs. The reduction in performance was shown to be between 4 and 8 dB over more than a decade of teaching. The rig was a sealed box with a speaker fed by white noise. The ear canal was represented by a 8 mm hole drilled into a block of wood and intercepted by another hole in which a Sound Level Meter was inserted. An ear muff was placed over the hole. It was necessary to have the noise source in the box for teaching, as it would have been unacceptable to expose a classroom to high levels of sound for the demonstration. Also, communication would cease during the demonstration.

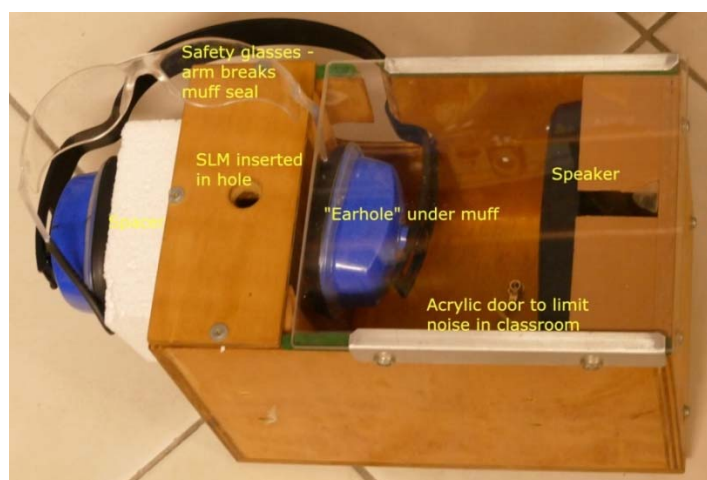


Figure 20 Ear muff /plug teaching test rig

This arrangement, while useful for demonstrating the effects of reduction of fit of muffs by safety eyewear, was knowingly not under free field conditions as various resonances could be expected inside the sealed box.

### Equipment

A similar arrangement but without the box, was developed for this work to better emulate free field conditions. The 8 mm diameter of an ear canal and 25 mm length are reasonable representative of the size of actual air canals (Staub, 2014). A larger hole was bored in a block of pine wood to intercept this hole and accommodate the Sound Level Meter. This larger hole for the Sound Level Meter allowed O-rings to be placed on the stem of the microphone. Narrow O-rings were used nearer to the microphone to centre the instrument but limit sound conduction from the wood. The heavy O-rings provided a better noise seal, but required the instrument to be twisted during insertion into the test rig.

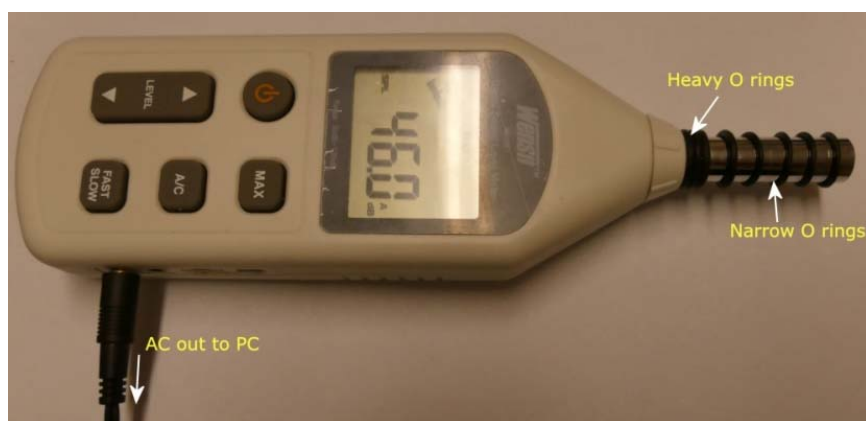


Figure 21 Sound Level Meter and O-rings

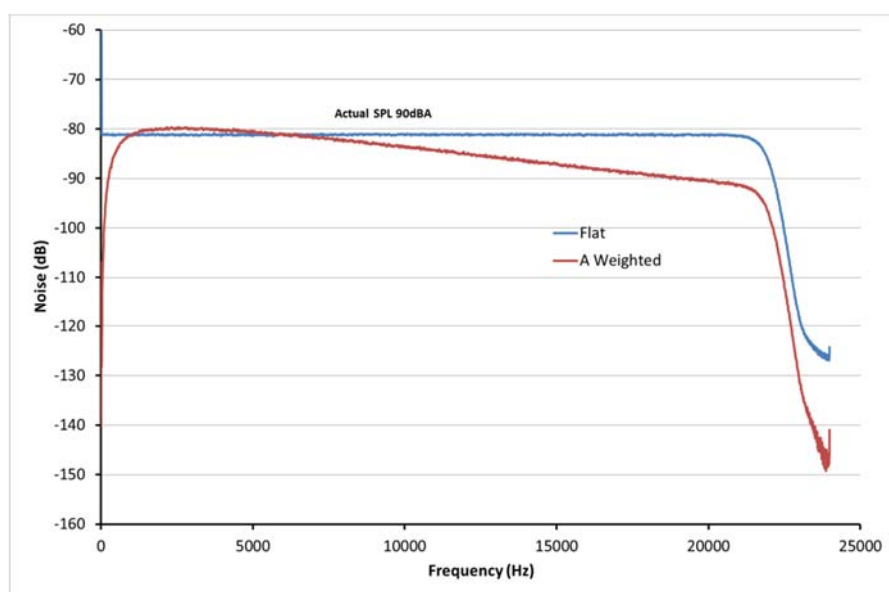
The Sound Level Meter (cheap generic Wensen brand with an electret microphone; AC, DC and USB output; claim of IEC651 and ANSI S1.4 Class 2 performance, but not certified). As the measurements were relative, the quality of the instrument was a minor concern.



**Figure 22 Sound Level Meter inserted in muff /plug test block (L), Test rig ( R )**

The advent of free noise generator “apps” for tablets and phones (Keuwlsoft Function Generator, keuwl.com) allowed white noise to be generated and fed with a Bluetooth link to an amplified stereo speaker bar (Jensen JSBW-650). The Function Generator was demonstrated to give a flat response from zero to over 20 kHz with a real time spectrum analyser (Simple Audio Spectrum Analyser v3.9 techmind.org) using a Fast Fourier Transform. The PC ran at 2.67 GHz, 16 GB RAM, 64 bit Windows 10, Asus PT6 motherboard with a built-in Realtek High Definition Sound card. The Function generator was directly connected to the Spectrum Analyser to demonstrate its frequency response at this stage.

The Spectrum Analyser could also calculate the A-weighted response, which is more appropriate for work with hearing protection. The Spectrum Analyser sampled at 44.1 kHz, 16 bit stereo (averaged) with a FFT length 4096 using a Hanning Window. The speaker volume on the Function Generator and Sound Bar were adjusted to prevent clipping. The software produced an output that could be pasted into a spreadsheet (Excel 2010, microsoft.com ).



**Figure 23 Flat frequency response 20 Hz-20 kHz, using Keuwlsoft Function Generator**

Note that the Sound Level Meter response was about -80 dBA, whilst the calibrated output of the Sound Level Meter was +90 dBA. The readings could be aligned by adding -80 +90 = 170 dB to the plot. The absolute dB measurements are of limited interest.

The sound level (dBA) on the Sound Level Meter was noted for each trial.

### Methodology

For most measurements except check measurements, the trials were performed in triplicate for about 10 seconds using white noise. This allowed about 500 samples to be analysed by the Spectrum Analyser and the Sound Level Meter reading to stabilise on Slow.

Where hairnets, safety glasses and “hair” were used to modify the muff performance, the items were moved slightly between each trial to determine repeatability and better simulate real-world performance.

All decibel averages, including smoothing of the spectra were calculated using the formula, which was written as an Excel function.

$$\text{Average dB} = 10 \text{Log} \sum_{i=1}^n 10^{dB_i/10}$$

The distance between the stereo speaker-bar was kept at 60 cm, about arm’s length and these positions marked with tape to allow accurate repositioning. The “ear hole” and speaker bar were located 25 cm above the surface of a bench. The rig was placed at the centre of a room 3.4 x 4.3 m, with a 2.3 m ceiling.

During each trial, the room doors were closed. The observer, who read the Sound Level Meter (set on Slow) and turned on the white noise generator, stood at the same place to the side of the rig for each trial, to assist repeatability.

During the trials it was found that earmuff use greatly affected their performance (8.2 dB), presumably by making the seal more pliable during handling, so the muff seals were massaged for a minute before testing.

The Sound Level Meter was calibrated with a calibrated calibrator (Bruel and Kjaer) before the trials. To minimise the effects of jolts to the Sound Level Meter, reference measurements with white noise and ear muffs were made in each session of trials.

### Earmuffs

Two earmuffs were trialled, a new yellow 3M H9A 290 and a much smaller, used blue Protector Safety Cat No. EMLU-80. The muffs will be identified by their colour in this paper.

### Earplugs

Two earplugs were tested, a green earplug (Uvex X fit) and a blue corded plug (UMATTA Corded Disposable Earplug). These too will be identified by their colour.

### Hairnets

Two non-woven hairnets were sourced. They both appeared to be of a flat, non-woven spun polymer construction, with a light elasticised band. Only the blue hairnet was tested.



Figure 24 Hairnet structure

### Smoothing spectrums

The complex spectrums were derived by Fast Fourier Transform of the AC output of the Sound Level Meter.

## RESULTS AND DISCUSSION

It should be noted that degradation of performance of muffs and plugs by 3 dB is very significant – halving the performance. This is equivalent to just wearing the device for half a shift. Degradation by 6 dB is equivalent to wearing the device for only quarter of the shift.

The repeatability within a set of three trials with the same conditions was generally within 1 dB, despite the movement of the muff, hairnet, safety glasses and “hair”, so the “Effect”, the reduction in performance relative to the Yellow muff without these factors, was measurable in all cases.

### First measurement session

The performance of the quality yellow muff was investigated with the hairnet flat and scrunched as found in workplaces and then with safety glasses and hair added to further break the seal to the head.

**Table 3 Effect of Hairnet, Safety glasses and ‘hair’ on yellow muff performance**

Summary	Hairnet	Safety glasses	Hair	dBA	Ref (dB)	Effect (dB)
Room background				56.4		
White noise				92.5		
Yellow muff				76.5	16.0	
Yellow muff	flat			82.6		6.0
Yellow muff	scrunched			80.8		4.3
Yellow muff	scrunched	y		84.8		8.2
Yellow Muff	scrunched	y	y	82.8		6.3

Flat hairnet flat under the seal

Scrunched hairnet breaking seal similar to that in Figure 1.

Hair A 12 mm paint brush inserted under seal to simulate hair

Ref (dB) The amount the ear muff reduced the noise without things under the seal

Effect The reduction in performance of the ear muff with various elements breaking the seal

The yellow muff gave a 16 dB reduction in the noise. With the hairnet spread flat – impossible in the real world, the performance was degraded by 6dB. With the hairnet scrunched as in Figure 1, so that the seal was cut by multiple layers of the hairnet, the degrading effect was 4.3 dB when the hairnet was repositioned before each trial, perhaps due to warming of the muff and the seal bedding-in.

When other factors such as safety glasses and hair were added, the picture was more complex and not fully understood. Adding the safety glasses added nearly 4 dB to the degradation (8.2 dB total), but hairnet, safety glasses and hair only reduced performance by 2 dB (6.3 dB total).

### Second measurement session

A second session of measurements was undertaken to investigate:

- the performance of earplugs with hairnets, as the UK Health and Safety Laboratories had reported earplugs being used with hairnets in place
- the individual effects of the hairnets, spectacle frames and hair
- the practice of removing a comfort rubber covering on safety spectacles (which was observed in another workplace)

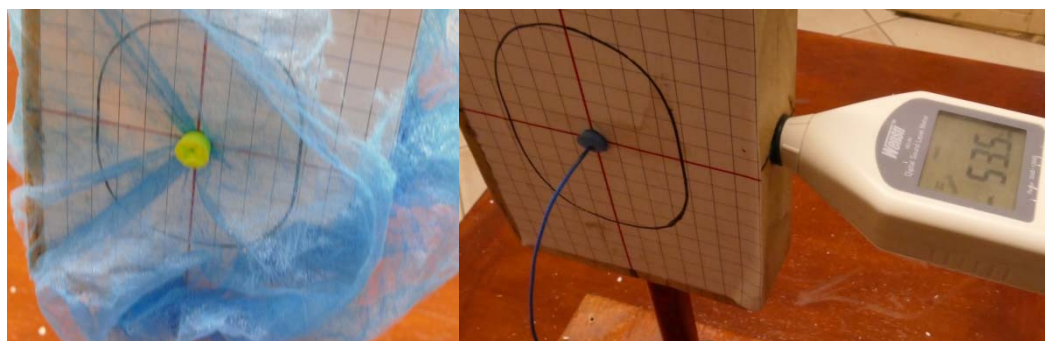


Figure 25 Green earplug inserted into hair net; blue corded earplug without hairnet



Figure 26 Yellow muff and safety glasses with and without the comfort rubber on the frame

All measurements were referred to the performance of the yellow ear muff.

Table 4 Second measurement session

Summary	Hairnet	Safety glasses	Hair	dBA	Ref (dB)	Effect (dB)
White noise				87.1		
Yellow muff				73.6	13.5	
Green plug				85.2		11.7
Blue plug				85.6		12.0
Blue plug	y			84.3		10.8
Yellow muff			y	77.2		3.6
Yellow muff		y		83.0		9.5
Yellow muff		bare frame		82.4		8.8
Blue muff				76.1		2.5
Blue muff	flat			76.0		2.4
Blue muff	scrunched			75.0		1.4

The results for the earplugs were not as expected and are questionable as the initial performance was poor. The reason is not known, but it may relate to the hole being too rough and not providing a good seal as the performance actually improved with the presence of the hairnet. However, the performance was repeatable and the results are presented in the hope that others will attempt to quantify the effect of using earplugs. There was not sufficient time to investigate the matter.

The removal of the rubber comfort cover from the frames of safety spectacles with the yellow earmuffs only improved the protection by 0.7 dB, a very small amount and would not justify the practice.



**Figure 27 Blue muff with scrunched hairnet**

With the blue ear muffs, the performance was 2.5 dB worse than the yellow muffs. It may be that the smaller size permitted a greater clamping pressure. Once the hairnet was spread flat under the muff, its performance improved slightly and even more when it was scrunched. These results appear anomalous, but were highly repeatable. They may be explicable if the clamping pressure was higher than for the yellow muffs.

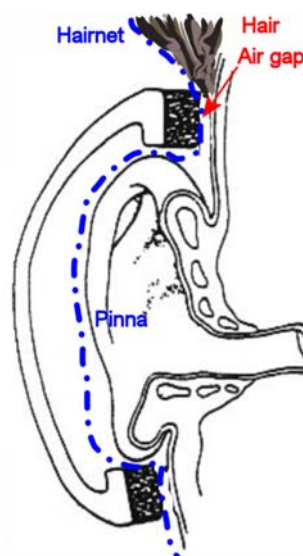
### Spectral Analysis

In the analysis of the white noise reduction by the ear muffs and earplugs under various conditions it was discovered that the spectral data was corrupted – some 50,000 data points. The source of the corruption (also present to some extent in an earlier pilot study) had not been determined at the time of submission of the paper. It is suspected that the Sound Level Meter output was at fault.

The purpose of the spectral analysis was to pinpoint if there was a spectral element to the degraded performance of the ear muffs and earplugs.

### Limitations of study

One of the limitations of the study is that it is laboratory based. The fit of earmuffs could be expected to be better than the real-world as the surface of the wood is flat but the seal around the ear is bumpy, with some contours that most muff seals could not follow. The pinna (the visible part of the ear), would tend to hold a hairnet away from the ear, particularly if the hair was bulky and the hairnet was taut.



**Figure 28 Effects of pinna and hair on hairnet,(based on figure by Kalb J T (2013))**

Thus the results of this study would be expected to be overly optimistic. To properly estimate the effect of the pinna and surrounding hair, established dual microphone stems to measure noise inside and outside the muff could be used. Dual microphones could also be used with earplugs, but only a microphone placed close to the eardrum would give measurements closely approximating the real-world.

Another significant limitation is operator error with reading the dBA on the Sound Level Meter. There was 1-2 dB variability with the levels which were “averaged” by the operator and software solutions are being investigated.

## CONCLUSIONS

This study does not purport to be a definitive study, but has explored some of the factors required to properly research the effects of hairnets, safety glasses and hair on the performance of ear muffs. Credible results were obtained with the yellow 3M H9A 290 ear muffs which suggested that hairnets, safety glasses and hair all significantly degraded the performance of ear muffs.

The practice of placing earplugs after donning a hairnet was not shown to affect the performance of the earplugs, but the measured protection provided by an earplug was far less than expected, so this part of the study is not seen as reliable. Despite this, the practice is not recommended.

The practice of removing the outer comfort rubber on safety glasses to provide a thinner profile through a muff seal appears to have limited benefit.

The seal on quality muffs can improve significantly with use as the seal material becomes more compliant.

The workplace culture of dominance of food safety over occupational health in the food industry is of concern and would make any changes to improve hearing protection in the food industry very difficult. Unless otherwise indicated, it would be prudent to de-rate protection by at least 6 dB where.

As a result of this work, one major international company in the food industry now requires workers in Queensland to place hearing protection before donning hairnets.

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## FUNCTIONAL EFFECTS RESULTING FROM SHORT TERM EXPOSURES TO HAND-ARM VIBRATION IN MINE MAINTENANCE WORKERS

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Rio Tinto

### ABSTRACT

Mine maintenance workers use a range of tools that generate hand-arm vibration. Some of these tools include drills, grinders, other rotary tools, percussive metalworking tools, and saws. There is a link between the use of these tools and vibration associated disorders of the bones, joints, muscles, and peripheral nerves. However, there are very few studies on the magnitude and frequency of the hand-transmitted vibration and its functional effect.

The outcome of the study was to identify the tools that created the highest hand-transmitted vibration levels, and to identify the frequency patterns that likely affect functional effects in maintenance workers in the short term.

The study used a triaxial hand-arm accelerometer to measure the magnitude and frequency of the hand-transmitted vibration. The accelerometer was placed inside a rubber strap that is attached to the subject's hand while the subject used different tools. The results were plotted in a 1/3 octave band frequency versus magnitude graph.

The functional tests were completed by using a handgrip dynamometer, Semmes Weinstein monofilament screening, and Purdue Pegboard dexterity test before and after vibration exposure.

Following high hand-arm vibration exposures, the test group results showed increased handgrip strength and increased hand dexterity. However, the control group, not exposed to vibration, had even higher hand dexterity results without increase in handgrip strength. No significant change was found with the tactile sensitivity test. It was also found that the frequencies that most likely affect hand-arm vibration are over 40Hz range.

Finally, these functionality tests have shown that these low cost tools can supplement existing health surveillance programs and follow up studies.

**Keywords:** hand-arm vibration, functional effects, handgrip strength, tactile sensitivity, dexterity

### INTRODUCTION:

The use of certain power tools, such as drills, grinders and percussive metalworking tools, generate hand-arm vibration (HAV) in high levels, which can cause functional and sensorineural effects on workers. (Griffin, 2012). Others have studied these effects, including disorders of muscles and peripheral nerves, on either long-term epidemiological studies (Sakakibara et al., 2005, Cederlund et al., 1999, Bovenzi, 2012, Wasserman, 1996, Tominaga, 2005, Sandén et al., 2010, Putz-Anderson et al., 1997, Bovenzi, 2005), or short term studies on laboratory-controlled sinusoidal vibration experiments (Stuart et al., 2003, Lundström et al., 2007, Gerhardsson et al., 2013, Dong et al., 2004). However, very few studies on short-term health effects from random hand-arm vibration exist.

The purpose of this study was to identify the tools that created the highest short-term hand-transmitted vibration magnitudes, and to identify the frequency patterns that likely affect functional effects in mine maintenance workers.

Hand-arm vibration was measured 1/3 octave band frequency versus magnitude in the entire frequency range from 4Hz to 2000 Hz; which extends beyond the current AS ISO 5349.1 (Standards Australia, 2013). Several studies suggest that ISO 5349.1 do not accurately represent the entire range of possible HAV induced health effects, which was based on vibration discomfort or perception (Adewusi et al., 2010, Bovenzi, 2005, Govindaraju et al., 2008).

For example, Wasserman (1996) discussed that hand-arm vibration in the 100 to 205Hz frequency range resonate with human hand structures, therefore a very small amount of impinging vibration yields an internal response greater than the impinging vibration. Dong et al. (2004) found that the fingers readily absorb hand-arm vibration in the 100 to 250Hz frequency range. Later, Dong et al. (2005) found that entire hand-arm system resonated in the frequency range of 20 to 50Hz. A review by Bovenzi (2005) summarises that hand-arm vibration in the range of 6.3Hz to 1250Hz can induce disorders hand-arm vibration syndromes.

Some authors have gone beyond challenging ISO 5349.1 and proposed new frequency weightings (Bovenzi, 2012) (Dong et al., 2006) (Tominaga, 2005). Bovenzi et al. (2015) discussed all these findings and proposals and suggested that one of the frequency weighting that could be the most suitable to assess sensory function will be Dong et al. (2006) proposal, which is derived from finger vibration power absorption.

The assessable functional and sensorineural tests studied include handgrip strength, tactile sensitivity and hand dexterity. Many studies have found these tests suitable for either health surveillance or confirmatory diagnosis of HAV disorders. (Ahn et al., 2013, Cederlund et al., 1999, Gerhardsson et al., 2013, Gerhardsson et al., 2014a, Sakakibara et al., 2005)

## **METHODS**

### ***Participants***

Fifty subjects participated in the study (47 males and 3 females), mean age of 36.8 years (SD = 10.5). Twenty nine of them, grouped as the 'control group', work in supervisory, planning, electrical trade, engineering and other desk-based occupations; and they all reported little to no use of powered tools. The rest, 21 employees, grouped as the 'test group' included automotive, heavy mobile plant, power plant and processing plant maintainers, boilermakers and carpenters; and they all reported frequent to daily use of powered tools.

### ***Vibration exposure***

From May 2016 to August 2016, the author completed short duration hand-arm vibration measurements on the test group with a Svantek SVAN106 human vibration meter and 1/3 octave band analyser (Serial number 20906) and a Svantek SV105A Triaxial accelerometer (Serial number 53256), both with current manufacturer's calibration dated 15/01/2016. One hundred forty and four samples under real world conditions were obtained and were recorded as 1/3 octave band analysis.

The accelerometer was placed inside a rubber strap that is attached to the subject's hand while the subject used different tools. The results were plotted in a 1/3 octave band frequency versus magnitude graph.

Calculation of the hand-transmitted vibration dose between 'pretest-posttest' was based on Standards Australia (2013), but instead of reporting a normalised hand-transmitted vibration exposure to 8 hours, it was just reported on the total time of the vibration measurement before the two sets of functional tests as described below.

### ***Experimental procedures***

A 'pretest-posttest' design that included hand function tests were based on Bovenzi et al. (2015) procedures.

- Participants completed a handgrip strength test with a Jamar hydraulic dynamometer model 5030J1. The participant flexed his elbow to 90 degrees, with the wrist in a neutral position, and forearm supported. The participant squeezed the dynamometer three times, with 10-second interval between each attempt. The author recorded each attempt, but only reported the average value and expressed it in Kilograms-force.
- Participants completed a manipulative dexterity test with the Purdue peg-board (Lafayette Instruments) as per standardised procedure.
- The author assessed participant's tactile sensitivity with Semmes Weinstein monofilaments, by pressing the monofilament against participant's pulp of the second and fifth fingertip, for at least 1.5 second to generate a response.

The control group completed two set of tests after having a break of a least an hour. The test group completed a set of functional tests before hand-arm vibration measurement, and another set of functional tests right after them. The test group completed the assessments just after their mid-shift breaks, which usually last a minimum of half an hour to ensure their hand functionality were completely recovered as per Lundström et al. (2007).

Due to the time consuming nature of the tests they were carried out in a quiet room to avoid distractions. Six control group participants completed all the required functional tests, while 11 of the test group completed handgrip tests, and only six of these completed the dexterity and tactile sensitivity tests before and after vibration exposure.

### Data Analysis

Analysis of covariance (ANCOVA) was used to compare the functional tests results between control groups and test groups, since it provides the benefits of Analysis of Variance (ANOVA) and regression analysis. It also reduces group selection bias as it excludes the covariate from the calculations (Dimitrov and Rumrill Jr, 2003, Laird, 1983, Stevens, 2002).

For handgrip strength, the covariate describes the pre-existing stronger handgrip force by the test group, who often perform heavy manual tasks. For the manipulative dexterity test, the covariate describes the learning effect from doing the test twice. Finally, for the tactile sensitivity tests, the covariate describes the pre-existing sensorineural damage from extensive power tool use from the test group.

### RESULTS

Six participants from the control group and eleven participants from the test group completed the handgrip strength testing. Table 1 shows a tabular comparison on the handgrip strength before and after vibration exposure for the test group, and the two sets of handgrip strength for the control group.

The average pre-test handgrip results from both groups are within 2kg-force for dominant hand and 4kg-force for non-dominant hand, and variability as standard deviation is similar. Average post-test results for dominant hand; show a decrease of handgrip strength for control group, while it shows an increase of handgrip strength for test group. No marked improvement or degradation occurs for both groups in the non-dominant hand.

**Table 5: Dominant and non-dominant Handgrip strength pretests-posstest comparison between control group and test group**

Participant		Dominant Hand				Non-dominant hand			
ID	ID	Pretest hand grip		Posttest hand grip		Pretest hand grip		Posttest hand grip	
Control	Test	Control	Test	Control	Test	Control	Test	Control	Test
39	1	56.0	50.3	59.7 ↓	52.8 ↑	53.3	49.7	62.0 ↑	52.7 ↑
41	3	66.7	61.7	55.0 ↓	65.7 ↑	66.7	64.3	65.3 ↓	70.3 ↑
42	6	48.3	54.0	55.3 ↓	54.0 -	43.0	52.3	57.3 ↑	52.3 -
45	10	64.3	66.7	58.7 ↓	67.3 ↑	62.7	65.0	63.7 ↑	63.7 ↓
48	11	35.3	32.3	33.7 ↓	35.3 ↑	32.7	48.3	32.0 ↓	48.0 ↓
49	19	55.7	52.0	55.0 ↓	52.7 ↑	54.3	52.0	55.3 ↑	51.3 ↓
	24		54.7		60.3 ↑		48.7		49.3 ↑
	25		87.3		86.0 ↓		79.3		77.3 ↓
	31		62.3		64.0 ↑		56.7		57.3 ↑
	35		52.7		60.3 ↑		50.3		59.0 ↑
	37		63.3		62.0 ↓		61.7		58.3 ↓
Average (SD)		54.4 (11.5)	52.8 (13.4)	52.9 ↓ (9.6)	60.0 ↑ (12.4)	52.1 (12.6)	57.1 (9.6)	55.9 ↑ (12.3)	58.1 ↑ (9.2)

Note: The following symbols ↑ shows an increase, ↓ shows a decrease and - 'shows no change between pretest-posttest.

The significance of the variation between pretest-posttest was tested with ANCOVA and the results are shown in Table 2. For the dominant hand, there is a significant difference ( $p < 0.005$ ) between the test and control groups; however, the pre-existing initial grip strength force, or covariate, from both groups also make a significant difference in the outcome ( $p < 0.005$ ). For the non-dominant hand, the covariate shows a significant difference ( $p < 0.005$ ); however no significant difference was found between the groups ( $p = 0.36$ ). These results could indicate that in the short-term, hand vibration could raise worker's grip strength, which is consistent with the findings of Radwin et al. (1987) and Wasserman (1996)

**Table 6: Analysis of covariance for pretests-posttest handgrip strength results between control and test groups**

ANCOVA for dominant hand					
	<i>Sum of squares</i>	<i>df</i>	<i>MS</i>	<i>F-value</i>	<i>p-value</i>
Covariate	1753.8	1	1753.8	101.7	<0.005
Between	198.8	1	198.8	11.5	<0.005
Within	241.5	14	17.3		
Total	2194.2	16			

ANCOVA for non-dominant hand					
	<i>Sum of squares</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>
Covariate	1304.6	1	1304.6	61.9	<0.005
Between	18.9	1	18.9	0.9	0.359
Within	294.9	14	21.1		
Total	1618.4	16			

Table 3 shows that the overall score for dominant, non-dominant and both hands dexterity tests for both groups were within 3 points of each other for the pre-test on average. Variability, shown as standard deviation was also similar. Post-test dexterity results for dominant hand increased in both groups; however, there was a marked larger increase of dexterity for control group. No marked improvements or degradation occurred for both groups in the assembly test (not shown).

**Table 7: Pretests-Posttests hand dexterity score that includes use of dominant, non-dominant and both hands, between control group and test groups. Figures highlighted represent the highest variation on the vibration-exposed group.**

Participant ID		Pretest score		Posttest score	
<u>Control</u>	<u>Test group</u>	<u>Control</u>	<u>Test group</u>	<u>Control</u>	<u>Test group</u>
39	10	46	46	43 ↓	47 ↑
41	11	42	47	43 ↑	44 ↓
42	24	41	40	49 ↑	45 ↑
45	25	45	40	50 ↑	41 ↑
48	35	49	40	51 ↑	40 -
49	37	47	42	49 ↑	44 ↑
Average (SD)		45 (3.0)	42.5 (3.2)	47.5 (3.6)	43.5 (2.6)

The significance of the variation between pretest-posttest was tested with ANCOVA and the results are shown in Table 4. There is a significant difference ( $p < 0.05$ ) between the test and control groups, while the covariate is not significant ( $p > 0.5$ ). This can be interpreted as the hand-arm vibration exposure played a significant role in dexterity performance.

**Table 8: Analysis of covariance for hand dexterity scores between control group and test group, where covariate is the pretest.**

ANCOVA for dexterity scores					
	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>
Covariate	21.23333	1	21.23333	2.522217	0.147
Between	48	1	48	5.701716	0.041
Within	75.76667	9	8.418519		
Total	145	11			

Tactile sensitivity test results for both groups are shown in Table 5. No significant differences were found between pretests or posttests for both groups.

**Table 9: Comparison of dominant and non-dominant hand tactile sensitivity pretest-posttest scores, based on the sum of second and fifth finger, between control and test groups. Figures highlighted represent the highest variation on the vibration-exposed group.**

Participant ID		Dominant hand				Non-dominant hand			
		Pretest		Posttest		Pretest		Posttest	
<u>Control</u>	<u>Test</u>	<u>Control</u>	<u>Test</u>	<u>Control</u>	<u>Test</u>	<u>Control</u>	<u>Test</u>	<u>Control</u>	<u>Test</u>
39	11	5.66	5.66	5.66	5.66	5.66	5.66	5.66	5.66
41	24	7.22	5.66	6.44	5.66	7.22	5.66	7.22	5.66
42	25	5.66	5.66	5.66	6.44	5.66	5.66	5.66	5.66
45	31	5.66	5.66	7.22	5.66	5.66	7.22	5.66	6.44
48	35	5.66	5.66	5.66	5.66	5.66	5.66	5.66	5.66
49	37	5.66	7.22	5.66	5.66	5.66	7.22	5.66	5.66
Average (SD)		5.92 (0.6)	5.92 (0.6)	6.05 (0.7)	5.79 (0.3)	5.92 (0.6)	6.18 (0.8)	5.92 (0.6)	5.79 (0.3)

The participants that returned the highest functional tests variation were the ones who also returned the highest short-term hand-arm vibration between pretest -posttests. These results are summarised in the Table 6.

**Table 10: Calculated total hand-arm vibration exposure for participants that returned highest variability between functional pretest-posttest**

Subject	Trade / position	Activity	Average Weighted vibration level (RMS) $A_i$ , m/s <sup>2</sup>	Time $T_i$ , s	Partial vibration exposure $A_i^2 \times T_i$	Total HAV exposure between pretest-posttest $A_T = \sqrt{\frac{\sum A_i^2 T_i}{\sum T_i}}$
1	Automotive mechanic	Bolting up tyres to 4WD with Atlas Copco W2216 Impact wrench 22mm	3.568	84	1070	5.342 m/s <sup>2</sup>
		Chiselling automotive part with Blue Point Heavy Duty Air Hammer	9.743	20	1898	
6	Processing plant boilermaker	Polishing mild steel plate with a Bosch GPO12E 7" angle grinder with wire brush	3.847	32	471	4.739 m/s <sup>2</sup>
		Grinding mild steel plate with a Hitachi G185E3 7" angle grinder with a 5" disk	5.383	38	1101	
10	Mobile boilermaker	Grinding loader bucket with Makita GA54020 Electric Angle grinder 5"	4.441	64	1262	4.441 m/s <sup>2</sup>
11	M. Boilermaker apprentice	Cleaning loader bucket dirt with Von Arx 12B Needle gun	9.038	290	23689	9.038 m/s <sup>2</sup>
19	Carpenter	Drilling concrete with Hilti 7e70-ATC combi hammer	12.281	79	12986	10.804 m/s <sup>2</sup>
		Planing wood 82mm thick with Makita KP08 planner	2.911	100	847	
		Drilling concrete with Makita HR300C 850W Combi hammer	15.311	60	14066	
24	Processing plant maintainer	Polishing metal with Hitachi G13SR3 electric angle Grinder 5" with wire brush	4.294	273	5034	3.891 m/s <sup>2</sup>
		Bolting up screen upper deck with Ingersoll Rand Impact Wrench 3/4"	3.612	430	5610	
31	Tailings dam maintainer	Connecting water pipes with Caterpillar 222-3053 Impact Wrench 3/4"	4.755	130	2939	4.755 m/s <sup>2</sup>
37	Power plant mechanic	Grinding metal plate with Makita 9565C angle grinder 5"	3.984	234	3715	6.691 m/s <sup>2</sup>
		Screwing bolt with Ingersoll Rand 2990P Impactool Impact Wrench	8.738	214	16340	

The following charts (Figure 1 to 7) show the un-weighted average 1/3 octave band vibration RMS levels for the participants who had the highest functional test variation and highest short duration hand-arm vibration. These levels are also compared

graphically to the current AS ISO 5349.1 (Standards Australia, 2013) and the Dong et al. (2006) proposed finger vibration power absorption weighting.

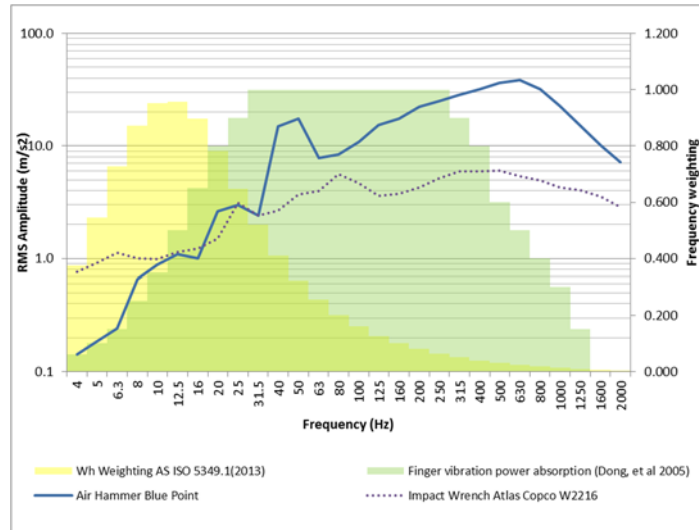


Figure 29: Participant 1 Automotive mechanic's HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)

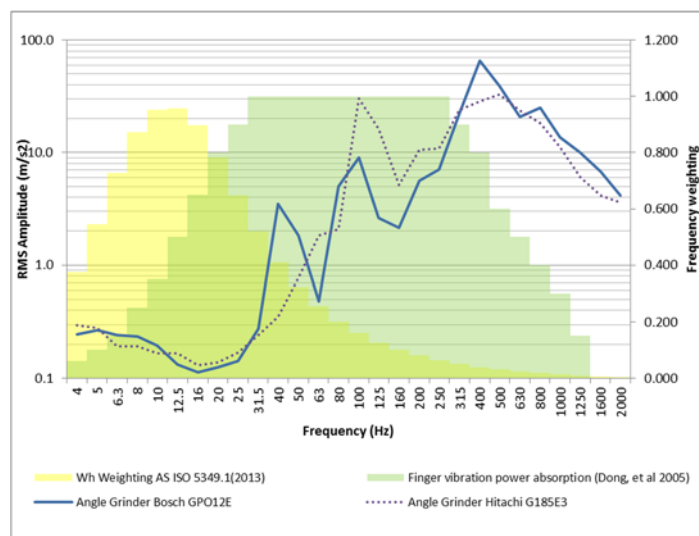


Figure 30: Participant 6 Processing plant boilermaker's HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)

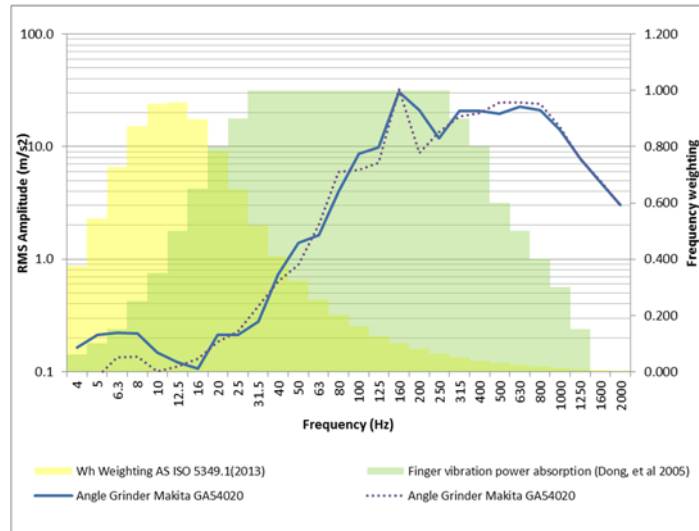


Figure 31: Participant 10 M. maintenance boilermaker's HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)

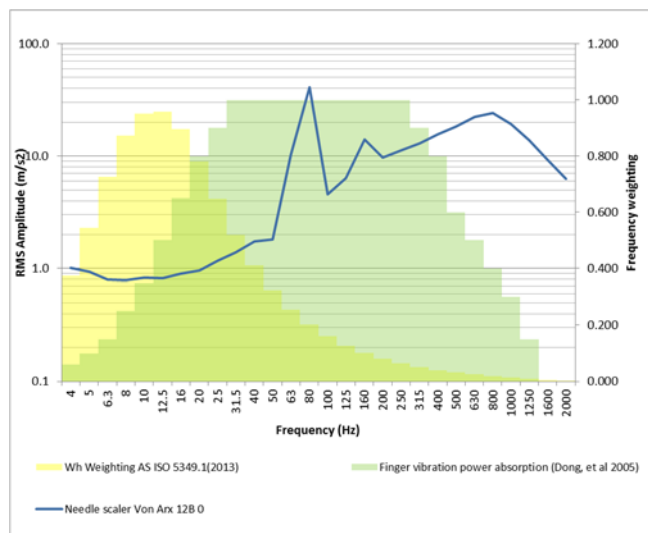


Figure 32: Participant 11 M. boilermaker's apprentice HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)

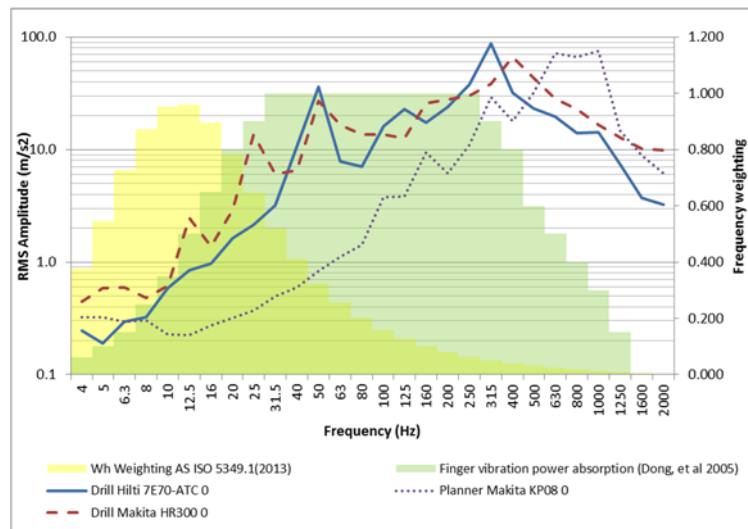


Figure 33: Participant 19 - Carpenter's HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)

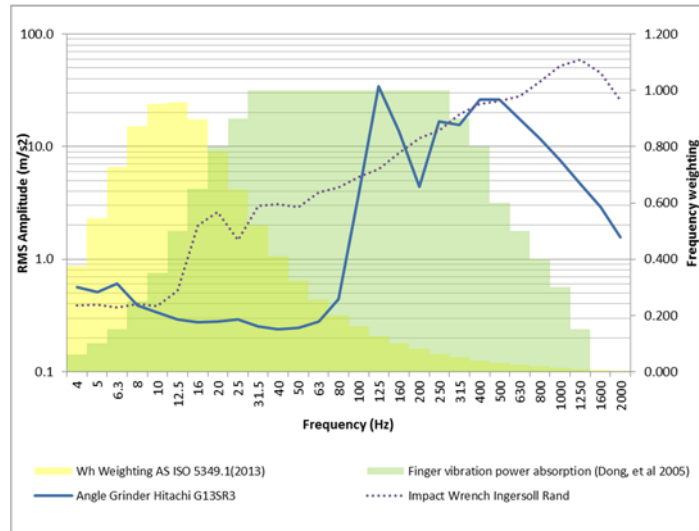


Figure 34: Participant 24 processing plant maintainer's HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)

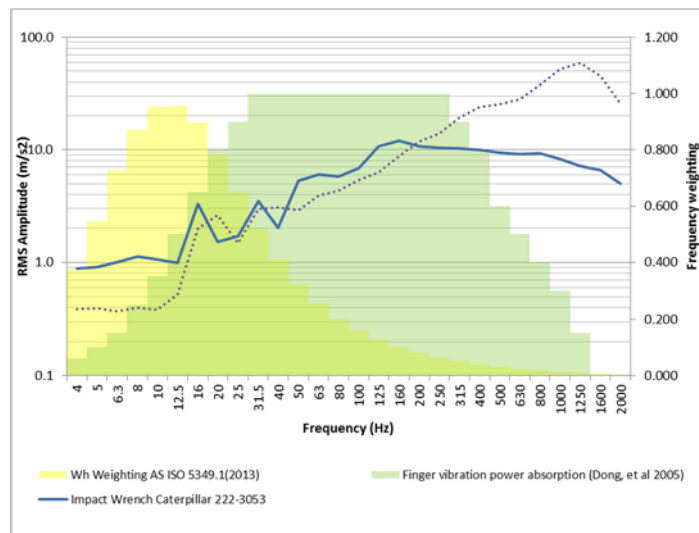


Figure 35: Participant 31 Tailings Mechanic's HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)

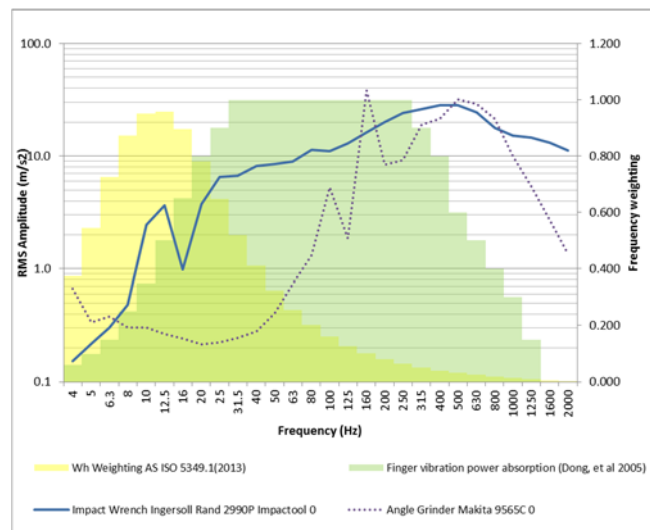


Figure 36: Participant 37 Power-plant maintainer's HAV exposure spectra compared to AS ISO 5349.1 (2013) and Dong, et al (2006)



From the charts above, the first resonant frequencies occur between 12.5 Hz and 200 Hz. In the majority of cases, the amplitude in RMS is over 10 m/s<sup>2</sup> on frequencies above 40Hz. In addition, large amplitudes are also found in 63 Hz, 125Hz, and 200Hz.

## DISCUSSION

The handgrip results have shown that hand-arm vibration causes an increase of grip strength following a short, high-level exposure. This can be explained as by the 'tonic vibration reflex' due to an increase of muscle firings. The downside is the numbing of the fingers, decrease of vibrotactile perception thresholds and the long term muscular fatigue (Wasserman, 1996)

Furthermore, this study also confirms the reliability and repeatability of the handgrip tests as a measure of induced muscular effects; as has been shown before by others (Cederlund et al., 1999, Gerhardsson et al., 2014a, Haward and Griffin, 2002, Sakakibara et al., 2005).

Hand dexterity results have also shown a smaller, but significant indication of vibration induced hand dexterity loss, making it also valuable for worker's health surveillance and follow up studies, as described by with others (Gerhardsson et al., 2014b). The possible loss of dexterity mechanism could be demyelination of the motor and sensory nerves (Pelmeur and Leong, 2000). Govindaraju et al. (2008) explained that swelling of the myelinated nerve fibres, or even worse, demyelination can occur in frequencies higher than 30 Hz, while frequencies higher than 800 Hz can be more damaging. Strömberg et al. (1997) added that vibration induced demyelination, can exert effects beyond the hand and affect the wrist.

The combination of these two tests could offer a powerful battery of tests in health surveillance for muscular dysfunction as discussed by (Ahn et al., 2013, Sakakibara et al., 2005)

Regarding tactile sensitivity, while others have found the use of Semmes Weinstein monofilament screening the most discriminating tool for long-term hand-arm vibration induced disorders (Gerhardsson et al., 2014a, Gerhardsson et al., 2013, Cederlund et al., 1999). This study has not shown significance. This could be explained by the taxonomy of the current mine workforce, but potentially can be a valuable tool with bigger sample size and over longer term.

The hand-arm vibration measurement results from workers that recorded the highest functional variation supports Dong, et al (2006) proposed frequency weighting, and also challenges the current AS ISO 5349.1 (2013) to whether it truly covers all hand-arm vibration induced disorders. It is suggested that several frequencies weighting should exist, perhaps one to measure potential exposures that can cause vascular disorders, and another for potential motor and sensoryneural disorders.

Finally, this results can also serve for re-analyse the utility of anti-vibration gloves. Gloves can be useful to attenuate vibration in the frequencies 30 Hz to 300 Hz and protect potential motor and sensorineural effects (Wimer et al., 2010, Hewitt et al., 2015). However as discussed by Wimer et al. (2010) and Hewitt et al. (2015) caution should be applied to provide gloves that are too thick, which might increase the grip effort.

## Limitations

While the ANCOVA analysis utilised has reduced group selection bias, it is important to recognise that the covariate could be interpreted in different ways. An opportunity from this study is to conduct a larger study, apply multiple analyses of covariate (MANCOVAS), and identify other independent variables, such as vibration exposure level, experience, gender, etc.

The selected functional tests are reliable, portable and low costs (Haward and Griffin, 2002), but there are other methods available that perhaps are specialised, but access to them is limited (Griffin and Bovenzi, 2007).

## CONCLUSION

This study has shown the utility and benefits of handgrip strength and hand dexterity for assessing short-term effects in a workplace. First, it shows that that hand-arm vibration can effectively induce a muscular 'tonic reflex' effect on workers, and reduce their hand dexterity.

In addition, these functionality tests provide a low cost supplement to existing health surveillance programs in the mining industry, and potential follow up studies.

Finally, it suggests that high vibration levels above 40Hz might also affect the function of hand, which supports alternative frequencies weighting, and suggests revision of the current AS ISO 5349.1 (2013) weighting.

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## NEW INNOVATIONS IN SCREENING FOR COAL MINERS' PNEUMOCONIOSIS (BLACK LUNG)

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### ABSTRACT

In recent years there has been an increase in the incidence of coal worker pneumoconiosis (CWP) globally. Of particular concern is the point that new cases include many relatively young miners less than 50 years of age. This increase indicates a potential failing in current coal dust exposure controls and CWP surveillance. Potential issues include the need for improved health surveillance systems, increase in industry compliance, and innovative engineering approaches to coal mining that increase productivity and have the potential to increase dust exposures.

Current health surveillance focuses on assessment of pulmonary function and chest x-rays which primarily identify disease after irreversible damage has already occurred. There is a need to explore emerging information and identify new biological markers that will aid in the early, pre-symptomatic diagnosis of disease onset and identification of susceptible sub-groups within the mine workers population.

This paper will discuss the need for changes in how we undertake health surveillance in the coal mining industry including the potential to develop a state of the art approach for evaluating the toxicology of coal dusts by simultaneous monitoring of particle composition and *in vitro* approaches to modelling cellular response to insult and injury. This presentation will provide a review on the current state of knowledge regarding the re-emergence of CWP in Australia and abroad; its pathophysiology and toxicological models for aerosol exposure.

### INTRODUCTION

In recent years there has been an increase in the incidence of coal worker pneumoconiosis (CWP) globally. An area of concern is the incidence of new cases which includes many relatively young miners, who are less than 50 years of age. (Cohen et al. 2015) This increase in incidence indicates a potential failing in current coal dust exposure controls and CWP surveillance, which is problematic because prevention is critical for reducing the incidence and prevalence of coal mine dust lung diseases (CMDL) such as CWP. (Laney & Weissman, 2014) There appears to be a need for improved health surveillance systems, increased industry awareness that new innovative engineering approaches to coal mining that have the potential to increase dust exposures and alter the chemistry of the particulate composition of dust. (ILO, 1983) Mine operators need to appreciate that any changes in mining technology that increases productivity will potentially overwhelm existing dust control measures.

In Australia there are two types of coal mined; black coal and brown coal. Their physicochemical properties differ. Black coal is primarily composed of 71 to 91% carbon, 3 to 13% hydrogen, varying amounts of oxygen, sulphur and nitrogen and has less than a 10% moisture content. Brown coal has lower carbon content (60 to 75%) with a high oxygen content (30%) in addition to a high moisture content (30 to 70 %). (ILO, 1983)

### METHODS

The aim of this review was to undertake a gap analysis to identify potential approaches to address the issues related to the re-emergence of coal worker pneumoconiosis both in Australia and internationally. To achieve this aim, the gap analysis focuses on three research objectives, which include:

1. History and re-emergence of CWP in Australia and abroad.
2. Recent studies harnessing the latest molecular approaches to study the pathophysiology of coal dust.
3. A brief review of current trends in toxicological models for aerosol exposure.

The review was undertaken using a range of search terms to find appropriate sources as follows:

1. History and re-emergence of CWP in Australia and abroad – reviewed papers which met the key search terms of coal worker pneumoconiosis (CWP), Black Lung and progressive massive fibrosis in the PubMed and Science Direct search engines.

2. Latest molecular approaches to study the pathophysiology of coal dust – reviewed papers which met the key search terms of *In vitro*, dust exposure and Real time in the Science Direct, Ebesco, Google Scholar and Web of Science search engines.
3. A brief review of current trends in toxicological models for aerosol exposure – reviewed papers which met the key search terms of epigenetic, genomic, transcriptomic, metabolomics, proteomic, massively parallel, high throughput, next generation, pyrosequencing, in the Pubmed and Medline search engines.

### History and Re-emergence of Coal Workers Pneumoconiosis

Pneumoconiosis is a medical term that refers to a group of lung diseases caused by chronic inhalation of dust and so it is classified as an occupational disease. This disease was very common among British underground coal miners and the first case was reported in 1831 (Raffle et al, 1987). The disease became known as Coal Workers Pneumoconiosis (CWP), or more commonly Black Lung. This disease is irreversible and with heavy dust exposure progressive massive fibrosis (PMF) develops which is fatal. In spite of the fact that this disease and its cause was first recognised more than 180 years ago it is still a killer, especially in the developing world but also in Australia. In 2013 CWP killed 25 000 workers across the globe. (Zosky et al, 2016)

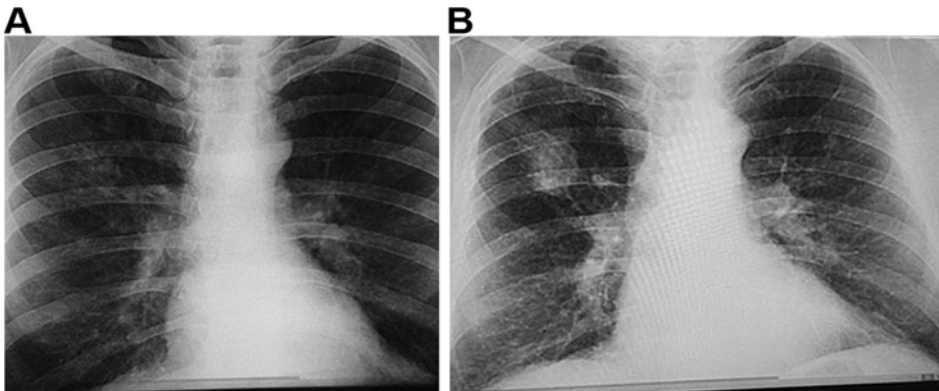
Inhaled dust at work was first described as major cause of disability and death in Europe in the 1600's (Ogden, 2005). In Britain in 1954 and in 1957 it was estimated that two million workers were affected by dust related diseases. Due to rapid industrialisation, by the middle of the 20<sup>th</sup> century British workers had the highest reported rates of pneumoconiosis in Europe, mainly among coal miners who accepted breathing impairment as a normal outcome of work. Among miners CWP has been given different names including miners' asthma, miners' lung, black lung, black spit, and the dust. Official records show that approximately 1000 British miners died each year from pneumoconiosis in the period of 1950 through to the end of 1960. (McIvor et al, 2007)

In the 1930s, there was mounting x-ray evidence that working in Welsh anthracite mines produced distinctive lung x-ray images and it was conceded that excessive coal dust inhalation may cause bronchitis but the significance of dust in lung disease was still played down. During the 1930's there was mounting evidence from autopsies, clinical, x-ray studies and mortality data which finally established that mine dust was the major cause of miners' respiratory diseases and research was needed develop dust sampling methods , as well as dust suppression techniques. By the mid 1930's the first effective respirator was available but it was not meant to replace dust reduction measures, such as ventilation. It took another 50 years before miners regularly started to use respirators around the world. (McIvor et al, 2007)

In Australia pneumoconiosis was very prevalent in the early 1900's and in 1946 the Joint Coal Board was established with the goal of implementing stringent dust control and health surveillance measures in Australian coal mines. The disease remained a problem throughout the 1950's and 1960's but by the late 1970's it was believed to have been eradicated. (Zosky et al, 2016)

In the 1960's and 70's, a cohort of 213 Western Australian coal miners were followed over a 14 year period to assess respiratory symptoms and smoking habits in conjunction with occupational history and radiographic evidence of pneumoconiosis. Overall they did not exhibit a higher than expected mortality and the coal miners had a lower than expected lung cancer rate. (Armstrong, 1979)

Symptoms of CWP vary depending on the stage of disease and physicochemical composition of the inhaled dust. The disease latency period is approximately ten years and it is difficult to diagnose the disease early. The first symptoms are a mild cough which progresses to breathlessness with wheezing. Affected workers eventually cough up black sputum and have significant airflow obstruction, lung fibrosis and eventually death. Chronic bronchitis and emphysema also present with similar symptoms which complicates diagnosis. The chest x-ray below (Figure 1) shows how the disease progressed in a patient over a 12 year period and Figure 2 shows a section of a dead coal workers lung.



**Figure 1: Chest x-rays of a coal worker (A) showing background nodulation and early progressive massive fibrosis (PMF) in the right upper zone, and (B) 12 years later, showing PMF (Source: Zosky et al, 2016, p416)**



**Figure 2: Gough section of a coal worker's lung showing coal workers' pneumoconiosis with progressive massive fibrosis (Source: Zosky et al, 2016, p416)**

In the late 1990's in Australia, underground longwall mining became the most common technology used to extract coal with continuous mining machines. In this method the roof is allowed to collapse behind the shearer generating up to four times as much dust as more conventional methods. As this technology has been rolled out across Australia it is likely that many workers have been exposed for a decade or more to excessive levels of coal dust. (Kizil and Donoghue, 2002) However, between December 2015 and February 2016 six new cases were diagnosed among Queensland coal miners. This is a great cause for concern as it may mean that dust controls and routine health surveillance measures are no longer effective in coping with modern high output coal mining methods. (Zosky, 2016)

#### **Molecular Approaches to Study the Pathophysiology of Coal Dust**

The opportunity now exists for Australia to revisit current coal dust occupational exposure limits, which vary from 3 mg/m<sup>3</sup> for coal dust (containing < 5% quartz) (AIOH, 2009; Safe Work Australia, 2016); 0.1 mg/m<sup>3</sup> for quartz containing respirable dust (AIOH, 2009), and 2.5 to 3mg/m<sup>3</sup> for non-quartz containing respirable dust (Coal Services Pty Limited, 2008; Safe Work Australia, 2016). New "omics" approaches in molecular biology and cell culture exposure models could facilitate research in the development of protective occupational exposure level (OEL) as well as identification of important biomarkers for early detection of coalminer's lung disease (CMLD), including lung cancer. The new cell and tissue based *in vitro*, *ex vivo*, and *in silico* approaches are potentially more representative of real world exposure aerosols, including coal dust and other airborne pollutants in the occupational environment. These exposure models could be applied in conjunction with phenotypic and genotypic studies to identify early biomarkers of disease, as well as develop exposure limits for sensitive and general populations.

Respiratory epithelial cells can be relatively non-invasively harvested from the nasal passages, as well as the cheek lining of workers using cytology brushes, cuvettes or nasal lavage. These samples could be rapidly sequenced to search for genetic markers and protein expression, or alternatively passaged in the lab to form a multicellular substrate that can be utilised for dose-response studies. The advantage of using these cells is that they are more reflective of real-world conditions (protective

and vulnerable traits), and provide a more realistic insight into the biological response of naïve and experienced workers than working with animal models or immortalised commercial cell lines. Harvesting of pulmonary epithelial cells could be undertaken with worker consent as part of an induction and routine medical surveillance program, and combined with routine health monitoring data, as well as exposure monitoring to observe for changes in lung function, cellular expression and gene-by-environment changes. This data combined with controlled experimental trials could provide the necessary information required for the development of an exposure limit relative to the physical chemical properties of Australian coal varieties, which is essential for CWP where there is no cure other than prevention.

Traditionally exposure studies were undertaken using submerged cell culture. However, submerged models may not be as physiologically realistic in comparison to alternative approaches using differentiated cells grown on porous substrates. Zinc oxide nanoparticles have been reported to have less toxicity in submerged cell models when compared with porous substrate models. (Lenz et al. 2013) However, there is a conflicting study that reports silver nanoparticles are less toxic in submerged cell cultures. (Panas et al. 2014) In addition to conflicting results for *in vitro* exposure studies using small airway epithelia cells, there is also conflicting evidence regarding the pathophysiological properties of coal dust. Researchers have reported contraindicating cellular responses in relation to silica and/or iron content of coal dust (Cohen et al. 2015; McCunney, Morfeld and Payne, 2009), as well as in the expression of specific cytokines (Gaffney and Christiani, 2015; Gulumian et al. 2006; Castranova and Vallyathan, 2000). This may be related to variation in population genetics, or other intrinsic and extrinsic effect modifiers such as biological constituents, worker behaviours or the home/occupational environment (Peksoy et al. 2004; Donbak et al. 2005). The combination of massively parallel sequencing with scanning electron microscopy can be applied to develop a more precise biological and chemical finger print of coal dust with which to identify the potential agents of insult and injury through dose response studies.

Published Australian epidemiological coal dust studies to date have included spirometry, exposure assessment and mortality surveillance (Badham & Taylor, 1941; Kinnear, 2001; Kizil and Donoghue, 2002; Armstrong et al. 1979; Smith & Leggat 2006; Glick, Outhred & McKenzie 1972; Fletcher & Gough, 1950). Recently international research has been undertaken on the genotoxicity, mutagenicity and inflammatory potential of coal dust by polymerase chain reaction (PCR), cell counts and morphology, ELISA and next generation sequencing. (Volobaev et al. 2016; Borm and Schins 2001; Wang et al. 2005; da Silva, 2015; Zhai et al. 2002; Ji et al. 2015; Guo et al. 2013) However, to the authors' knowledge, Australian epidemiological studies have been undertaken with emergent and emerging omic technologies.

Omic can be used to describe the large scale collection and study of biological data, including the field of genomics, transcriptomics, metabolomics, nucleosomics and proteomics (Plopper, Sharp & Skitorski, 2012; Cox, Doudna & O'Donnell, 2015). The omics approach to toxicology can be harnessed to observe the genotypic and phenotypic effects of environmental and occupational exposures, as well as in the development of personalised medicine. With regards to coal dust, the combination of *in vitro* studies with health monitoring could be undertaken to predict its potential genotypic and phenotypic effects based on content (silica, iron, organics), environment and co-exposures, as well as exposure period. Genotyping could be carried out on both cell lines and worker biological samples to look for protective or susceptible gene variants in relation to transcript upregulation, protein expression and/or changes in lung function. Candidate genes could provide information of potential vulnerable workers that may require extra protection factors built in to occupational exposure limits and/or more frequent health checks to ensure no adverse response is experienced in the occupational environment. In addition, epigenetic studies could be undertaken to look for external modifications to DNA (histones etc) from environmental exposures, which may be related to phenotypic changes such as lung function or cytokine expression observed in individuals. Study of the transcriptome, proteome and metabolome could be leveraged to explore the relationship between the abundance and array of transcripts, proteins and metabolites to identify causation coal dust exposures, genes expression and cellular response in exposed and non-exposed cells. It is proposed that omics based research be undertaken to characterise the toxicology of Australian coal dust and to inform the development of personalised and environment specific exposure limits.

## CONCLUSION

Current health surveillance only involves assessment of pulmonary function and chest x-rays which primarily identify disease after irreversible damage has already occurred. There is a need to develop new biological markers that will aid in the early, pre-symptomatic diagnosis of disease onset and identification of susceptible sub-groups within the mine workers population.

Earlier detection of CWP disease will allow for the identification of potentially vulnerable individuals before the symptoms become significant. The use of alternative markers for exposure will enable more representative occupational exposure limits to be developed. Alternative biological markers will also promote prevention in preference to treatment.

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## EVALUATION OF INORGANIC ARSENIC EXPOSURE AT MULTI METAL PROCESSING FACILITY WHEN AIR MONITORING ALONE JUST DOESN'T WORK!

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### ABSTRACT

Metals smelting and processing has been associated with exposure to airborne inorganic arsenic and an increased risk of health effects. Biological monitoring on a metals processing site identified urinary arsenic concentrations exceeding corporate and ACGIH guidelines at levels associated with increased risks of health effects. Plant operators considered the inhalation of arsenic trioxide powder ( $As_2O_3$ ), used in the process, as the source of their exposure.

This study's initial objective was to determine operator exposures to airborne inorganic arsenic. Two groups of plant operators participated in full shift personal air monitoring and biological monitoring over their working weeks. In parallel, wipe samples were taken from control rooms and grab sampling for arsine was carried out to capture a wider range of potential exposure routes.

Air monitoring results did not approach exposure standards, with many below the limit of detection. In contrast, biological monitoring results exceeded corporate and the ACGIH guidelines indicating exposure via routes other than inhalation. This demonstrates that relying on air monitoring alone for exposure assessment is inadequate.

The findings informed management and workers of practical measures required to adequately control process emissions, secondary exposure due to contaminated surfaces, and poor personal hygiene, prior to the closure of the plant and cessation of all associated processes in early 2015.

Assessment of occupational exposure to substances with multiple exposure routes should not rely on air monitoring alone; but integrate other evaluative techniques such as biological monitoring (where available) to ensure exposure risk via all routes is adequately evaluated.

### INTRODUCTION

Concerns had been raised by a work group about exposure to airborne inorganic arsenic (As) during the treatment of slurry to remove impurities enabling the recovery of zinc through electrowinning. During the purification process a fine arsenic trioxide ( $As_2O_3$ ) powder was manually added to treatment tanks. A review of biological monitoring data found the urinary As concentrations of plant operators in all roles varied considerably but had on occasion exceeded corporate standards and the American Conference of Governmental Industrial Hygienists (ACGIH) biological exposure indices (BEI). Plant operators were adamant that exposure to the  $As_2O_3$  powder was responsible for their elevated urinary As results, and that this had only become a problem since they switched from a granular to powder form of  $As_2O_3$ .

Air monitoring for As in the plant had previously been carried out, however current exposures, the routes of entry associated with elevated urinary inorganic arsenic, or the reason for the large variability in these results remained undefined.

An initial appraisal was carried out comprising a preliminary walk through survey on 18<sup>th</sup> March 2014. This was followed by full shift personal air and daily biological monitoring of 2 individual plant operating teams, over separate working weeks 24<sup>th</sup> - 27<sup>th</sup> March and 3<sup>rd</sup> - 6<sup>th</sup> April 2014. In addition, surface wipe samples were collected from a number of operator contact surfaces. Further assessment was carried out on 16 April 2014 when grab sampling for arsine was undertaken.

The purpose of the assessment was to;

- Assess the effectiveness of current control measures
- Determine operator exposures to airborne As
- Evaluate compliance to regulatory duties under the South Australian WHS Regulations 2012 relating to the management of risk and workplace exposure standards
- Identify sources of As exposure, and

- Determine the potential risk of adverse health effects for plant operators.

A literature review was carried out using data bases including Scopus; Pub Med and Web of Science. Search terms included, arsenic exposure, arsenic trioxide, smelting, zinc leaching, hydro metallurgy. There is an extensive body of literature on the toxicology of As and known health effects particularly relating to environmental exposure via contaminated drinking water. By comparison there is a relatively small body of information and limited epidemiological studies on occupational exposure to As and associated risks to health (*Lubin JH, 2000*).

There are limited numbers of studies on occupational exposure via ingestion or skin absorption with most focused on exposure via inhalation and the association with lung cancer (*IARC, 100C*). There was an absence of information regarding As exposure associated with hydro-metallurgical zinc purification; addition of As<sub>2</sub>O<sub>3</sub> during metal refining or processing; or the removal of filtration residues.

Inorganic Arsenic is classified as a group 1A carcinogen via all routes of exposure (*IARC, 100C*), with acute health effects including, diarrhoea, vomiting and damage to the peripheral nervous system. Chronic effects can range from cerebrovascular and cardiovascular disease to skin disorders and cancer (*Ratnaike, RN, 2003*). The risk of adverse health effects associated with arsenic exposure follows a dose response relationship with Lubin JH, 2008 finding the dose intensity to be a major influencing factor.

The principal routes of occupational exposure for inorganic As are inhalation and ingestion with Inhalation considered the principal route (*IARC, 100C*). While As can enter via the skin, absorption via this route not typically considered significant (*Lundström NG, 2007*), with the exception of As in solution and organic forms used in pesticides (*Wenzel R, 2001, ACGIH, 2001b*).

The Australian exposure standard for As and inorganic compounds is 50µg/m<sup>3</sup> (*HSIS, 2016*). This is significantly higher than the voluntary standard the company has implemented of 10µg/m<sup>3</sup>, which is equivalent to the US Occupational Safety and Health Administration Standard (*OSHA, 1910*) and health based Threshold Limit Value listed by the ACGIH (*ACGIH 2016*).

The collection of urine samples and analysis for inorganic As and its metabolites is the recommended biological monitoring method for assessing exposure to As via all routes (*ACGIH, 2001b*). The Australian regulatory authority SafeWork Australia has not set a biological exposure limit for As, though SWA, 2013a advises urinary total concentrations of inorganic As and its metabolites > 35µg/L are indicative of occupational exposure and should be investigated. This aligns with the value adopted by the company and BEI given by ACGIH, 2016 of 35µgAs/L relating to exposure via inhalation at the 10µg/m<sup>3</sup> TLV.

## PROCESS DESCRIPTION

The zinc leach plant was a large open plan workspace within an enclosed structure. The plant housed a series of sequential operations where a process known as cementation was used to remove impurities such as antimony; cobalt and cadmium from a zinc rich slurry, resulting in a "Purified" liquor suitable for the recovery of zinc through electrowinning in an adjacent plant.

A continual batching process operated through 2 identical parallel systems, with 5 batches purified on a typical working shift. Slurry entered the east end of the plant moving through the system, maintained around 85°C until the final product exited the plant for storage in a large open tank.

The multi stage process commenced with iron purification in initial leach tanks where electrolytic acid and iron were added to separate coarse solids and some impurities from a slurry. The treated solution was then pumped through a series of Burt filters which extracted the available solids with the filtered liquor passing through into a staging tank.

The liquor then entered 1st stage purification tanks where additional acid, copper sulphate, zinc dust and As<sub>2</sub>O<sub>3</sub> were added initiating a cementation reaction whereby most impurities dropped out of the solution forming a solid.

When the 1<sup>st</sup> stage purification was completed the solution passed through a filter press located to the west of the purification tanks, separating the solids from the liquor which passed through to 2nd stage purification tanks to continue further cementation. After allowing further time from cementation the solution was is passed through another finer filter press exiting the process into external holding tanks ready for electrowinning.

The plant operated continuously, manned by 4 operators working 12 hour shifts with a 1 hour break over a 48 hour weekly roster. Shift blocks consisted of 2 days 5.30am-5.30pm followed by 2 nights 5.30pm-5.30am and 4 days off, though occasional overtime could be worked on rostered days off. Tasks carried out in the plant primarily occurred on the first floor level aligned with the top of the tanks.

Operators were permanently assigned one of 4 primary roles known as Initial Leach; Burt filtration; Purification and Filter press/water treatment. While operators moved throughout the workspace each role was associated with a particular stage in the overall process and localised area where the majority of the operator's tasks were performed.

The purification operator was the only team member in direct contact with  $As_2O_3$ , handling or adding it into the process during typical production, occasionally the filtration/water treatment operator occasionally performed this function when acting as relief.

The purification operator carried out the following tasks where potential contact with  $As_2O_3$  or process solution was observed; Collection and deposit of  $As_2O_3$  Billie cans from storage; adding  $As_2O_3$  into stage 1 purification tanks; sampling and analysis of tank liquor in particular for pH levels; adding zinc dust, copper sulphate and spent to systems; data entry and monitoring of system information in purification control; general cleaning of the area.

All 4 purification tanks had level sensing systems in place and extraction systems built into the lids, configured as 2 independent fans and ducts of the same diameter, with one travelling in a straight line before changing direction vertically to form an exhaust stack.

The second duct joining the first at an angle with no change in the diameter of the now merged duct (Image 1).

The capture face of the ducts penetrated well below the height of the lids into the tanks.



Image 1: Purification tank extraction system (Roseberg 2015)

Despite the extraction system in place, emissions from the tanks were frequently observed with operators commenting this was exacerbated by high solution levels.

Purification tank samples were continually tested throughout each batch with a heavy focus on pH levels particularly prior to  $As_2O_3$  addition. Examination of a plant risk assessment from 2014 found the combination of zinc, and  $As_2O_3$  results in a risk of arsine generation if the solution is allowed to drop below 3.4 pH. Operators did not typically wear gloves during the collection or analysis of samples.

Plant procedures required the 2 kg of  $As_2O_3$  in the billy to be added from the via a raised chute in the purification tank lids the chute was located adjacent to hole in the lid where samples were collected using a long handled dip stick. The billys of  $As_2O_3$  powder were transported and stored in a trolley cart adjacent to the stage 1A tank fill point (Image2).  $As_2O_3$  addition took less than 2 minutes occurring at the start of each batch, then at 25 and 60 minutes intervals.

When adding  $As_2O_3$  (Image 3) operators wore a disposable single use P2 half face respirator (3M model 9926) and (Excalibur W6300R) chemical gloves; one operator wore (Uvex Profi-Ergo ENB 20A) gloves.

Both gloves and disposable respirators were re-used for the entire shift and occasionally more than one.

A Drager Pac III arsine gas monitor (PAC-III) Serial No ERXE-0137 calibrated 03/12/2013 was worn intermittently, at other times it was left inside an adjacent sample room as operators complained  $SO_2$  emissions from nearby processes caused it to alarm.



Image 2: As<sub>2</sub>O<sub>3</sub> trolley, chute and sample opening (Roseberg 2014) Image 3: Addition of As<sub>2</sub>O<sub>3</sub> (Roseberg 2014)

Operators carried out data entry and system monitoring in the purification control room where breaks were also taken; most contact surfaces and equipment in the room were heavily soiled. There was an airlock in place but the external door was damaged and remained open.

## METHODS AND MEASUREMENT

An initial appraisal was carried out comprising a preliminary walk through survey on 18<sup>th</sup> March 2014, followed by full shift personal air and daily biological monitoring of 2 individual plant operating teams over separate working weeks 24<sup>th</sup> - 27<sup>th</sup> March and 3<sup>rd</sup> - 6<sup>th</sup> April 2014. Surface wipe samples were also collected from a number of operator contact surfaces. Further assessment was carried out on 16 April 2014 when grab sampling for arsine was undertaken.

Personal air monitoring was carried out to collect the inhalable dust fraction in accordance with (AS 3640:2009). Operators were fitted with SKC Airchek Universal Sampling pumps model 224-PCXR4, drawing air through Institute of Occupational Medicine (IOM) samplers located in the breathing zone. Samplers were fitted with 0.8µm x25mm SKC Cellulose Ester Membrane filters (Lot, 13178-7DD-028 Expiry Date 2/2018) with a field blank accompanying each batch as discussed by Cherrie J, 2010; p40.

Flow rates were set to 2 L/m for each sampling train, on commencement and verified at the completion of monitoring using a Dwyer Veriflow rotameter, model VFB-65-SSY-10B Identification Number NPP-4, calibrated against a primary bubble flow meter 03/03/2014. All flow rates were found to have deviations of <10% resulting in no samples being discarded.

Analysis of personal air monitoring samples was carried out by the onsite NATA accredited laboratory to (NIOSH method 7300) using inductively coupled argon plasma (ICP), atomic emission spectroscopy (AES). All analytical results were downloaded to an excel spread sheet from the sites internal data management system.

A unique sample numbering system incorporated the 4 digit laboratory analytical process number (3072), followed by the sampler/badge number (5) and the date relating to when sampling commenced 23/03/2014 (23314) written as 3072-5-23314. Filters used for personal monitoring were not weighed before or after sampling as a microbalance with the necessary accuracy was not available. This prevented determination of metals as a percentage of total dust.

To account for all potential exposure routes all operators participating personal air monitoring also underwent biological monitoring for As in urine. Operators provided a sample at the commencement of the working week to establish a base line, and at the completion of each shift. Due to cost constraints sampling at the start of each shift could not be included in the biological monitoring strategy. Analysis of urine samples via solvent extraction and ICP-MS was carried out by an external NATA accredited provider speciated to provide the results as the sum of inorganic As and its metabolites following the guidance of SWA,2013a.

To assist evaluating current the site biological monitoring program and ensure sample contamination was minimised, a trial method was implemented for the collection and handling of urine samples following the guidance of (AS 4985:2002).

To assess contamination of control room surfaces wipe samples were taken on 26/03/2014 with one field blank accompanying the samples for analysis. Wipe tests were carried out using Environmental Express 150 x 150mm Ghost Wipes™ Metal Testing Wipes (Batch# 4210). Areas of 300x300mm<sup>2</sup> were sampled following the guidance of Appendix 13.1 Guidelines

for the Evaluation and Control of Lead Based Paint Hazards in Housing (*US HUD, 2012*) with analysis carried out by the onsite Laboratory following a NATA accredited in house method 653-00045 for metals via ICP-AES.

The four primary roles in the plant, their locations and potential exposures were distinct from each other. As a result no operator roles could be combined to form a SEG. However the activities and potential exposures of the operational roles were consistent both daily and across the 4 shifts, therefore operators across the 2 shifts performing the same role were considered SEGs during the analysis and evaluation of results.

Statistical analysis of personal air monitoring and biological monitoring results was carried out using IHSTAT + V, 235 (*AIHA, 2013*). Following the method explained by (*Hewett P, 2007*) results below the analytical limit of detection (LOD) given by the laboratory as 0.2µg, were divided by half and entered as 0.1µg.

The Australian exposure standard for As and its compounds is an 8hr TWA of 50µg/m<sup>3</sup> (*HSIS, 2015*). The company adopted a more conservative corporate exposure standard of 10µg/m<sup>3</sup>. Using the IRSST utility for the adjustment of TWA (*IRSST, 2015a*) discussed by (*AIOH, 2013*) a correction factor of 0.8 was applied for the 12 hour shift being worked, resulting an adjusted regulatory standard of 41µgAs/m<sup>3</sup> and corporate standard of 8µgAs/m<sup>3</sup>

The company implemented an action/ investigation level of 20µgAs/gCr and a removal level of 35µgAs/gCr, above which the operator should be removed from As risk work. As recommended by (*ACGIH 2016; p109-111*) these levels were not adjusted for extended working hours.

## RESULTS AND DISCUSSION

Monitoring and sampling comprised 32 personal air-monitoring samples with 8 controls; 36 urine samples (8 pre and 28 post shift) and 4 surface wipe samples including 1 control. Subsequent grab sampling for arsine included 6 measurements 3 with a direct reading instrument and 3 using colorimetric indicator tubes.

### Personal Air Monitoring

Personal air monitoring results were calculated following (*AS3640, 2009; p15*) and summarised by assigned operator number for teams 1 and 2 in tables 1 and 2 respectively. Due to the more conservative nature, comparison of personal air monitoring results was carried out against the adjusted corporate standard. Protection factors for respiratory protective equipment were not taken into consideration as its use was not commonplace within the plant.

Table 1: Team 1 Personal Monitoring Results in µgAs/m<sup>3</sup>

Operator No	Results 24/03/14	Results 25/03/14	Results 26/03/14	Results 27/03/14
1	<0.2	0.25	<0.2	<0.2
2	0.65	<0.2	0.22	<0.2
3	0.53	0.47	0.76	0.59
4	<0.2	0.78	<0.2	<0.2

Table 2: Team 2 Personal Monitoring Results in  $\mu\text{gAs}/\text{m}^3$

Operator No	Results 03/04/14	Results 04/04/14	Results 05/04/14	Results 06/04/14
5	0.35	<0.2	0.56	<0.2
6	<0.2	<0.2	<0.2	Absent
7	3.03	0.99	0.31	0.61
8	Absent	<0.2	<0.2	<0.2
9	<0.2			
10				2.36

These results should be viewed with consideration to a number of observations. On 25/03/14 operator 4 spent an extended period cleaning up a filter press 1 residue spill while not wearing an apron or gloves. The operator also spent time assisting in purification. Maintenance carried out a test of the purification control pressurising unit without warning on 03/04/14. This caused a significant amount of accumulated dust to be blown around the room where operator 7 was working.

Team 1 production was reduced to 3 batches per shift with individual  $\text{As}_2\text{O}_3$  additions of 6kg during across the sampling period. Team 2 operated under full production of 5 batches per day and increased  $\text{As}_2\text{O}_3$  additions to 8kg. A large amount of steam was frequently observed being emitted from the  $\text{As}_2\text{O}_3$  addition chute (Image 4). The operators were observed adding  $\text{As}_2\text{O}_3$  through the adjacent sampling grate (Image 5) and cited concerns that the escaping steam could result in the  $\text{As}_2\text{O}_3$  being blown back out of the chute as the reason.



Image 4: Steam rising from chute (Roseberg, 2014)



Image 5: Grate used to add arsenic (Roseberg, 2014)

The cumulative results for team 2 were higher than those of Team 1 however included 1 significant high outlier. With the exception of the purification operator SEG, air monitoring statistics (tables 3 and 4) did not pass the W-test applied by the IH-Stat tool. Failing to fit either a normal or log-normal distribution the statistics derived are observational only. The arithmetic mean was used to examine the data due to this lack of distributional fit, in addition to being a more appropriate measure for substances associated with acute health risks compared to the GM which may underestimate exposures. Note; for statistical analysis results below LOD entered as 0.1



Table 3: Team 1 Personal Monitoring Results in  $\mu\text{gAs}/\text{m}^3$ 

Operator No	No Samples	Min	Max	Range	Arithmetic Mean
1	4	<0.2	0.25	0.15	0.14
2	4	<0.2	0.65	0.55	0.27
3	4	0.47	0.76	0.29	0.59
4	4	<0.2	0.78	0.68	0.27

 Table 4: Team 2 Personal Monitoring Results in  $\mu\text{gAs}/\text{m}^3$ 

Operator No	No Samples	Min	Max	Range	Arithmetic Mean
5	4	<0.2	0.56	0.46	0.28
6	3	<0.2	<0.2	0	0.1
7	4	0.31	3.03	2.72	0.31
8	3	<0.2	<0.2	0	0.1
9	1	<0.2	<0.2	NA	NA
10	1	2.36	2.36	NA	NA

The purification operators had the highest exposure profile within the plant both individually and as a SEG though this was still less than 15% of the adjusted corporate standard. The statistics for this SEG (table 5) formed a log normal distribution with a geometric mean > 3 times that of any other SEG or team statistic, despite being more conservative than the arithmetic mean used for those groups.

 Table 5: Purification operator statistics in  $\mu\text{gAs}/\text{m}^3$ 

No Samples	Range	GM	GSD	95th percentile	UCL	UTL
8	2.71	0.85	2.20	3.09	2.74	10.4

### Wipe Samples;

Wipe samples were taken on 26/03/14 of contact surfaces in the control rooms with results detailed in table 6. Lead is a common accumulating contaminant on site and a good measure of hygiene practices, so its presence was also assessed.

 Table 6: Surface Sample Locations and Results in  $\mu\text{g}$ 

Date	Sample	Location	As	Pb
26/03/2014	3072-20-26314	Control	0.38	14.4
26/03/2014	3072-21-26314	Control room CPU desk	27.6	1305.2

26/03/2014	3072-22-26314	Control room dining table	5.6	172.1
26/03/2014	3072-23-26314	Purification CPU desk	21.3	135.5

There are no Australia regulatory standards relating to surface contamination of a workplace by As or lead. The results in table 6, show elevated levels of both As and lead on all surfaces tested, with lead concentrations exceeding the site standard of 100µg/300mm<sup>2</sup>.

### Biological Monitoring

There were no samples rejected with all observed creatinine concentrations within the World Health Organisation guidelines of > 0.3 g/l and <3.0 g/l (ACGIH, 2016, pg109). Samples were not provided by team 1 operators 1 and 3 on Thursday 27-3-2014 or operator 4 on Friday 28/3/2014. Overall the compliance rate for biological monitoring was 90% during the trial which was sufficient for a representative data set.

Repeating the pattern seen in personal air monitoring the biological monitoring results for team 2 were statistically higher than those of team 1 for all groups; in particular the end of week sample. Figure 1 highlights the variation between the 2 teams in addition to the progressive increase in urinary concentration from the baseline over the working week.

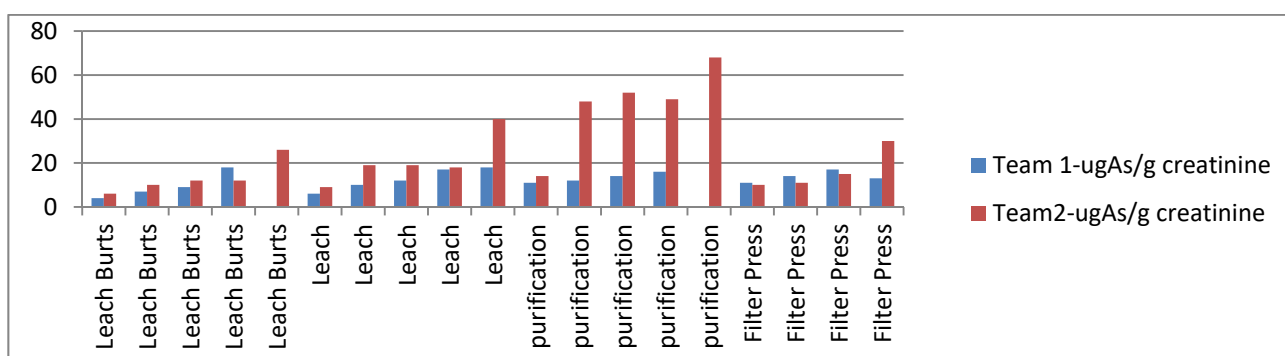


Figure 1: comparison of team biological monitoring results

The consolidated biological monitoring results for both team 1 and 2 formed a log normal distribution. Comparison of the of the teams GM for urinary As (table 7) further demonstrated the significantly higher end of week urinary As concentration of team 2 compared to team 1. The end of week urinary As GM were significantly higher than the baseline GM for both teams, with increases over the working week compared to the baselines in the teams GM urinary arsenic of 180% and 254 % for teams 1 and 2 respectively.

Table 7: Team GM urinary As in µg/gCr

Name	No of samples	GM - Pre shift baseline sample	GM - End of week sample	% change in GM over week compared to baseline
Team 1	17	7.3	13.1	180%
Team 2	19	9.3	23.6	254%

With one exception figures 2 and 3 show creatinine corrected urinary As levels consistently increased as the week progressed from the pre shift baseline for both team 1 and 2 respectively. The results also highlight the potential fluctuations in urinary As concentrations over the working week, reflecting both the reasonably short biological half-life and variability in exposure. The urinary As results of operators on their first day back from a standard roster break, did not significantly exceed the background levels expected from non-occupationally exposed populations between 8-10µg/gCr (WHO, 2000). This indicates the consistent increase in urinary As observed across the working week reflects occupational exposure.

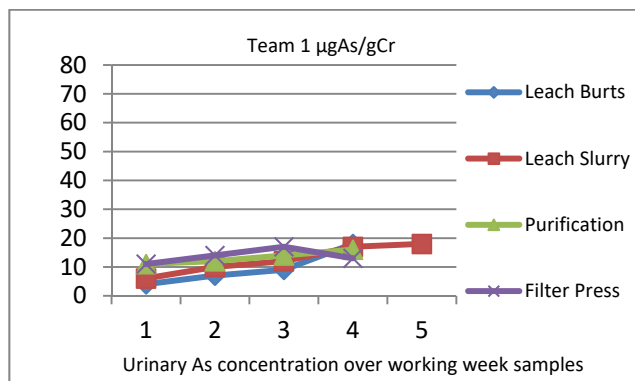


Figure 2: Team 1 biological monitoring results from baseline

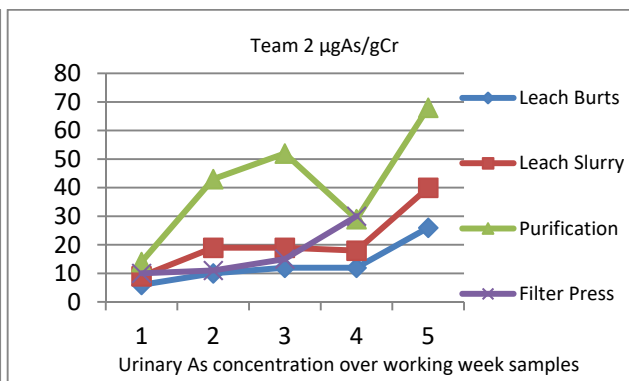


Figure 3: Team 2 progressive sample results from baseline

A number of creatinine corrected results particularly from team 2 exceeded the corporate action  $20\mu\text{g/gCr}$  and removal levels  $35\mu\text{g/gCr}$ . Additionally a number of uncorrected results exceeded the ACGIH BEI of  $35\mu\text{gAs/L}$ . The ACGIH BEI  $35\mu\text{gAs/L}$  is representative of exposure to airborne As at the TLV of  $10\mu\text{g/m}^3$  (ACGIH 2016: p13&107-111). As no personal air monitoring results for inorganic As exceeded 30% of the TLV, the urinary As results observed indicated exposure to inorganic As is occurring via the skin; ingestion; or to another form of As such as arsine.

Consistent with the personal air monitoring results, biological monitoring statistics for the purification SEG significantly exceeded those of the other groups. The group results for team 2 were again higher than team 1 for all statistical measures.

With the exception of production volume there were no significant differences in the activities of the teams or tasks carried out. Urinary As concentrations typically increased across the work week with team 2 returning significantly higher overall results. This indicates exposure to As in the plant is directly related to and influenced by production levels/ batch numbers, and regular activities.

The purification operator statistics indicated a high probability of creatinine corrected urinary arsenic concentrations exceeding the corporate removal level. Statistics summarising post shift urinary results indicate a potential for all SEGs to return creatinine corrected urinary arsenic concentrations exceeding the removal level.

### Sampling for Arsine

When investigating alternative sources of As exposure the potential for an unidentified exposure to arsine became apparent. Arsine is metabolised and eliminated almost identically to As (NOHSC, 1989), resulting in the same metabolites with a longer half-life (Yoshimura Y, 2011).

Exposure to 0.005ppm arsine is associated with urinary As concentration of approximately  $48\mu\text{gAs/L}$  (ACGIH, 2007). The Australian regulatory and corporate exposure standard for arsine is 0.05ppm (HSIS, 2016a). STEL or BEI are not recommended for arsine due to its acute toxicity (ACGIH, 2007). The adjusted exposure standard for a 12 hour work shift calculated using the IRSST utility, was 0.03ppm.

Grab sampling for the assessment of arsine was carried out on 16/04/2014 in the area surrounding the stage 1 purification tanks detailed in table 8. This was where  $\text{As}_2\text{O}_3$  addition occurred therefore where arsine was most likely to be found. Three measurements were taken using the plants PAC-III, fitted with an arsenic hydride sensor, Serial No ERXE-0137 calibrated 03/12/2013. The PAC-III also has positive cross sensitivity to Sulphur Dioxide  $\text{SO}_2$  (Drager, 2015) which can enter the plant from adjacent processes.

To control for this interference three concurrent samples were taken, using CH25001 Drager colorimetric Indicator tubes; batch FF-0581; expiry date August 2015 which are unaffected by this cross sensitivity. Air was drawn through the tube using a Drager 100 millilitre gas detector pump, model 31 Serial No 000596/89, compressed 20 times for a volume of 2L per sample giving a detection range of 0.05 - 3ppm (Drager 2011).

Table 8: Grab Sampling Locations and Results in PPM

Date and Time	Time mins	Location	Result PAC III ppm	Result -increment range shown on indicator Tube ppm
16/04/2014 - 14:20	2	North western side stage 1 purification tank A	0.08	>0.05 - <0.25
16/04/2014 - 14:25	2	South side stage 1 purification tanks A	0.02	<0.05
16/04/2014 - 14:30	2	Upper platform stage 1 purification tank A	0.08	>0.05 - <0.25

While these measurements represent only a single assessment and time period, the results confirmed there was a potential for arsine to be present at concentrations equal to or exceeding the corrected exposure standard. Unprotected exposure to the concentrations identified had the capacity to result in urinary As concentrations well in excess of the corporate standards.

When questioned, most operators reported they are familiar with and often smell the garlic odour of arsine; particularly after As<sub>2</sub>O<sub>3</sub> addition. Arsine has an odour threshold of 0.5ppm (*ASTDR, 2015*) 10 times the PAC-III alarm level set at the regulatory exposure standard of 0.05ppm. the odour threshold is well above the concentrations between 1 - 3 ppm where prolonged exposure is associated with adverse acute health effects (*ACGIH, 2007*).

## CONCLUSIONS

Despite operator concerns and observable potential exposure to airborne As, personal exposures did not exceed the corporate exposure standard of 8µgAs/m<sup>3</sup>, and were well below the regulatory exposure standard of 50µg/m<sup>3</sup>. While statistics for the purification SEG indicate a slight potential for exposures to airborne As in the vicinity of 10µg/m<sup>3</sup>, operator exposures determined were not at concentrations typically associated with acute health effects or those associated with an increased risk of chronic health effects. The purification SEG results may have represented the culmination of very short high intensity exposures during As<sub>2</sub>O<sub>3</sub> addition <2minutes which may require further investigation.

The report findings identified practices resulting in direct skin contact with process solutions and contamination of control rooms and internal surfaces by As and Pb. Poor personal hygiene practices were also observed by plant operators who were at risk of secondary exposures via ingestion in addition to a lesser but still potentially relevant exposure via dermal absorption.

Despite the implementation of considerable control measures to minimise the potential for the generation of arsine and reduce exposure, the sampling results indicated plant operators were at risk of exposure to arsine at concentrations potentially exceeding corporate and regulatory exposure standards.

Contrasting the findings of personal air monitoring; biological monitoring results exceed the site action, removal levels and the ACGIH BEI guidance value of 35µgAs/L. Biological monitoring results indicated a reasonable likelihood that under normal operating conditions these values may be significantly exceeded, particularly by the purification SEG with a UCL of 66.8µgAs/gCr. Urinary As concentrations of plant operators exceeding these values for any extended periods may result in an increased risk of chronic adverse health effects (*ATSDR, 2007; ACGIH, 2001a*).

With the exception of production volume there were no significant differences in the activities of the teams or tasks carried out. Urinary As concentrations typically increased across the work week with team 2 returning significantly higher overall results. This indicates exposure to As in the plant is related to and influenced by production levels/ batch numbers, and regular activities.

The trial method for the collection and handling of biological monitoring resulted in a significantly reduced range and variability, compared to past results across the site. This demonstrated the existing site collection practices were not adequately minimising sample contamination

The results of this assessment indicate elevated urinary As observed is a result of plant operators being exposed to As via multiple exposure routes and exposure to arsine also strongly indicated. The capture face of the extraction ducts were found to penetrate into the tank well below the inner surface of the lid which had numerous openings. This allowed a significant

vapour space behind the capture zone in the top of the tank. Issues with level indicating equipment resulted in purification tanks often being overfilled bringing the surface of the solution very close to the capture face of the ducts visibly increasing tank emissions from the lid. Combined with the ineffective use of pH control systems, these matters were likely to be significant factors influencing the risk of arsine generation and any subsequent emission from the purification tanks.

The previous assessment carried out in the plant found no detectable exposures to As but did not incorporate surface sampling or biological monitoring. The results of this appraisal clearly demonstrate current practices using air monitoring alone for exposure assessment are not adequate when evaluating exposure to substances with multiple routes of entry.

## RECOMMENDATIONS AND OUTCOMES

### Immediate Implementation;

Electronic PH monitoring equipment and automated tank level indicating systems required inspection and reinstatement to working order.

An investigation into granulated or liquid alternatives to the  $As_2O_3$  was undertaken. The use of liquid alternatives was determined to introduce significant hazards and risks to health. No manufacturers were able to provide a granulated alternative in the quantities required. As a result an evaluation of closed chemical transfer systems was initiated.

A full review of all PPE used in the plant was required. At the time of this assessment filters certified for arsine use were not available. At the request of the company, 3M Australia had their ABEK acid gas filter evaluated and verified for protection against arsine. This use of the ABEK in combination with a P2 filter was recommended to be made mandatory for respiratory protective devices worn in areas where there is a risk of arsine exposure and during the handling and addition of  $As_2O_3$ . The Uvex Profi-Ergo ENB 20A were recommended to be replaced with PVC gauntlets listed as suitable by the  $As_2O_3$  safety data sheet and meeting the requirements of AS/NZS2161.1:2000.

Plant operators to be provided with refresher training in personal hygiene requirements. Plant hygiene practices were to be reviewed with a thorough clean of all control rooms focusing on internal contact surfaces.

Plant operators with elevated urinary As are to be referred to the site medical practitioner for a medical assessment relating to As exposure and investigation of any symptoms or signs of adverse health effects.

The trial method applied for the collection and processing of urine samples was adopted site wide and incorporated into the site biological monitoring protocol for all substance. A review of the sites biological monitoring program was also required and completed late 2014 ensuring all operators at risk of exposure to As including maintenance personnel were captured.

For all future exposure assessments on site encompassing substances with multiple exposure routes biological monitoring is required where practicable methods and BEIs are available.

### Further Considerations;

The purification extraction system required assessment by a ventilation engineer, with particular attention to duct work design and airflow balance between the independent fans following the guidance provided in (*HSG 258; DOE 1989; Reed et, al 2013: p116-123*)

The alarm levels of the PAC-III arsine monitors should be altered from 0.05ppm to 0.03ppm to reflect the exposure standard adjusted for 12 work shifts.

Once corrective measures have been undertaken to address tank emissions and pH control systems, a review of surface contamination and biological monitoring results should be carried out to evaluate the effectiveness of the control measures in place. This review should coincide with a more detailed investigation of operator exposure to arsine due to its potential for acute toxicity following (*NIOSH method 6001*).

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## CASE STUDY: REDUCING EXPOSURE TO ISOCYANATES DURING SURFBOARD BLANKS MANUFACTURE

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### ABSTRACT

The manufacture of surfboard blanks are usually constructed with polyurethane foam made from aromatic diisocyanates. The isocyanates are reasonably inexpensive and give the board the required strength, flexibility and durability needed for a quality product. However, significant exposure to isocyanates can cause irritation of the skin, eyes and respiratory system, and can cause occupational asthma and other pulmonary diseases.

We report on a case study at a surfboard blanks manufacturing facility where air monitoring for toluene diisocyanates (TDI) and solvent vapours were conducted to determine if workers were exposed to these chemicals above the current Workplace Exposure Standards (WES). Biological monitoring was also carried out to estimate the total individual exposure to isocyanates and styrene and to consequently determine the effectiveness of control measures.

Initial air monitoring results showed that volatile organic compounds (VOC) were only detected at levels well below their individual compound WES. Personal monitoring of the single operator for isocyanates in air was 0.03 mg/m<sup>3</sup>, which is above the Workplace Exposure Standard (WES) of 0.02 mg/m<sup>3</sup>. Biological monitoring revealed that the isocyanate metabolites 2,6-Toluenediamine (2,4-TDA) and 2,4-Toluenediamine (2,6-TDA) were detected in the urine at significantly high concentrations of 7.36 and 4.80 µmol/mol creatinine. These test results are above the UK Health & Safety Executive (HSE) biological monitoring guidance value of 1 µmol/mol creatinine for isocyanate derived diamine metabolites. The monitoring results indicated that current control measures were not adequate to protect workers from exposure to TDIs.

Workplace procedures were then reviewed and a number of control measures were recommended with the aim of decreasing the workers' exposure to TDI. This included training and information for the mainly young male workers on the hazards of isocyanates and safe work practices, changes to PPE (respirator), wearing of long sleeves and nitrile gloves for skin protection, improved housekeeping and hygiene practices regarding smoking, eating at work and hand washing.

A follow-up assessment was conducted after three months and showed significantly lower worker exposure to TDI. Biological monitoring isocyanate metabolite concentrations of 0.98, 2.50 and 3.98 µmol/mol creatinine of 2,6-TDA and 2.37 µmol/mol creatinine of 2,4-TDA were found. Although biological monitoring test results are still slightly above the recommended limits, this case study showed how an occupational hygiene assessment program was able to reduce workers' exposures to isocyanates at this small business enterprise.

### 1. INTRODUCTION

Workers manufacturing or repairing surfboards may be exposed to a number of hazardous chemicals that can cause health problems. There are three main work processes where exposure to these hazardous chemicals can take place during surfboard manufacture: (i) making the surfboard blanks, (ii) shaping the blanks and (iii) laminating and glassing the blanks.

Chemically, isocyanates are compounds containing one or more -N=C=O groups which can react with polyols such as ethylene glycol to form polyurethanes which are long chain polymeric molecules. The most widely used diisocyanates are toluene diisocyanate (TDI), methylene diphenyl diisocyanate (MDI) in the surfboard manufacture of the blanks and hexamethylene diisocyanate (HDI) can be used in the spray painting of the board.

Isocyanates are harmful chemicals as they are powerful irritants to the skin, eyes and respiratory tract and can cause sensitisation which can lead to occupational asthma (HSE 2016). Once sensitisation has occurred, people can develop asthma attacks if exposed again even at a much lower concentration (SafeWork 2015). It has been reported that diisocyanates are the most common cause of occupational asthma in the UK (HSE 2016).

The International Agency for Research on Cancer (IARC) has determined TDI as possibly carcinogenic to humans (Group 2B). The health effects of exposure to TDI are headache, fatigue dizziness, confusion, drowsiness, malaise, difficulty in concentrating and feeling of intoxication. TDI also appears to accelerate loss of pulmonary function and prolonged exposure could result in the development of chronic pulmonary diseases (IARC 1999).

The shaping process of surfboard blanks can also produce partially-cured isocyanate fine foam dust which can be released in the air and can cause respiratory problems in the lungs if inhaled. The solvent acetone is also used in the process and is a respiratory irritant and can affect the central nervous system causing behavioural changes. Inhalation of the vapour can cause dizziness and it has been reported to have synergistic effects with other solvents (Hathaway *et al* 1991).

The surfboard laminating/glassing process involves the use of polyester resin which produces polystyrene during the polymerisation process. Styrene is a colourless liquid that is highly flammable, evaporates quickly and can be smelled even at low concentrations. Styrene is an irritant to the eyes and mucous membranes and can cause drowsiness and gastrointestinal effects. Long term exposure to styrene is known to affect the central nervous system, can cause hearing loss, vision impairment, slower reaction time as well as concentration and balance problems (NTP 2011).

Currently, there are no published studies on exposure to isocyanates during surfboard blanks manufacture.

## 2. PURPOSE OF MONITORING

This workplace monitoring was conducted as part of the SafeWork NSW regulatory verification program for working safely in the surfboard manufacturing and repair industry.

The purpose of air monitoring was to find whether workers were exposed to isocyanates, styrene and other hazardous chemicals above the acceptable workplace exposure limits. The Workplace Exposure Standard (WES) in Australia for a chemical in air is a mandatory limit under the Work Health and Safety Regulation (WHS) Regulation 2011. Workers must not be exposed to levels above the WES limit.

Biological monitoring was done to estimate the total individual exposure to any chemicals used at workplace. This can indicate whether the control measures used at the workplace are effective in protecting the worker from exposure to that chemical. There is a SafeWork NSW recommended Biological Occupational Exposure Limit (BOEL) to help in the interpretation of the biological monitoring test results..

## 3. WORKPLACE DESCRIPTION

The study assessed a small family owned surfboard blanks manufacturing facility that produces approximately 200 surfboard blanks per day. The production line involves two workers in the morning shift and two workers in the afternoon shift.

The production area consisted of a large open area with a number of longboard and shortboard polyurethane moulding machines. The process of making surfboard blanks involves mixing Part A (polyurethane) and Part B (polyol) chemicals and then pouring the mixed liquid into the mould and heating to 60°C for 30 minutes. After heating, the dense white foam is produced. The hardened foam is inspected for defects and set aside for 24 hours to complete the hardening process. The hardened blanks are then shipped to various external surfboard finishers for shaping and laminating/glassing.

## 4. METHODS

An initial survey was conducted at one surfboard blank manufacturing site. Static air sampling for solvent exposure and biological monitoring for isocyanates of one moulding operator was conducted as per the sampling strategy is outlined below. A follow-up survey was then undertaken 3 months later to observe what improvements had been made to the worksite. This follow-up survey entailed personal and static air sampling and biological monitoring for isocyanates.

### (a) Static Air Sampling for Solvent Vapours

Organic vapour monitors (3M - OVM 3500 Passive monitoring badge) were positioned at various locations and stages of the surfboard blanks manufacturing process to determine the concentration of volatile organic chemicals (VOCs) in the workplace. The badges were positioned next to the source of airborne contaminants and at breathing zone height to give a good estimate of worker's exposure. Static samples were collected for a period of approximately 3 hours (about 180 minutes) which is well within the recommended maximum sampling time of the OVM. The analysis of the samples was performed by SafeWork NSW, Chemical Analysis Branch Laboratory using the in-house method WCA.207 screen for 73 VOCs. This analytical method uses carbon disulfide desorption of the charcoal badge with gas chromatography/mass spectrometry analysis based on NIOSH 1500 method. The method has a limit of quantitation of 1µg/sample aromatic hydrocarbons, 5µg/sample aliphatic hydrocarbons, 25µg/sample oxygenated hydrocarbons and 50µg/sample Total VOCs. This is equivalent to an air concentration of styrene = 0.05 ppm, acetone = 0.30 ppm, Total VOC = 2.0 ppm after a 180 mins air sample is taken.

### (b) *Static and Personal Air Sampling for Isocyanates*

A combination of impinger and filter in series were used to collect mixtures of airborne isocyanate aerosols and vapours. Static samples were collected at key locations in the workplace to evaluate the risk of exposure to the workers. A personal sample of a worker involved in surfboard blanks manufacture was collected around the breathing zone. Both personal and static samples were collected at a flow rate of 1 L/min for  $95 \pm 5$  min.

After sampling, the content of the impinger was transferred to a sealed glass vial while the filter was placed in an desorbing solution to trap and react the isocyanates to a stable urea derivative. Samples were then transported to SafeWork NSW, Chemical Analysis Branch Laboratory for total isocyanates in air analysis by derivatisation of the –NCO groups with 1-(2-methoxyphenyl)-piperazine to their urea derivatives and subsequently analysed using high performance liquid chromatography with ultra-violet photodiode array and electrochemical detection based on the UK HSE MDHS25/4 analysis method. The method has a limit of quantitation of 0.1µg Total NCO/sample giving an equivalent air concentration of 0.001 mg/m<sup>3</sup> for a 100 L air volume sampled.

### (c) *Biological monitoring for exposure to solvents and isocyanates*

Urine samples were collected from workers who had read, agreed and completed a biological monitoring consent form. A total of six workers provided urine samples for biological monitoring for solvent metabolites. The sample was collected in a labeled, fresh specimen container, stored in an esky with a frozen ice block (at 4°C) and transported to SafeWork NSW Chemical Analysis Branch Laboratory for analysis.

Urine samples were analysed for the following solvent metabolites:

- Isocyanate metabolites: 2,4-TDA & 2,6-TDA for exposure to 2,4-TDI & 2,6-TDI
- Mandelic acid the metabolite of styrene exposure
- S-Phenyl mercapturic acid the metabolite of benzene exposure
- Hippuric acid the metabolite of toluene exposure
- Toluric acid the metabolite of xylene exposure

All urine test results were reported normalise to the amount of creatinine in the sample to account for the worker's hydration level.

The analysis for isocyanates was performed using an in-house analytical method of derivatisation to the perfluorofatty amides and subsequent analysis by ultra-high performance liquid chromatography tandem mass spectrometry with a limit of quantitation for the method is 0.5 µg diamine/L urine. This is equivalent to 0.5 µmol diamine/mol creatinine in urine. The other solvent metabolites were analysed by in-house methods using high performance liquid chromatography with ultra-violet photodiode array detection with limits of quantitation of mandelic acid 0.3mmol/L, S-Phenyl mercapturic acid 2.0µg/L, hippuric acid 0.5mmol/L, toluric acid 0.05 mmol/L urine.

## 5. STANDARDS AND LEGISLATION

### **Workplace Exposure Standards for contaminants in the air**

The WHS Regulation 2011 requires a person conducting a business or undertaking (PCBU) to ensure that airborne concentration of contaminant in the workplace does not exceed its Workplace Exposure Standard (WES). WES established in Australia are published in the Safe Work Australia *Workplace Exposure Standard for Airborne Contaminants* (Safe Work Australia, April 2013).

The WESs of the chemicals of interest are: Isocyanates – 0.02 mg/m<sup>3</sup> TWA, 0.07 mg/m<sup>3</sup> STEL; Styrene – 50ppm TWA, 100 ppm STEL; Acetone – 500 ppm TWA; 1000 ppm STEL.

### **Biological Occupational Exposure Limits (BOEL)**

BOELs are not mandatory in Australia, however, SafeWork NSW has proposed some BOELs as guidelines to help interpret exposures to some common chemicals used in Australia that can affect a worker's health (TestSafe Handbook 9th Ed).

Exposure to Isocyanates by the analysis of the Diamine metabolites BOEL = 1.0 µmol/mol creatinine; Exposure to Styrene by the analysis of the metabolite Mandelic acid BOEL = 297 mmol/mol creatinine; Exposure to Benzene by the analysis of the metabolite S-Phenyl mercapturic acid BOEL = 25 µg/g creatinine; Exposure to Toluene by the analysis of the metabolite

Hippuric acid BOEL = 1010 mmol/mol creatinine; Exposure to Xylene by the analysis of the metabolite Toluric acid BOEL = 650 mmol/mol creatinine.

If exposure to the chemical is below the BOEL, workers exposed on a daily basis would not experience adverse health effects. Higher results than BOEL would indicate that current control measures are inadequate to prevent exposures and work practices need to be reviewed.

For isocyanates, the value of 1  $\mu\text{mol/mol}$  creatinine for isocyanate derived diamine metabolites is a guidance value. This value is based on good work practices and not necessarily on worker health outcomes.

Isocyanate is listed as a chemical requiring health monitoring under Schedule 14 of the WHS Regulation 2011. Styrene is not listed in Schedule 14 of the WHS Regulation 2011. However, monitoring for urinary mandelic acid for styrene exposure is listed by Safe Work Australia as one of the tests that may be considered by a PCBU in a health monitoring program.

## 6. RESULTS

**Table 1: Analysis of static air monitoring for solvent vapours conducted in the initial survey**

Locations	Sampling Time (min)	Total VOC (ppm)	Styrene (ppm)	Acetone (ppm)
Dispenser A	180	< 2.0	< 0.05	< 0.30
Dispenser B	180	< 2.0	< 0.05	<b>0.34</b>
Longboard Mixing	180	< 2.0	< 0.05	<b>1.43</b>
Shortboard Mixing	180	< 2.0	< 0.05	<b>2.38</b>
Moulding	180	< 2.0	< 0.05	<b>5.00</b>
General Walkway	180	< 2.0	< 0.05	<b>2.21</b>
WES (TWA in ppm)			50	500

Limit of Quantitation: Total VOC = 2.0 ppm; styrene = 0.05 ppm; acetone = 0.30 ppm;  
 NA = Not Applicable; ppm = parts per million

**Table 2: Analysis of personal and static air monitoring for isocyanates in the follow-up survey**

Sampling Locations	Sample Type	Total Volume (L)	Isocyanates Impinger ( $\text{mg}/\text{m}^3$ )	Isocyanates Filter ( $\text{mg}/\text{m}^3$ )
Worker in all locations	Personal	85	<b>0.03</b>	< 0.001
Dispenser	Static	105	<b>0.04</b>	< 0.001
Mixer	Static	90	<b>0.02</b>	< 0.001
General Area	Static	95	<b>0.02</b>	< 0.001
WES (TWA in $\text{mg}/\text{m}^3$ )			0.02	0.02

Limit of Quantitation: 0.001  $\text{mg}/\text{m}^3$  Total –NCO

**Table 3: Analysis of biological monitoring for isocyanate metabolites in urine in initial and follow-up survey**

Sample ID	2,4-Toluenediamine ( $\mu\text{mol/mol creat}$ )	2,6-Toluenediamine ( $\mu\text{mol/mol creat}$ )
<b>Initial Study</b>		
Worker 1a	<b>4.80</b>	<b>7.36</b>
<b>Follow-up Study</b>		
Worker 1b	<b>2.37</b>	<b>3.98</b>
Worker 2	< 0.34	<b>2.50</b>
Worker 3	< 0.34	<b>0.98</b>
Worker 4	< 0.34	< 0.34
Worker 5	< 0.34	< 0.34
BOEL = 1.0 $\mu\text{mol/mol creat}$		

 Limit of Quantitation: 0.34  $\mu\text{mol/mol creat}$ ;

creat = creatinine

## 7. DISCUSSION

### *Initial Survey*

Low levels of volatile organic compounds (VOC) such as acetone were detected in the air with levels ranging from < 0.30 to 5.00 ppm. The highest concentration of 5 ppm acetone was found during the moulding process. This is equivalent to 1% of the WES of 500 ppm. Styrene, a major component of the fibre glass polymer coating used to laminate the surfboards during the glassing process was not detected in the air as it was not used during surfboard blanks preparation.

Biological monitoring of the solvent metabolites of styrene, benzene and xylene were not detected in the urine of the worker monitored. However, hippuric acid the metabolite of toluene was detected at a level of 50 mmol/mol creatinine. This is equivalent to 5% of the BOEL and is consistent with background levels often found due to diet.

Biological monitoring showed that isocyanate metabolites were detected in the worker's urine. The isocyanate metabolites 2,4-TDA and 2,6-TDA were detected in the urine at significant concentrations of 4.80 and 7.36  $\mu\text{mol/mol creatinine}$  respectively.

The Health & Safety Executive (UK) has set a biological monitoring guidance value of 1  $\mu\text{mol/mol creatinine}$  for isocyanate derived diamine metabolites. This would indicate therefore that the worker is significantly exposed to TDI and that the control measures in the workplace are not adequate. It was suggested to the employer that workplace procedures should be reviewed with the aim of decreasing the worker's exposure.

The facility does not have local exhaust ventilation but relied on natural ventilation by opening the side doors of the premises to dilute the airborne contaminants. The high levels of TDI metabolites found in the urine of the worker further vindicates that natural ventilation alone is inadequate in removing TDI from the workplace air. It also indicates that the cartridge respirator worn by the worker is ineffective in providing protection from these chemical contaminants in the air. This could be because the respirator is not properly fitted or poorly maintained or the cartridge had been exhausted.

During the initial monitoring, it was observed that the worker was only wearing t-shirt and shorts. This could have contributed to the worker's exposure to isocyanates. Isocyanates enter the body primarily through inhalation, however, skin contact can also be a significant route of exposure. It was emphasised to the employer these types of work practices and the poor housekeeping observed were probable causes of the exposure and that the worker should be wearing long sleeves and pants to protect his skin from contact with the isocyanates.

### **Follow-up Survey**

The follow-up survey was conducted three months after the initial survey and investigated exposure of five workers at the site, two of the workers were in the production area including one operator from the initial survey.

The isocyanate aerosol/vapours in this situation were detected in the impinger sampling solution alone, with no isocyanate aerosol or vapours found on the following sampling filters. The static monitoring test results for isocyanates ranged from 0.02 to 0.04 mg/m<sup>3</sup>. Personal air monitoring of the operator showed an isocyanate level of 0.03 mg/m<sup>3</sup>, which is above the WES of 0.02 mg/m<sup>3</sup>. The known health effects of exposure to isocyanates were reinforced with the employer. It was explained that exposure to airborne isocyanates should be minimised as they are known to cause respiratory sensitisation and occupational asthma. Most isocyanates are also considered skin and eyes sensitisers.

The presence of isocyanates in the workplace air and in the breathing zone of the worker indicates that the ventilation control system is not very effective in removing airborne isocyanates. This was confirmed by the isocyanate levels of 0.04 and 0.02 mg/m<sup>3</sup> found during dispensing and mixing of the isocyanate chemicals. It was suggested that additional local exhaust ventilation should be introduced around these areas for efficient removal of the contaminants. The local exhaust ventilation should be placed as close to the source of the contaminants as possible and it should have enough flow velocity for optimum removal of the contaminants. The isocyanate level of 0.02 mg/m<sup>3</sup> found in the general work area is also an indication that the natural ventilation is inadequate in diluting airborne contaminants in the air. It was emphasised to the employer that ventilation in the facility should be improved to effectively remove the isocyanates from the workplace air and to prevent the isocyanates from dispersing and contaminating other work areas.

Poor housekeeping was observed during the assessment and the general work areas were very dusty with considerable hardened isocyanate wastes were present. This could also have contributed to the high isocyanate results as dusts can be a potential source of airborne isocyanates. It was suggested that an effective dusts extraction system be installed to minimize the accumulation of the dust and that more attention should be given to more regular housekeeping in the production area to reduce potential exposure sources of airborne isocyanates.

Biological monitoring in the follow-up survey revealed that the isocyanate metabolites 2,4-TDA and 2,6-TDA were detected in the urine of three of the five workers monitored. This included a non-production worker, namely the operations manager that would have otherwise been assumed to be unexposed. Concentrations of the isocyanates metabolites in urine were 2.37 µmol/mol creatinine of 2,4-TDA and 0.98, 2.50 and 3.98 µmol/mol creatinine of 2,6-TDA were found. Again these test results are above the UK Health & Safety Executive (HSE) biological monitoring guidance value of 1 µmol/mol creatinine for isocyanate derived diamine metabolites. The two workers in the production area are therefore still exposed to TDIs above the acceptable limit.

It should be noted however that the follow-up survey gave lower results than the initial monitoring. This could be due to the hygiene program that was adopted after the initial assessment which has contributed in reducing the workers' exposure to the isocyanates. The basic measures of the hygiene program included training and information on the hazards of isocyanates and the required safe work practices, changes to PPE including the correct fitting and maintenance of the respirator, the wearing of long sleeves and nitrile gloves for skin protection, improved housekeeping and occupational hygiene practices regarding smoking, eating at work and hand washing.

Although the follow-up survey showed lower exposures than the initial survey, other control measures may need to be considered to further decrease the workers' exposure to reduce exposures to below the recommended limits. It was explained to the employer that workers whose test result significantly exceeds the BOEL has an increased risk of adverse health effects.

The dusty work environment could have contributed to the workers' isocyanate exposure. This could be the cause especially of the presence of TDI in the non-production worker who, it was noted, visited the production area regularly.

The results of the monitoring showed that there is a significant exposure to isocyanates. A program of health monitoring should be established for the two production workers as required under the WHS Regulation 2011. Under the regulation, health monitoring should be provided to the worker when there is a significant risk to the worker's health because of

exposure to a hazardous chemical. Isocyanate is listed as a chemical requiring health monitoring under Schedule 14 of the WHS Regulation and therefore such monitoring is mandatory.

## 8. CONCLUSIONS AND RECOMMENDATIONS

The results of monitoring showed that there is a significant exposure to isocyanates during surfboard blanks manufacture. A combination of engineering controls, administrative controls, good hygiene practices and appropriate use of PPE is required to control the risks.

Although the follow-up monitoring results were lower than the initial monitoring, other control measures should be considered to further decrease the workers' exposure to toluene diisocyanates (TDIs) to below the recommended exposure limits. In particular, additional local exhaust ventilation should be introduced for efficient removal of contaminants. An effective dust extraction system and regular housekeeping should be considered to reduce potential sources of airborne isocyanates. A regular health monitoring program should also be established for the two production workers as there is a significant risk to health from exposure to isocyanates and isocyanates is listed as a chemical requiring health monitoring under Schedule 14 of the WHS Regulation.

Workers should be provided with appropriate PPE designed for isocyanate exposure such as respirator and skin protection and workers must wear them when performing their tasks. The recommended respirator in surfboard blanks manufacture is half mask respirator with particulate filters. Proper skin protection includes impermeable overalls or aprons, chemically resistant gloves and goggles. A further follow-up air monitoring and biological monitoring study is planned to be conducted to ensure that these additional control measures are protecting workers from exposure to the isocyanates and solvents present.

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## 10. DISCLAIMER

The views expressed in this paper are those of the authors and not necessarily of SafeWork NSW.

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## THE AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION (ANSTO) – DEVELOPING AN EXPOSURE ASSESSMENT PROGRAMME IN A RESEARCH ENVIRONMENT

*Dr Catherine Field and Carmen Smith*

ANSTO

### SITUATION

The Australian Nuclear Science and Technology Organisation (ANSTO) is the centre of Australia's nuclear science capabilities and expertise. As a large research facility that undertakes studies in a variety of fields, there is a much wider assortment of materials used compared to many other organisations. Many of these substances are only used periodically and often for short durations. Because of this, there may be less in-depth knowledge about the various material hazards and therefore the potential for unknown hazards must be pre-empted.

Based on a proactive vs reactive exposure assessment programme ANSTO has applied a baseline exposure assessment programme to assist in determining appropriate health monitoring requirements. The exposure assessment programme takes into account both routine operations and the special characteristics of research operations.

### INTRODUCTION

ANSTO is a rapidly growing company in Lucas Heights (NSW). It is home to Australia's nuclear science and technical expertise. More than a 1000 scientists, engineers and experts work at ANSTO and use nuclear science and technology in research that ranges from improving health outcomes, increasing our understanding of the environment and climate change, and identifying new opportunities for Australian Industry. In addition, ANSTO operate much of our countries landmark science facilities including one of the world's most modern nuclear research reactors (OPAL).

At ANSTO employees' and contractors' potential occupational exposures are extensive. Physical agents include noise, vibration, electromagnetic radiation, ionising and non-ionising radiation and situations that may cause thermal stress/discomfort. Exposure to chemical agents include harmful airborne or surface chemical contaminants (dusts, mists, metal fume, gases and vapours), including schedule 10 or 14 substances of the WHS Regulations. Biological agents also exist including hazards such as mould, bacteria, work with non-potable water systems and other materials of biological origin. It is therefore important that an exposure profile of all ANSTO employees and contractors to harmful agents is established. Identifying and assessing these hazards will assist in instituting a best practice occupational hygiene monitoring and health surveillance programme.

Between January 2016 and December 2016 a baseline assessment was conducted to evaluate employee exposure to workplace hazards. A comprehensive exposure assessment for each Similarly Exposed Group (SEGs) was carried out. This process involved collecting information in a structured and systematic way to characterise the workplace, the workforce and environmental harmful agents. Health hazard identification and assessment principles were applied under best practice protocols in accordance with the Australian Institute of Occupational Hygienists (AIOH) "Simplified Occupational Hygiene Risk Management Strategies" (AIOH 2006).

The purpose of the exposure risk profile review is to focus resources for controlling hazards that pose the highest risk to employees. On completion of the review the information obtained for each SEG was assessed and the need for controls and medical surveillance programmes implemented as required.

## Legislative Requirements

The requirement to protect employees is central to WHS Regulations 2011.

**Regulation 32-38:** In order to manage risk under the WHS Regulations, a duty holder must:

- a) identify reasonably foreseeable hazards that could give rise to the risk
- b) eliminate the risk so far as is reasonably practicable
- c) if it is not reasonably practicable to eliminate the risk – minimise the risk so far as is reasonably practicable by implementing control measures in accordance with the hierarchy of risk control
- d) maintain the implemented control measure so that it remains effective
- e) review, and if necessary revise all risk control measures so as to maintain, so far as is reasonably practicable, a work environment that is without risks to health and safety.

WHS Regulation 49 directly related to hazardous substances in the workplace.

**Regulation 49:** A person conducting a business or undertaking must ensure that no person at the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the relevant exposure standard for the substance or mixture.

In addition Regulation 368 outlines the need for health monitoring for hazardous chemicals listed in Schedule 14 where exposure is deemed to be significant.

**Regulation 368:** A person conducting a business or undertaking must ensure health monitoring is provided to a worker carrying out work for the business or undertaking if:

- the worker is carrying out ongoing work using, handling generating or storing hazardous chemicals and there is a significant risk to the worker's health because of exposure to a hazardous chemical referred to in Schedule 14, table 14.1
- the person identifies that because of ongoing work carried out by a worker using, handling generating or storing hazardous chemicals there is a significant risk that the worker will be exposed to a hazardous chemical (other than a hazardous chemical referred to in Schedule 14, table 14.1) and either valid techniques are available to detect the effect on the worker's health or a valid way of determining biological exposure to the hazardous chemical is available and it is uncertain, on reasonable grounds whether the exposure to the hazardous chemical has resulted in the biological exposure standard being exceeded.

The health and safety of workers at ANSTO is governed by the WHS Act and Regulations and compliance with the Act and Regulations is overseen by ComCare.

The regulations require ANSTO to make an assessment of the risk to health and safety of workers who may be exposed to the job task or activity. Therefore, Occupational Hygiene monitoring of workplace contaminant levels for chemicals with exposure standards may need to be carried out to define if workplace controls are adequate.

To assist with ANSTO meeting these obligations exposure assessment and health monitoring are important. Occupational hazards that were identified as having the potential to adversely affect human health were the focus of this baseline assessment.

### Exposure Assessment Procedure

The ANSTO Occupational Health Exposure Assessment Procedure was developed in 2015 and provides a framework for the evaluation and control of occupational workplace exposures at ANSTO.

The basic steps of the baseline exposure assessment are acknowledged in this procedure and are in accordance with Australian Institute of Occupational Hygienists (AIOH) Simplified Occupational Hygiene Risk Management Strategies (AIOH 2006). This guideline has been developed to meet Safe Work Australia's requirements for employers to identify, assess and control risks arising from workplace exposures. The baseline risk review was conducted in accordance with the following steps:

1. Workplace Characterisation - Establishing Similar Exposure Groups (SEGs);
2. Hazard Identification - Identify Hazards and their health impact
3. Exposure Characterisation - Consider likelihood of exposure that could result in the health impact
4. Risk Assessment - Determine level of health risk
5. Risk Control or Treatment
6. Monitoring and Review of Controls
7. Documentation of the risks identified and the actions decided upon.

Health and hygiene hazards considered during the assessment were systematically identified from Information Collection and Walk Through Surveys assessing workplace layout, processes, and environmental conditions. Discussions with experienced personnel, Health and Safety Representatives (HSRs) and management was also invaluable identifying hazards.

There were three main categories of hazards: physical, chemical or biological agents. Agents assessed were as follows:

- Chemical such as harmful particulates (Inhalable, Respirable, Crystalline Silica, Welding Fume, Nanomaterials), Synthetic and man-made fibres (Asbestos), liquids, gases and vapours;
- Physical (Noise, Ultraviolet Light, Vibration, Electromagnetic Radiation, Excessively Hot or Cold environments, Muscular Skeletal Disorder (MSD) risk factors) Note:
- Biological agents such as viruses, bacteria, and other materials of biological origin.

A preliminary assessment was conducted to determine whether an agent was likely to have an adverse health effect. Information on particular types of hazards which predominate were gathered (e.g. Safety Data Sheets) and their routes of exposure (inhalation, ingestion, injection or by passing through the skin) was considered.

Risks that were judged to be insignificant were documented but were not considered in the review. In addition this review does not include Ionising and Non-Ionising Radiation, which is outside the remit of Work Health and Safety Division at ANSTO. These exclusions are also important to ensure the assessment was manageable in size.

The above hazard identification and workplace characterisation identified the hazards that posed the highest risk to ANSTO staff. Some of these common and not-so-common hazards and their potential health effects are discussed in the below sections.

### **Workplace Characterisation (SEGs)**

The first step of workplace characterisation is the selection of similar exposure groups or SEGs (AIOH 2006). This is an efficient way to group employees whose exposure may be similar. SEGs are commonly developed based on job types; however this process requires caution in a research environment such as ANSTO. Such titles as "Lab Technician" have a different job or different exposure from lab to lab. Therefore it was often more beneficial to characterise workers based on their job demands or task information, for example, sample preparation, solvent extraction etc. AIHA (2015) refer to this as Similar Exposure Tasks (SETs).

## Hazard Identification

To obtain the best estimate of exposures for each SEG an initial appraisal to identify health hazards is necessary. There are a number of characteristics of a research environment that set ANSTO apart from other workplace settings. These factors increase the complexity of hazard identification and include:

Characteristic	ANSTO Typically has
Variety of materials	Much wider assortment
Duration of use	Much more variability, shorter
Duration of employment	Many Year In Industry Students, Users that pass through, Contractors and International Visitors
Engineering Controls	Better enclosures, ventilation/ extraction systems to contain hazards
Understanding of materials	Increasing use of new emerging materials e.g. nano particulates
Speed of change	New research and experiments added routinely
Regulatory Bodies	A wide-range of regulatory bodies including, but not limited to, ARPANSA, ASNO, Comcare and the Therapeutic Goods Administration (TGA).

(Adapted from AIHA 2015 Laboratory Characteristics)

Given the complexities associated with a research environment only hazards that were routinely encountered during normal ANSTO operations were assessed as part of the baseline risk review. This exclusion was necessary to ensure the exposure profile was manageable in size.

AIHA (2015) recommends following a similar “recipe” of hazard identification and evaluation in research environments. Many research complexes have support services and maintenance operations present in both (AIHA 2015). Additionally some laboratory operations include repetitive use of the same type of agents and use a standard set of chemicals. Therefore a valid conclusion regarding exposure can still be made by following traditional health hazard risk management models.

Examples of hazards inherent to activities conducted at ANSTO are described in the below sections.

### Airborne Dusts

Exposure to airborne dusts will vary widely depending on the sources. This can include the following at ANSTO, machining, grinding, milling, building decommissioning and construction activities, part of the work place (e.g. surface dusts), windborne dusts, by products from support processes such as welding, waste products or handling and transfer of raw materials.

Inhalable (dusts that penetrate the upper airways) and respirable sized particles (may penetrate in deepest parts of lung and alveoli) are generated from many workplace activities at ANSTO. These size classifications have Workplace Exposure Standards listed in the Hazardous Substances Information System (HSIS) on the Safe Work Australia website and must be applied (SWA 2016).

Respirable Crystalline Silica is known as a group one (Carcinogenic to humans) according to the International Agency for Research on Cancer (IARC 2016) and is present in processes that generate dust from sand, hard rocks and materials such as concrete. The major health effects associated with Crystalline Silica include lung fibrosis (“silicosis”) and respiratory cancers as a result of inhalation.

Asbestos is a known group 1 carcinogen and may also be encountered during building demolition or refurbishment activities (IARC 2012). Although all forms of asbestos has been prohibited, it is still found in many structures and building materials at ANSTO.

It is important to note the number of substances used in a research environment often exceeds the number of substances that have listed exposure standards. Therefore doing a good job of compliance with Exposure Standards does not in itself mean all exposures to hazards are controlled (AIHA 2015). In these situations a precautionary approach is always applied, also known as the ALARA principle (As Low as Reasonably Achievable).

### **Lead and Other Heavy Metals**

Other particulates such as heavy metals may be drawn from work surfaces at ANSTO. For example due to its physical properties, such as its uniform density and ease of fabrication, lead is an effective radiation shielding material. Lead is present in many forms at ANSTO, for example, metal sheets, slabs, bricks and glass. Precautions need to be taken for inhalation, skin contact and ingestion of Lead and Other Metals.

Once absorbed lead can affect numerous organs in the body. It is associated with respiratory cancers as a result of exposures from inhalation. In terms of carcinogenicity the International Agency for Research on Cancer (IARC 2006) has changed the category from possible to a probable human carcinogen (Group 2A). In addition health effects can possibly include high blood pressure, anaemia (low red blood cell counts), kidney damage, nervous system damage and damage to the reproductive system (AIOH 2009).

### **Sulphuric and Other Acid Mists**

Possible health effects depend on the chemical compound and exposure duration. Sulphuric acid is one of the most commonly used chemicals onsite at ANSTO and is used in a variety of applications, such as leaching metals from ores.

The health effects of sulphuric acid has been associated with short term irritation of eyes and skin, irritant dermatitis, irritation of lungs and upper respiratory tract (AIOH 2015)

Sulphuric acid mists from strong inorganic acids are classified by IARC as a group 1 carcinogen (known human carcinogen) (IARC 2012).

### **Noise**

Noise induced hearing loss (NIHL) is caused by excessive exposure to high levels of noise. Maintenance activities historically generate excessive noise sources. Noise exposures vary depending on plant or equipment type, job tasks and environment.

### **Heat Strain**

There is also risk of thermal strain. Examples include situations of thermal discomfort while wearing personal protective equipment, working outdoors in hot environments. Exposure to heat stress can increase the risk of heat stroke, heat exhaustion, heat cramps or rashes. Heat and dehydration can also aggravate underlying medical conditions such as cardiovascular disease.

### **Ergonomics**

Ergonomic injuries are often caused by the presence of ergonomic risk factors, including: continuous or repetitive movement, awkward or sustained postures e.g. when a load is located above shoulder height or below mid-thigh, or requires reach. Other factors to consider also include, fitness for work, work surfaces, lighting, climatic conditions and exposure to vibration.

High risk work such as construction, demolition activities, work at heights, confined spaces or donning PPE that hinders movement such as wearing compressed air breathing apparatus are some activities that require higher levels of exertion at ANSTO.

### **Microbial Hazards in Water**

Exposures to microbiological hazards are associated with a range of environments or processes. Most pose no threat to human health but there are some that may cause serious health effects (for example, legionella, salmonella, Escherichia coli). The main types of workers at risk from microorganisms include staff involved or working near sewage systems or standing waters, staff in biological laboratories, health care workers, waste collectors and environmental staff.

## Exposure Characterisation

Once health hazards have been identified an estimate of the likelihood of exposure is the next step. In deciding the degree of harm, the intensity of exposure viewed as frequency or time (e.g. how long one is exposed) and the concentration of that substance is considered. Qualitative and quantitative descriptors provided in the AIOH Simplified Occupational Risk Management Strategies (AIOH 200) was used to provide a consistent approach in this process. This guidebook provides exposure descriptors for microbiological, chemical (In Air and Dermal), ergonomic hazards, noise and vibration. A generic model is displayed below.

### Likelihood Descriptors

A	Almost Certain	Regular contact with the potential hazard at very high levels
B	Likely	Periodic contact with the potential hazard at very high levels or regular contact with the potential hazard at high levels
C	Possible	Periodic contact with the potential hazard at high levels or regular contact with the potential hazard at moderate levels
D	Unlikely	Periodic contact with the potential hazard at moderate levels or regular contact with the potential hazard at low levels
E	Rare	Periodic contact with the potential hazard at low levels

(Adapted from AIOH Simplified Occupational Hygiene Risk Management Strategies 2006)

### Risk Assessment

A risk assessment will identify the control actions required. There are four main possibilities from the risk assessment outcome (AIOH 2006)

1. Very High: Needs urgent and immediate senior executive management attention
2. High: Requires Proactive Management
3. Medium: Requires active Monitoring
4. Low: Will likely not require active management, other than existing routine procedures.

### Decentralised Exposure Assessment

ANSTO is highly research intensive, meaning that potential occupational exposures are subject to routine change and thus defining SEGs based on tasks or chemicals used would be impossible to define. This centralised exposure assessment process does not allow for real time assessment of exposure risk. Management of change is a critical element in maintaining a safe environment in a research environment (AIHA 2015). For this reason it is recommended to employ a “hybrid” exposure assessment program taking into account routine operations but also the special characteristics of a research/ laboratory environment (AIHA 2015). This process should run concurrently to the model described above, AIHA refer to this as a Decentralised Exposure Assessment Process (AIHA 2015).

At ANSTO risk assessments are carried out day to day, and often the worker or the supervisor are the one doing the initial risk assessment. Designated hazardous areas or activities require a current Safety Assurance Committee (SAC) approval. Hazardous activities that involve or will involve a hazard that has an inherent very high, high and medium risk (i.e. risk in the absence of mitigation or control strategies) required this process. It is a staged system that requires identification of the hazard and control measures and initial risk assessment by employees. These safety assessments are validated by the SAC Manager, and SAC Assessors (Work Health and Safety, Radiation Protection Advisors, Systems Safety and Reliability).

Low risk or well proven industry processes that do not require unique control measures these do not require SAC submission. However, these assessments require local approval and employee involvement establishing Safe Work Methods and

Procedures, and controls as per hierarchy of controls. These risk assessments are also used to validate the exposure risk profile.

## RESULTS

Having considered each potential source following basic occupational hygiene principles it is then possible to identify exposure assessment and health monitoring requirements. This process was useful for:

- Better understanding of laboratory/ worker exposures, to allow more accurate assessment and monitoring of potential risks to health
- Useful for determining exposures requiring additional exposure assessment and/ or health monitoring
- Validating engineering controls and PPE selection
- Prevention of long term occupational diseases in the workforce

In conclusion while the unique characteristics of research operations need to be taken into account, standardised exposure assessment and hazard risk assessment methodologies can still be applied when undertaking a baseline risk assessment. The outcome of this is systematic elimination or control of occupational hazards and protection of worker health.

## OCCUPATIONAL HEALTH SURVEILLANCE

Occupational health surveillance, or health monitoring, as defined by Safe Work Australia is *“the monitoring of a person’s health to detect if any changes in that person’s health status occurs to due occupational exposure to certain substances”* <sup>11</sup>.

Thus whereas occupational hygiene is concerned with the primary prevention of adverse health effects due to workplace exposures, health surveillance and monitoring represents secondary prevention, i.e. detecting health effects or illness early, ideally to stop or slow disease progression.

Health surveillance can also assist in evaluating the effectiveness of workplace hazard and risk controls. However just as personal protective equipment is the last control measure in the hierarchy of controls, health surveillance should not be used as a replacement for instituting and maintaining appropriate workplace controls.

### When is health surveillance undertaken?

Health surveillance may be undertaken to fulfil legislative requirements, or when a workplace has identified in their exposure and risk assessment that there are substances being used in the workplace which are potentially hazardous to health.

When developing a health surveillance programme there are several important principles to consider, including:

- Define your objectives and design a specific programme to meet them
- Engage the stakeholders
- Report and take action, and review the programme periodically.

The health surveillance programme needs to be appropriate for the hazards and risks involved in each particular case or workplace. Performing generic “medicals” is to be discouraged, because the results obtained may not be relevant to the particular risk and may thus be difficult to interpret; or relevant abnormalities may be missed if they are not specifically looked for with the appropriate clinical examination and/or tests.

This is where the exposure and risk assessment strategies outlined above are invaluable, by providing information about the type/s of hazards involved and the potential routes and levels of exposure.

The health monitoring should also be safe, easy to perform, acceptable to workers and where possible, non-invasive<sup>1</sup>.

Work, Health and Safety legislation also states that health surveillance must be developed or supervised by a medical practitioner with experience in occupational health monitoring. Specific competencies for medical practitioners who are supervising or conducting occupational health surveillance are outlined in the Safe Work Australia document, **“Health Monitoring for Exposure to Hazardous Chemicals: Guide for Medical Practitioners”**, (February 2013, Safe Work Australia).

### What does occupational health monitoring consist of?

1. History – questionnaire for occupational and medical history, and may also include additional standardised screening questionnaires such as a standardised respiratory questionnaire for respiratory disease.
2. Medical examination – clinical assessment, physical examination, relevant tests such as lung function tests (i.e. spirometry), basic urinalysis, chest x-ray.
3. Specific tests for:
  - biological exposure monitoring – i.e. measuring levels of a hazardous chemical or its metabolites in the body. For example, spot urine s-phenylmercapturic acid (s-PMA), which is a highly specific marker for benzene exposure and which we use at ANSTO. Blood lead level is another measure, again used at ANSTO for relevant workers; OR
  - biological effect monitoring – i.e. the measurement of early biological effects in exposed workers, before health impairment occurs. For example, measuring plasma and red cell cholinesterase levels in workers exposed to organophosphate pesticides.

Often more than one method of monitoring is used. For example, a workplace may undertake routine proactive biological exposure monitoring with additional “reactive” medical examinations in the case of an accidental exposure.

The frequency of health surveillance medical examinations depends partly on latency of exposure to disease development.

### Interpretation, review and action

When designing and undertaking occupational health surveillance, it is important to understand any limitations of a test and/or results. For example, a level of a hazardous chemical in the body does not necessarily mean that the worker has been exposed to that chemical at work; or that there is disease or damage to health.

Furthermore, it is important to know what you will do with a test result before you do the test, and to be aware of the potential benefits versus harms of performing a test. One must keep in mind that workers that are undergoing the health surveillance screening are *well* at the time of the assessment.

Screening chest x-rays are a good example of this. Chest x-rays subject a person to a level of ionising radiation. In the case of exposure to asbestos or silica, there is a long latency period between exposure and the development of disease. Different levels of exposure may also infer a different level of risk. Therefore requiring workers with low level exposures to have regular chest x-rays from the time of likely exposure may subject them to an increased risk of long term adverse health effects due to ionising radiation from the chest x-rays, as well possibly as increasing the worker’s level of anxiety; despite a low overall risk of developing the disease in question. For this reason it is important in some cases to *individualise* the risk assessment and subsequent health surveillance for each worker, where appropriate and possible.

Hence also the importance of workplace exposure assessment and risk characterisation, as described above.

Health monitoring for beryllium exposed workers provides another good example of the limitations of a test, and how just because a test may be available, does not mean that it should be conducted on every worker.

Beryllium is used as an alloy to add strength to other metals and it was used for research at ANSTO in the past. Therefore there may be a potential for environmental exposures.

Inhaling beryllium dust can cause:

1. an acute chemical pneumonitis.
2. a chronic granulomatous lung disease, called “berylliosis” or chronic beryllium disease.
3. IARC Group 1 carcinogen for lung cancer.

There is a test available for use in screening for chronic beryllium disease, the Beryllium lymphocyte proliferation test (BeLPT). The BeLPT measures sensitisation to beryllium, sensitisation appearing to be involved in the development of chronic berylliosis. However sensitisation does not necessarily cause disease. International studies suggest that 2-12% of workers



exposed to beryllium become sensitised, but only 44-50% of those develop chronic beryllium disease<sup>12</sup>. The sensitivity of a single peripheral blood BeLPT is 0.683 and the specificity 0.96<sup>12</sup>, i.e. there is a high rate of false positive tests on peripheral blood.

The BeLPT is also unreliable: there is a high level of inter- and intra-laboratory variability, test reversibility, false negatives and false positives. It is estimated that 3-4% of tests are unreliable<sup>12</sup>. Thus if one is going to do the test, undertaking two tests simultaneously using two different laboratories is recommended. The BeLPT test is not available in any laboratory in Australia, so the blood would need to be sent overseas (e.g. to the UK or USA) for testing.

Approximately 10 to 35 percent of patients with beryllium sensitivity have a negative BeLPT test on peripheral blood, but a positive test on bronchoalveolar lavage mononuclear cells. If positive, BeLPT on bronchial lavage lymphocytes is most accurate for diagnosis of berylliosis. Endobronchial and transbronchial biopsies and lavage are usually obtained at the time of flexible fiberoptic bronchoscopy to fulfil the criterion for the diagnosis of chronic beryllium disease. Therefore a positive BeLPT blood test requires the worker to then undergo a bronchoscopy for accurate confirmation or exclusion of the diagnosis of berylliosis.

Performing a bronchoscopy is an invasive procedure with its own inherent risks; a procedure which in this case would be done on a *well* person. In addition only 25% of patients with exposure to beryllium and a positive BeLPT had chronic beryllium disease at bronchoscopy<sup>12</sup>.

Furthermore, there is no specific treatment for berylliosis. Its clinical presentation and treatment is similar to that of sarcoidosis.

For these reasons the BeLPT is not currently recommended for routine screening, and it is not done at ANSTO. High risk work for beryllium exposure and subsequent berylliosis includes primary production of beryllium, metal manufacturing and reclaiming scrap alloys. Current ANSTO workers not routinely working with beryllium, thus there is a low risk of exposure.

At ANSTO therefore, the recommended beryllium health surveillance consists of a medical assessment focusing on the respiratory system, including an administered standardised respiratory questionnaire; spirometry and consideration of a chest x-ray, depending on the worker's individualised risk assessment.

Thus the BeLPT provides a good example of some of the important principles of screening tests, and occupational health surveillance: e.g. knowing what you will do with a test result before you order it; knowing the potential benefits versus potential harms of a screening test; and accurately characterising your risk to assist in deciding what, if any, medical tests to do.

### **Review and action**

Occupational health surveillance should result in some sort of action. This might be a review of workplace controls and their effectiveness, specific medical advice for individual workers, or evaluation of the data to assess trends of results in individuals and/or work groups.

Occupational health surveillance can also lead to new links being made between hazards and disease, thus adding to medical and occupational hygiene knowledge and helping to prevent illness in other workers in the future.

### **Profile:**

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## CONSIDERATION OF NON-AUDITORY SYNERGISTIC IMPACTS ON OCCUPATIONAL HEARING LOSS

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### ABSTRACT

Occupational noise exposure is a major workplace health risk. There is clear evidence that there are other non-auditory or non-noise factors that can cause hearing loss in addition to the direct exposure from noise. This paper provides an update on the indicative effects of these non-auditory factors and discusses the complex interaction with noise exposure. These factors are noted for consideration in workplace noise assessments in the Safe Work Australia WHS Code of Practice 2015 and include: ototoxic substances, human vibration (hand-arm and whole-body vibration) and extended work shifts. The additive and synergistic impact in combination with noise can lead to greater hearing loss than would be experienced from noise alone. This area presents a challenge to occupational health professionals as it is complex and has had only limited study. Assessing the interaction and relationships between the factors and the mechanisms or extent of hearing loss can be tenuous due to piecemeal or contradictory evidence from epidemiological and longitudinal studies, and there is a high risk of influence from other confounding factors. A summary of the recent research is provided along with examples from results of studies and workplace data. The determination of overall exposure and health risk assessment are discussed. Improved hearing loss management plans and controls are required to minimize the risk from non-auditory factors.

### 1. INTRODUCTION

In the workplace there are non-auditory or non-noise factors that can cause hearing loss in addition to the direct exposure from occupational noise. Factors including ototoxic substances and human vibration have a complex interaction with noise exposure and other workplace factors such as extended work shifts can exacerbate the effects. The Safe Work Australia WHS Code of Practice (2015) states that such factors should be noted for consideration in workplace noise assessments and suggests adoption of a lower exposure limit of  $L_{Aeq,8h}$  80 dB<sup>1</sup>. Understanding the relationships and interaction between the factors and the extent of hearing loss is difficult due to limited evidence from a range of research studies. This paper provides a summary of some recent research, discussion on the challenges and an example of an approach to overall exposure risk assessment that takes into consideration non-auditory factors.

<sup>1</sup> Note: In the international context it is acknowledged that expressing the limit in terms of  $L_{Aeq,8h}$  means the A weighting has already been defined in the metric and so the unit for the limit value should only be dB. This is notwithstanding the use of A in the unit as dB(A) in the Safe Work Australia WHS Code of Practice (2015) and AS/NZS 1269, noting that these should be aligned in the future with international standard practice.

### 2. RANGE OF NON-AUDITORY FACTORS AND EFFECTS

The factors that in combination with noise can increase the risk of additional hearing loss include:

1. ototoxic substances or chemicals,
2. human vibration (hand-arm vibration and whole body vibration), and
3. extended work shift durations (greater than 8 hours).

In terms of the dose-response relationship, the interaction and combination of these effects can be purely additive or even greater through a compounded or synergistic effect. Assessing the interaction and relationships between the factors and the mechanisms or extent of hearing loss can be tenuous due to piecemeal or contradictory evidence from epidemiological and longitudinal studies. Also there is a high risk of influence from other confounding factors such as age, medical, chemical and genetic factors.

#### 2.1 Ototoxic Substances

Substances or chemicals that have been found to have potential ototoxic effects in the workplace are generally classified into three main classes, namely Solvents, Heavy Metals, and Asphyxiants (Fuente et al., 2012; Safe Work Australia, 2015). These are known as ototoxic agents/substances or ototoxins (or ototoxicants) and alone they can cause chemically-induced hearing

impairment. The primary audiological symptom of ototoxicity is impaired hearing thresholds compared to that expected relative to age-related hearing loss or presbycusis (Morata et al., 1993, 2003, 2007).

The European Agency for Safety and Health at Work (EU-OSHA, 2009) recognises this as an *Emerging Risk* at the workplace. The EU-OSHA defines ototoxic agents as all substances that may affect the structures and/or the function of the inner ear (auditory plus vestibular apparatus) and the connected neural pathways. *Ototoxicity* refers to toxic damage to the sensory or secretory epithelia of the labyrinth and the auditory nerve, i.e. the pathology within the temporal bone. *Neurotoxicity* refers to toxicity in the central auditory pathway (AIOH Position Paper, 2016; Groothoff, 2006). Campo et al. (2013) noted that several clinical and epidemiological studies confirmed an association between exposure to several ototoxic agents in the workplace and increased prevalence of hearing loss, as well as poor hearing thresholds beyond the traditional 4 kHz noise-related audiometric notch.

It is thought that there are over 700 different groups of chemicals that are or could be ototoxic in nature, however, only a limited number of these have been studied for their association with hearing loss. Appendix A of the Australian Code of Practice for Managing Noise and Preventing Hearing Loss at Work (Safe Work Australia, 2015) provides a list of the more commonly known ototoxic substances. It is noted that some medications and drugs, including quinine and salicylic acids (e.g. aspirin) can also be ototoxic. Some workplace trade types or activities where ototoxic substances are used and cause exposure (in addition to noise) include: painting, printing, dry cleaning, construction, vehicle and aircraft maintenance, metal/chemical/leather/furniture manufacturing, boat building, fuelling, degreasing, agricultural workers/farmers, firearm/weapons firing and fire-fighting. Ototoxic substances are common in marine, mining, vehicle and defence industries; for example, specifically, fuels and carbon monoxide in engine spaces and maintenance personnel who are exposed to fuels, metals and solvents.

Safe Work Australia's Hazardous Substances Information System (HSIS) provides the exposure standards for different hazardous chemicals and substances (<http://hsis.safeworkaustralia.gov.au/>) including some that are ototoxic. Material Safety Data Sheets (MSDS) generally do not provide information on ototoxicity (AIOH, 2016). In addition, it is not known to what extent a mixture of different ototoxic substances affects the overall cumulative exposure level and the overall dose-response relationship and therefore likely resultant hearing loss. Further research and studies are required in this area.

There are three comprehensive literature studies which have investigated different ototoxic agents in workplaces and their level of influence or confirmed effect on hearing. The studies were carried out by: 1) Canadian Institut de Recherche Robert-Sauvé en santé et en sécurité du travail (IRSST, 2012), 2) European Agency for Safety and Health at Work (EU-OSHA, 2009) and 3) US National Institute for Occupational Safety and Health (NIOSH) and the Nordic Expert Group (NEG) (Nies, 2012). A recent review paper (Mahbub, Williams & Connolly, 2016) provides a comprehensive list of ototoxic agents/types and their industrial uses, in addition to the hearing impact mechanisms and results from a range of studies on co-exposure.

Ototoxic substances are absorbed into the bloodstream (through pathways of respiratory/inhalation or dermal/skin or mucous membrane or ingestion) and may affect the structures and/or the function of the inner ear and the connected neurological pathways (EU-OSHA, 2009; Safe Work Australia, 2015). For ototoxic solvents, studies show that hearing loss due to exposure can affect the inner ear, peripheral and central auditory pathways. Hearing losses generally occur in the high frequency region but may affect a wider range of frequencies. Human epidemiological studies show that exposure to ototoxic solvents affects cochlear hair cells and can aggravate irreversible hearing impairment (Hodkinson et al., 2006).

Hearing threshold shifts can be produced by ototoxic agents alone and, in combination with excessive noise ('co-exposure'), may compound those produced by noise exposure alone. Exposures to ototoxic substances and noise have shown adverse interactive effects on hearing which could be additive or synergistic. This interaction can be classified into three categories. Firstly, "additive" interaction in which the effect of a combination of agents is that expected from their dose-response relationship. Secondly, "antagonism" is when the effect is less than expected from the dose-response relationship. Thirdly, "synergism" is when it is greater (EU-OSHA, 2009, Berenbaum, 1989; Calabrese, 1991; Greco et al. 1992; Niall, 1998).

The dose-response relationship between ototoxic substances and noise on hearing impairment is difficult to assess due to the complexity of workplace environments. It is difficult to investigate the influence of a single ototoxic agent with noise on hearing where there is concomitant exposure to different ototoxic substances (EU-OSHA, 2009). Many current human epidemiological studies are often limited due to insufficient characterisation of the exposure levels for chemicals and noise,

and lack of details on whether and how other risk factors were accounted for. As a result, the findings often do not allow identification of the type of interaction between noise and ototoxic substances, how their results can be used to estimate the dose-response relationships and the lowest airborne concentrations necessary for an effect to be detected for ototoxic substances (Johnson and Morata, 2010; Campo et al., 2013).

Fuente et al (2012) found, from a cross-sectional study of plant workers, that simultaneous exposure to solvents (e.g. toluene at levels greater than 50-100 ppm) and noise (at levels greater than  $L_{Aeq,8h}$  88 dB can cause significant increase in the predicted probability of developing hearing loss (particularly at higher frequencies) compared to a group of workers exposed to comparable noise levels. For combined solvent-noise or metal-noise exposures (e.g. for toluene and styrene, and for lead and mercury), the risk of hearing loss is higher than for exposures to the agents alone (Johnson and Morata, 2010). For carbon monoxide exposed groups, significantly higher hearing thresholds occur at high frequencies (3 kHz, 4 kHz and 6 kHz) and more pronounced effects are observed as the duration of exposure increases (Lacerda et al, 2005).

## 2.2 Human Vibration

Human vibration can be manifested as hand-arm vibration (HAV) or whole body vibration (WBV). There is increasing evidence (and also widely recognised throughout industry) that there is a link between exposure to HAV and hearing loss (Pyykko et al. 1987, Hamernik 1989, Zhu 1997, House et al, 2010, Pettersson et al. 2012). Note that significant levels of HAV in conjunction with noise may occur with the use of a range of hand tools, pneumatic tools, machinery/vehicles and small to medium calibre automatic firearms. It is suggested that vibration exposure from hand-held tools reduces the blood flow in the cochlea by activating the sympathetic nervous system, leading to increased risk of hearing loss (Pyykko et al, 1987).

Longitudinal and case-control studies on subjects who have contracted vibration-related disorders found that subjects with vibration white fingers (VWF) have an increased risk of developing hearing loss. The risk of hearing loss is confounded by several factors such as age, medical, chemical and genetic factors. It is also suggested that whole body vibration (WBV) from operating machinery and vehicles may also increase the risk further, as could low frequency airborne infrasound.

Pettersson et al (2012) conducted noise, vibration and audiometric testing on a cohort of heavy machinery workers between 1987 and 2008. His findings concluded that in an environment with noise exposure and vibrating machinery, there was an increased risk of noise-induced hearing loss. Several limitations to this study are observed and noted including;

- a) only having one set of detailed noise measurements conducted in 2008, and relying on manufacturer's data and an estimation of noise results from previous years;
- b) allowing for an estimation of HAV and noise exposure rather than measured data; and
- c) the Klockhoff method for audiograms states that any small change in hearing for one frequency can result in a noise-induced hearing loss consequently allowing for a greater number of workers resulting in a classification of hearing loss.

Only results from 2008 data were analysed with consideration of hearing protector usage. The estimation of HAV exposure by workers in the study allowed for a greater uncertainty in results, given that workers tend to overestimate their vibration exposure. This consequently may lead to a biased relationship toward an association of HAV noise and hearing loss.

In contrast, Pyykko et al (1987) assessed forest workers between the age ranges of 30 to 55. Permanent hearing loss in forestry workers exposed to a combination of noise and vibration did not exceed the permanent hearing loss from exposure to noise only. However they did find that those working in combination with vibration white finger as well as diastolic blood pressure run a higher risk of hearing loss. The HAV exposure in forestry workers is somewhat different to traditional HAV exposure in construction as the exposure is concentrated in the low frequencies; ranging from 63 to 250 Hz.

Further research and studies are needed in this area given that the evidence for the direct link between HAV and hearing loss is not conclusive and maybe contradictory in some cases.

## 2.3 Extended Work Shifts

Long work shifts impose a higher health risk to exposed workers. While the longer time exposure is taken into consideration with the normalisation to 8 hours, the risk of damage may be further increased by the reduced recovery time between

successive working shifts. This effect can be further accentuated when the place of rest is close to the place of work such as for a seafarer (or naval personnel) on-board a vessel for 24 hours a day. The approach in Australia is to retain the normalisation to 8 hours but apply an additional penalty to allow for the long shift. AS/NZS 1269 (2005) suggests that the penalty as an additional 1 dB, 2 dB or 3 dB when the shift length is between 10 and 14 hours, 14 and 20 hours and 20 and 24 hours respectively.

Similarly, when the work week is greater than 5 days (e.g. for Navy crew that can be at sea continuously for weeks at a time), there is further reduced recovery time. The AS/NZS 1269.1 provides a procedure to normalise to a 5 day week which effectively places a penalty on the allowable exposure each day.

Although it can lead to confusion some industries choose to apply a noise exposure based on time periods other than 8 hour. For example the marine industry code (IMO Code 2012) gives an  $L_{Aeq,24h}$  criterion of 80 dB. In some mining industries, where long shifts are the norm, the exposure limit goal is expressed at 82 dB  $L_{Aeq,12h}$  for 12-hour shifts. For regular long shifts and extended work weeks, the allowable daily noise exposure can further reduce to 80 dB  $L_{Aeq,12h}$ .

An additional penalty may need to be considered for situations where co-exposure (excessive noise levels and ototoxic agents and/or HAV) is regularly present during extended work-shifts, and the allowable daily noise exposure may need to be reduced further in such cases.

### 3. EXPOSURE RISK ASSESSMENT

For noise exposure assessment, the applicable Noise Exposure Standard stated in the WHS Regulations 2011 is given as:  $L_{Aeq,8h}$  85 dB(A) and  $L_{Cpeak}$  140 dB(C). The Australian Code of Practice for Managing Noise and Preventing Hearing Loss at Work (Safe Work Australia, 2015) further advises in the Appendix A that the daily noise exposure of workers exposed to ototoxic agents should be reduced to an  $L_{Aeq,8h}$  of 80 dB. The Code of Practice requires regular audiometric testing be conducted where workers are exposed to:

- any of the ototoxic substances (listed in the COP Appendix A) where the airborne exposure (without regard to respiratory protection worn) is greater than 50% of the national exposure standard for the substance, regardless of the noise level; or
- ototoxic substances at any level and noise with  $L_{Aeq,8h}$  greater than 80 dB or  $L_{Cpeak}$  greater than 135 dB.

This implies that audiometric testing should be carried out on a more regular basis than every two years (stipulated in Regulation 58 of the WHS Regulations 2011) for such cases; for example, to at least annual intervals. The Australian Institute of Occupational Hygienists (AIOH) Exposure Standards Committee recommended in a position paper (AIOH, 2016) that in the absence of ototoxicity information in an MSDS, workers exposed to both noise and ototoxic agents or even ototoxic agents alone should be included in an annual audiometric testing program for the detection of synergistic effects.

The combination of more than one non-auditory factor with excessive noise can occur in some workplaces and this can greatly increase the risk of excessive exposure. For example, worker trade types such as aircraft refuellers and vehicle/workshop mechanics can be exposed to high peak noise levels, extended work-shift noise exposure, several ototoxic substances (e.g. fuels, solvents, carbon monoxide) and HAV, often during the same work-shift. Such situations require careful exposure assessment (including a lower noise exposure standard or additional adjustments) and application of a range of specific control practices.

Due to the limited data and studies to date in this area, it remains difficult to determine accurate exposure standards for a combination of effects (such as noise, ototoxic agents and HAV) given that the dose-response relationships have not been established to any degree of certainty. Exposure standards for chemicals and noise have not yet been adjusted to take into account the increased risk to hearing; as such, revised standards should be established in the future.

The airborne concentration and total exposure levels of various ototoxic agents (and the combined effects of different ototoxic agents) will vary substantially depending on a range of factors such as source type, emission mechanisms, emission rates, operating scenarios, frequency of use during shifts, atmospheric/weather conditions, air flow and ventilation, body absorption mechanisms (respiratory, skin/dermal, mucous membranes etc.), combination mechanisms (whether additive or synergistic) etc. The influence of ototoxic substances and noise on hearing loss will depend on a number of parameters

including, but not limited to, magnitude of noise, impulsive characteristics, the frequency content and the ototoxic substances' exposure levels.

In addition, the lowest airborne concentrations necessary for a hearing impact or effect to be caused or detected for the wide range of ototoxic substances has not been determined. Indeed, it is not known to what extent a mixture of different ototoxic substances affects the overall cumulative exposure level and the overall dose-response relationship and therefore the expected resultant hearing loss.

Until better data is available, it is important to employ a precautionary and conservative approach where ototoxic substances are clearly accounted for in noise exposure assessments, the use of lower noise exposure standards and special considerations included in noise control programs. This is the basis of the approach in the Code of Practice (2015) and the guidance from published reviews (Mahbub, Williams & Connolly, 2016, Burgess & Williams, 2006, EU-OSHA, 2009).

An extensive project in Australia has been the development of an occupational noise reduction program for Defence. Previous papers have described the process, findings and progress outcomes from this project work (Teague et al, 2014, 2015, 2016). An important part of this project was to accurately characterize the extent and impact of the major Defence noise sources/hazards and high noise exposure groups, activities and areas, which included taking into account any exposure to ototoxic substances and HAV for a sample of major ADF bases. The findings from this project can be used to illustrate possible approaches to the assessment of workplace exposures where there is a combination of non-auditory and auditory hazards.

The project noise assessments noted any concomitant exposure to ototoxic substances (such as fuels, solvents, heavy metals etc.) and/or vibration (particularly hand-arm vibration) present in combination with any noise. The results showed that a number of worker trade types were found to be regularly exposed to excessive noise, several ototoxic substances and HAV, often during the same work-shift and over extended work-shifts in many instances. The types of trades that experience some of the highest exposure levels in combination with ototoxic substances and/or HAV included: fitters, vehicle mechanics, maintainers, welders, painters, metalsmiths, structural repair technicians, aircrew, aircraft/avionics technicians, aircraft refuellers, air terminal/hangar operators, weapon/ordnance operators and artillery/combat troops.

A wide range in noise levels and noise exposures were measured at the various ADF facilities (Teague et al., 2014, 2015, 2016). The 8-hour equivalent  $L_{Aeq,8h}$  noise exposure levels were often over 85 dB, and many areas (such as workshops, maintenance sections, hangars, flightlines etc.) showed exposure levels over 90 and 100 dB. In some cases,  $L_{Aeq}$  noise levels reached between 110 and 120 dB during some tasks (such as vehicle maintenance tasks, hand tools, sand blasting etc.). The  $L_{Cpeak}$  levels often exceed the exposure standard of 140 dB during specific activities, such as maintenance tasks (impacts during hand tool use), and reach up to 180 dB during weapons firing (e.g. large calibre artillery).

Noise dosimetry over typical shift periods for different trades in the ADF showed variations in noise exposure depending on task type and duration. For example, the cumulative noise exposure rises significantly during relatively brief and intense tasks (such as riveting, drilling, grinding, cutting, hammering, rattle/needle guns, surface finishing etc.) and can remain quite high, and in fact well above the exposure standard, until the end of the shift period. In addition, ADF personnel can often work extended shift periods (up to 12-16 hours) in close proximity to major noise sources (with very high noise exposure levels) while being exposed to a range of ototoxic substances and/or HAV at the same time.

During such excessive noise activities, it was demonstrated that such tasks also involved concomitant exposure to HAV and ototoxicants such as carbon monoxide (exhaust from engines), fuel vapours (refuelling) and solvents (preparing/cleaning metal and machinery components) in addition to lead (and other ototoxic agents) from weapon firing. The airborne chemical exposure levels were not able to be determined during the tasks; however, it is likely in general that they were less than the Australian exposure standard for each specific chemical.

Live weapon firing (large and small-medium calibre) is known to generate ototoxic chemicals, including lead, manganese, arsenic, hydrogen cyanide and carbon monoxide (and toluene compounds), via airborne inhalation and dermal contact (Quemerais, 2013). The airborne concentration and total exposure levels (and the combined effects of different ototoxic agents) will vary depending on a range of factors such as weapon type, propellant charge types, firing scenarios, number/frequency of firing rounds, directivity, local weather conditions etc.

A Similar Exposure Group (SEG) risk assessment showed that a wide range of trades/SEGs display high to very high risk ratings. A resultant exposure risk profile was determined from a SEG risk assessment that took into account non-auditory factors (such as ototoxic exposure, HAV and extended work-shifts) as well as noise exposure. An example of a risk profile for a major Defence facility is shown in Figure 1. There is no prescribed procedure to take these non-auditory factors into account, so a 'penalty points' approach was taken to obtain qualitative guidance using a rating system. A penalty point was added for each ototoxic agent present, extra penalty points added for HAV and extended work shifts, and further penalties added if insufficient controls or procedures were observed at the site; as a result, a total of three additional penalty points would nominally push the risk rating to the next level. Using this approach in this workplace, the highest risk ratings were found to be for mechanics performing vehicle maintenance tasks, during which they are exposed to fuels, solvents and carbon monoxide and HAV from hand/pneumatic tools as well as high average  $L_{Aeq,8h}$  and high peak noise levels over long work-shifts. Using the guidance from the exposure risk profile, a cautious approach would be to adopt a lower noise exposure standard, such as  $L_{Aeq,8h}$  75 dB, for those with the higher risk profile.

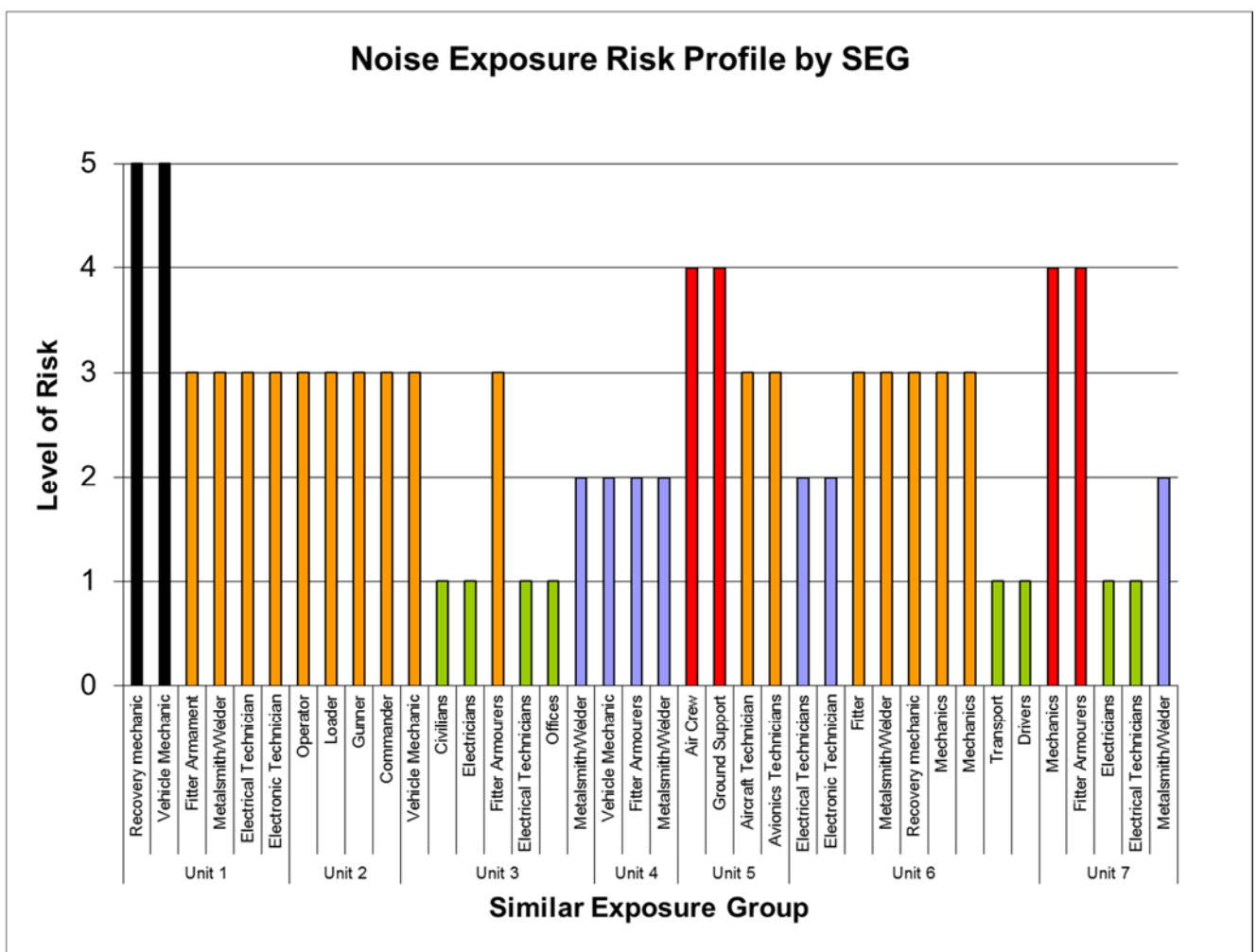


Figure 1: Example exposure risk profile, including penalty points for non-auditory factors, for the range of SEGs at a major ADF facility.

#### 4. CONTROL OF NON-AUDITORY IMPACTS AND NOISE

Given the uncertainty of combined non-auditory and noise exposures and the lack of combined exposure standards, it is vital to employ a precautionary approach whereby sufficient controls are put in place to reduce the risk of hearing loss due to co-exposure to various non-auditory factors and noise.

Noise sources (and worker/SEG groups) and non-auditory factors should be ranked and prioritized for control and treatment based on a risk assessment, using the collected data on non-auditory factors and noise exposure and applying a standard WHS/Occupational Hygiene matrix of likelihood and consequence/severity.



A detailed Noise Management Plan (NMP) should include the controls for noise and other non-auditory sources, particularly for high risk worker/SEG groups. Noise and other control measures should be prioritized based on the hierarchy of control, the action type and the level and urgency required; the measures should be specific and practical, with any functionality or performance constraints noted, and should be reviewed regularly. This plan can include:

- a) The hierarchy of noise control should be used where feasible with engineering noise control and alternate quieter noise sources (i.e. “buy quiet”) as the preferred method of noise reduction.
- b) Administrative control measures include job rotation, work scheduling, changing work processes etc. need to consider not just the exposure time to noise but also the extent of exposure to ototoxic substances and hand-arm vibration and the combinations of multiple non-auditory factors.
- c) The application of personal protective equipment (PPE), such as Hearing Protection Devices (HPDs) should consider not just protecting from the audible sound but also providing protection from hand arm and whole body vibration and ototoxic chemicals. This may include respiratory (and skin) protection and effective ventilation (and use of fume hoods etc.) It should especially be noted that Material Safety Data Sheets generally do not provide information on ototoxicity; however, the Safe Work Australia’s Hazardous Substances Information System (HSIS) should be consulted to determine the exposure standards for different hazardous chemicals and substances (<http://hsis.safeworkaustralia.gov.au/>) which will inform the type/level of control measures.
- d) Control measures to reduce exposure to hand-arm vibration may include finding alternative ways to do the work that eliminates or reduces the need to use vibrating equipment or to purchase tools that produce less vibration. The use of damping materials and vibration isolators could also be applied to existing equipment to reduce vibration levels and impacts. Excessive whole-body vibration should be minimized where possible.
- e) Increasing the level of PPE to account for the possible increase in combined effects from co-exposure should also be considered. For example, the use of HPDs with a higher attenuation/class rating than would be required for the noise exposure alone. In addition, to avoid the under-attenuation due to the improper fitting of HPDs such as ear plugs, regular checks and training should be undertaken.
- f) Warning signs should be placed in areas of excessive noise exposure and ototoxic exposure with specific information on the level of risk and types and levels of protection required to be worn by workers in the area.
- g) Risk or Hazard Registers (and Safety Data Sheets or Standard Operating Procedures) at sites should be updated with specific information on any ototoxic agents used, safe exposure levels of ototoxic agents and noise, adjusted exposure standards and the specific controls required to reduce risk. Awareness and training programs for workers should include the risks associated with ototoxic substances and noise, and hearing conservation programs.
- h) More regular audiometric testing for co-exposed workers plus careful review of the audiogram results – statistical and longitudinal data could be analysed to identify any increased hearing loss due to combined exposures.
- i) For assessing hearing damage, advances in audiometric testing techniques are being made (beyond the standard pure-tone audiometry method). For example, the measurement of evoked otoacoustic emissions (OAE), such as DP (Distortion Product) and TE (Transient Evoked) testing, can provide a more objective, sensitive and accurate clinical determination of hearing damage (to auditory stimuli in real-time) than standard pure-tone audiometry (Carter, Williams & Seeto, 2015). DPOAEs could also be considered to differentiate between the individual and the combined effects of noise and ototoxic agents on hearing, and used as a diagnostic tool. Brainstem auditory evoked potentials (BAEPs) could also be used to monitor ototoxic-induced hearing damage.

## 5. CONCLUSIONS

The combination of more than one non-auditory factor with excessive noise can occur in some workplaces and this can exacerbate and increase the risk of excessive exposure and result in greater hearing loss – this can occur in a range of industrial situations where workers can be exposed to high peak levels, extended work-shift noise exposure, several ototoxic substances (e.g. fuels, solvents, carbon monoxide) and hand-arm vibration, often during the same work-shift.

It is difficult to determine accurate exposure standards for co-exposure situations (such as noise, ototoxic agents and HAV) given that the dose-response relationships have not been established to any degree of certainty, due to the limited data and studies to date in this area. Exposure standards for chemicals and noise have not yet been adjusted to take into account the increased risk to hearing, and revised standards should be established in the future.

Comprehensive databases and longitudinal studies need to be developed across various industries to include the different types/SEGs of workers exposed to various ototoxic agents, HAV and noise (for situations in isolation or in different combinations) with relevant exposure level information over typical work-shifts and other pertinent worker information.

Until better data is available, it will be important to employ a precautionary and conservative approach where ototoxic substances are clearly noted and accounted for in noise exposure assessments, lower noise exposure standards are applied and special considerations are incorporated into noise control programs. In particular, improved noise and non-auditory control practices are required to reduce the risk and level of noise-induced and ototoxic-induced hearing loss.

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## DEVELOPMENT AND TRIAL OF AN EVIDENCE-BASED AUDIT TOOL FOR CYTOTOXIC DRUGS IN HOSPITALS

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### ABSTRACT

Healthcare workers may be at risk from exposure to cytotoxic drugs, notably by skin contact with contaminated surfaces. The project aimed to (i) develop and trial an evidence-based audit tool to profile risk management and “regulation preparedness” of hospitals across South Australia with respect to the restricted carcinogen cyclophosphamide; and (ii) to validate the tool by objective measurement of cyclophosphamide residues on work surfaces

An audit tool was developed based on first principles to appraise risk management procedures and gain information on actual work practices relating to cytotoxic drugs. The audit tool was used along with observation of work practices and selected surface residue sampling of cyclophosphamide in selected areas. Twenty four representative SA healthcare facilities participated in the trial

Visited facilities demonstrated compliance with most requirements of the SA WHS Regulations 2012. Safety controls and good work practices were in place. Engineering controls were effective in isolating workers from exposure to cyclophosphamide whilst preparing and administering the restricted carcinogen. To meet policy requirements most SOPs were generated from either or both the eviQ guidelines and SA Health guidelines. However, some discrepancies in work practices and SOPs were identified, relating to PPE and cleaning regime. For the 24 healthcare facilities, 4% (4/93) yielded detectable levels of cyclophosphamide in pharmacies, and 6% (22/376) in a clinical setting (range 3 – 6 ng/cm<sup>2</sup>)

On the day of testing the potential exposure to cyclophosphamide residue was found to be insignificant across all assessed facilities. The minimal levels of cyclophosphamide detected may be attributed to critical adherence to handling practices for cytotoxic agents and cleaning practices for chemical and infection control. The audit tool can assist health care facilities to critically appraise their risk management procedures for cytotoxic drugs, and ultimately minimise exposure and adverse health impacts.

Michael has worked in Occupational Hygiene and Health in the Discipline of Public Health for 25 years and currently works part-time in the School of Public Health. Michael has carried out research work in glutaraldehyde use in South Australia and its use as a high level disinfectant. He has also carried out work regarding surface contamination by cytotoxic drugs in hospitals and hospital pharmacies. The other research projects he has work on include; exposure to anaesthetic waste gases in operating theatres, vets and dental surgeries; permeation of pesticides through gloves, permeation of isocyanates and MOCA through gloves and exposure to wood dust.

Michael has worked as a Technical Advice Coordinator (with 4 other Occupational Hygienists and Toxicologists) on a 24/7 basis for 18 years providing advice to emergency facilities in South Australia regarding CBR incidents. Michael also works part time at Health Safety Environment Australia as an Occupational Hygiene Consultant.

The authors would like to acknowledge the contribution of the project Steering Committee:

- Ms Shelley Rowett, SafeWork SA
- Ms Antonietta Colella, SA Health

### INTRODUCTION

There is previous research from around the globe which has reported the potential for cytotoxic drug contamination throughout the hospital medication system due to the various surfaces contacted by health care workers (Fransman et al., 2004; Nussbaumer et al., 2012; Hon et al., 2013). This may result in the potential exposure of workers to cytotoxic drugs through the process flow of drugs within a facility from delivery to waste disposal. Published literature suggests very low level exposure to cytotoxic drugs is almost ubiquitous within clinical areas that administer cytotoxic drugs to patients for medical treatment (Chu et al 2012).

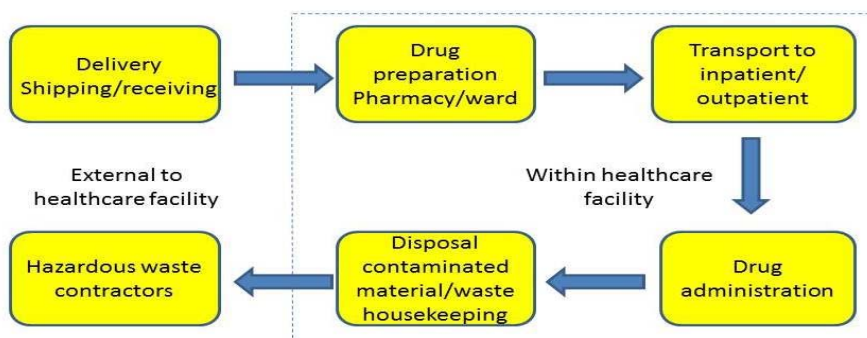
In Australia, there are limited studies investigating surface contamination and exposure potential of cytotoxic drugs, or the role of risk control measures in the mitigation of exposure (Lee et al., 2007; Siderov et al., 2009; 2010). A study conducted in ten metropolitan hospitals in Melbourne reported cytotoxic drug contamination detected on a variety of surfaces in preparation and administration areas (Siderov et al., 2009).

The only previous research undertaken in South Australia has been a pilot study at one metropolitan hospital and looked at the surface contamination potential with cytotoxic drugs (Lee et al, 2007). The study demonstrated the risk of dermal contamination and accidental ingestion from inappropriate use of gloves, hand washing and cleaning, during and after preparation and administration of cytotoxic drugs. The study recommended the implementation of effective cleaning practices to decontaminate work surfaces, and suggested regular environmental monitoring in key areas to ensure that background contamination is kept to a minimum and that decontamination protocols are adhered to.

Although there is little scientific evidence linking the handling chemotherapeutic drugs (and related waste) and worker development of cancer from exposure, there is an increasing concern that long term low level exposure by healthcare workers may be a risk. In the absence of such data, a strategy of practical avoidance is recommended.

Personnel working in and outside of the healthcare facilities likely to be involved in activities that expose them to cytotoxic drugs and its related waste include pharmacists, nursing and medical staff, laboratory staff, cleaners, maintenance and waste disposal staff. Exposure may be through skin contact, skin absorption, inhalation of aerosols and drug particles, ingestion and needle stick injuries resulting from the following activities (and shown in the flow diagram):

- delivery
- drug preparation
- transport to drug administration area
- drug administration
- handling, transport and waste disposal
- waste retrieval



### Health effects of exposure

Most cancer chemotherapeutic drugs are known to be carcinogenic, mutagenic and teratogenic. In the course of cancer treatment where benefits outweigh risk to the patient, the drug intended to interfere with cell DNA and cell metabolism is, in many cases, a known Group 1 human carcinogen (IARC 2015). At least 9 of 56 commonly used cytotoxic drugs pose a carcinogenic risk to humans, of which there is no known safe level of exposure (IARC 2015). Epidemiological evidence of cancer patients treated with chemotherapeutic drugs has shown the development of secondary tumours not linked to the individual's primary cancer (Travis et al 1995). The chemotherapeutic drug cyclophosphamide (CP) used for medical cancer therapy is one of these drugs that has been linked to damaged DNA and bladder cancer in patients treated for other unrelated cancers (Bryant *et al.* 1989; Moore *et al.* 1995, Khan et al 1998). The toxic metabolites of cyclophosphamide accumulates in the urinary bladder, induces haemorrhagic cystitis and if untreated may initiate bladder carcinogenesis (Chabner *et al.* 1996, Dobrek & Thor 2015, Beringer et al 2015).

### Aims of the study

The aims of the research project were to:

- Develop and trial an evidence-based audit tool to profile risk management and “regulation preparedness” for the restricted carcinogen cyclophosphamide used in public and private hospitals across South Australia; and to
- Utilize the audit tool by objective measurement of cyclophosphamide residues on work surfaces. Areas likely to have high potential for surface contamination such as pharmacy and clinical areas are targeted for surface wipe sampling. The project was undertaken by experienced Occupational Hygienists and a researcher who is also a Registered Nurse.

Expected benefits of the audit tool were to generate information on work practices relating to cytotoxic drugs, pertinent under *Regulation 383 (2)(i) and underpin an evidence-based framework for controlling exposure to cytotoxic drugs in the workplace*. Regulation 383 (2) (i) requires that the PCBU must apply to obtain authorisation to use, handle or store a restricted carcinogen and must provide the following information;

(i) how the person will manage risks to health and safety including a summary of the steps taken, or to be taken, by the person in relation to the following:

(i) hazard identification;

(ii) control measures;

(iii) if elimination or substitution of the carcinogen is not reasonably practicable—why the elimination or substitution is not reasonably practicable;

Recommendations arising from the research are to assist health care facilities to assess their risk management procedures for cytotoxic drugs and other carcinogens, and ultimately minimise worker exposure and adverse health impacts.

### **Skin Permeation Testing**

Furthermore, testing of cyclophosphamide, at intravenous concentrations (10-15 mg/kg or 800 mg/500 mL ) and 20 mg/mL for cyclophosphamide when applied to human skin, in Franz cells, to determine if cyclophosphamide would penetrate and/or be absorbed by human skin will be reported.

### **Skin integrity**

Skin barrier integrity was tested before exposure using a visual microscopic examination followed by measurement of the electrical impedance (EI) of the skin (Davis et al 2004, Lawrence J (1997) Diembeck et al ((1999)). A Tinsley LCR Databridge6401 (Fasano et al (2004)) was used set in Resistance (R), Parallel Equivalent (PAR), and 100 Hz modes. After each skin testing period, a second microscopic visual examination was made to check for obvious physical damage to skin due to chemical-exposure, and post-exposure skin barrier integrity was determined for selected replicates.

### **Workplaces visited**

In total 34 public and private healthcare facilities in metropolitan and regional areas authorised to handle and store cyclophosphamide were contacted and 24 public and private healthcare facilities were visited over a 10 month period in 2015. The workplaces visited were pharmaceutical facilities, and inpatient and outpatient facilities located at public, private metropolitan and country based healthcare facilities.

Three work areas were identified with potential exposure to cytotoxic drugs: in-hospital pharmaceutical compounding units, outpatient oncology departments and inpatient oncology wards. The project involved exploratory and observational workplace practices with high potential for exposure to hazardous chemicals relating to handling of cytotoxic drugs pertinent under Regulation 383 (2)(i). Skin exposure potential to cytotoxic drugs via contaminated surfaces was assessed by measurement of work surface contamination with cyclophosphamide.

The audit tool was designed and validation of the audit tool which adopts a risk management approach and contains hazard identification and risk control measures for cytotoxic drugs. The tool was used to gain information on actual work practices relating to cytotoxic drugs, and incorporates information outlined pertinent under Regulation 383 (2)(i).

Dermal contact is considered to be a major route of exposure from cytotoxic drugs. Cyclophosphamide was chosen to determine potential skin exposure using wipe sampling from surface contamination as it is a restricted carcinogen. Samples

were collected using alcohol swabs, thoroughly wiping areas of approximately 100 cm<sup>2</sup> in frequently contacted surfaces from selected work areas

### Results of Workplace Audits

All health facilities verbally confirmed authorisation to store, handle, and use cyclophosphamide. However, on the day of the audit 60% of healthcare facilities could not locate the authorisations.

Personnel and environment protection during drug preparation was by way of an isolated room containing a cytotoxic drug safety cabinet (CDSC). During dilution of the cytotoxic drug cyclophosphamide both the conventional mixing system (open) and the closed drug transfer system was observed. Workers within the isolated room were limited to one person performing the allocated work over a 2 to 3 hour period. Emergency showers were readily accessible except for two healthcare facilities; one being where chemotherapeutic drugs were prepared, and the other was where the drug was being administered.

Administrative controls and work place practices were foremost at minimising exposure to chemotherapeutic drugs and its waste. All worksites had spill kits accompanied with clean up procedures enclosed; however the choice of cleaning agents differed considerably from one facility to another. The rationale for using a specified cleaning agent was unclear whether it was for chemical degradation or infection control. Unless tested the product may be introducing a new hazard that to date has not been identified. A systematic cleaning protocol that renders the cytotoxic residue harmless will be based on a risk assessment and a clearly documented SOP for workers to follow is recommended.

Appropriate signage, adequate packaging and labelling were evident. SDS information and SOPs were available either electronically or as hard copies. At one healthcare facility, on the day of auditing, the intranet was down and no hard copies were available. Two healthcare facilities could not find any documented SOPs, despite these being required for authorisation.

During administration of intravenous cyclophosphamide preparations (IV) 58% of healthcare facilities would routinely place plastic backed absorbent sheets onto the top treatment trolleys to capture potential spills. The SOP directive for all healthcare facilities state 'during administration of the drug', work must be undertaken on non-porous, level and uncluttered surfaces.

Of the 24 healthcare facilities audited, 100% of workers preparing the chemotherapeutic drugs were trained and every worker involved in administering the chemotherapeutic drugs was accredited to do so by Australian Health Practitioner Regulation Agency (AHPRA) and SA Health recognised training courses. However, no documentation of formal training for volunteer and casual shift workers involved in ad hoc daily activities relating to patient care and cytotoxic drug waste handling was found.

The workplace SOP directive for 24 healthcare facilities recommends a P2 (N95) respirator be worn, which are designed for particulate or biological-active airborne particles. A number of workers in half of the healthcare facilities did not wear the recommended respiratory protective equipment (RPE) whilst preparing and administering the cytotoxic drug. A major reason for non-compliance was that workers believed that no airborne chemical was generated during the administration of the drug. Some workers wore face shields in place of the P2 respirator whilst others considered the patients psychological needs over their own health and safety, and wore no respiratory protection. During drug preparation some workers considered engineering controls (e.g. CDSC) to be a barrier against exposure to airborne particles.

Safety glasses are designed to be worn for protection against particle impact and are not sufficient for chemical splashes. However the choice of wording in the SOP directive for wearing of protective eyewear in 58% of healthcare facilities assessed was 'safety glasses'. In 18% of healthcare facilities some workers wore their own prescription glasses as safety glasses. The SOP states a risk assessment for wearing prescription glasses in place of goggles / face shields is to be conducted. No personal risk assessments had been conducted.

Workers in 25% of healthcare facilities shared disposable gowns amongst each other on a daily basis. Reuse of disposable gowns across the working week was found in 8% of healthcare facilities. Workers in 8% of healthcare facilities discarded gloves used for drug administration directly into general waste bins.

In 42% of healthcare facilities alcohol-based hand hygiene gel was used to clean hands after IV administration procedure for cytotoxic drugs. The use of alcohol-based hand gel will not remove the chemical from the skin but transfer or potentially assist skin absorption of the chemical. Hand washing with soap and water is recommended.

An SOP directive for cytotoxic spills and health monitoring specific to incident/hazard was present in all healthcare facilities. Of the 24 healthcare facilities no health surveillance programme was in place but 21% of healthcare facilities offered workers some form of annual health monitoring.

For 17% of healthcare facilities “A statement of exposure to be given to workers” as required by WHS Regulation 387 was provided. The basis for such low compliance was that most healthcare facilities were unaware of the WHS requirement.

### **Results of environmental wipe sampling**

The results of the chemical analysis of environmental wipe samples are summarised in Table 3. A total of 469 samples were collected and analysed from 24 healthcare facilities. Analysis results indicated the presence of cyclophosphamide in 24 of the 469 samples within the detection range:

- 4/93 (4%) yielded detectable levels, (3 – 6 ng/cm<sup>2</sup>) in preparation rooms of pharmacies
- 20/376 (5.3%) yielded detectable levels (3 – 6 ng/cm<sup>2</sup>) within the clinical setting
- All other wipe samples were below lower limit of detection (<3 ng/cm<sup>2</sup>).

Of the 93 wipe samples collected on surfaces within the compounding pharmacies, 4% were positive for cyclophosphamide residue, found on surfaces within the preparation room. These low numbers are possibly attributed to the importance of utilising engineering controls and correct handling practices. Of 376 sample wipes taken from numerous locations within the clinical areas only 5% were positive for cyclophosphamide. On the day of sampling the equipment used for IV drug administration showed higher incidence of contamination (7/376) and at the time of sampling some of these items were being utilised during treatment. On surfaces inside the patient rooms, contamination was evident in a small number of cases (5/376). On the day of sampling, the patients residing in these rooms were being treated or had been treated with IV cyclophosphamide. One wipe sample taken from a computer key board in the administrative area was positive for low levels of cyclophosphamide.



**Table 3 Surface wipe sampling outcomes for cyclophosphamide contamination across all healthcare facilities.**

Locations	Surfaces sampled (100 cm <sup>2</sup> )	Number of positive* contaminated samples (% , total samples collected)
Preparation area in pharmacy	Containers, pre-packed drug bags, BSC, bench in prep room, computer keys, mouse, telephone handset	4 (4%, 93)
Drug storage clinical area	Refrigerator shelves/handles/containers	2 (5%, 43)
Treatment	Infusion equipment, treatment chairs, treatment trolley	7 (8%, 84)
Administration clinical area	Computer key boards, mouse, telephone handset, printers, desk top	1 (2%, 48)
PPE in clinical/pharmacy	Used disposable gowns, gloves, face shields	0 (0%,17)
Waste purple/yellow bins in clinical areas	Outer rim, inner lid, waste bins on trolleys	1 (4%, 25)
Dirty/waste room	Top of sluice, rim of sluice, urinals	0 (0%, 24)
Patient toilets	Wash basin, tap handles, door handle, floor, emergency bell, floor	5 (19%, 26)
Patient/visitor area	Over-way table, drinking utensils, tea room	3 (30%, 10)
Outside area	Staff facilities	1 (0%, 6)

\*denotes presence of cyclophosphamide in the range 3 – 6 ng/cm<sup>2</sup>

### Limitations of the study

Information was lacking in some healthcare facilities specific to chemical cleaning agents and waste disposal of cytotoxic drug waste. Many of the practices focus on infection control and less towards chemical decontamination efficiency.

Interviewing workers was not a part of this study therefore information regarding the knowledge, perception of risk or lack of knowledge regarding control measures, rigor with which the SOPs are developed and views on standardised SOPs was not achieved, and may be warranted in further research.

Some workers for example those involved in operating room procedures, may theoretically be exposed via inhalation and skin contact due to the increasing use of cytotoxic drugs in perfusion and intra-peritoneal treatment, however access to operating rooms was beyond the scope of this study. This may be an important area to further characterise in the future given its increasing practice.

The audit tool and surface wipe sampling was conducted on a single day for each site, thus providing a snapshot of work practices which may not necessarily reflect all work practices.

This study was directed at the use and handling of cyclophosphamide as it is a restricted carcinogen. However, a large range of cytotoxic drugs are in use in the work areas and exposure to other cytotoxic drugs was not assessed, so the overall risk from exposure to all cytotoxic drugs in use was not known, neither is there knowledge regarding the additive or synergistic effects of environmental exposure to a mix of cytotoxic drugs.

## CONCLUSIONS

The audit tool was used to profile “regulation preparedness” for the use of the restricted carcinogen cyclophosphamide used in public and private hospitals across South Australia and demonstrate compliance with requirements in the SA WHS Regulations 2012 under the WHS Act 2012. Safety controls were in place and good work practices observed in both public and private healthcare facilities. There is however considerable scope for improvement with the development, implementation and interpretation of the healthcare facility SOPs. To ensure the safe handling of cytotoxic drugs; documented SOPs, policies and procedures for preparation, administration of cytotoxic drugs and waste control need to be communicated to the end-user as a directive in a step by step process. The individual worker should not have to undertake their own risk assessment preceding a task. SOPs need to ‘translate the requirements into a useable form’ and be representative of the respective functional areas on how to execute the task. Standard operating procedures need to be routinely reviewed or risk assessed to ensure they are practical for activities undertaken.

The results of the skin permeation testing of cyclophosphamide will be presented at the conference.

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## ASSESSMENT OF CUTTING FLUIDS

*Philip J Turner, MAIOH, CIH, MSafSc (UNSW)*

### 1. ABSTRACT

Cutting fluids are used during the machining of metals and composites to provide lubrication, cooling, corrosion protection, and transport of waste swarf. They improve machine performance, and prolong the life of the cutting tool, but can also cause irritation, dermatitis, and lung disease. In the past, occupational hygienists have used the exposure standard for mineral oil mist, but more-specific recommendations have now been issued for semi-synthetic and synthetic fluids. Microbial growth is also a potential hazard. The Health and Safety Executive (HSE) in the United Kingdom has issued useful guidance material, including a methodology and recommended guideline for the microbial quality of fluids. Two case studies assessing microbial growth are presented.

### 2. INTRODUCTION

#### 2.1 Cutting Fluids

Cutting fluids are used during the machining and grinding of metals and composites to provide lubrication, cooling, corrosion protection, and transport of waste swarf. They can reduce smoke and mist, improve machine performance, and prolong the life of the cutting tool.

#### 2.2 Formulations

Straight (neat) oil, soluble oil, semi-synthetic and synthetic cutting fluids can contain oil (animal, vegetable, petroleum, or synthetic), emulsifiers (for soluble oils), antifoams, anti-mist agents, buffers (alkalinity/pH)extreme pressure/anti-weld agents, biocides, chelating agents, cleaning agents (acid, alkali, emulsion, or solvent), corrosion inhibitors, detergents, dispersants, dyes, fragrances, odorants, passivators, pH stabilisers, plasticisers, and viscosity modifiers. Contaminants include metal (or composite) fines and chips, machine lubricants (tramp oils) and waste oils, oxidation products, food scraps, floor sweepings (and mop water), cigarette butts, and microbial growth (bacteria or fungi).

#### 2.1 Aerosol Emissions

Aerosol emissions are influenced by many factors including the type of fluid, application pressure, nozzles (size, type and position), temperature, tool type and speed, use of chip drags, lack of splash guarding, ventilation, and air cleaners.

#### 2.2 Potential Health Effects

Acute respiratory effects can include airway irritation, asthma, chronic bronchitis, Pontiac fever and lipid pneumonia. Chronic respiratory effects include hard metal lung disease and hypersensitivity pneumonitis. Skin effects include irritant dermatitis, allergic dermatitis and occupational acne. Cancer risks have been reduced by the elimination of unrefined oils.

#### 2.4 Exposure Standards

Historically, many cutting fluids were pure petroleum oils, and occupational hygienists applied the exposure standard for mineral oil mist. Most fluids are now synthetic or semi-synthetic, with many additives. The ACGIH excluded metalworking fluids from the oil mist TLV in 2009.

Substance	TWA Standard
Safe Work Australia	10 mg/m <sup>3</sup> (all inhalable dust + mist) 2 mg/m <sup>3</sup> (all inhalable fibre - for composites)
NIOSH (1998)	0.4 mg/m <sup>3</sup> (thoracic aerosol – fluid only) 0.5 mg/m <sup>3</sup> (total aerosol – fluid only)
OSHA (1999)	5 mg/m <sup>3</sup> (as mineral oil mist)
HSE (2002)	3 mg/m <sup>3</sup> (mineral oil) - Now withdrawn 1 mg/m <sup>3</sup> (water miscible) – Now withdrawn
ACGIH (2009)	Mineral oil TLV excludes metalworking fluid
AIOH (2016)	5 mg/m <sup>3</sup> (all inhalable dust + mist)

Fluids can also contain solvents, and testing might be appropriate. Microbial action on alkanolamines can result in the emission of ammonia. Sulphate-reducing bacteria acting in stagnant fluids can create hydrogen sulphide, which can then be released on Monday mornings.

## 2.5 Fluid Quality Guidance

The Health and Safety Executive (HSE) in the United Kingdom has published guidance for bacterial quality of fluids.

Condition	Guideline
Good control	less than 10 <sup>3</sup> (1000) cfu/mL (bacteria in bulk fluid)
Reasonable control	less than 10 <sup>6</sup> (1 000 000) cfu/mL (bacteria in bulk fluid)
Poor control	greater than 10 <sup>6</sup> (1 000 000) cfu/mL (bacteria in bulk fluid)

The Quaker Chemical Corporation has published guidance for fungal counts

Condition	Guideline
Maximum count	200 cfu/mL (fungi in bulk fluid)
No concern	10-50 cfu/mL (fungi in bulk fluid)

## 2.5 Test Methods

NIOSH 5026 is an infra-red (IR) air-sampling method applicable to water-insoluble petroleum-based oils – synthetic and semi-synthetic fluids are excluded. The test is available in Australia, and the laboratory requires a sample of bulk fluid (for calibration).

NIOSH 5524 is a gravimetric air-sampling method for total particulate, including dust. Fluids are removed by solvent extraction, and the difference provides the fluid mass. The laboratory requires a sample of bulk fluid (for solubility testing), and shipping to an overseas facility may be required.

Laboratory bacterial culture methods require additional neutralisation or dilution for samples that contain biocides. Samples of flowing (well-mixed) fluid should be collected, and jars must include ullage to ensure adequate oxygen. A field method using dip slides with 2-5 day incubation is available.

### 3. METHODS

Samples of cutting fluid were collected in a sterile bottle, cooled, and then submitted for analysis to a microbiology laboratory accredited by the National Association of Testing Authorities (NATA). The reference method was *AS 4276.3.2 Water Microbiology - Heterotrophic Colony Count Methods - Plate Count of Water Containing Biocides*.

### 4. RESULTS

#### 4.1 Case Study 1 (Composites & Metals)

Sample	Sample Type	Results (bacteria)
Cutting fluid - Machine 1	Bulk fluid	<1 cfu/mL
Cutting fluid - Machine 2	Bulk fluid	<1 cfu/mL
Cutting fluid - Machine 3	Bulk fluid	<1 cfu/mL
Cutting fluid - Machine 4	Bulk fluid	<1 cfu/mL
Cutting fluid - Machine 5	Bulk fluid	<1 cfu/mL
Cutting fluid - Machine 6	Bulk fluid	<1 cfu/mL

#### 4.2 Case Study 2 (Composites)

Sample	Sample Type	Results (bacteria)
Cutting Fluid – Before maintenance	Bulk fluid	1 000 000 cfu/mL
Cutting Fluid – After maintenance	Bulk fluid	<1 cfu/mL

There was no obvious odour, and no adverse health effects were reported

### 5. DISCUSSION

#### 5.1 Exposure Standards

In the absence of an Australian exposure standard for cuttings fluids, or metalworking fluids, an appropriate exposure standard is a matter for professional judgement for most commercially-available fluids. The situation is more clear-cut for the (now less-common) mineral oils.

#### 5.2 Control Measures

Eye protection, gloves and overalls may be required. Barrier creams will assist the removal of contaminants from the hands. Respiratory protection is not normally needed. Fluids should be kept at recommended volumes and concentrations, sumps should be covered, frequent machine cleaning is recommended, only use coolant to flush chips, avoid other contaminants, align nozzles and hoses, use tramp oil skimmers when appropriate, ensure filters are operating, contain spillages, provide suitable ventilation, and eliminate dead legs in fluid lines. The HSE recommends weekly dip slide testing. Dump, clean and recharge dirty coolants – remove any debris or sludge, and abrade if required to remove bacterial slimes and fungal mats.

### 6. CONCLUSIONS

Microbial results from cutting fluid risk assessments in two workplaces have been presented.

### 7. ACKNOWLEDGMENTS

Thank you to the clients who have authorised the publication of data obtained at their premises, for the sole purpose of professional education.

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## ROYAL AUSTRALIAN AIR FORCE AIRCRAFT SURFACE FINISHER: HEALTH MONITORING DETERMINATION AND RISK CONTROL PLAN PROJECT

*Sean Walden*

Royal Australian Air Force

### ABSTRACT

Aircraft Surface Finishers (ASURFIN) are a small trade within the Air Force exposed to a significant hazard suite of physical and chemical hazards including (but not limited to); noise, hand arm vibration, manual handling, isocyanates, hexavalent chromium, methyl ethyl ketone, dichloromethane and phosphoric acid. They form part of the Aviation maintenance workforce and are responsible for the application of protective paints and coatings to Australian Defence Force (ADF) Aircraft.

The ADF identified the requirement for strategic management of this cohort to ensure the complex hazards and risks to personnel are managed so far as is reasonably practical (SFARP). A multi-disciplinary and multi-faceted project was commenced to address this aim. A small project team was formed including management, organisational and consulting occupational hygienists and technical specialists. The team worked in consultation with the work force, engineering agencies, occupational physicians and health care providers, product/equipment manufacturers and even the regulatory authority (Comcare).

The key objective of the project was to ensure legal obligations pursuant of the Work Health and Safety (*Cth*) Act 2011 for the assessment of health monitoring requirements were met for noise (section 57-58 – WHS Regulations (*Cth*) 2011), chromium (inorganic) and isocyanates (schedule 14 – WHS Regulations (*Cth*) 2011). The project includes the following activities.

1. Occupational Hygiene Exposure and Risk Assessment
2. Health Monitoring Determination
3. Risk Control Plan
4. Process Gap Analysis
5. Workforce Engagement Activity
6. Regulator Engagement

To date, the project has achieved significant outcomes for the improvement of worker safety and hazard management. A robust health monitoring program is in effect and enhanced risk control strategies from across the hierarchy of controls have been identified; including implementation of substitution, engineering, administrative controls and enhancement of PPE usage and management. Workforce consultation and health education objectives have also been achieved.

This case study highlights the role that Occupational Hygienists have to play in strategic management of complex occupational hazards.

### INTRODUCTION

Following the introduction of the new model WHS Act in 2011, primary duties of the 'Persons conducting a business or undertaking' (PCBUs) were articulated in a new and more enhanced manner. For Defence, the release of the new model Act was a key catalyst in the maturation of the organisation's Workplace Health and Safety Management Systems. The identification of 'Officers' of the PCBU meant that senior executives were significantly more aware of their organisational obligation (both legal and moral) in the provision of a safe workplace for their workers.

Throughout this period, the ASURFIN trade experienced a small number of significant accidents and incidents that were escalated through the Safety Network to senior management. Preliminary investigations were initiated and quickly identified that improvements to ASURFIN risk management were required. In addition, it was identified that a robust health monitoring determination was required for the trade to monitor their exposure to noise, isocyanates and chromates.



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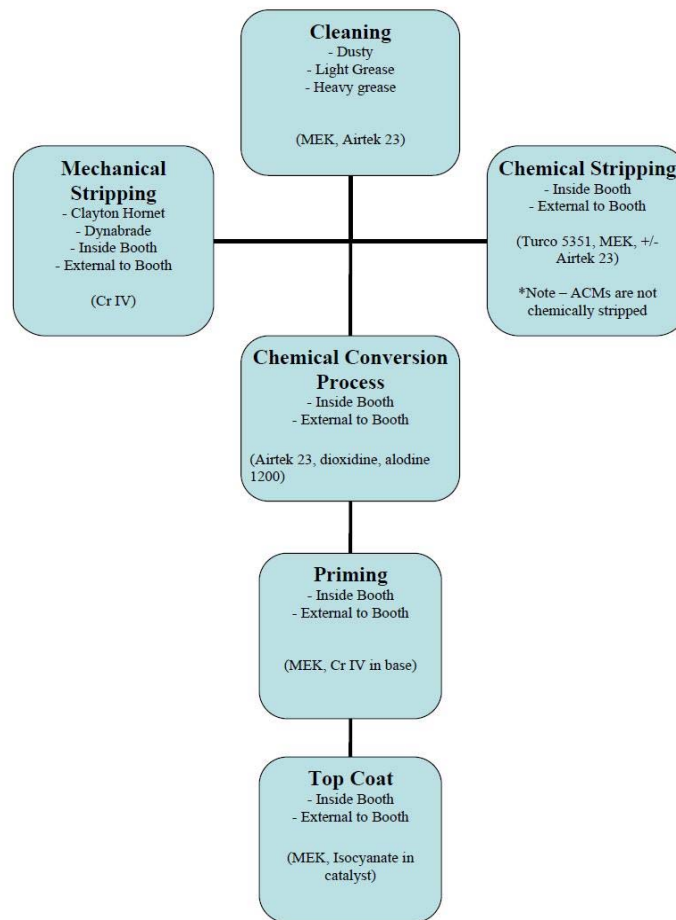
## AIRCRAFT SURFACE FINISHER WORKFORCE

Aircraft Surface Finishers are a small trade of less than 50 personnel within the aviation technical trades realm of the Royal Australian Air Force. They are responsible for the application of protective paint coatings to ADF aircraft. Air Force Surface Finishers are employed on duties which include the paint stripping and painting of metallic and composite surfaces of aircraft; corrosion prevention processes; preparation and use of aircraft support equipment; identification and procurement of aircraft paint equipment and materials; maintenance of spray painting equipment and amendment and maintenance of technical publications. Surface Finishers are also involved in stencilling, and the application of tapes and decals.

Their current training pipeline is to enter the Air Force as a qualified tradesman with civilian qualifications in Motor Vehicle spray painting. Competence is deemed by the attainment of a Certificate III Automotive Engineering (Automotive Body Refinishing) or equivalent. There is also scope for new applicants to obtain this qualification after joining the Air Force following the completion of recruit training. Once trade qualification and recruit training is complete, Aircraft Surface Finishers undertake approximately 10 weeks of Core Aviation Trade Skills training at RAAF Base Wagga. This training covers common aspects of basic maintenance, processes, procedures and documentation in the aviation environment. It is designed to provide Aviation tradesmen with common operating skills and competencies consistent to all tradesmen who operate in an Aviation workplace. Aircraft Surface Finishers are then posted to an operational unit to commence trade specific employment training designed for qualified automotive spray painters to become competent Aircraft Surface Finishers. The training provides theoretical and practical On-the-Job Training (OJT) in Aircraft Surface Finishing and is conducted as a self-paced course that can be completed in 15 to 35 weeks. On completion of the initial trade training continuum, Aircraft Surface Finishers can be posted to a number of Air Force bases including; RAAF Base Edinburgh (SA), RAAF Base Richmond (NSW), and RAAF Base Williamstown (NSW), RAAF Base Amberley (QLD) and RAAF Tindal (NT). Aircraft Surface Finishers conduct work on the full range of aircraft platforms in the Air Force's inventory.

## HAZARDS SUITE

The conduct of Aircraft Surface Finishing is largely considered the most hazardous (peacetime) occupational activity in the Royal Australian Air Force. The list of hazards is significant and their resultant risk profiles generally possess dire consequences to both the worker and the environment, should effective control not be achieved. To understand the hazard suite, the work process must first be explored. Aircraft Surface Finishing activities are conducted on a wide range of platforms in a wide range of task locations and geographic environments. Despite this, the general process of workflow remains consistent across the range current fourth and fifth generation aircraft in the RAAF's inventory. As such, the inherent hazards remain consistent across the spectrum of the trade—with variances only owed to the minor nuances concerned with the airframe, task location or environmental factors.



**Figure 1 – ASURFIN Workflow**

Figure 1 illustrates the common workflow for ASURFIN tasks. Every task required by the trade (ie surface finishing activity) will follow this general process flow, entering and exiting the continuum at various points to feed into the wider Aviation maintenance process. There are two decision points that need to be highlighted, as they determine critical variances in the either the hazard suite (for that given task) or the applicability of available controls. These points are:

1. Use of Mechanical or Chemical Stripping techniques
  - Determined by substrate type and/or location on the aircraft
2. Conduct of all tasks in a Dedicated Facility or Uncontrolled Environment (ie, Spray booth operations)
  - Determined by ability to remove component from aircraft

The hazard suite that ASURFIN members are exposed to is vast. The following list illustrates the most significant threats to worker health outcomes in the conduct of their trade. They predominately stem from physical and chemical hazards.

Physical:

1. Noise
  - Conduct of work tasks in high noise aviation work environments
  - Ventilation and blower systems
  - Pneumatically operated power tools – ie, palm sanders
2. Hand Arm Vibration

- Palm sanders
- Plastic media blasting

### 3. Manual Handling

- Lifting and manipulating aircraft components
- Conducting work in restrictive areas
- Requirement for awkward body positioning
- Kinetic and force driven tasks

### 4. Lighting

- Fine inspection and detail driven tasks
- Night operations required

### 5. Heat Injury

- Range of geographic locations
- High work rate tasks
- Use of high levels of PPE

### Chemical:

#### 1. Hexamethylene Diisocyanate (HDI)

- Atomisation of two pack top coat paints

#### 2. Volatile Organic Compounds (VOCs)

- Wide range of organic solvents used in paints, stippers, cleaners and pre-treatment chemicals

#### 3. Methyl ethyl ketone (MEK)

- Extensively used as a surface preparation and cleaning solution
- Equipment cleaner (ie, Spray guns)

#### 4. Heavy Metals (ingredients in surface coatings)

- Inorganic Chromium (Alodine and Primers/Pre-treatments)
- Zinc Oxide
- Titanium dioxide
- Iron oxide

#### 5. Inhalable Dusts

- Mechanical sanding of painted surfaces
- General workplace dusts

#### 6. Dichloromethane (Turco 5351)

- Used in chemical stripping processes

#### 7. Phosphoric Acid (Deoxidine 624)

- Utilised as a conversion coating and mild corrosion remover in the chemical conversion process

## HEALTH MONITORING DETERMINATION

The underpinning factor to the health monitoring determination activities was to ensure legal obligations pursuant of the Work Health and Safety (*Cth*) Act 2011 for the assessment of health monitoring requirements were met for noise (section 57-58 – WHS Regulations (*Cth*) 2011), chromium (inorganic) and isocyanates (schedule 14 – WHS Regulations (*Cth*) 2011). In addition to the hazards which had a specific legal requirement, it was determined to be imperative to assess the entire hazard suite to determine actual exposure risk and effectiveness of applied controls. Whilst mechanisms were in place for the investigations of such requirements; the trade had not had these requirements assessed in a holistic and robust manner. There were a number of health surveillance activities conducted across various locations and bases, the content of which was largely determined by local healthcare providers without proper information by either exposure and or risk assessment methodologies. There was also limited organisational justification to the surveillance activities, with most activities based on legacy issues. Although inconsistent in application, health policy was extant for ASURFIN members relating to health surveillance activities on exposure to isocyanates and noise exposure.

The provision of healthcare to the Australian Defence Force in the domestic setting (ie, non-operational) is the responsibility of Joint Health Command (JHC). JHC have procedural policy for workplaces to access the support of an Occupational Physician specialist as a Legally Qualified Medical Practitioner (LQMPs). The LQMP is authorized to provide a legal determination of health surveillance requirements for workers based on information provided in a thorough risk and exposure assessment investigations.

The conduct of the Exposure and Risk Assessment was coordinated by the Occupational Health Team within the Directorate of Defence and Aviation Safety (DDAAFS), commencing in mid 2014. A scope of work was developed in order to engage an Occupational Hygiene consultant, a Certified Occupational Hygienist, with experience in conducting work with the Defence Department.

Following the completion of preliminary tasks, exposure assessments were conducted between October and November 2014 at ASURFIN facilities at RAAF Williamtown, Richmond and Edinburgh. The assessments included the following activities:

1. Review of primary Orders, Instructions and Publications
2. Process Review
3. Noise – area measurements and personal dosimetry
4. Qualitative assessment of Hand arm vibration and ototoxic substances
5. Review of Personal Protective Equipment
6. Isocyanates – utilising methoxy phenyl piperazine impregnated glass fibre filters
7. Volatile Organic Compounds – area and personal samples utilising SKC 226-01 sorbent tubes
8. Heavy metals (including Cr(VI), Cr, Fe<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, ZnO and inhalable dusts) area and personal samples using IOM heads
9. Heat Stress
10. Lighting
11. Ventilation

Following the issue of the consultant's report in February 2015, a determination was provided by Joint Health Command under the technical authority of the Command's LQMP and the organisational authority of the Surgeon General Australian Defence Force (Commander Joint Health Command) in September 2015. The determination advised:

1. 'no additional health monitoring needs to be established as a result of this risk assessment unless recommended control measures cannot be implemented. Health monitoring needs to continue for isocyanate and noise exposures'
2. HAV exposure needs to be managed
3. Recommended the installation of Clayton Hornet Sanders to minimise Cr(VI) exposure (orbital sanders with LEV)

4. Health surveillance for Cr(IV) is not required if effective implementation of identified controls is achieved

#### MANAGING ORGANISATIONAL RISK – THE RISK CONTROL PLAN

Although the Exposure and Risk Assessment scope was developed to ultimately form a Health Monitoring Determination for the ASURFIN trade, there were a number of observations and recommendations made by the consultant. In addition, the process risk assessments identified that a number of hazards required additional (or more effective) application of controls to ensure that the legal obligations of the Work Health and Safety (Cth) Act 2011—particularly section 17 – Management of Risks—are met.

Section 17 requires (the duty holder) ‘to eliminate risks to health and safety, so far as reasonably practicable; and if it is not reasonably practicable to eliminate risks to health and safety, to minimise those risks as far as is reasonably practicable.’

Within Defence, the term SFARP has been developed as a tool to capture this overarching legal obligation. Key to the obligation is the principle of reasonable practicability with the focus on the application of controls, rather than residual risk. Figure 2 demonstrates the elements of reasonable practicability that assist organisations to systematically address its underlying principles and provide an ‘SFARP Judgement’.



Figure 2 – ‘The SFARP Wheel’

In order to appropriately capture the recommendations identified in the Exposure and Risk Assessment, Headquarters Air Command Safety developed the ASURFIN Risk Control Plan (RCP). The development of the RCP firstly involved the compilation, contextualisation and critical analysis of the recommendations raised in the Exposure and Risk Assessment. Recommendations were broken down by the hazards groups identified in the Assessment. An initial SFARP judgement was conducted to address the requirements for the application of additional controls. In addition, the requirement of the application of interim control measures were examined; to ensure that current risks were reduced in the short term, whilst high order (and potentially systemic) control measures were also addressed. Table 1 summarises the recommendations of the Exposure and Risk Assessment as developed in the RCP.

Occupational Hazard	Serial	Activities	Initial Risk Level	SFARP	Interim controls required	Subject to RCP
Isocyanates	1	Mixing paints	Very low	Yes	No	No
	2	Spray painting in spray booth	Low	Yes	No	No
	3	Application of paint by brush, roller or sponge	Very low	Yes	No	No
Volatile Organic Compounds	4	Paint stripping using Turco 5351	Medium	No	Yes	Yes
	5	Pre-treatment of aluminium surfaces	Very low	Yes	No	No
	6	MEK cleaning of surfaces and spray guns	Medium	No	Yes	Yes
	7	Mixing paints	Very low	Yes	No	No
	8	Spray application of paints in spray booth	Very low	Yes	No	No
	9	Application of paint by brush, roller or sponge	Very low	Yes	No	No
Heavy Metals (including CrVI)	10	Sanding of painted surfaces using Dynabrade sander	Medium	No	Yes	Yes
	11	Sanding of painted surfaces using a Clayton Hornet 1000 sander and vacuum system	Low	Yes	No	No
	12	Mixing Alodine 1200S with water	Low	No	Yes	Yes
Noise	13	Noise created from typical ASURFIN related activities including sanding with pneumatic systems, air blower and workshop ventilation noise	Low	Yes	No	No
Hand Arm Vibration	14	Sanding using pneumatic orbital sanders	Medium	No	Yes	Yes
Heat Stress	15	Heat stress encountered during typical ASURFIN related workplace activities	Low	Yes	No	No
ASURFIN hazard awareness training	16	During ASURFIN activities, extant training may not adequately address hazard awareness	Low	No	No	Yes

**Table 1 – Recommendation Summary**

During the development of the RCP, four areas were identified to have a current risk rating of MEDUIM based on the sum assessment of their consequence and likelihood. Immediate control recommendations were developed to ensure the short term reduction of risk for the effected workforce. These risks primarily stemmed from the incorrect application (selection and/or use) of personal protective equipment or implementation/adherence of Order, Instructions and Publications.

Hazard	Observation	Recommended immediate action
Volatile organic compounds	Chemical paint stripping Ansell 38-514 ChemTek butyl gloves do not provide good protection against Dichloromethane 14 (<5 min breakthrough time) and Dichloromethane 28 as found in Turco 5351 paint stripper.	1. Wear Ansell ChemTek 38-612 Viton/butyl gloves, or similar, for paint stripping with Turco 5351. 2. Wear North Silver Shield gloves under the Viton/butyl gloves for large stripping tasks
MEK	North Butyl gloves are generally worn over the nitrile gloves when cleaning surfaces or spray gun cleaning with MEK, however it was noted that this was not always the case during the onsite assessment. Nitrile gloves are unsuitable for use with MEK.	1. Wear Ansell ChemTek 38-612 Viton/butyl gloves, or Ansell ChemTek 38-514 or North butyl gloves for tasks using MEK. 2. Ensure ASURFINs are aware that nitrile gloves are not suitable for use with MEK.
Heavy Metals (including CrVI)	Results of the sampling during sanding indicate that the area in the vicinity of the task would be significantly contaminated by dust containing CrVI as a result of sanding.	1. Wear disposable boot covers over safety boots for mechanical sanding. 2. Ensure that clean-up and decontamination procedures are compliant with Air Command/ACG (where applicable) chromate management OIP.

Table 2 – Immediate Controls

The RCP was developed to cover longer term requirements for the management of organisational level risks identified in the Exposure and Risk Assessment. The Command authority for the plan was Air Commander Australia; with responsibility practically executed by the Headquarters Air Command Safety team. A collaborative approach was identified to include Occupational Hygiene subject matter experts, trade technical advisors and policy guidance from DDAAFS.

Hazard Group	Serial	ASURFIN Activity	Hazard	Initial risk level	Reputable standards	Recommended control	Cost Assessment	Analysis of control effectiveness	Implementation strategy	Implementation responsibility	Schedule	Residual exposure
		Paint stripping using Turco	Exposure to Hazardous Chemicals (Inadequate protection from		-WHS Regs s44 and s46 -WHS CoP 2012 Hazardous Chemicals – Managing Risk of Hazardous	Wear Ansell ChemTek 38-612 Viton/Butyl gloves, or similar	When considering the likelihood and degree of harm from HazChem exposure, the cost of	-The use of PPE is unavoidable for this hazard. Specified PPE is effective when worn	-Units to replace existing PPE as specified in ACAUST Directive. -Units to update OIP to	-DDAAFS ENVH SME retains technical control of	As per AC1424518 specified PPE directed for use NLT 15 Jul 15. -Unit OIP reg	

Figure 3 – RCP Implementation Strategy

The RCP identified the following discrete activities:

1. Application of Immediate Controls – to immediately reduce medium level risks
2. Development of an RPE and Glove Program – to provide a robust and contextualized framework for the application of PPE controls for ASURFIN activities
3. Introduction of the Clayton Hornet Sanding System (orbital sander) – to introduce an engineering control for mechanical sanding activities
4. Investigate introduction of Plastic Media Blasting – commissioning of plant available, but not in use, at a number of ASURFIN facilities.
5. Substitute the use of Alodine S (a powered formulating requiring mixing) with Alodine L (a liquid premix formulation)
6. Substitution investigations for Chromate free primers/pre-treatments and other Haz Chem
7. Hand Arm Vibration Assessment of the Clayton Hornet orbital sander
8. Implementation of administrative time limits for the current in service orbital sander – currently assessed but ineffectively implemented

## 9. Development of an On-the-job/Continuation Training Package specific to ASURFIN hazards, risk and controls

### LESSONS LEARNT

Following the authorisation and promulgation of the RCP, a workplace incident occurred following the introduction of an identified control. Specifically, a recommended viton/butyl glove delaminated, following a solvent cleaning task using Methyl ethyl ketone (butanone). The resultant investigation identified that the viton/butyl glove was recommended as it would provide appropriate (and adequate) protection for use with methyl ethyl ketone and dichloromethane (the active ingredient in chemical stripper). A glove solution that provides protection against each chemical was required as they are used in conjunction with one another during the 'chemical stripping' work process. Furthermore, it was not practical to provide a solution that required gloves to be changed or swapped. The incident occurred when the glove was used in an application that was contradictory to what was communicated to the hygienist during the assessment. The glove was appropriate to protect against 'splash' contact with MEK, however delamination occurred when the glove was used in a task requiring 'immersion' contact—this was outside of the scope of the recommendation and as such, the control failed.

This incident highlighted that there was an immediate need to conduct a workforce engagement activity as a part of the RCP implementation strategy. A two person team from DDAAFS was identified, consisting of the senior ASURFIN tradesmen and an occupational hygienist. The team subsequently developed an engagement plan and schedule for workforce engagement. The primary objectives of the engagement were to improve the communication/implementation strategy for the RCP—particularly the introduction of controls to the workforce and management. In addition, it was identified that a process 'gap analysis' was required to ensure that the scope of the Exposure and Risk Assessment (developed as an exposure assessment to determine health surveillance requirements) and a holistic trade wide risk mitigation project.

As an assurance measure for the organisation's philosophical direction for the conduct of the RCP, regulator engagement was implemented as a part of this project. As the ADF falls under the legal jurisdiction of Commonwealth model Work Health and Safety (*Cth*) Act 2011, its regulatory authority is Comcare. Whilst Defence, including Air Force, enjoy largely positive relations with its regulator, their engagement in this project was identified as an extremely valuable activity for both agencies. To this end, a Comcare inspector was invited to participate in the proceedings at one of the workplace engagement activities. Regulator feedback was positive and Air Force was assured of the execution of a successful project. Ongoing feedback to Comcare regarding the RCP was requested to continue through existing mechanisms of the Air Force Safety Board—the organisation's pinnacle strategic level Workplace Health and Safety meeting forum.

As the project progressed and work on the action items commenced, it became clear that the project team (consisting of 'safety' representatives) lacked the required breadth of organisational expertise and authority to execute the wide range of sub tasks involved in the action items. For example, many of the action items identified in the plan had overarching safety improvement outcomes, but implementation required coordination and (sometimes) implementation responsibilities to be with aircraft engineering authorities or estate/facilities management agencies. Unfortunately, the effectiveness of the project team to implement robust change was impaired by the requirement for authorisations, organisational bureaucracies, organisational silos and inertia.

The ASURFIN RCP was the first project of its kind since the release of the new model Act, which aimed to address and mitigate organisational level hazard/s (and their associated risks). In order to address the shortcomings of this RCP, an enhanced (and more robust) systemic procedure was developed by Headquarters Air Command.



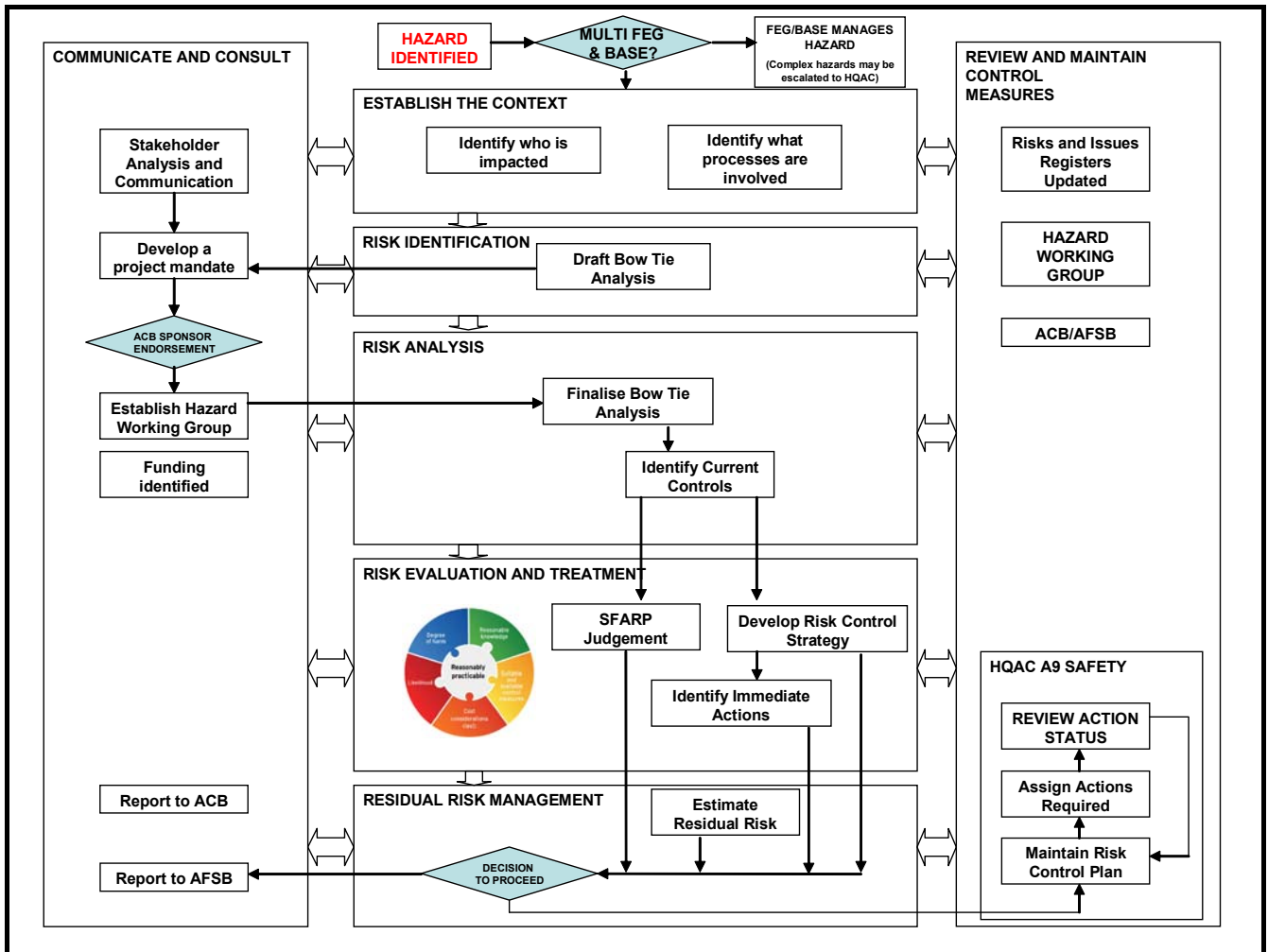


Figure 4 – Organisational Hazard Management Framework

Figure 4 above illustrates the new procedure in the form of flowchart. It aligns with the risk management framework documented in organisational policy; modelled of the risk management framework in ISO 31000. However, the key improvements to the processes include:

1. The establishment of a 'Hazard Working Group' – to include stakeholders from the relevant agencies such as, management, engineering and technical authorities, capability managers, estate management, logistics specialists, command safety representatives and policy agencies etc.
2. Identification of responsible agencies for action items – including responsible positions, funding streams etc
3. Risk Assessment and Analysis processes conducted utilising Bow Tie Risk Assessment Methodology – provides a framework that is commensurate with the requirements of investigating organisational hazards. They are also used to provide contextualised guidance to tactical level hazard and risk management.

## CONCLUSIONS

The Aircraft Surface Finisher Health Monitoring Determination and associated Risk Control Plan have led to the wide range improvements in the hazards and risks to workers conducting ASURFIN tasks. Tangible outcomes have been achieved across hierarchy of controls; including improvements to the publications/policy framework, hazards and control awareness for workers, equipment improvements, hazard management and substitution activities. These outcomes have served to highlight management priorities, meet legal and moral obligations of health surveillance requirements and ultimately, create a safer workplace for the ASURFIN work force. Importantly, empowerment of the workforce through increased knowledge, and consultation has been evident.

For the organisation, there has also been a great number of learning opportunities and systemic improvements in the way that organisational level hazards and risks are addressed. These outcomes have successfully been developed in to a framework and incorporated into organisational policy, with the support and endorsement of Command within the Air Force. Regulator relations have also been enhanced by the proactive engagements and formal reporting conducted throughout the project.

A key lynch pin to the ultimate success of the project has been the involvement of the Occupational Hygienist. The hygienists played pivotal roles in the identification of hazards, quantification of risk, control recommendations, informing health surveillance requirements, engaging with the workforce, enhancing project implementation and providing sound expert advice to management and technical authorities.

## COMMUNICATING A NEGLIGIBLE HEALTH RISK TO CONCERNED EMPLOYEES

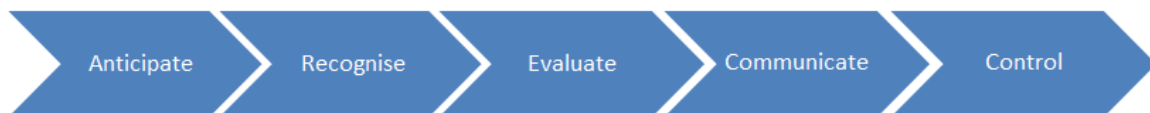
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### BACKGROUND

Occupational Hygiene is an area of Science dedicated to the preservation of worker health. Key to the successful execution of the role of an Occupational Hygienist is the effective communication of *risk* (or otherwise) to the employer and/or workforce. One could say that in order to have Hygiene that works; there must be effective communication.

The Australian Institute of Occupational Hygiene (AIOH) defines occupational hygiene as “the art and science dedicated to the Anticipation, Recognition, Evaluation, Communication and Control of environmental hazards in, or arising from, the workplace that can result in injury, illness, impairment, or affect the well-being of workers and members of the community. These hazards are normally divided into the categories Biological, Chemical, Physical, Ergonomic and Psychosocial.”



Trained and competent Hygienists spend their days (and often nights) anticipating, recognising, evaluating and controlling *significant* workplace hazards. The process, in the most simplistic of forms would usually follow something similar to:

1. A hazard, usually above or approaching a quantum of concern is noted.
2. The hazard is then assessed in some way, this may be by direct monitoring (active or passive sampling) or risk assessment, either way the outcome is usually a metric or classification of risk – numbers on a page!
3. This assessment result would then be compared with a relevant standard, guideline, risk matrix, company policy etc.
4. This comparison will allow for the categorisation of the risk as either acceptable or unacceptable. As an example, where the measured value is at or greater than 50% of the prescribed standard the process can be deemed to be out of control/unacceptable (that is there is a statistical likelihood that workers are being exposed at or above the relevant standard noted during their works).
5. Where a risk is identified as unacceptable, there would then be an obligation (be that moral, legal or both) on the employer to put controls in place to reduce this risk of worker exposure below the threshold of acceptance.
6. In an ideal world the choice of control would be in accordance with hierarchy of control, however in reality these decisions are influenced (often heavily) by consideration of what is reasonably practicable from a cost benefit point of view.
7. Often there will be a second measurement to demonstrate that the controls have been effective in reducing the degree of risk.

### OBJECTIVE

The objective of this investigation is to look at what happens when the assessment result returns an ‘acceptable’ result. In particular what happens when the perception of risk between worker and technical expert differs? Is that the end of a Hygienist or Safety professional’s involvement? Who and how is a negligible or ‘safe’ scientific result communicated?

There are many investigations out there that address the subject of risk perception in the general public, however many of these focus on environmental factors, as opposed to the workplace. This paper will briefly look at two workplace case studies collected over a 10+ year career, where the workers initial worker health concerns, upon investigation were found to be unsubstantiated.

Any Occupational Hygienist or Safety Professional will attest, the term ‘safe’ is subjective, or more appropriate in many cases ‘perceptive’, and one they have no doubt battled with on many an occasion. Risks can and are perceived differently by

different people, but interestingly it has also been noted that the same individual can perceive risk differently over time - what doesn't worry you today, may concern you tomorrow. Further to this, it is **personal** 'people do not make the same estimate when they rate the risk to themselves' Sjoberg, 2000, 'Peoples judgments and evaluations of hazards **they** are or might be exposed to' Rohrmann, 1996.

Hazard perception is a critical life skill, something we want children to learn and so fundamental to everyday life that it is a taste one is required to pass before being deemed competent to drive a car. It is the ability to assess our surroundings and maintaining personal safety. However, this hazard perception in some cases can be difficult to manage in the modern day and can be misaligned at times and across populations. To quote the AngloAmerican comedian turned neuro-scientist Ruby Wax, our ancestors very skill of scanning the horizon for a sabre tooth tiger (risk perception) was the basics of life preservation, however *'the problem these days as modern man is that when we perceive danger, adrenaline shoots into us but because we can't kill a traffic warden or eat an estate agent, the juice never comes back down. We're in a constant state of red light alert, like a car siren that drives us nuts'*.

Through appraisal of real world case studies it will be investigated if there are common recurring factors that are contributing to the perception of risk more than others for workers. We will also consider what external push and pull factors may contribute to, or encourage these concerns to be raised as a formal complaint?

## CASE STUDIES

### CASE STUDY 1: IMPORTATION OF A VESSEL CONTAINING ASBESTOS INTO AUSTRALIAN WATERS TO BE MANNED BY AUSTRALIAN WORKFORCE

An internationally registered ship which had been constructed circa 1970s had been sourced to conduct several months of work in Australian waters. The ship had approximate dimensions: length 190 metres, breath 35 metres and a depth of 15 metres and included five decks and a superstructure comprising six levels. The vessel had facilities to sleep over 350 construction workers and marine crew on board. The master, senior construction staff and senior marine personnel were European nationals while the bulk of the construction workforce and marine crew were Australian nationals.

**Challenges** facing the project included: Australian importation regulations, specifically with regard to importation of asbestos; diverse mix of nationalities and cultures on-board, differing expectations with regard to safety and compliance standards; magnified by the close working and living conditions, extended work shifts and periods of time away from family/friends, all lead to a climate of high pressure.

The **perception** of the company running the project and many of the international crew, most of whom had spent many months prior working on same or similar vessel, was that the workplace was adequate. The perception of the Australian workforce however was that the vessel was below expected standards. A particular concern voiced by the workforce was the presence of asbestos containing materials on-board the vessel. The perception of risk the workforce held that swiftly became apparent was that 'one fibre kills' and any level of asbestos on-board was not acceptable.

A series of negotiations between management and the workforce immediately commenced. During this period however the vessel and the workforce were effectively 'grounded' in Singapore. The operational impact of this delay, which lasted two days, was the financial burden of vessel hire and workers compensations during the period of nonproduction, as well as delays to project schedule.

The **resolution** to the negotiations was two-fold; short term actions included the mobilisation of Australian trained and competent asbestos consultants to monitor and execute the safe management of asbestos-containing materials (both fixed and installed, and otherwise). The longer term solution arrived upon was that there would be a permanent presence of specialist asbestos consultants on-board the vessel for the duration of the works.

Communication during the project was multifaceted; vessel and project management negotiated with Australian Border Protection and the ship was granted entry to Australian waters. This required support and technical advice from subject matter experts, who could produce evidence demonstrating asbestos containing materials were being safely managed on-board. An asbestos management plan (AMP) was drafted specific to the vessel, which outlined tasks and responsibilities for the ongoing management of asbestos. Included in the AMP were safe work procedures such as unanticipated disturbance of

suspected materials and procurement of goods and consumables such as gaskets etc, the establishment of an emergency response team (ERT), a labelling protocol for identified asbestos and synthetic mineral fibre materials (SMF). The ERT would be a collection of workers trained in safe work procedures in proximity to known asbestos containing materials, to allow them to conduct essential maintenance whilst the vessel was at sea. The general workforce population was directly engaged by the asbestos consultants, this including the compulsory attendance an induction session outlining details of AMP. The training covered concepts of hazard verses risk, as well as the single fibre theory and dose/response relationship with regard to asbestos exposure. Additional to the induction and training sessions the onsite consultant attended weekly safety committee meetings, conducted daily site walks and visual inspections and monitoring. The OHS committee was an open and transparent communication between management and worker representatives, the consultant attended as an independent and competent person with regard to asbestos and was able to assist with any concerns regarding asbestos or SMF management as and when they arose. Daily airborne asbestos fibre monitoring was conducted in representative areas of the vessel, for the duration of the project works; and during all ERT works. Airborne asbestos fibre monitoring results demonstrate a 'snapshot' risk assessment of a specific area, or activity at a certain point of time. As such and given the scale of the vessel and amount of dynamic activity conducted these results were regularly reassessed and certificate of analysis were posted daily in the lunchroom so it was accessible by all workforce. During the first five months of monitoring over 1,500 airborne fibre tests were taken; all results were well below the Australian exposure standard, with only four instances reported results above the limit of detection (<0.01 f/ml). These results related to ERT works over a four day period that was conducted under controlled conditions, fibre levels were reported at 0.02f/ml, which is five times less than the TWA exposure standard.

## CASE STUDY 2: ODOUR CONCERN IN AUSTRALIAN CBD OFFICE BUILDING

The site was a multi-tenancy office building in an Australian central business district (CBD). The company (client) at the centre of the concern leased and occupied three floors. Several construction sites were adjacent to building at the time the concerns were raised. The construction sites were managed by different parties and were at varying stages of completion. Occupants in clients' office areas reported intermittent odour in the building, it was often described as a 'burnt' diesel smell. Smell was reportedly having negative health impacts on building occupants such as headaches, dizziness etc.

The initial **challenge** of investigating and addressing such a concern is defining the concern is and what if anything can and should be investigated.

The **perception** of the employees working in this building was that the presence of an odour indicated a problem or a potential exposure. There was an expectation that monitoring for 'anything harmful' could and should be quickly conducted. Further to this workers were beginning to believe and discuss with one another that their concerns were not being taken seriously nor addressed in a timely manner by management. Emotions were running high within worker population; there were questions and comments such as:

"What are you doing to ensure the safety of pregnant workers unborn baby?"

"I want an assurance that the building is safe!"

"What about the risk of explosion inside the building?"

"Would you work here?"

Workers were so concerned that they were actively leaving the office if and when the odour was detected. Some would work from home or alternate office facilities in different buildings, whilst others felt so unwell that they were unable to perform their duties in any location and as such were claiming medical leave.

The initial **communications** between management/Occupational Health & Safety (OHS) team and employees was ad-hoc. The scale complexity of the organisation and building ownership also slowed response: multiple stakeholders were involved such as Building owner, internal leasing team, the department within which workers were employed, Facilities Management (FM), Human Resources (HR) and OHS. Each department, whilst actively assisting with investigation was reluctant to take ownership of the concern and timeliness of response from these stakeholders was not aligned. Although there may have been efforts and investigations occurring this was not adequately communicated to workers, who were increasingly becoming disgruntled with lack of response and communication from the investigation team.

Initial in-house **investigations** included informal consultation with concerned staff, visual review of building air conditioning systems and high level review of areas immediately adjacent to the site. Workers were asked to record, report and collate all instances of odour occurrences, so that any potential trends could be identified. A site inspection conducted by persons competent in building operations (FM department), included a visual inspection of fresh air intakes and air conditioning plant for the building. Nothing of concern was noted and no obvious internal source of odour was identified either during the site walk through, including an overview of occupant activities within the building. Adjacent areas were investigated to identify potential external sources of odours: two adjacent construction sites within one city block were noted. One was well into construction and had a structure that was standing approximately six levels above the ground with regular concrete pours occurring. Concrete trucks were noted to be idling onsite during operations, plus there was use of chemicals such as concrete curing and formwork release agents. The second site, after consultation with Builder, was known to have had recent hydrocarbon spill from an underground tank, presumed to be diesel or petrol. The client was advised that the associated contaminated materials including soils, were handled and removed offsite in a manner consistent with Legislative and EPA requirements. The builder had engaged their own Environmental Consultant to take readings for presence of hydrocarbons in the atmosphere at point of previous contamination, no reading exceeded 3.7ppm. Further to these construction activities, general CBD contributors to air quality such as vehicular traffic, trams, local restaurants, other building exhausts, bin storage, laneways etc were noted in the local area, although nothing was found to be significant or differing from similar city locations. EPA and local council were both contacted by the client to see if they could offer support/advice on this matter, unfortunately neither was able to assist due to scope of legal powers and no evidence of breach of compliance.

The anecdotal information provided by these initial in-house investigations indicated that base building was operating as anticipated and was not a potential source of contaminant of concern. However there were multiple possible external sources identified, all of which appeared to be being managed in accordance with legislative requirements, however documented evidence of this was in short supply. As such, the client decided to engage an external Occupational Hygienist for assistance and assessment of general indoor air quality (IAQ). The Occupational Hygienist recommended monitoring of 'representative' contaminants of concerns such as volatile organic compounds (VOCs). Data loggers were installed in representative areas of the office and air conditioning plant for one week initially, which was extended to a second week as there had not been any reported occurrences of the odour during the first week. Additional to this building occupants were provided with passive VOC sampler (SKC 575-001) which could be deployed during odour occurrence. One VOC badge was utilised during the sampling period, during a suspected odour event over a period of 15 minutes. The badge was analysed by a NATA accredited laboratory for benzene and hydrocarbons in the range C66 to C34; no benzene was detected (below the limit of detection) and a minor concentration of hydrocarbons was identified although this was not significant and only slightly above the limit of detection for the approved methodology of analysis.

Upon engagement of the Occupational Hygienist and commencement of their investigation and onsite monitoring (prior to results/report) the client was able to hold a 'town hall' style meeting, in which all levels of concerned stakeholders were invited to attend. The forum ran through the process that had been followed to date and highlighted the engagement of an independent and competent consultant to conduct additional and specific investigation into client occupied spaces. This forum also provided an opportunity for stakeholders to voice their concerns in public and to management team. During this session was when some of the emotive statements/questions listed above were communicated, these concerns were documented and passed to the Occupational Hygienist to ensure they were covered off in the investigation and report. Additional to this charcoal pre-filters were installed to the air intakes for the building. Although this resulted in a cost to the business (Landlord was not willing to fund) it was seen to be low cost for resolution of the issue.

The ultimate **resolution** to this case was a second more informal consultation with interested parties in which the findings of the Occupational Hygienist report was tabled. Workers were satisfied with the findings and no additional instances have been noted to date. The client has a supply of passive samplers should there be any further occurrences and a list of observations/details to be taken note of during deployment to allow for correlation to possible source of odour.

## DISCUSSION

A workplace is also usually, and as demonstrated in our case studies, a social (more than one worker) environment with its own unique culture. A strong safety culture will be generated from open communication which will in turn foster trust between workers and employees.

Framing these case studies through the lens of Covello and Sandman their definition of Risk = Hazard + Outrage. In their paper *'Risk Communication: Evolution and Revolution'* which includes a long list of (twenty to be exact) outrage factors. The top outrage factors that can be noted to be common in both of these case studies documented here are:

- **voluntariness** – workplace by their nature do not allow for persons to 'opt' out, unless this means leaving (through their own choice) or being forced to leave the workplace either temporarily or more permanently. To this point recall the odour case study in that workers were in some cases provided with alternate work spaces in which to perform their duties, however this was not resolving the crux of the concern e.g. the odour, but temporarily placating the workers concerned who were willing to relocate. A note of caution here is that in some cases, provided workers with an option such as temporarily working in another location, may be considered in some lights, as an admission of concern, therefore careful communications around these options would be required.
- **familiarity** – the perceived risk agent was something unusual to the routine work environment;
- **personal stake** – what about me?;
- **catastrophic potential** – the perception was that the unknown as an 'agent of death' and due to the nature of the workplace being a collection of persons in the same proximity, this personal stake can becoming amplified to be a social problem;
- **trust** in the risk communicator/message; and
- **uncertainty** – whilst the 'risk' remains uncertain one cannot satisfy a concerned worker.
- Particularly for asbestos related cases, other contributing outrage factors would include: **media attention**, which is not unusual for other environmental contaminants, or new technologies too; and latency period (**delayed effects**).

Looking at this risk definition in a purely mathematical sense, if the hazard is acceptable at its current level and is demonstrable (by an adequate body of data); the only way to reduce the 'risk' (perceived risk) is by decreasing the outrage. If we consider each factor noted above; personal stake, media attention and latency period (certainly in the case of asbestos) cannot readily be influenced. Therefore the key contributing factors to potential workplace risk perception would appear to be uncertainty, familiarity, and trust. These can and should be addressed by assessment and education, wrapped up in clear and open communications.

So what observations or learnings can be drawn from these case studies to assist Occupational Hygienists in the science and art of risk communication? How can we make *this* Hygiene work?

## KEY OBSERVATIONS

**Observation #1:** The first and critical observation from this investigation is that **psychosocial impact of perceived risks** at the workplace *can* be a real burden to employers and businesses in Australia. The case studies documented in this study show that potential impacts can be direct: due to lost time as a result of absenteeism, presenteeism, as well as management, OHS and/or HR time required to address and close out concerns. Not to mention indirect due to degradation of internal relationships and trust between workers and employer/management, as well as perception of the business to wider audience and general public.

Psychosocial impacts to workers and economies at large are increasing the subject of investigation, both internationally and in Australia. Leonie's 2010 work titled *'What drives the perception of health and safety risks in the workplace? Evidence from European labour markets'* reviewed information from the European Working Conditions Survey (EWCS) and noted *'one out of three European workers considers their health and safety is at risk because of work'*. There is no quantification as to if these perceptions are founded or not, one would have to consider that amongst the study there would be valid health concerns within the group, regardless the level of stress attributed to a third of the working population perceiving themselves as at risk as a result of their work is significant.

*'Work related stress represents a 'huge cost' for worker health and productivity'* European Agency for Safety and Health at Work, 2009 and *'more broadly is regarded as an important social determinant of global health'* Commission on Social

Determinants of Health, 2008. *'By 2020, stress-related illnesses such as depression and cardiovascular disease are forecast to be the leading causes of the global disease burden'* Murray & Lopez, 1996.

In Australia, a person conducting a business or undertaking (PCBU) has the primary duty of care under the WHS Act (OHS Act in Victoria) to ensure, so far as is reasonably practicable, the health and safety of workers and that other persons at the workplace are not put at risk during work or at the workplace. 'Health' is defined in these Acts as both physical and psychological health. Further to this Safe Work Australia recently commissioned The Australian Workplace Barometer (AWB) project which aims to provide scientific evidence of Australian work conditions and their relationships to workplace health and productivity. The AWB is a surveillance system that monitors and benchmarks psychosocial risk factors in Australian workplaces and investigates their relationship to employee health and wellbeing and engagement outcomes. The most recent AWB report published in 2012 notes *'a standout finding here is that depression costs Australian employers approximately AUD\$8 billion per annum as a result of sickness absence and presenteeism and AUD\$693 million per annum of this is due to job strain and bullying'*.

The above points are looking at the high level effects of psychosocial impacts in general, indeed during research for this paper there was no discernible measure associated with costs of perceived risk. This investigation is not advocating that perceived risk accounts for all or any of the noted financial burdens noted the above, however it can certainly be a contributing factor to increased risk of an employee suffering psychosocial stress resulting in illness and/or absenteeism. In many cases if addressed in an appropriate and timely manner it may in some cases be an opportunity for a company to get a 'win' outside with its workers by listening to and responding appropriately to their concerns. Certainly the case studies put forward in this investigation demonstrate that financial impacts however varied they may be, in some cases be significant six figure sums.

The case studies that have just been explored, clearly demonstrate that there were clear and tangible actions by the workforce as a result of a perceived risk that resulted in a negative impact on the productivity of the commercial entity for a period of time. Although upon investigation there was no evidence of a problem (unacceptable health risk) and it can be proved with science that the concern was unfounded the consequence of responding to it, or not responding to it is real and comes at a cost both financial and reputational consequences.

Noting above estimated costs related to psychosocial impacts, Australian Government (Comcare) notes that claims for psychological injury have a major impact on workers' compensation premiums, therefore another indirect cost to employers. If there is an *'incident or state of affairs in the workplace, and an employee's **perception** of that has been established as contributing to a psychological injury, it is compensable unless exclusionary provisions apply'*. As of 13 April 2007, key points considered by Comcare decision makers are:

- whether an incident or state of affairs occurred in the course of employment;
- whether that incident or state of affairs created a perception in the mind of an employee; **and**
- whether that perception contributed in a significant degree to the psychological injury.

Given the specific inclusion of perception in this definition and the key decision makers noted above, employers are at risk of Comcare claims.

**Observation #2:** In order to address perceived risk in an appropriate manner it is critical for the employer **understand stakeholders concerns**

Literature review in preparation for this investigation threw up many interesting research findings into factors that may influence stakeholders perceptions of risk in the workplace: Gaba & Viscusi 1998 demonstrated that college-educated persons were more likely to define a job as 'risky' when the hazard probability was small, where as those without college education tended to define a job as dangerous only when there was a much higher probability of injury; Cas & Paxson 2005, noted females are more ready than men to report health problems. If we again look to Leonie EWCS study, several factors of interest jump out that can and may be applicable in the understanding of stakeholder perception and also motivation for reporting. The presence of real risk in a workplace has a positive impact (that is, increases the likelihood of) risk perception, the effect of this was noted to be most significant for exposure to smoke & fumes, as well as tasks with ergonomic stressors. Lone parents appear to be more likely than others to perceive their job as risky. There is a general expectation that low-skilled jobs tend to be more dangerous than high-skilled ones; and better educated persons are more prone than others to



perceive a job as risky. This brief summary of some of the findings show how broadly a person's individual status, background and to some degree personality may affect their perceptions.

Stakeholders may be wide and varied dependent upon the incident, in the case of the odour concern, these included: office workers who had and hadn't experienced an 'episode', health and safety representatives (HSRs), Union representatives, management, adjacent construction workers, internal departments, HR, OHS, FM etc. As such, stakeholder analysis to attempt to identify and understand individual and group motivations, interest and power of each, can assist with the initial triaging of an enquiry or concern. It is entirely possible that there are environmental factors (potentially unknown to the business owner/operator) that may trigger an individual's desire or readiness to report a concern at a particular point of time, however if there is no data or documentation that can evidence that the health concern is unfounded, can the concern be dismissed? And, more importantly from a due diligence or corporate responsibility point of view, can the concern be answered to the satisfaction of the complainant? An example here where policy and legislation has dictated the risk based need for regular monitoring would be Cooling Tower management. Should a concern be raised with regard to Legionella and cooling towers there is a clear prescription of the monitoring and documentation that should be available. Of particular note are those stakeholders that have both high interest and high influence over the situation, in this case would include HSRs, union representatives and management of staff effected. These 'promoter' stakeholders in particular should be managed closely, in cases of a workplace concern these may be health and safety reps, managers with particular interest, union representatives and or media. One simple and easy way to foster trust (or more importantly to not destroy it) is to commit to timeline and scope and deliver outcomes.

An open forum with personnel including formally acknowledging raised concerns, provides workers with an opportunity to 'air their grievances' and articulate their concerns. This would not necessarily need to be face to face, in the case of the odour issue, for example concerns were also canvassed via an anonymous web forum. Being afforded an opportunity to voice ones concerns is often a cathartic experience that will often alleviate much personal tension and in some cases may even diffuse the situation. Counter to this is noted that there is a need to control such public forums, so that they are not hi-jacked, however finding that delicate balance may be a task for a purist communication professional. Encouraging and empowering the workforce to come forward with OHS fosters trust and a proactive safety culture. This was evidenced over the life of the project on-board the vessel as number of reported near misses increased, incidents fell and the general moral of the crew increased, albeit somewhat encouraged by the safety awards!

It may be a rather crude summation but the above would seem to indicate that a comparison of industry to office workplaces: may show less 'real' risk, but more concern for workers in the latter. In fact this is quite nicely articulated by Leonie 'persons who are less likely to sort into risky jobs are also more likely to worry about health risks at the workplace'. Noting the increased perception of risk around 'smoke and fumes' relative to other hazards, these very visible and easily identifiable risk factors could be extrapolated to be attributed similarly to odour also. When something unfamiliar is detected in the workplace that can be attributed or perceived as a health risk, it would intuitively seem to have a greater effect in an office environment to an industrial setting with regard to risk perception.

**Observation #3:** In order to address perceived risk in an appropriate manner it is critical for the employer open up **two way communications** as soon as possible

Fundamental to being able to answer any question fully and to the satisfaction of all parties, is ensuring the concern is explored, fully understood, and where possible the objective is documented and agreed to by all stakeholders. Comcare identify poor communication being a key risk to psychological health at work. Most commonly from an Occupational Hygiene the objective is to increase risk awareness, however in these cases of risk perception the objective of risk communication is to reduce concerns about risk (or perceived risks) in other words, mitigate some of the outrage factors previously discussed.

Fischhoff notes the importance of opening up of communications quite nicely in the following quotes: 'Ones very willingness to talk sends a message', however 'if it becomes an issue... preceding silence may raise suspicion'. He further observed that 'people want to be treated respectfully in addition to being levelled with'. The vessel case study demonstrates how personnel during the communication phase could be satisfied with the facts as they were and a clear action plan of who and how the asbestos concerns could be dealt with, by engaging a competent person to assess and provide advice to Australian standards. Once a satisfactory action plan was in place workers were placated.

Promoting two way communications between the workers and management not only allows for information flow, but it also assists in fostering trust between the employee and their employer. Including and empowering workers through consultation can have a multitude of benefits. This is documented in several studies notably Bernhart, 1992 *'paying attention to stakeholders is that they are – by definition- in a position to influence the wellbeing of an organisation or the achievement of its objectives'* and evidenced by Boudier, 2010 *'trust building is best done before any crisis arises'*. The antithesis of this is also noted in Boudier 2010 work titled *'Can practitioners do better at risk communication? Using evidence to develop best practice'* in that bad or even worse no communication can further damage an already strained situation, he states *'poor risk communication to add fuel to risk controversies'*. This is certainly a statement that many Occupational Hygienists and Safety professionals can identify with. Pay attention to stakeholders *'mobilise, neutralise and defeat'* Brugha & Varvasivszky 2000 & Bernhart 1992.

To ensure effective dialogue, workers should be kept informed throughout the investigation process, for example after initial appraisal of the noted concern and consultation with concerned workers, the anticipated degree and timeliness of a response should be clearly outlined to align expectations for all stakeholders. Also not being afraid to openly discuss and explain the hazards and risks associated with any identified contaminants of concern demystifies or decatastrophise (reduces their catastrophic potential) of them, as well as increasing the stakeholders familiarly to them. As noted in the vessel case study, once the exposure routes to asbestos were explained and controls could be demonstrated that managed the risk of airborne fibre levels the concern was elevated (in conjunction with other works and effective communication).

**Observation #4:** To completely satisfy a concerned workforce hard evidence is required

Particularly where there is mistrust or conflict, an opinion – no matter how informed or educated it may be, will not cut it - hard evidence, data, tables, graphs are required! When certified and independent data can be presented showing concerns are under control, it often doesn't leave much room for counter argument. Obviously it is critical that the monitoring is appropriate, accurate, representative and repeatable; being accredited or conducted by qualified persons also adds weight. Noting the statement of independence, this does not always need to be an external entity, it could well be in-house technical expert, HSR or supervisor, as an example, but the importance is the *perceived* independence and competence to adequately perform the works.

There obviously can and always be the 'what about me, what about now' concern 'why wasn't my desk monitored', 'you monitored on Tuesday and the smell is always worse on a Friday'. This should as far as possible be addressed in the scoping of the works and ensure the old adage of 'measure twice, cut once' comes into play, although for Hygienists it is more like monitor twice and report once! Make sure assessment is 'representative' time & location, look for worst case results. Taking this observation through the lens of Covello and Sandman, generating a dataset or some other form of tangible evidence is trying to take away the uncertainty from our list of contributing outrage factors.

Looking at the odour issue empowering and involving the building user to assist in the monitoring, by providing them with a limited supply of charcoal badges that they could deploy as and when they sensed an occurrence resulted in only helped to bolster the 'experts' findings. Also this data was useful, albeit limited as it was now possible to *infer* but not confirm a potential cause, to be vehicular fumes, therefore demystifying the 'occurrence', the unknown was now a little less unknown.

To ensure communications can be complete and appropriate, it would be important to ensure the any assessment of risk is also. Occupational Hygienists are required to ensure there is adequate planning and scoping of the investigation and that any monitoring is 'representative' in time and location (where necessary consider worst case results also). Recalling the odour case study, when it was found that during the initial week of data logging there was not a reportable event, the cost benefit of rolling the monitoring on to a second week was immediately apparent and a great point to communicate to demonstrate how committed the company was to fully investigating and resolving the concern.

What has been outlined in our case studies and literature reviews can be summarised in so much that; effective communication needs to understand concerns and work to align the beliefs of the technical experts and the layperson, through trust building and clear and appropriate explanation and presentation of facts/data. Lay persons more readily understand probabilistic presentation, consideration of dataset and presentation. Define what safe means and put it in context, 'other' safe/similar levels – non-risk comparisons.

**Observation #5: Clear and appropriate presentation of facts/message to address stakeholders concerns**

Fischhoff 1995 stated 'Clearly communicating any number is a complicated task' 'telling much more than people need to know can be (and be seen as) deliberately unhelpful', the key is to bridge the gap between 'what people know and then need to know'. There is no benefit (in fact we are more likely to alienate our stakeholders) if we inundate them with scientific jargon or overly technical explanations. Simple communication tips such as placing simple message in the beginning of a text or communication and gradually increasing to the complex issues. In all cases using a technical expert and competent persons, with appropriate skills and qualifications is critical to producing a valuable monitoring strategy and dataset. However, this is not always the case for communicating the outcome. Ensure the report is appropriate for the audience.

Interestingly Fischhoff notes in his fourth development stage 'all we have to do is show them that they've accepted similar risks in the past' cautions heavily on the use of risk comparisons. It is the experience of the author that in cases of disproving a perceived risk and having conducted the steps noted above and having documented evidence to verify this, risk comparisons, or perhaps in this case more appropriately 'no-risk comparison' has been a powerful tool to demonstrate that 'building X or day 1 was no different to building Y or day 10'. An alternate way of framing this is that it is putting the data set in context, an easy to understand comparison, monitoring one building/workspace perceived to be 'safe' verses 'less safe' how does the data stack up?

'Research suggests that trust is more important for perceived risks... when people know little about a hazard' Siegrist and Cverkovich, 2000. 'Demonstrating expertise and knowledge is less effective in crisis situation since this affects confidence, which people then seem to rely on less than trust' Visschers & Siegrist, 2008.

Is education always the answer? Slovic et al noted 'New evidence appears reliable and informative if it is consistent with one's initial beliefs; contrary evidence tends to be dismissed as unreliable, erroneous or unrepresentative'. Individuals will actively seek out information that supports their view of the world. Another case study (not covered in this paper) an internet article, that was presented as a scientific paper, complete with references, bibliography was found by a concerned workforce and although it did not stand up to scientific scrutiny, the workforce used this as 'evidence' that their concerns were founded. On closer inspection the 'paper' was a sensationalised story written by a consulting business noting much needed additional monitoring work.

**Observation #6: Environmental factors** at play that may affect risk perception. **Amplification of risk** occurs and continues without direct and clear communications to counter.

Bockerman and Ilmakunnas 2006 demonstrated that job dissatisfaction can be directly related to adverse working conditions and a perception of unfair remuneration. Additional to this workers who are poorly informed about health hazards in the workplace are more likely to think that their health and safety is at risk. Lee, Scheufele & Lewenstein, noted 'strong emotional responses can limit the influence of new knowledge on people's attitudes towards risk'.

In the example of the vessel, there were a plethora of 'real' heavy duty hazards on (and off)-board: piracy, noise, radiation from non-destructive testing of pipes, heat stress in engine room, ergonomics, plant and machinery, deep sea divers, helicopter activities, however it was the somewhat more benign presence of a small amount of asbestos that became the emotive and critical subject. The irony being that some months later the vessel was actually involved in an incident with a tropical storm! Other case studies where building users are becoming increasingly disgruntled over demolition impacts from nearby construction: noise, vibration, traffic management etc. Complaining about the project will not illicit an effective outcome, but if one is to frame their concern around a health concern with regard to 'dust' and throw in the words asbestos and silica, will I get the option of me moving offices?

Rohrmann, 1996 defined risk perception as a 'social and cultural construction' as is evident in the case studies the environment can be a huge contributor to the workplace perception and satisfaction. Given that we must consider the role that peers, the media play in risk perception; consider the many media stories related to asbestos that have been in the press even in the last months. Example headlines that can easily be found on a quick media search would include: 'Kids Crayons laced with asbestos'; 'Thousands of brake pads containing deadly asbestos are being sold illegally'; and 'Traces of deadly asbestos have been found in roof panels imported from China'.

With such emotive language commonplace in the media, it is no wonder that the stock-standard response from a lay-person at the mention of asbestos is to be actively recoil. Add to that ever increasingly more empowered and educated workers, living in a society of 'where there's blame there's a claim'!

**Observation #7:** Response must be commercial *cost-benefit decision to employer*

As with many things taking proactive verses a reactive approach is often more cost effective in the longer term. In many cases it is cheaper to take the sample and demonstrate the result, rather than waste time and potential infuriate stakeholders by debating the potential outcome. It may be more cost effective to engage a specialist to conduct monitoring and write a report that states there are 'safe' readings for the telecoms tower that is fixed to the roof of their office building, even though you 'know' this is the case, rather than deal with the cost and negative press and potential back lash from employees who believe there is something to hide.

Fishcoff discusses communications as 'like an insurance policy. Fixed cost that can prevent future damage' that are most easily justified where there is a threat of catastrophic damage.

From a legal perspective there is of course the consideration of reasonably practicable. Was it reasonably practicable for the vessel to have a review of its Asbestos Register and accessible non-fixed or installed asbestos items remediated? Yes it was. Was it reasonably practicable for the vessel to have all asbestos items removed prior to entry to Australian waters? No it was demonstrated not to be.

Comcare identify poor communication being a key risk to psychological health at work, including: poor worker health, both physical and psychological; poor morale and erosion of worker loyalty and commitment; reduced efficiency, productivity, and profitability; poor public image and reputation; increased costs associated with counselling, worker assistance, mediation; increased absenteeism and staff turnover; increased costs with recruitment and training of new workers; and increased workers' compensation claims and legal costs.

## THE FUTURE

Based on the cost benefit outcome drivers we have discussed in the final observation, at a company level, what are the potential costs of either managing or not managing the outrage? Financial costs of conducting investigations and sampling, verses potential cost of absenteeism and potential reputational risk if they don't take workers concerns seriously and address them adequately.

It would be impracticable to ever attest that any workplace (or environment) could or would ever have assessment of all potentially perceived hazards, particularly given our understanding of how diverse risk perception can be. However as corporations and employers increasingly trend to risk adverse position, they will lean to having data and documentation that can place them in a legally defensible position. As such, the proactive assessment and monitoring of common place perceived workplace risks may be one aspect of the future of Occupational Hygiene.

However, considering the ever increasingly sophistication of 'big brother' tools, or facilities and building management systems, there is certainly an opportunity here. Having an easily accessible set of baseline data, to allow for high level performance of equipment such as heating, ventilation and air conditioning (HVAC) systems that could constitute a basic IAQ assessment and used as an early indicator to support or refute a health complaint, particularly in a more benign environment such as an office.

Fischhoff noted organisations require expertise in four fields to work: subject matter experts, risk and decision analysts, behavioural scientists, and communication professionals, in order to generate and deliver effective risk communications. It is suggested that given this paper looks at non-risk communications, the role of the Hygienist could be a one-stop shop. Based on scale of the problem and consideration of the audience, they will play a crucial role in the response team, or in some cases may *be* the response team. Looking at our case studies, in particular the vessel example, the Occupational Hygienist was best placed to work with the client representative to recognise, evaluate and communicate with the concerned workforce to alleviate their concerns.

## THE COMMON LAW AND OCCUPATIONAL HYGIENE – RESPONSIBILITY, ACCOUNTABILITY AND LIABILITY

*Michael Weller*

Workplace exposure standards prescribed in workplace health and safety regulations are often used to determine if exposures to hazardous agents are likely to be harmful to workers' health. Statutory obligations are usually considered satisfied if exposures do not exceed the workplace exposure standard notwithstanding the caveats associated with their use. However the obligations under the common law regarding exposure to hazardous agents are not so easily satisfied.

This paper examines some significant court judgements concerning negligent exposures to asbestos where defendants have included state entities, contractors and suppliers of asbestos products. In one noteworthy case the state of New South Wales was sued, albeit unsuccessfully, for failing to use its regulatory powers to prevent workplace exposures to asbestos. These judgements shed some light on the status of exposure standards and what should be considered, at the time of exposure, regarding the state of knowledge with respect to the health effects of the hazardous agent. The implications for contemporary exposure assessment and control are discussed using crystalline silica and diesel exhaust emissions as examples.

It is concluded that it is not enough, for a defence against a claim of damages resulting from negligent exposure, to demonstrate that exposures were below a workplace exposure standard. Furthermore, while the state is responsible for setting regulatory exposure standards it seems unlikely it will be held accountable when an exposure standard turns out to be insufficiently protective. Therefore exposure assessments will need to be able to withstand close scrutiny as issues of liability may arise when and if claims for damages are made.

### INTRODUCTION

The industrial and commercial use of asbestos has resulted in Australia's largest occupational health disaster. According to the Asbestos, Safety and Eradication Agency (2016) 19,427 additional cases of mesothelioma are predicted in Australia between 2015 and 2100, although the peak annual number of cases (712) occurred in 2015. Fifty eight per cent of these (11,264 cases) are attributed to the run-off of industrial exposures from the first and second waves, with the remaining forty two percent (8,163 cases) coming from the third wave (including background mesotheliomas). These figures do not include other asbestos related disease such as lung cancer.

Workers and others suffering from asbestos related disease turn to the courts to seek damages. Defendants in the claims for damages include industrial companies and government entities such as shipyards, power stations and railways (Jackson 2004 Annexure J p 118). With a focus on New South Wales (NSW) this paper examines: a) some significant asbestos related court judgements and the implications these have for contemporary exposure assessment, exposure standards and control; and b) the challenges these implications present to employers, health and safety professionals and in particular occupational hygienists.

### BACKGROUND

In NSW the Dust Diseases Tribunal (DDT) was established in 1989, exclusively to hear plaintiffs' cases for damages arising from negligence or breach of statutory duty from exposure to agents such as asbestos. It was established because plaintiffs often died before their cases could be heard (O'Meally 2007 p1213).

The tort of negligence comprises three elements

- "The defendant must have owed the plaintiff a duty of care;
- That duty must have been breached
- The breach must have caused damage to the plaintiff" (Sappideen, Vines and Watson 2012 p179).

The action for breach of statutory duty is different to the action for negligence as it is claim for a breach of a statutory duty which has resulted in the injury. An action for breach of statutory duty may not always be available; however the breach of a statute also provides evidence a defendant has been negligent (Sappideen, Vines and Watson 2012). Subsequently there is a vast amount of case law which examines the roles of employers, contractors, suppliers of asbestos containing products

and even the regulatory authorities responsible for enforcing the health and safety regulations. The courts in their judgements have had to determine the history of asbestos product manufacture and supply, its use and resultant exposures which have provided a valuable source of information, which perhaps would otherwise never have seen the light of day.

The question of reasonable foreseeability is central in determining whether a duty of care is owed and is always the first question asked, as it has been argued that if one cannot foresee a risk, one cannot avoid it. Consequently, without being able to consider the significance of the risk one cannot decide whether it should have been avoided (Sappideen, Vines and Watson 2012). Therefore in asbestos cases considerable effort has been made in establishing the knowledge defendants' had (or should have had) and in what period, regarding the risk from differing levels of exposure to different types of asbestos.

James Hardie and Company Pty. Ltd. was the dominant consumer of asbestos fibre for its manufactured asbestos products in Australia (Jackson 2004, Annexure J p121). It manufactured asbestos cement products until 1987 but it also manufactured insulation products from the 1930's until 1974, the latter years in a partnership with CSR known as Hardie-BI (Jackson 2004, Annexure J p123). These insulation products contained significant quantities of amosite fibre (*Berry v. Aultas Pty. Ltd & others 1997 DDT NSW CCR 266*), a well known potent carcinogen. It stands to reason that many of the claims against the company especially with respect to mesothelioma arose from worker exposure to these insulation products. The company undertook substantial restructures between 1995 and 1998 as part of further manufacturing expansion into the United States. The remnant James Hardie and Company Pty. Ltd. (hereafter referred to as James Hardie) changed its name to Amaca Pty. Ltd. in 2001, the company that was to retain the asbestos liabilities (Jackson 2004 Vol 1. p18).

Section 5 of the *Law Reform (Miscellaneous Provision) Act 1946* (NSW) proves to be particularly problematic for any previous supplier of asbestos product as it allows for parties to recover contributions for damages. If a worker sues an employer for damages resulting from asbestos exposure, the employer may sue the supplier of the product for the purpose of recovering contributions they made to the injured worker. Significantly the court has the power to exempt any person from liability to make such contributions (e.g. if such contributions would not be just or equitable), or to direct that the contribution to be recovered from any person shall amount to a complete indemnity. It is in this context that companies and government entities, being found to having negligently exposed their workers to asbestos, claimed financial contributions from asbestos product suppliers thus greatly magnifying their potential liabilities. For instance using "Amaca" as a search term in the "parties" field of the NSW Government case law website (2015), produces 213 cases involving James Hardie as a party to court proceedings.

### **Knowledge of the Asbestos Hazard**

In *State Rail Authority NSW v Wallaby Grip Ltd and another; Re Raynor [1999] NSW DDT 12* and *(Ampol Refineries NSW Pty. Ltd. v James Hardie and Co. Pty. Ltd. and another; Re Raynor [1999] NSW DDT 12)* the State Rail Authority (SRA) and Ampol were seeking financial recovery from Wallaby Grip Ltd, formerly known as Bells Asbestos and Engineering Ltd (Bells) and James Hardie. The plaintiff, the late Mr Bruce Raynor had contracted mesothelioma in 1995 and sued his employers the SRA of NSW (the successor to the NSW Railways) and Ampol, where he had been exposed to asbestos from the periods of 1938 to 1950 and 1954 to 1985 respectively (para 3).

Curtis J found that the state of NSW through the NSW Department of Health had actual knowledge of the dangers of asbestos from 1938. A Department of Occupational Health was established in NSW in 1932 and in 1938 the Director Dr Charles Badham, in his report to Parliament, discussed the asbestos hazard for workers manufacturing insulation materials (para 74). James Hardie sought to impute the state's knowledge of the hazards of asbestos to the SRA; on the basis it was indistinguishable from the state (para 75) thereby relieving James Hardie of any duty of care to the SRA employees (para 74). Ironically the SRA submitted it was the state, presumably because the crown was exempt from the relevant *Factories, Shops and Industries Act 1912* (NSW) (para 75) and so the SRA could not be held liable for any breach of statutory duty. However Curtis J stated that the SRA was not the crown, the Commissioner of Railways had been constituted as a corporation distinct from the crown (para 76) and the state may not be sued in respect of the Commissioner's actions. This is a key point as Curtis J stated that there was no evidence that the NSW Railways had actual knowledge of the dangers of visible clouds of asbestos dust between 1938 and 1950, while the state of NSW and Hardies did (para 108). From a laypersons perspective it is hard to reconcile why the Commissioner of Railways was considered to have had less knowledge of the hazards of asbestos than government departments.

In *Harlander Pty Limited (in liquidation) v State of New South Wales [2002] NSWCA 323* the plaintiff, the late Mrs Jane Edwards contracted mesothelioma while working between 1973 and 1975 as clerical support for a company called Harlander which supplied educational scientific equipment under contract to the NSW Education Department (para 5). Harlander occupied the same premises as a related company, Betta Industries Pty. Ltd. which manufactured asbestos mats for the NSW Education Department. The plaintiff spent about one and half hours each day in the premises used by Betta and successfully sued her employer and Wallaby Grip, the asbestos supplier (paras 5,6).

Harlander Pty. Ltd. unsuccessfully claimed against the State of NSW in the DDT and then appealed in the NSW Court of Appeal. Santow J stated that “the (asbestos) hazard was not appreciated at the time as extending to bystanders in the position of the plaintiff. So that extending the relevant duty to embrace the contiguous bystander simply fails to take account of the State’s limited knowledge of the hazard, insofar as the hazard is only now known to extend to such a bystander”(para 74).

In *Rolls Royce Industrial Power Ltd v James Hardie and Coy Pty. Ltd. Re: Hay No.4 [1999] NSW DDT 5* the late Mr Warren Hay had contracted mesothelioma, exposed during asbestos lagging although not a lagger himself, while working for John Thompson Industrial (now Rolls Royce Industrial Power). This was during the construction of boilers at the Wallerawang power station from 1958 to 1961 for the former Electricity Commission of NSW (now Pacific Power). The late WH had sued Rolls Royce and Pacific Power for breach of statutory duty and negligence, and these companies cross claimed against James Hardie as it supplied the asbestos insulation. With respect to the cross claim by Rolls Royce, James Hardie argued Rolls Royce as his employer knew of the dangers of asbestos so it did not owe a duty of care to the late WH (para 111) and that even if warnings on the dangers of asbestos had been supplied, no action would have been taken to prevent the exposure to asbestos insulation. This was evidenced by reports of dust readings taken by the NSW Department of Public Health (Division of Industrial Hygiene) which were forwarded to the John Thompson office at Wallerawang in which one reading was in excess of the international recommended workplace exposure standard of 5 million particles per cubic foot (5mppcf) (para 176). However no action was taken by the John Thompson site or project engineers. In the end the court found James Hardie and Rolls Royce were more or less equally culpable for the damage suffered by the late WH (para 161). According to Curtis J there were two major factors in the culpability of James Hardie: the first lay in its size and profitability with the capacity to widely publish warnings but which would compete against its desire to promote its products, and secondly the extent of its knowledge as to the reality of the risk faced by persons exposed to its products (para 125).

In *Dunning v BHP Billiton Limited [2014] NSW DDT 3* the plaintiff alleged that negligent exposure to asbestos while conducting work at the Newcastle steelworks between 1979 and 1981 resulted in his mesothelioma. The plaintiff also sued for breach of statutory duty. Kearns J stated that critical to the hearing was the extent of exposure to asbestos and the knowledge the defendant had or ought to have had on the dangers of asbestos (para 19). The defendant stated that the plaintiff was either not exposed to asbestos dust or only minimally, and that the risk of injury was not foreseeable (para 18). Kearns J disagreed on a number of matters, including that by 1979 there was knowledge that mesothelioma could be caused by asbestos other than crocidolite and that brief intermittent exposures could be dangerous (para 721). The defendant knew or ought to have known these facts.

### ***The Duty and Breach of Care***

Justice Beazley of the NSW Court of Appeal in *Wallaby Grip (Bae) Pty Limited (In Liq) v Macleay Area Health Service Matter No [1998] NSWSC 694* stated “a plaintiff can have considerable difficulty when suing multiple defendants in circumstances where it is unclear which defendant(s) may be liable”. In other words it is not sufficient for a plaintiff to identify that an exposure may have increased the risk of mesothelioma, but rather must prove on the balance of probabilities that the exposure was causative of the disease. In this case the NSW Court of Appeal upheld an appeal by *Wallaby Grip (Bae) Pty Limited (In Liq)*, arising from a decision in the DDT where although being the supplier of asbestos, its negligence could not be proven as the cause of the plaintiff’s disease.

At the initial trial in *State Rail Authority NSW v Wallaby Grip Ltd and another; Re Raynor [1999] NSW DDT 12* and *(Ampol Refineries NSW Pty. Ltd. v James Hardie and Co. Pty. Ltd. and another; Re Raynor [1999] NSW DDT 12)* the SRA and Ampol were found to be equally liable to the plaintiff. The SRA cross-claimed against Bells and James Hardie, suppliers of the asbestos insulation, who asserted in defence that exposure to asbestos merely increased the risk of contracting disease but they could not be held liable as the identity and source of the fibres causing the disease could not be determined.

Nevertheless Curtis J was of the view that the exposure concentration, the time since first exposure and duration of exposure led him to believe that it was the plaintiff's exposure at the SRA and not Ampol, which caused the late BR's mesothelioma (para 45).

In *Harlander* the appellant argued the state of NSW possessed the knowledge and power to issue a warning concerning the hazards of asbestos to Betta. The appellant produced a letter written by the Acting Director of the Division of Occupational Health, to the Boilermakers and Blacksmith's Association warning of the dangers associated with using asbestos, especially in confined spaces. The letter stated "generally speaking, the degree of disability due to asbestos will become noticeable after a lengthy period of exposure if the concentration of asbestos dust in the atmosphere exceeds the maximum allowable concentration" in reference to 5 mppcf (para 48). The reference to 5mppcf seems somewhat odd given the National Health and Medical Research Council (NHMRC) had recommended an asbestos exposure standard of 4 f/ml in 1970 (Leigh 2007).

The appellant contended that the plaintiff, the late JE, was amongst a class of people that the State owed a duty of care to. Santow J stated that the warning provided in Acting Director's letter was not "speaking to the situation involving the plaintiff, as an occasional bystander" but workers continually handling and working with asbestos materials (paras 63, 70) so the exposure scenarios were not comparable. Santow J stated that such a class of people would have included every employee in every manufacturing facility supplying asbestos products to the state of NSW and it could be logically questioned whether the duty could stop at that point, to not include everyone who worked in a factory manufacturing asbestos products (para 56).

James Hardie alleged In *James Hardie and Co. Pty. Ltd. v State of New South Wales: Re Hay No.4 DDT [1999] NSW DDT 5*, that if the State had been sued by the late WH (as distinct from the Electricity Commission of NSW) the state would have been found liable to him in negligence (para 10). Curtis J stated that the question to be answered was: did the state fail to discharge a duty owed to the late WH? James Hardie submitted that the state of NSW breached its duty towards the late WH because "it failed to exercise its statutory powers of direct interference with the liberties of the contractors at Wallerawang" (para 193) e.g. by not ensuring contractor compliance with the *Scaffolding and Lifts Act 1912* (NSW). It also failed to exercise its "prerogative powers to discharge a common law duty because of the relationship between the NSW government and the late WH" (para 194) e.g. by not following up and acting on the report of dust measurements.

The Scaffolding and Lifts Act regulated the work at the construction site which included ensuring controls were in place to "prevent the inhalation of dusts and fumes which may be injurious to health". Curtis J held that the Scaffolding and Lifts Act did not confer powers on the government to control risks at Wallerawang but it was the inspectors who had the power, but whom were "not subject to Ministerial control or direction in the performance of their duties" (para 231).

The manager at the Wallerawang power station construction site gave evidence that inspectors from the Department of Labour and Industry visited frequently. Curtis J stated that "it was reasonable to suppose that these inspectors did from time to time observe concentrations of visible dust, and men working without respiratory protection, which must have been in excess of the Dreessen Standard" i.e. 5 mppcf (para 168). This standard was based on a 1938 study in the United States asbestos textile industry where "clear cut cases of asbestosis did not occur below 5mppcf" however it was suggested as a tentative value (Dreessen at al 1938).

Significantly, the court held that it was not necessary to determine whether the state owed a duty to the late WH. This was because it would not be just and equitable for the state to contribute to the liability of James Hardie, because it was asking for such losses to be borne in part by the taxpayer and not from the profits of a commercial enterprise which had a greater knowledge of the dangers of asbestos (para 253). James Hardie appealed the DDT's decision in *James Hardie and Co. Pty. Ltd. v State of New South Wales: Re Hay No.4 DDT [1999]* in 2001. In dismissing the appeal, there was again no decision by the NSW Court of Appeal as to whether the state owed a duty of care to the plaintiff, the late WH.

In 2003 James Hardie was permitted to appeal to the High Court of Australia (*Amaca Pty. Ltd. (formerly known as James Hardie and Co. Pty. Ltd.) v State of New South Wales [2003] HCA 44*) which held that the trial judge made two errors regarding James Hardie seeking contributions from the state. The first, that James Hardie was a commercial enterprise and the state an entity raising its money from taxation, were not relevant considerations (para 19). Secondly, the High Court stated that "neither the duty nor the breach was identified with any particularity. Without identifying the duty owed and the breach or



breaches committed, it was not and is not possible to identify the extent of that party's responsibility for the damage" (para 20). As a result the High Court returned the case to the NSW Court of Appeal for it to determine whether the state owed a duty of care to the late WH.

Some five years after James Hardie had commenced its claim against the state of NSW, the NSW Court of Appeal in *Amaca Pty. Ltd. (formerly known as James Hardie and Co. Pty. Ltd.) v the State of NSW [2004] NSWCA 124* unanimously held in a thirty six page judgement that a "duty of care as contended for by James Hardie should not be imposed" on the state (para 11). The NSW Court of Appeal stated that the government inspectors were subject to Ministerial control and consequently the knowledge that the inspectors had of the hazards of exposure to asbestos could be attributed to the state (para 132 and 133). In finding against James Hardie the NSW Court of Appeal stated that, "generally a public authority which is under no statutory obligation to exercise a power owes no common law duty of care to do so" (para 140). Furthermore the Court referred to *Woolcock Street Investments Pty Ltd v CDG Pty Ltd (2004) HCA 16* where the High Court stated that; "in determining whether the common law should recognise a duty of care, the possibility that its recognition might lead to a flood of claims is a ground for rejecting the existence of the duty" (para 158) and "the common law has always been reluctant to impose a duty to control others" (para 159).

The defendant, in *Dunning v BHP Billiton Limited [2014] NSW DDT 3*, relied on a defence of there being no evidence the NHMRC recommended exposure for asbestos had been exceeded. It argued that the risk of exposure had not been quantified and therefore the injury was not reasonably foreseeable (para 734), and the plaintiff had not demonstrated exposures were in excess of the NHMRC recommended exposure standard. According to the defendant the NHMRC asbestos exposure standard was the authoritative document and that a competent occupational hygienist would not have advised that a worker could not be exposed to any asbestos (para 707). Kearns J stated that another competent hygienist "might have advised that it was courting disaster to merely comply with the standard (para 710) and there was no scientific consensus that one could be exposed to asbestos within the standard and not be at risk of injury" (para 736). In fact Kearns J implies that "the hypothetical hygienist the defendant was relying on must have been a minimally qualified one" (para 711). Kearns J stated that by 1979 it was known that there were no known safe levels of exposure to asbestos and that "doubts, if not outright rejection, were being expressed about the ability of standards to deal with carcinogenic illness" (para 712).

Kearns J referred to Lord Dyson in *Baker v Quantum Clothing Group Limited and others [2011] UK SC 17*. Lord Dyson stated that "there is no rule of law that a relevant code of practice or other official or regulatory instrument necessarily sets the standard of care for the tort of negligence". Compliance with a standard or code will often afford a defence to a claim of negligence but there are circumstances where it will not:

"For example it may be shown that the code of practice or regulatory instrument is compromised because the standard that it requires have been lowered as a result of heavy lobbying by interested parties; or because it covers a field in which apathy and fatalism has prevailed amongst workers, trade unions, employers and legislators; or because the instrument has failed to keep abreast of the latest technology and scientific understanding" (para 101).

The court in *Dunning v BHP Billiton Limited [2014] NSW DDT 3* concluded that "the (NHMRC) standard did not have a status that trumped all other information" (para 720).

The defendant also argued that it did not breach the Factories, Shops and Industries Act because the reference to the requirement to prevent the "accumulation of dust and fumes, injurious to health in any workroom", needed to be read in context of the subsection which allows the regulations to impose a maximum concentration for any dust or fume. That is, if the concentration was below the limit then it followed that the level of accumulation of dust or fume was not deemed injurious to health. However Kearns J disagreed, stating that the latter was not to be qualified by the former and held that the defendant had breached its statutory duty. This decision in the DDT was later appealed by the defendant without success in *BHP Billiton Ltd. v Dunning (2015) NSWCA 42*.

In *James Hardie and Co. Pty. Ltd. v State of New South Wales: Re Hay No.4 DDT [1999]* Curtis J elaborated on the resources and knowledge of the NSW Department of Health's Division of Industrial Hygiene. A Division of Industrial Hygiene report of dust sampling taken during the installation of the insulation at Wallerawang power station showed results ranging from 1.5 mppcf to 13 mppcf, but mostly below 5 mppcf. A copy of this report was provided to a Mr Bill Slade an inspector appointed

under the Factories, Shops and Industries Act and the Scaffolding and Lifts Act (para 179). According to Curtis J the above facts, inter alia, demonstrated that during this time it was beyond any doubt that the state of NSW knew that exposures in excess of the Dreessen standard were harmful (para 183).

James Hardie submitted that Mr Slade's knowledge of asbestos together with the dust sampling report should have put Mr Slade on notice as to the seriousness and risk of the situation. Curtis J concluded that while the report revealed breaches of the regulations, it only identified a risk for ladders among whose number the late WH was *not* included (author emphasis in italics). While Curtis J accepted that workers other than ladders may be exposed to harmful levels of dust in excess of the Dreessen standard, the report did not put Mr Slade on notice that the workers might be repeatedly exposed over a number of years to harmful levels of dust (para 238). He stated that while it was careless for Mr. Slade not to have arranged for inspectors to follow up on the report which required only minimal effort, the circumstances of the situation did not warrant his intervention using the statutory powers available under the Scaffolding and Lifts Act (paras 238 & 239). Curtis's J reasoning that the state had a diminished responsibility to intervene because the late WH's exposure was lower than the other workers and not in breach of the regulations, seems paradoxical. At what level of exposure to airborne asbestos did the court consider it serious enough to require intervention by the state, even if only for the sake of the ladders?

### ***Implications for Exposure Assessment***

#### **The Foreseeability of Harm**

Part of the exposure assessment paradigm involves determining the likely health effects of exposure to a hazardous agent based on current knowledge. However the case law demonstrates that there are some significant challenges when evaluating potential health effects. When a claim is made for negligence a plaintiff must establish that injury was reasonably foreseeable, although it is not necessary for the defendant to have foreseen the particular injury (Briggs 1997). The court in *Dunning* held that it was not necessary for the plaintiff to prove that it was foreseeable that mesothelioma would result, only that some sort of injury may arise (para 723). In *Raynor and Hay*, the court found in favour of the plaintiffs suffering from mesothelioma but their periods of tortious exposure to amosite had ceased by 1950 and 1961 respectively. The earliest definitive reports of an association between mesothelioma and asbestos were from 1959 to 1960, and then almost exclusively to crocidolite (Leigh 2007). Therefore the risk of contracting mesothelioma from exposure to amosite could not possibly have been foreseen prior to about 1960.

This seems to run counter to the principle that one needs to be able to judge the significance of the risk if one is to choose whether it should be avoided. It therefore presents a practical problem in terms of recommending control measures according to the paradigm of exposure assessment and control. For example crystalline silica is a relatively common workplace contaminant which is similar to asbestos in the sense that its ability to cause pneumoconiosis was recognised before it was classified as a lung carcinogen. Silicosis is recognised as one of the oldest known occupational diseases (Bagchi 1992) and crystalline silica was classified as a Group 1 human carcinogen by the International Agency for Research on Cancer in 1997 (IARC 1997) and a Group 2A probable human carcinogen in 1987 (IARC 1987). Consequently in a negligence case for silica induced lung cancer, it would be no defence to argue that controls introduced prior to 1987 were designed with the intention of preventing silicosis because the risk of lung cancer, assuming a lower exposure threshold, was not foreseeable.

#### **Responsibility and Accountability for Workplace Exposure Standards**

Workplace exposure standards play a central role in the risk assessment of working with hazardous agents. Clause 49 of the national model Work Health and Safety (WHS) Regulation 2011 states that "no person must be exposed to a substance or mixture that exceeds its workplace exposure standard". Typically compliance by an employer with a workplace exposure standard will satisfy any regulatory intervention, notwithstanding that the model WHS Act 2011 requires risks to be reduced to as low as reasonably practical. It's probably fair to say that should an occupational hygienist declare compliance with an exposure standard, then in most cases no significant action or major control measures would be recommended.

The problem is that exposure standards do vary over time and by jurisdiction. This predicament can be illustrated by crystalline silica and another relatively common workplace contaminant, diesel exhaust emissions. The Safe Work Australia (SWA) (2013) workplace exposure standard for crystalline silica of  $0.1 \text{ mg/m}^3 \text{ TWA-8hr}$  has a long history initially designed to protect against silicosis. The Australian value over the last few decades has been higher than published values from the

American Conference of Governmental Industrial Hygienists (ACGIH) and the United States National Institute of Occupational Safety and Health (NIOSH). The NHMRC in 1978 recommended a workplace exposure standard of  $0.2 \text{ mg/m}^3 \text{ TWA-8hr}$  for crystalline silica (quartz) but it was not a regulatory standard (Division Workplace Health and Safety Queensland 2005). It was only in 2005 that the workplace exposure standard for crystalline silica (respirable quartz) was reduced to  $0.1 \text{ mg/m}^3 \text{ TWA-8hr}$  (SWA 2015). In contrast the ACGIH had established a Threshold Limit Value (TLV) of  $0.1 \text{ mg/m}^3 \text{ TWA-8hr}$  (quartz as respirable dust) in 1986 but by 2006 had reduced it to  $0.025 \text{ mg/m}^3 \text{ TWA-8hr}$  (ACGIH 2012). Compare these values to the NIOSH Recommended Exposure Limit (REL) for crystalline silica of  $0.05 \text{ mg/m}^3 \text{ TWA-8hr}$  established as early as 1974 (NIOSH 2012).

Diesel exhaust emissions were classified as a Group 1 human carcinogen in 2012 (IARC 2012) yet no SWA workplace exposure standard exists at all under the model WHS Regulation 2011. A value of  $0.1 \text{ mg/m}^3 \text{ TWA-8hr}$  for diesel particulate matter (measured as submicron elemental carbon) has been recommended in some mining jurisdictions (NSW Dept. of Primary Industries 2008, Western Australia Dept. Mines and Petroleum 2013) and is also used in general industry. However Vermeulen et al (2014) cast doubt on the degree of protection afforded by an exposure standard of  $0.1 \text{ mg/m}^3 \text{ TWA-8hr}$  with respect to lung cancer. The U.K Health and Safety Executive (2014) have not set a Workplace Exposure Limit (WEL) for diesel exhaust emissions citing “insufficient data for a range of health outcomes”.

The recent reporting of cases of coal workers’ pneumoconiosis in Queensland (QLD) has highlighted the difference between the NSW and QLD mine safety exposure standards for respirable coal dust of  $2.5 \text{ mg/m}^3 \text{ TWA-8hr}$  (WHS Mine Safety Regulation 2014, NSW) and  $3.0 \text{ mg/m}^3 \text{ TWA-8hr}$  (Coal Mining Safety and Health Regulation 2001, QLD) respectively. It is not known by the writer whether any of the affected workers were exposed in excess of the standard, but regardless of this, the workers’ could sue for negligent exposure to the coal dust which resulted in their injury (Workcover QLD 2016). In 1995 NIOSH reviewed data and found the United States federal mandated  $2.0 \text{ mg/m}^3$  exposure limit for coal dust to be too high and recommended an exposure limit of  $1.0 \text{ mg/m}^3$  based on a 40 year working lifetime (NIOSH 2011).

The question then arises, who is to be held accountable if an exposure standard turns to be insufficiently protective resulting in occupational disease? The *Dunning* case highlighted that no single standard can necessarily be considered the authoritative one. The court in *James Hardie* held that the state did not owe a duty of care to workers exposed to asbestos on a construction site, when its labour inspectors had actual knowledge of, and the power to prevent the hazardous exposures. The *Harlander* case showed that the state through the Acting Director of the NSW Division of Occupational Health endorsed a 5 mppcf asbestos exposure standard in November 1972, and that lung cancer and mesothelioma were likely to only arise in sufferers of asbestosis; implying that brief or irregular but significant exposures were acceptable.

## CONCLUSION

The courts have subscribed to the notion that there is generally no safe level of exposure to asbestos in relation to mesothelioma and the disease is nearly always attributed to asbestos exposure (Stapleton 2010). Although this places asbestos into a category of hazardous agent which is probably atypical of most occupational exposures, the judgements in this paper when viewed together make it seem unlikely courts will hold the State accountable where current regulatory workplace exposure standards prove to be insufficiently protective. This is because the courts have not placed a great deal of weight on their relevance, and in any event, the courts appear reluctant to impose a duty of care on the state where they deem the outcome to be not just or equitable.

Employers and contractors as principal duty holders can be held liable for any negligent exposures resulting in injury to their workers or subcontractors. If an employer has relied on the advice of an occupational hygienist that little or no further action was required based on compliance with an exposure standard, could liability then become an issue for the hygienist? There appears to be no reason why the occupational hygienist would be considered differently to other professionals providing services. Where there is no contract there is an implied term that a professional will exercise reasonable care and skill and that concurrent liabilities in both contract and tort may exist. On the other hand a contract can effect the standard of care at tort (Zipser 1999).

It is recommended, especially for agents such as carcinogens, that occupational hygienists do not solely rely on workplace exposure standards when assessing exposures and recommending controls. It would be prudent for the occupational hygienist to assess exposures in the context of any uncertainty (local and international) surrounding the health effects and

any workplace exposure standards, when weighing up the options for control measures. While it could be argued this is standard occupational hygiene practice the common law experience to date might suggest otherwise.

### **Conflict of Interest**

The author was employed by James Hardie and Company Pty. Ltd. from 1986 to 1996 and holds shares in James Hardie Industries plc.

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## HYGIENE THAT WORKS, OR MAKES US WORK?

### EXAMINING THE “WORK OF BREATHING” THROUGH NEGATIVE PRESSURE RESPIRATORS.

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#### ABSTRACT

Respiratory protective devices (RPD) are commonly used to protect workers against the health effects of many substances including carcinogenic substances such as lead, silica and diesel particulate emissions; even though they are the lowest order in the Hierarchy of Control and require careful selection, fit, training and maintenance.

AS/NZS 1715: 2009 and AS/NZS 1716:2012 have provided guidance for manufacturers and end users on factors affecting performance such as filtration efficiency, filter resistance and user fit; however little has been done on useability.

A recent series of studies on negative pressure RPD's at the University of Wollongong are informing the current development of a suite of ISO standards anticipated to be adopted by Standards Australia in the near future.

The new ISO standards (Draft ISO 16975 RPDs- Selection, use and maintenance) introduces the concept of adding measured work rates to the selection criteria.

A significant gap in the research is that the physiological burden of respirator use in heavy industry, and the workplace evaluation of real time breathing rates for negative pressure respirators has not been conducted in the field.

This paper outlines the laboratory based studies conducted to date, examines the transferability of the findings to industrial settings, and identifies the information that Hygienists require to make informed decisions when recommending RPD's.

## TRIAL OF A BARRIER CREAM TO REDUCE COAL TAR PITCH EXPOSURE IN A GREEN CARBON PLANT

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### ABSTRACT

Poly Aromatic Hydrocarbons (PAHs) associated with Coal Tar Pitch Volatiles (CTPV) have been confirmed as human carcinogens by the International Agency for Research on Cancer (IARC). Despite the potential for CPTV exposure via inhalation, ingestion and skin absorption, to date Occupational Exposure Limits (OELs) only exist for airborne CTPV contaminants.

Biological monitoring of 1-hydroxypyrene was used to assess the total body burden of CTPV in green anode manufacturing plant workers. Results of 1-hydroxypyrene monitoring across years 1 to 4 showed the total CTPV body burden in workers was above guideline health values.

An additional control intervention commenced at the end of year 4, described herein as the "trial" year. The trial involved the use of a dry barrier cream in addition to the existing controls in place. This paper outlines the result of the trial of the barrier cream.

During operations the 1-hydroxypyrene in urine 95<sup>th</sup>ile decreased from 11.5  $\mu\text{mol/mol}$  in year 4 to 7.64  $\mu\text{mol/mol}$  (34% reduction) in the trial. The geometric mean decreased from 3.85  $\mu\text{mol/mol}$  in year 4 to 2.54  $\mu\text{mol/mol}$  (34% reduction) in the trial. The standard deviation decreased from 4.26 in year 4 to 2.71 in the trial.

During shut down operations the 1-hydroxypyrene in urine 95<sup>th</sup>ile decreased from 4.96  $\mu\text{mol/mol}$  in year 4 to 2.92  $\mu\text{mol/mol}$  (67% reduction) in the trial. The geometric mean decreased from 2.86  $\mu\text{mol/mol}$  in year 4 to 1.86  $\mu\text{mol/mol}$  (50% reduction) in the trial. The standard deviation decreased from 1.3 in year 4 to 0.8 in the trial.

Although worker skin assessment using fluorescence showed that skin contact with CTPV was still occurring during the trial, the study showed that the use of the dry barrier cream as an additional control reduced the total body burden as measured as 1-hydroxypyrene in urine levels of both operators during operation and shut down operations in the green anode manufacturing plant. The addition of the barrier cream resulted in the geomean being below the guideline level of 4  $\mu\text{mol/mol}$ .

### KEYWORDS

Barrier cream, coal tar pitch (CTP), green carbon plant, green anode, 1-hydroxypyrene,

### INTRODUCTION

Green anodes are manufactured in green anode plants as a part of the aluminium smelting process. Coal tar pitch (CTP) is used as a binding agent in the manufacturing of green anodes. CTP is classified as a confirmed human carcinogen (A1)<sup>1</sup> and classified as a Hazardous substance according to Worksafe Australia<sup>7</sup>. During the tasks carried out in the manufacturing of the green anode (operating conditions) and breakdown/shutdown (non-operating conditions) there is potential for operator exposure to the CTP through inhalation of the volatiles, ingestion through contaminated hands and eating/smoking and absorption through the skin from skin contamination. At the plant where the trial was conducted, the green anode plant is typically run by two (2) operators per shift. Typically one operator manages the green anode production in the control room and the other operator performs the daily plant tasks. Typically the operators rotate each shift between control room and the plant. The operator role when the plant is operating includes control room operation, sampling, cleaning and unplanned breakdown maintenance. The operator role when the plant is shutdown includes cleaning (sweeping, hosing, blowing down, and steam cleaning), equipment maintenance and the back loading of anodes.

To control operator exposure, there is a CTP Management Plan in place which outlines a number of controls implemented, ranging from engineering through to personal protective equipment (PPE). One control that was in place was a wet barrier cream. From observation and interviews of operators it was determined that the wet barrier cream was not being used as it was not practicable. Being wet, it was very difficult to hold/use tools in the plant to conduct required tasks, had to be wiped off and re applied frequently, and as a result operators stopped using it.

An annual monitoring program is in place to measure airborne and biological exposures and effectiveness of the controls. Biological monitoring and skin staining testing results showed that dermal exposure was still occurring with the controls in place. Four years of data was collected prior to the trial of the new dry barrier cream.

## PURPOSE

The purpose of the study was to determine if the addition of the use of a dry barrier cream in conjunction with the other implemented controls would reduce the worker dermal exposure to coal tar pitch volatiles (CTPV) as measured by biological monitoring.

## DEFINITIONS

Green anode – blocks of green anode are produced from calcined petroleum coke, recycled green and baked anode scrap. Liquid coal tar pitch is added as binder utilizing a fully automated process. The carbon materials are continuously mixed to produce homogenous paste before molding it into green anode blocks on vibrocompacting machines. Once formed are transferred to the carbon bake for further processing.

Barrier cream – a cream used to place a physical barrier between the skin and contaminant to protect the skin from damage or infection. A wet barrier cream is a cream which does not dry after being applied to the skin.

Coal tar pitch (CTP) – the residue from distillation of coal tar. Most commonly it is tar derived from a coke oven, and the pitch is referred to as coal tar pitch. CTP is used as the binding agent in green anodes. CTP is also referred to as anode binder pitch, electrode binder pitch, and liquid pitch<sup>3</sup>.

Coal tar pitch volatiles (CTPV) - are composed of various chemical vapors that become airborne during the heating of coal tar pitch. Synonyms for CTPVs vary depending upon the specific compound (e.g., pyrene, phenanthrene, acridine, chrysene, anthracene and benzo(a)pyrene).

Green carbon plant – Plant where green anodes are manufactured for smelting activity.

1-hydroxypyrene – an excretory metabolite of pyrene in urine, used as a biological monitoring indicator of exposure to Poly Aromatic Hydrocarbons (PAHs).

## OPERATOR EXPOSURE

During the tasks carried out in the manufacturing of the green anode (operating conditions) and breakdown/shutdown (non-operating conditions) there is potential for operator exposure to the CTP through inhalation of the volatiles, ingestion through contaminated hands and eating/smoking and absorption through the skin from skin contamination. CTP is classified as a confirmed human carcinogen (A1)<sup>1</sup> and classified as a Hazardous substance according to Worksafe Australia (Risk phrases R36, 37, 38, 43, 45, 46, 60, 61, 68)<sup>7</sup>.

## EXPOSURE CONTROLS

To control operator exposure, there is a CTP Management Plan in place which outlines a number of controls implemented, ranging from engineering through to personal protective equipment (PPE). Controls implemented include enclosed ball mills, extraction systems to capture and filter particulate/vapours (including scheduled maintenance) from mixers/vibrocompacting machines, sealed controls rooms, during shift and post shift shower facilities with dirty/clean sides to avoid contamination, company cleaning of each shift work clothes (no work clothing to be taken home), housekeeping practices, inspections (e.g. leak prevention), maintenance, education and awareness on exposure hazards/controls, standard operating procedures, medical surveillance, coveralls, gloves, long sleeve cotton shirts/pants, ankle high boots, wet barrier cream, reusable respiratory protection with quantitative face fit testing.

## BARRIER CREAM

The barrier cream used for the study was a non-hazardous white lotion which dries on application to the skin. The ingredients are outlined below in Table 1.



Table 1: Barrier Cream Ingredients

INGREDIENT (INCL NAME)	FUNCTION	CAS#
Purified Water (Aqua)	Solvent	7732-18-5
Dimethicone	Film Forming Agent	9006-65-9
Stearic Acid	Emulsifier	822-16-2
Glycerin	Humectant	56-81-5
Cetyl Alcohol	Co-emulsifier	36653-82-4
Isopropyl Myristate	Emollient	110-27-0
Stearyl Alcohol	Co-emulsifier	112-92-5
Triethanolamine	pH adjuster	102-71-6
Xanthan Gum	Stabilizer	11138-66-2
Hypromellose	Film Former	9004-65-3
VP/Eicosene Copolymer	Film Former	28211-18-9, 77035-98-4
Steareth-21	Emulsifier	9005-00-9
Phenoxyethanol	Preservative	122-99-6

Figure 1 provides a visual representation of the function of a barrier cream on the skin (Reproduced with permission of blubutterflynailtips.com).

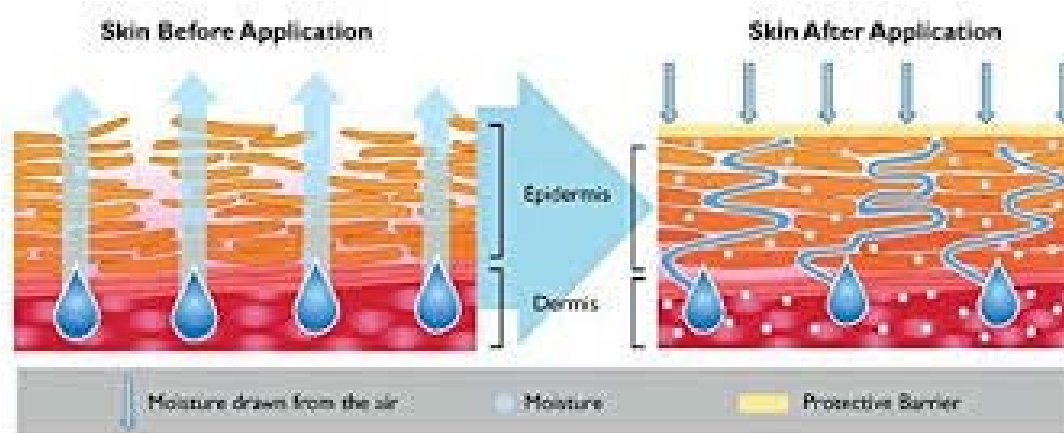


Figure 1: Barrier cream function on skin

## METHOD

Pre and Post urine samples were collected in accordance with the ACGIH<sup>1</sup>. Urine samples analysed according to WorkCover Authority NSW Method WCA 102, by high performance liquid chromatography with fluorescence, ultra-violet wavelength, electrochemical or conductivity detection<sup>7</sup> for 1-hydroxypyrene.

## METHODOLOGY

The trial with the barrier cream was conducted over six shift rotations on two male operators from the same shift. The trial was conducted during normal operating, shutdown and operating shifts where unplanned breakdowns occurred during the operating shift. The trial was conducted across shifts representative of the standard operational conditions (operating and non-operating).

The procedure carried out by operators for the trial:

- 1) Pre shift urine at start of first shift provided;

- 2) At start of shift, hands washed completely, a small amount of barrier cream applied (approx. 5 mL) and work in well to all exposed areas (hands, lower arms, neck and face [watch to not get any in eyes]) and allowed to dry completely
- 3) Reapplied every 4hrs for the entire shift (3 applications, start of shift, after 4hrs, after 8hrs);
- 4) Step 2 & 3 repeated each day while on shift
- 5) Activity log sheets filled out daily, outlining activities completed and timing;
- 6) Post last shift urine, after post shift shower

The pre shift and post shift urine samples were collected and analysed for 1-hydroxypyrene in urine, a suitable biological marker for exposures to polynuclear aromatic hydrocarbons.

Post shift skin staining detected by fluorescence was also carried out to visibly assess the staining of the skin from exposure in Green Carbon during the shift.

1-hydroxypyrene results were analysed using the AIHA ISTAT+ program<sup>2</sup> descriptive statistics, results were compared to pre-trial results and guidance/trigger values to determine if the addition of the dry barrier cream reduced dermal absorption.

#### BIOLOGICAL EXPOSURE INDICE (BEI)

There has been significant research conducted into PAH absorption<sup>7,8</sup>. There is no defined BEI for polycyclic aromatic hydrocarbons measured as 1-hydroxypyrene in urine due to insufficient data<sup>1</sup>.

#### LIMITATIONS

Limitations of the trial included a small sample size (Two operators, total 15 samples where dry barrier cream was used). Both participants were smokers.

#### RESULTS

The operators used the barrier cream as per the outlined methodology. As it was a dry based cream, easy to put on and only required to be put on 3 times per shift, operator acceptance was high and the benefit of it as an additional control was accepted.

The results are displayed graphically in Figures 2-4.

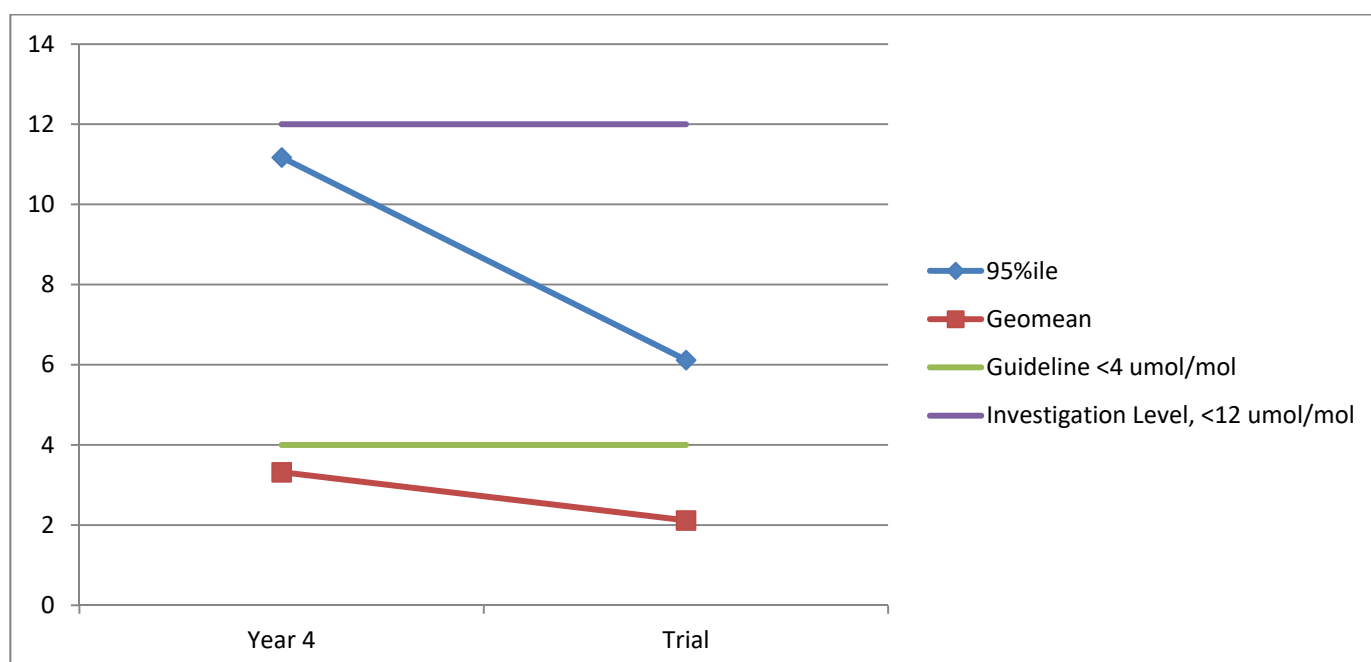


Figure 2: 1-hydroxypyrene in urine results – All operations (operating and shutdown combined)

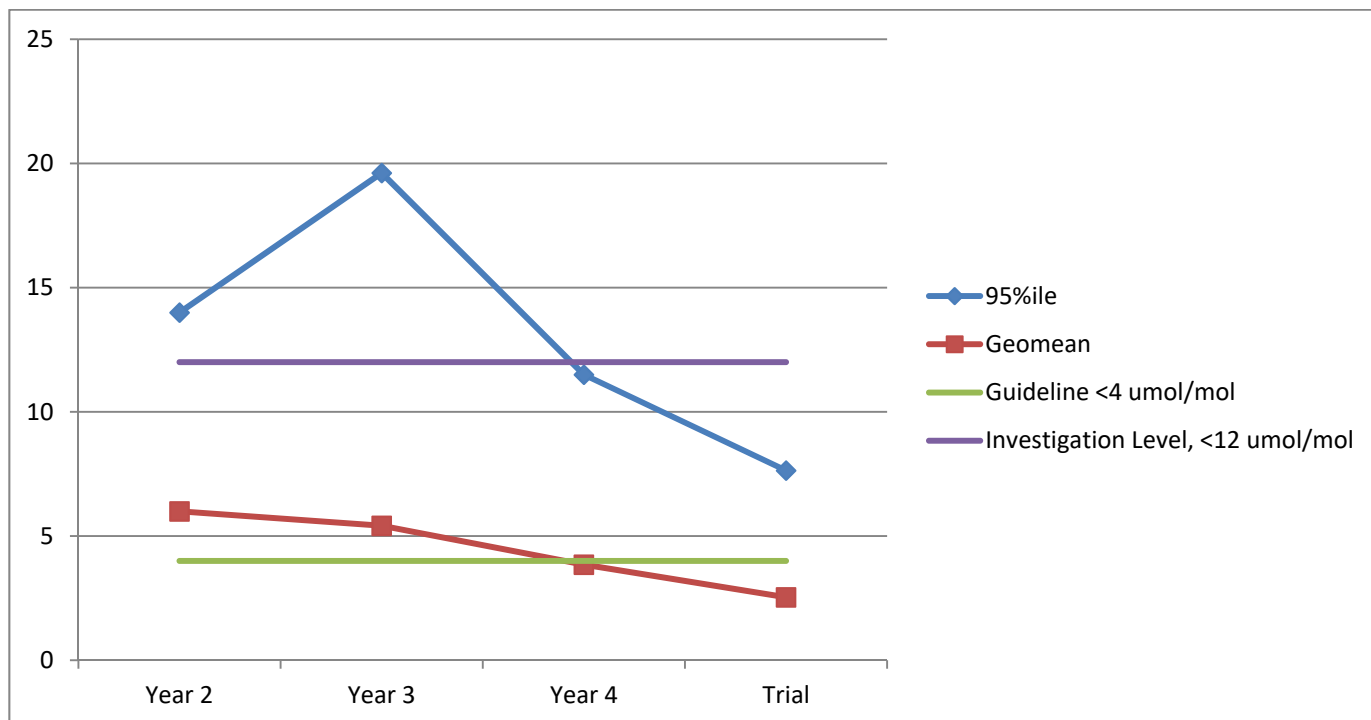


Figure 3: 1-hydroxypyrene in urine results – Operating

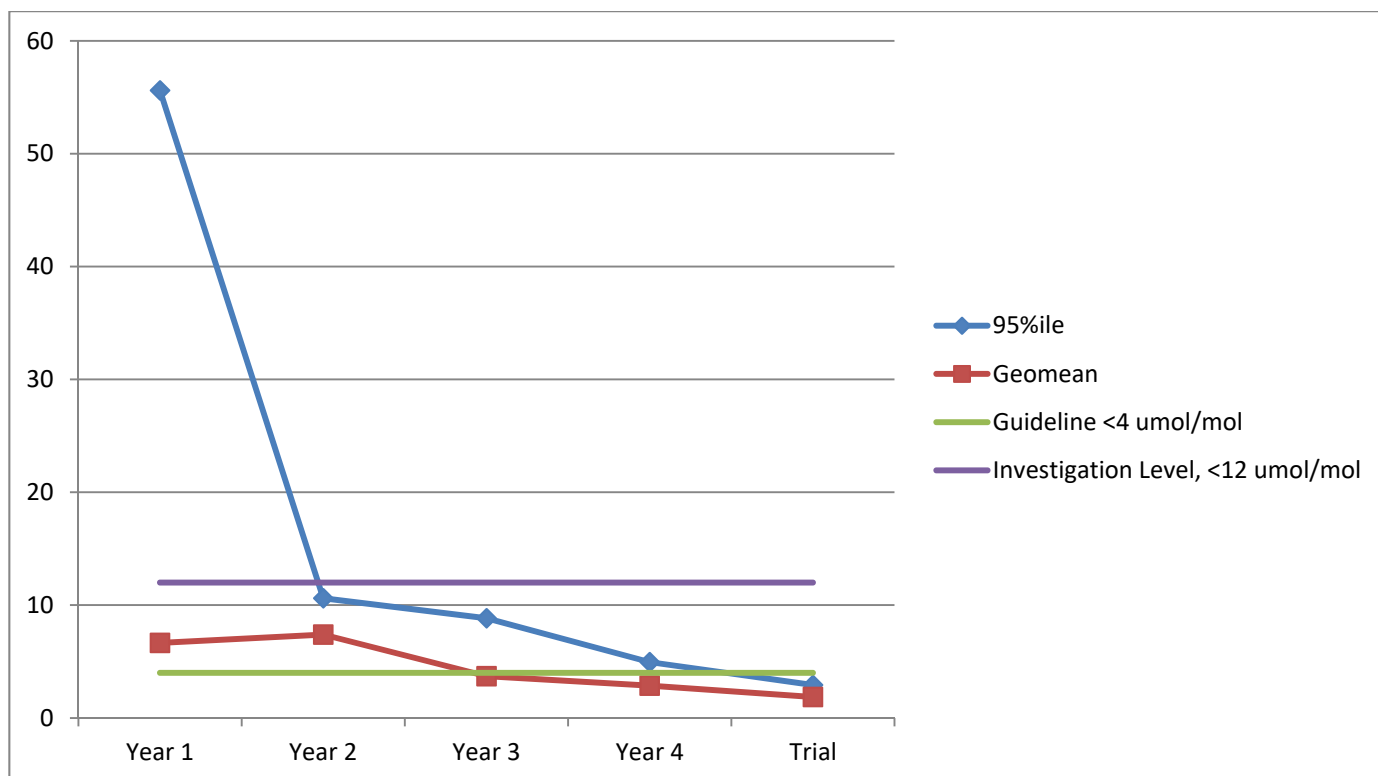


Figure 4: 1-hydroxypyrene in urine results – Shutdown

## DISCUSSION

The study showed that the use of the dry barrier cream as an additional control reduced the 1-hydroxypyrene in urine levels of both operators during operation and shut down operations in the green anode manufacturing plant. The addition of the barrier cream resulted in the geomean being below the guideline level of 4  $\mu\text{mol/mol}$ .

During operations the 1-hydroxypyrene in urine 95<sup>th</sup>ile decreased from 11.5 µmol/mol in year 4 to 7.64 µmol/mol (34% reduction) in the trial. The geometric mean decreased from 3.85 µmol/mol in year 4 to 2.54 µmol/mol (34% reduction) in the trial. The standard deviation decreased from 4.26 in year 4 to 2.71 in the trial.

During shut down operations the 1-hydroxypyrene in urine 95<sup>th</sup>ile decreased from 4.96 µmol/mol in year 4 to 2.92 µmol/mol (67% reduction) in the trial. The geometric mean decreased from 2.86 µmol/mol in year 4 to 1.86 µmol/mol (50% reduction) in the trial. The standard deviation decreased from 1.3 in year 4 to 0.8 in the trial.

For all results (operating and shutdown) the 1-hydroxypyrene in urine 95<sup>th</sup>ile decreased from 11.2 µmol/mol in year 4 to 6.12 µmol/mol (45% reduction) in the trial. The geometric mean decreased from 3.32 µmol/mol in year 4 to 2.12 µmol/mol (36% reduction) in the trial.

The standard deviation (variability) of the results for the trial for both operating and shutdown were reduced in comparison to previous monitoring, significantly for the shutdown operations, suggesting that skin absorption of CTP was varied prior to the use of barrier cream.

## CONCLUSION

The trial of a dry barrier cream as an additional control showed decreases in dermal exposure and total body burden of CTPV to the workers and as measured as 1-hydroxypyrene in urine. The trial showed the addition of the dry barrier cream as a control was effective in reducing the exposure to the workers.

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## POSTER ABSTRACTS & PAPERS

### COMPARISON OF APPROACHES FOR CAPTURE AND IDENTIFICATION OF VIABLE AIRBORNE PATHOGENIC BACTERIA IN A ROCKMELON PROCESSING PLANT

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Colorado State University; Edith Cowan University; University of Wyoming and McGill University

There is a need for methods that rapidly trace the source and transmission of foodborne pathogens, as well as assessing potential health risks for spread of infectious microorganisms in occupational environments. The aim of this pilot study was to investigate a rapid method for the collection and identification of viable airborne pathogenic bacteria. The method incorporated NIOSH BC-251 bioaerosol samplers loaded with a resuscitation buffer for collection of viable cells, selective and differential plating media and rapid molecular analysis by Ribotyping and matrix-assisted laser desorption ionization time-of-flight (MALDI-TOF) mass spectrometry (MS) couple with MALDI Biotyping software for microbial identification/characterization. Sampling was undertaken inside a cantaloupe sorting shed. Samples were plated on CHROMagar O157, CHROMagar Salmonella, RAPID L'Mono, phenylethanol moxalactam, MaConkey, trypticase soy agar modified with 5% sodium chloride, followed by isolation of presumptive pathogens on TSA prior to analysis. The method was successful in the capture and identification opportunistic human pathogens (*Pantoea agglomerans*, *Enterobacter cloacae* and *Pseudomonas stutzeri*). However, none of the target pathogens (*Escherichia coli* O157, *Salmonella* spp. and *Listeria* sp.) were detected. MALDI Biotyping was the preferred analytical approach because it typically provides superior taxonomic resolution, can analyse a greater number of isolates in the same amount of time and is a fraction of the cost of Ribotyping. The study found that the BC-251 is an ideal alternative to impingers and cascade impactors for sampling viable and culturable bacteria due to its adaptability for both personal and area of sampling, and that MALDI Biotyping superior to Ribotyping.

## RNA EXTRACTION: LESSONS FROM A LOST SUMMER

*Maggie Davidson, PhD MAIOH*

Colorado State University and Edith Cowan University

The Rhino-probe™ has been widely used in clinical occupational epidemiology to collect nasal cell samples to evaluate proinflammatory responses to inhalable particulates. The nasal curette has been reported to be a more consistent sampling device, providing greater cell quantities, than cytology brushes or nasal lavage. This presentation will be on the lessons learnt from QC/QA trials undertaken to optimise RNA yields for field samples that had previously been collected and stored in RNeasy. Nasal epithelia cells for the trial were collected from the inferior turbinate with Rhino-probes and extracted using Six RNA extraction kits (RNeasy, RNeasy Micro, TRIzol, Power Tissue and All Tissue Prep). These cells were stored in either RNeasy or RNA Lysis Buffer at -74°C. Samples stored in RNeasy were processed by adding 500µL of PBS and centrifuging to remove RNeasy, followed by RNA extraction according to kit instructions. Samples stored in lysis buffers did not require this process. All samples were homogenised with QIAshredder centrifugation and/or motorized pellet pestle prior to extraction, and the yields quantified using a NanoDrop. The combination of lysis buffer storage and QIAshredder homogenisation provided highest RNA yield and purity. The RNeasy is attributed to poor RNA yield and quality. The RNeasy's viscosity inhibited pellet formation, even with the addition of PBS, resulting in sample loss and RNeasy residue clogging the extraction columns. If this project could be done again it would be recommended that RNeasy be avoided, and that Rhino-Probe samples were stored in RNA lysis buffer and frozen in the field.

## METAL DUST SAMPLING

*Paul Paciullo*

Integrated Environmental

How to assess whether a surface is contaminated with metal dust?

Some screening levels have been developed for office areas and residential properties however these screening levels cannot be applied to all environments e.g, store rooms where access is short term and sporadic and metal fabrication workshops where metal contamination is expected.

The presentation will focus around the three main areas:

- The different approaches that other organisations and studies<sup>^</sup> have taken with regard to assessing metal dust on surfaces.
- The use of an equation to derive site specific screening levels for metal contamination;
- The application of surface dust sampling at ANSTO and the University of New England. Over 12000 samples were collected from ANSTO and 40 from UNE.

This presentation comes after seeing different consultancies and studies use many different methods of assessing metal contamination. The presentation will aim to provide consistency amongst the industry, a simplified approach for consultancies to use and different approaches to interpreting results.

<sup>^</sup> There are a few studies around including the U.S. Army Technical Guide 312, World Trade Centre Indoor Environment Assessment, BNL Surface Wipe Sampling Procedure IH75190 and AS 4361.2-1998 as well as studies by Mark Taylor of Macquarie University regarding lead on outdoor play equipment).

## RIDING A WAVE: WORKERS' EXPOSURE TO STYRENE AND OTHER HAZARDOUS CHEMICALS IN THE SURFBOARD MANUFACTURING INDUSTRY IN COASTAL NSW

*Mahinda Seneviratne*

SafeWork NSW

Surfboard manufacturing, an iconic niche industry along coastal NSW is mainly done by informal workers in small medium enterprises (SME). Hazardous chemicals such as styrene that can cause chronic health problems from prolonged use are used regularly in this industry. We surveyed exposure to styrene and other VOCs at 24 surfboard making and repairing workplaces. Organic Vapor Monitoring badges were used to sample personal exposure during glassing and other tasks. Samples were analysed to detect 73 different VOCs. Urine samples were collected from workers who gave prior consent and were analysed to detect mandelic acid, a metabolic marker of styrene exposure. Workers were also informally engaged to identify any health problems or symptoms that may be related to workplace chemical exposures.

Styrene and other VOC, such as acetone and methyl ethyl ketone (MEK) were detected in a number of the personal air samples but only a very few exceeded the relevant Australian Workplace Exposure Standard (WES). Mandelic acid was present in some workers' urine samples but no worker exceeded its recommended Biological Occupational Exposure Level (BOEL) of 297 mmol/mol creatinine. Workers who were predominantly young males who regularly surfed as a pastime did not report any significant work-related health problems. We will present a summary of this hygiene survey findings with a discussion of work practices and control measures in these workplaces. Measures taken to improve chemical management and workplace health and safety in general at these SME will also be presented.



## INVESTIGATION OF WORKPLACE ODOURS USING A SIMPLE HAND PUMP TO COLLECT GRAB SAMPLES FOR ANALYSIS IN THE LABORATORY.

*Bill Stavropoulos*

SGS Leeder Consulting

Investigation of odours in the workplace can be difficult and challenging. Odours can be sampled using a variety of techniques, each having its own inherent advantages and disadvantages. Often the odour is present for a short period at an unpredictable time and a simple grab sampling procedure may be the most appropriate. Grab samples can be collected using evacuated canisters, but they are only suitable for a limited range of volatiles compounds. Sorbent tubes are validated for a wide range of compounds including volatiles from n-C3 to n-C32 and above, phenols, phthalates, PAHs, and many polar and reactive VOCs.

In this investigation, a “Markes Easy-VOC” hand pump was used to collect air samples at a location where an odour had been reported. A Thermal Desorption sampling tube with a “Tennax” sorbent packing was used to collect the samples. “Tennax” sorbent was selected due to its ability to retain a wide range of heavier VOC

Analysis was undertaken using Thermal Desorption Gas Chromatography Mass Spectrometry (TD-GC/MS). The detection limit was 5 nanograms (total) per tube. Based on using the hand pump to collect 1 litre samples on the tube, the detection limit was 5 micrograms per cubic metre of air (ppb levels). This simple sampling technique, analytical method and detection limit are ideal for investigating a range of workplace related odour and VOC issues.

## CAN NOISY GARDENERS TURN OVER A NEW LEAF?

### EVALUATION OF LANDSCAPERS AND GARDENERS ON A UNIVERSITY CAMPUS

*Maziere L, Whitelaw J, Apthorpe L*

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Although over 22,000 Australian workers are employed as landscapers and gardeners and perform tasks that use a variety of tools increasing their risk of noise-induced hearing loss (NIHL), studies on their noise exposure are limited.

This study characterised the noise exposure of landscapers employed on an 82 hectare University campus. A combination of full shift personal dosimetry and task based monitoring was utilised (in accordance with AS/NZS 1269.1:2005) to evaluate and characterise their exposure. Participants also filled out an activity card to document their tasks, tools used, location and noise perception. Sound pressure levels produced by various pieces of equipment and tools were measured at under various conditions using a sound level meter. These measurements were used to assess worker noise exposure profiles, particularly the contributing source of noise and inform recommendations for control.

Hand-held power tools, mulchers and ride-on equipment contributed significantly to worker noise exposure. This study demonstrates that landscapers and gardeners may be routinely exposed to noise levels above the guidelines set out in Safe Work Australia "Model Codes of Practice - Managing Noise and Preventing Hearing Loss at Work" and state regulations; and that the implementation of effective hearing conservation programs is necessary to reduce their risk to NIHL.

## AN INVESTIGATION OF POTENTIAL FORMALDEHYDE EXPOSURE TO FORMALDEHYDE AND THE EFFECTIVENESS OF LOCAL EXHAUST VENTILATION (LEV) IN PATHOLOGY LABORATORIES

*Karen Wiersma*

Workplace Health and Safety Queensland

Formaldehyde is considered to be a carcinogen by the International Agency for Research on Cancer. However, it is still widely used in hospitals and pathology departments for tissue preservation. A review of scientific literature found limited information was available on Australian workplace exposure levels. The purpose of the project was to investigate formaldehyde levels in pathology units and the effectiveness of existing controls.

The project involved assessment of eight histology pathology sites within the greater Brisbane area. The variety of sites selected consisted of 4 small private pathologies and 4 large community pathologies, which included 2 hospital pathologies. Each assessment included a walk-through survey, followed by an evaluation of exposure to formaldehyde and an assessment of local exhaust ventilation (LEV).

Key findings identified:

- Ventilation controls for formaldehyde were mostly not maintained or implemented correctly.
- Seventy percent of workers monitored were exposed to low levels of formaldehyde.
- Storage and handling procedures for flammable hazardous chemicals were inadequate.

Recommendations include:

- Improving and maintaining LEV to ensure areas are adequately ventilated and capture velocities are efficient.
- Reviewing handling and storage procedures for all hazardous chemicals, including formaldehyde in pathology laboratories.
- Most importantly, implementation of preventive measures, Industry awareness and safety campaigns are essential.



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