AIOH2017
connect2prevent
Canberra, 2nd-6th December 2017

Australian Institute of Occupational Hygienists Inc
35th Annual Conference and Exhibition

Conference Proceedings

#AIOH2017

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35th Annual Conference & Exhibition of the
Australian Institute of Occupational Hygienist Inc.

2 – 6 December 2017

National Convention Centre
Canberra, Australia

Editors

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Kerrie Burton

Caroline Langley

2017 CONFERENCE PROCEEDINGS

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The Australian Institute of Occupational Hygienists Inc. is a non-profit organisation dedicated to the advancement of occupational hygiene and to the improvement of the knowledge, competence and standing of its practitioners. It is affiliated with the International Occupational Hygiene Association.

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A NOTE FROM THE 2017 AIOH PRESIDENT

Delegates, speakers, distinguished guests, sponsors, and trade exhibitors, on behalf of the AIOH Council, it is my distinct pleasure to extend to you a very warm welcome to AIOH2017, the 35th Annual Conference and Trade Exhibition of Australian Institute of Occupational Hygienists, Inc.

AIOH2017 is being held in Canberra, the nation's bush capital. The theme of this conference is 'Connect2Prevent' and will bring together researchers, practitioners, regulators and educators to discuss and address issues of worker health protection.

The organisers have assembled an outstanding group of local and international keynote and plenary speakers presenting on a diverse range of topics. The scientific program will include nine plenary sessions and 12 concurrent sessions. The professional development program to be held on the weekend before the conference comprises twenty continuing education sessions. This will provide delegates with plenty of options, so I hope you will take this opportunity to invest in your career by participating in the full range of professional development opportunities.

The scientific program is intermingled with a lively and entertaining social program and, in keeping with the conference theme, you are encouraged to 'Connect2Prevent' by networking with your colleagues, peers, and potential mentors.

The trade exhibition is an integral part of this event and allows delegates to see new technology and get their hands on new equipment. I encourage everyone to visit the trade exhibition and allow our exhibitors to show you their instrumentation, equipment and services.

If this is your first AIOH conference, we welcome you to the occupational hygiene community. I encourage you to make the most of the wonderful combination of professional development, networking and social events for which our conference is renowned.

Staging a conference of this size and complexity requires a great deal of organisation, dedication, and plain hard work. I would like to thank and congratulate Martin Jennings and his conference committee, our office staff, the presenters, and all those involved in organising and supporting what will be another outstanding conference.

I would also like to acknowledge and thank our major Sponsors: 3M Australia, Safety Equipment Australia, Dräger Safety Pacific, Air-Met Scientific, Active Environmental Solutions, Dupont, Industrial Scientific Corporation, and Scott Safety. Without the continued and extraordinarily generous support of our sponsors, the Institute would not be able to host this event in the format that it does, nor provide the range of exciting awards on offer.

Welcome. I wish you an enjoyable and rewarding conference.

Philip Hibbs
2017 AIOH President

A NOTE FROM THE 2017 ORGANISING COMMITTEE CHAIR

Welcome from the Chair of Conference Organising Committee.

On behalf of the AIOH 2017 Conference committee, I have great pleasure in welcoming you to Canberra and to the 35th annual AIOH Conference. The theme of this year's conference is Connect2Prevent. This theme highlights the role of the conference in bringing together occupational hygienists to discuss how to more effectively prevent the occurrence of occupational illness and disease.

The name "Canberra" is claimed to derive from the word Kambera or Canberry, which is generally taken to mean "meeting place" in Ngunnawal, one of the Indigenous languages spoken in the district before European settlers arrived. Although there is no clear evidence to support this, it nevertheless fits neatly with the theme.

The theme Connect2Prevent also includes the role of the media in connecting the community to the profession and ABC journalist Matt Peacock, will be providing an insight into this. The scientific program features a dazzling array of presenters and topics around preventing occupational illness and disease and this is due in no small part to the great work of the scientific sub-committee, chaired by Deborah Glass. Of course, one of the most enjoyable aspects of the AIOH conference is connecting with others, and the social program provides ample networking opportunities for this.

The conference would not be a success without the generous support of our sponsors. We encourage you to support them. It is fascinating to think just how long or major sponsors have supported us. By my reckoning, the initial 3M Award was presented at my first conference in 1987, which means our relationship with them is now entering a fourth decade. The following year, SEA sponsored the Sundstrom lecture and Air-Met Scientific was listed as a major sponsor in the 1989 Proceedings.

We invite you to spend some time connecting with our exhibitors, to discuss the range of products and services that they provide. As well as providing a networking venue, the Exhibition Hall will also be the venue for a new event, the "Excite" sessions. Based on the successful 'Ignite' format, the Excite session provides exhibitors with 5 minutes to present on, well, anything.

We recommend that everyone should spend some time to take in the attractions of Canberra. Parliament House, the National Gallery, the National Portrait Gallery, the National Museum and the Australian War Memorial are all within easy walking distance. For the more energetic, a run, jog or more sedate walk around Lake Burley Griffin will help get the blood circulating, while for kids or the young at heart, a visit to Questacon is definitely worthwhile.

I take this opportunity to thank all of the Conference Committee for their hard work over the last 2 years and I thank Council for their support. I particularly thank the President, Philip Hibbs who has been a tower of strength. Thanks Phil.

Welcome to the 35th Conference and Exhibition of the Australian Institute of Occupational Hygienists Inc.

Martin Jennings
2017 AIOH Conference Organising Chair

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Enquiries should be directed to the AIOH administration office.

BIOGRAPHICAL NOTES OF THE KEYNOTE SPEAKERS

Diane Smith-Gander

Diane Smith-Gander is non-Executive director AGL Energy, Wesfarmers Limited, Chair of Safe Work Australia, Asbestos Safety & Eradication Council, a board member of Keystart Loans, Henry Davis York, CEDA and immediate past President of Chief Executive Women, Australia's pre-eminent women's advocacy group. Diane has held a wide range of non-executive roles in the past including Chairman of Broadspectrum, Deputy Chairperson of NBNCo, non-executive director of the CBH Group, commissioner of Tourism WA and board member of the Committee for Perth. Her last executive role was Group Executive at Westpac; a member of the leadership team of the corporation, responsible for all Information Technology, back office operations, global vendor management and property. Diane was a General Manager at Westpac for 10 years in the 1990s responsible for back office functions, retail networks and support functions. Prior to re-joining Westpac Diane was a partner at McKinsey & Company in Washington and New Jersey serving clients in diverse industries globally. Diane became a senior advisor to McKinsey in Australia in 2016.

She has been active in sports administration and is a past Chairman of both Basketball Australia Limited, the sport's peak body, and the Australian Sports Drug Agency, the government agency responsible for deterring the use of performance enhancing drugs.

She holds an MBA from the University of Sydney and a BEc from the University of Western Australia (UWA). In 2015 she was awarded an Honorary Doctorate of Economics from UWA. She is a Fellow of the AICD and Governance Institute of Australia and an adjunct professor of corporate governance at UWA where she serves on the advisory board of the Business School. She is also a Council member of Perth's Methodist Ladies' College.

Diane is a keen downhill skier and operates a vineyard in Margaret River.

Matt Peacock

Keynote Speaker

Matt Peacock joined Australia's first current affairs TV program, ABC's This Day Tonight, as a researcher in 1973, working then at Four Corners, Monday Conference, AM and PM before moving to ABC's Radio's Science Unit where in 1977 he produced an award-winning series on asbestos. A radio career followed which took Peacock to Washington and New York, reporting for the ABC's AM, PM, and The World Today. In 1997, Peacock became chief political correspondent for ABC Radio's current affairs Canberra bureau and was subsequently posted to report from London. Since 2004, he has been a senior reporter with ABC's TV's 7.30 Report. Peacock is an award-winning journalist who has written for numerous newspapers, magazines and journals and has previously published two books based on his radio programs, Asbestos: Work as a Health Hazard and The Forgotten People -A History of the Australian South Sea Islander Community, before writing a book on the James Hardie asbestos scandal, Killer Company: James Hardie Exposed (HarperCollins 2009), which became a dramatic min-series Devil's Dust produced by Freemantle Media. He is an Adjunct Professor of Journalism at UTS and a staff-elected Director of the ABC.

Safety Equipment Australia Conference Keynote Speaker

John Cherrie

Keynote Speaker John Cherrie is Professor of Human Health at Heriot Watt University and a Principal Scientist at the Institute of Occupational Medicine (IOM) in Edinburgh, UK. He is a Past President of the British Occupational Hygiene Society and a winner of the Bedford Award for outstanding contributions to occupational hygiene. He has a wide range of research interests including exposure assessment for regulatory risk assessment, dermal exposure assessment, inadvertent ingestion of chemicals and several other topics including occupational and environmental epidemiology. He led the SHEcan project that provided estimates of health and socioeconomic impacts from possible changes to the Carcinogens Directive in Europe.

BIOGRAPHICAL NOTES OF THE PLENARY SPEAKERS

Karen Bufton

Karen has over 20 years' occupational hygiene experience within the petrochemical, manufacturing and pharmaceutical industries. She has worked in a variety of environments including: chemical and gas plants; oil refineries; oil and gas offshore platforms; manufacturing sites; research laboratories; and corporate events. Karen holds a BSc. in Environmental Science, and the Diploma of Professional Competence in Occupational Hygiene. She is a Member of the British Occupational Hygiene Society's (BOHS) Faculty of Occupational Hygiene, and is the BOHS President for 2017/2018.

Deborah Nelson

Deborah Imel Nelson, Ph.D., CIH, earned her B.S.E.S. and M.S.E.S. from the University of Oklahoma College of Engineering, and her M.P.H. and Ph.D. in Environmental Health at the University of Oklahoma Health Sciences Center. She has been certified in the comprehensive practice of industrial hygiene since 1981. Deborah has served as a US Department of Labor – Occupational Safety and Health Administration (OSHA) industrial hygiene compliance officer and as a professor of environmental science at the University of Oklahoma. For two years she was an Occupational Health Scientist with the World Health Organization in Geneva, Switzerland, where she conducted exposure assessments for the Global Burden of Occupational Injury and Illness. She recently retired as the Safety and Occupational Health Manager for the US Department of Agriculture, Veterinary Services, which was heavily involved in highly pathogenic avian influenza (HPAI) outbreaks in 2015 and 2016. She is a Fellow of the American Industrial Hygiene Association, and is currently serving as the AIHA President.

Tessa Keegal

Dr Tessa Keegal is a lecturer in the Centre for Ergonomics and Human Factors at La Trobe University and at the Monash Centre for Occupational and Environmental Health at Monash University. Prior to her current appointments, Tessa was supported by a National Health and Medical Research Council (NHMRC), Early Career Research Fellowship in the area of work and health. Tessa's research is all within the broad area of work and health. Specific research projects include: analysis of workers compensation claims data for occupational contact dermatitis; analysis of physical and psychosocial demands as reported by Australian workers; a qualitative research project exploring the decisions regarding return-to-work of workers after diagnosis with an occupational disease; and, an intervention project on job stress and mental health literacy among Victorian Police officers. In 2012 Tessa co-authored the VicHealth Creating Healthy Workplace project: Reducing Stress in the Workplace, an Evidence review. Tessa has training in occupational epidemiology and biostatistics. She is particularly interested in the ways an individual's health and well-being are contextualized within workplaces, with respect to occupational exposures and disease, as well as the ways that policy and legislation affect these interactions.

Jackii Shepherd

Jackii Shepherd is an Assistant Director, Occupational Hygiene Policy at Safe Work Australia. Jackii has a degree in Applied Science (Human Biology), qualifications in epidemiology and biostatistics, training in medical laboratory science and toxicology and is currently completing a Master of Public Health. She has worked as a senior scientist in pathology laboratories and as a senior regulatory toxicologist completing human health risk assessments with the Office of Chemical Safety. Within Safe Work Australia, Jackii has worked on policy for occupational hygiene, hazardous chemicals, lead and asbestos.

Alison Reid

Alison Reid is an Associate Professor in the School of Public Health, Curtin University, Western Australia. She has a background in anthropology and demography and is an occupational epidemiologist with a specific interest in the occupational causes of disease and risks among sub groups of the population. Specifically, she is interested in the working conditions of migrant workers, their hazard risks and prevalence of exposure to workplace hazards. Her other area of interest is low dose asbestos exposure and asbestos-related diseases and she has studied these among women and children exposed to blue asbestos at Wittenoom, Western Australia.

Noah Seixas

Noah Seixas is Professor of Exposure Sciences at the University of Washington, School of Public Health. Dr. Seixas received an MS in Industrial Hygiene at Harvard School of Public Health in 1982. After working for public health agencies in New Jersey for four years, Dr. Seixas returned to school at the University of Michigan, earning a PhD in Industrial Health in 1990, writing a dissertation on obstructive lung disease among coal miners and exploiting the large exposure database on coal dust exposures from the Mine Safety and Health Administration compliance activities. These activities were part of the growing recognition of exposure assessment as a crucial component of effective occupational epidemiology. Dr. Seixas was appointed Assistant Professor at the University of Washington in 1993 where he developed a teaching and research program on exposure assessment techniques, studying silica, noise, organic dusts and welding fume, among other risks, as part of several epidemiologic studies. In recent years, he has redirected his focus to address the needs of immigrant, minority and women workers, and exploring the future of occupational health research and practice with respect to work organization and precarious work. In 2013 Dr. Seixas was appointed as the Chief Editor of the Annals of Occupational Hygiene, recently renamed the Annals of Work Exposures and Health. He also serves as Director of the Northwest Center for Occupational Health and Safety, serving the Pacific Northwest region of the US.

Jane Canestra

Dr Jane Canestra has an extensive background in emergency management. Qualified as an Emergency Physician, her most recent clinical appointment was as Deputy Director of Emergency Medicine at Peninsula Health. More recently Jane has worked for the Victorian Department of Health and Human Services in the areas of public health and emergency management. Her main expertise is in health sector emergency preparedness, especially for chemical, biological and radiological (CBR) hazards. Jane's emergency management experience includes development of local hospital, health network, state and national preparedness arrangements. She has direct experience in mass casualty emergencies, Ash Wednesday and Black Saturday fires, floods, storms, pandemic influenza, smoke-logged communities, hazardous materials incidents, major power disruptions and public disorder events. This has included consequence management such as restoring shelter, access to clean drinking water and power, prevention of vector borne disease, and minimising exposure to hazardous materials. Jane has contributed to many Victorian and Australian chemical, biological and radiological committees over nearly two decades, including membership of the CBRNe Technical Panel of the Australian Health Protection Principal Committee; the Radiation Health and Safety Advisory Council; and as Chair of the national writing group for the Australian Clinical Guidelines for Radiological Emergencies.

Kate Cole

Kate is a Certified Occupational Hygienist (COH)® who has worked in the construction industry for almost two decades on projects in Australia, Hong Kong and the USA. She holds degrees in Science, Engineering, and Occupational Hygiene, and works on major projects involving complex contaminated land remediation and large-scale underground tunneling. Currently the Manager of Occupational Health and Hygiene with Ventia, Kate works across most tunnels under construction in Sydney. She is currently supporting Transport for NSW on Australia's largest public transport infrastructure project, the Sydney Metro as the Occupational Health and Hygiene Manager.

Kate was the recipient of the 2013 Draeger AIOH Young Hygienist Award, the 3M Top Student Prize at the University of Wollongong in 2014, the Thiess Managing Directors Award in 2014, a graduate of the American Industrial Hygiene Associations Future Leaders Institute, a past AIOH Councillor, and in 2016, was awarded a Churchill Fellowship from the Winston Churchill Memorial Trust.

Lance Islip

Lance is Health, Safety and Environment Coordinator, UNSW Sydney. The first 14 years after graduating with a BSc (hons) in Biological Sciences were spent working in research and teaching laboratories at UNSW. Lance then spent a few years managing PC2 and teaching labs before moving into full time WHS Management at Faculty level in 2004. Interests include laboratory safety, hazardous chemicals, fieldwork and chemical safety in schools.

Meagan McCool

Meagan has 20 years of experience in the NSW Public Service across a range of portfolios from Dangerous Goods, Explosives, Major Hazard Facilities, Self-insurers and High Risk Plant & Equipment at SafeWork NSW; to Builders & Tradespeople, Consumers, Tenants and Traders at NSW Fair Trading. Meagan also recently returned from a secondment to the Commerce Regulation Program, a key NSW Government initiative to make it easier to start, and stay, in business in NSW by improving the customer experience of those who need to navigate through the many regulating agencies.

Heidi Roberts

Heidi Roberts is Project Executive for the Coal Workers' Pneumoconiosis response. She leads the implementation of all 18 recommendations made by Monash University's review of the respiratory component of the Coal Workers Health Scheme. Heidi joined Queensland Department of Natural Resources and Mines in January 2017. Prior to that, she has held senior positions at Diversified Mining Services, the Gladstone Area Water Board and Xstrata Copper.

Carolyn Davis

Carolyn has more than twenty years' experience in work health and safety and workers' compensation management, policy, advocacy and implementation. She has held senior roles in major Australian companies and in academia as well as running her own consultancy for many years. Her early qualifications and background were in industrial chemistry and occupational hygiene. She has also been a lecturer in WHS in a tertiary institution. Until recently, Carolyn was Director Work Health, Safety and Workers Compensation Policy in the Australian Chamber Chamber of Commerce & Industry. She is a strong advocate for managing risks as a part of day to day business. In this role she worked to ensure practical information and support for all Australian businesses large and small, and not just in WHS. As a Safe Work Australia (SWA) member Carolyn advocated for sound practical approaches. Carolyn remains passionate about sustainable businesses. Businesses that value their people and have good systems in place to face the challenges of today. This includes sensible approaches to a range of issues in the workplace including mental or psychological health. Carolyn continues to bring this expertise and an understanding of the experiences of industry to Asbestos Safety Eradication Council. Carolyn's skills and experience include: chemistry and occupational hygiene, work health and safety and worker's compensation policy and management in small and large businesses, and mediation and alternative dispute resolution, operating a small business. Her professional memberships include Royal Australian Chemical Institute (RACI) and Association of Dispute Resolvers (LEADR).

Shelley Rowett

Shelley Rowett is Chief Advisor Work Environment at SafeWork SA (the South Australian Safety Regulator), she has been in this role for the past 8 years. Her current work remit is to provide high-level strategic advice to SafeWork SA Inspectors on current and emerging workplace hazards with particular focus on human factors and occupational hygiene. Shelley's working background in health and safety management has been largely in the University and Mining Sectors. She holds a Master's degree in Health and Safety Management from the University of Ballarat and a Graduate Diploma in Industrial Hygiene from Deakin University.

SafeWork SA regulates all work health and safety in South Australia across all industries (including the Mining Sector). Currently health and safety legislation in SA includes the majority of the National Harmonised Work Health and Safety Regulations. SA is the only state to introduce the unaltered national model WHS Mining Chapter into its WHS regulations.

Deborah Vallance

Deborah Vallance is the National Health and Safety Coordinator with the Australian Manufacturing Workers Union [AMWU]. The AMWU represents workers in a broad range of industries and occupations. Deborah has worked as a researcher for unions and government, and in clinical medicine.

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KEYNOTE & PLENARY ABSTRACTS

BEST PRACTICE: ABOVE AND BEYOND COMPLIANCE.

Diane Smith-Gander
Chair of Safe Work Australia

ABSTRACT

Diane Smith-Gander has held multiple leadership roles throughout her career and through these roles is a prominent supporter of best practice processes to exceed business objectives. In her role as Chair of Safe Work Australia and ASEA, Ms Smith-Gander promotes best practice as the critical method to protect workers and the community. She is keenly aware of the importance of managing risks posed in and by the workplace and the importance of working with professionals and industry to continue to identify and manage risks using continually improved practices.

In her presentation *Best Practice: Above and Beyond Compliance*, Ms Smith-Gander will discuss the importance of business leaders demonstrating and supporting best practice as a lever for both productivity and worker safety. She will explain how best practice is more than simply being compliant with WHS laws, but is an opportunity for employers and business leaders to protect workers and the wider community from harm while improving productivity and business efficiency. In particular, Ms Smith-Gander will discuss the critical role played by Safe Work Australia, the Asbestos Safety and Eradication Agency, and the Australian Institute of Occupational Hygienists in developing, testing and refining best practice for managing workplace hazards like chemicals, asbestos, noise, vibration and heat.

WHAT'S THE POINT OF THE OCCUPATIONAL EXPOSURE LIMITS?

John Cherrie
Heriot Watt University and the Institute of Occupational Medicine, UK

ABSTRACT

Occupational exposure limits (OELs) are central to the occupational hygiene paradigm. We have relied on OELs as a benchmark to judge acceptability of exposure measurements in workplaces around the world, and we have enshrined them in legislation so that we can punish employers who flagrantly disregard their obligations towards their employees. Ideally, we would like to set limits that are health-based so that compliance fully protects the worker, although this is difficult where there is no threshold for effects or where current exposures are well above any threshold. In these circumstances setting an OEL is problematic and the concept of compliance becomes moot; diesel engine exhaust particulate is a prime example of this problem. In such circumstances we are failing to properly protect the health of the working population. New developments in Europe challenge the conventional use of OELs in occupational hygiene. Central to these approaches is an emphasis on continually reducing exposure for the whole working population, rather than focusing narrowly on ensuring that individual exposure complies with the limit. Success is no longer measured by the proportion of workers below a limit but by the annual percent reduction in exposure for an industry sector, and in these circumstances OELs essentially become pointless.

RAISING THE BOHS PROFILE AND IMPACT WHILST IMPROVING WORKER HEALTH PROTECTION IN CONSTRUCTION.

Karen Bufton
BOHS President

ABSTRACT

The British Occupational Hygiene Society (BOHS) wanted to raise awareness of occupational hygiene externally as well as improve worker health protection in the UK. The idea was first formed as a result of one of the themes of the 2011-16 BOHS Strategy - 'Raising Raise Awareness of Occupational Hygiene'. The BOHS decided to focus on respiratory disease in the construction industry as it had recently emerged that 13,000 people die in the UK each year from respiratory disease, most of which were from the construction industry. In addition, awareness of occupational hygiene was low and few hygienists worked in the construction industry. The aim of the campaign was to convert the obvious need for worker health protection into demand from construction companies and increase the awareness and use of occupational hygienists.

In April 2015, the 'Breathe Freely' campaign was launched. My presentation will focus on what was done in preparation of the launch, what was achieved by volunteers, partners and sponsors, future plans, the impact on the BOHS, its profile and occupational hygiene in the construction industry.

AIHA SAFETY MATTERS PROGRAM.

Deborah Nelson
AIHA President

ABSTRACT

Work is a formative experience, having a positive impact on young people's lives. In the U.S., 80% of youth work while in high school (approximately ages 15 through 18 years old). In 2013, workers < 24 years old made up 13% of the workforce (18.1 million people). At the same time, working youth are at higher risk. A worker younger than 24 years is injured on the job every minute, and youth ages 15–24 years are injured at work at twice the rate of adults. The estimated cost of job injuries for youth (< 19) is 5 billion USD/year.

The American Industrial Hygiene Association (AIHA) and the National Institute for Occupational Safety and Health (NIOSH) have partnered to protect young workers by equipping young people with the skills and knowledge they need to participate in safe and healthy work environments throughout their working lives. Safety Matters is a 1-hour presentation for students in grades 7-12 (approximately ages 12-18), that has been adapted from the NIOSH Talking Safety curriculum for use by AIHA members to teach students critical OSH competencies. Safety Matters is free, fun, interactive, requires minimal preparation, and requires no teaching experience. The one-hour training consists of five sections: young worker injuries, finding hazards, controlling hazards, rights and responsibilities, and being prepared and taking action. Materials include learning objectives, key points, and step-by-step instructions and PowerPoint prompts. The occupational safety and health (OSH) competencies for the Safety Matters program include teaching students:

- that all workers can be injured, become sick, or even be killed on the job,
- that work-related injuries and illnesses are predictable and can be prevented,
- how to identify hazards at work,
- how to prevent injury and illness,
- how to identify emergencies at work and decide on the best ways to address them,
- that employers are responsible for, and workers have the right to, safe and healthy work,
- how to find resources that help keep workers safe and healthy on the job, and
- how workers can communicate when they feel unsafe or threatened.

Talking Safety is a foundational curriculum in OSH, designed for use by classroom teachers. Six basic and five supplemental lessons (45-minutes each) have been customized for each state, Washington D.C., Puerto Rico, and the U.S. Virgin Islands to address their specific child labor rules and regulations.

AIHA has encouraged our members to volunteer to teach AIHA/NIOSH Safety Matters, to bring the NIOSH Talking Safety curriculum to school districts, and to engage stakeholders and policymakers to make OSH part of career readiness. Oklahoma and Texas have passed state-level laws recognizing Safety Matters, and the AIHA local section in Colorado is advocating for similar legislation.

Providing OSH training to young people has an additional benefit of introducing them to potentially rewarding careers in industrial hygiene and occupational and environmental health and safety. The Safety Matters and Talking Safety materials are available at www.cdc.gov/niosh/topics/safetymatters/default.html and https://www.cdc.gov/niosh/talkingsafety/default.html.

WORKERS' COMPENSATION CLAIMS FOR OCCUPATIONAL CONTACT DERMATITIS: 20 YEARS OF DATA FROM VICTORIA.

Tessa Keegal
La Trobe University & Monash University

ABSTRACT

Background
Use of administrative data from workers' compensation schemes may provide useful information about patterns of workers' compensation claims, particularly when considering trends over time. The objective of this paper is to characterize patterns of occupational contact dermatitis (OCD) workers' compensation claims data.

Methods
We conducted a retrospective analysis of all workers' compensation claims for occupational contact dermatitis accepted by the Victorian WorkCover Authority in Victoria, Australia. The main outcome measures were accepted workers' compensation claims for occupational contact dermatitis per 100,000 person-years stratified by sex, age and industry.

Results
Between January 1996- December 2015 there were N=3,348 accepted claims for OCD. The average claims rate of OCD was estimated to be 6.72 (95%CI:6.49-6.95) per 100,000 person-years. There was a significant reduction in claims from 11.84 (95%CI:10.39-12.87) in 1996 to 1.78 (95%CI:1.34-2.33) in 2015. Males had a higher overall claims rate 7.97 (95% CI:7.64-8.32) compared to females 5.18 (95%CI:4.89-5.49). This difference has decreased from 14.46 in 1996 (95%CI: 12.38-16.80) to 1.74 in 2015 (95%CI:1.16-2.52) for males, compared to 8.41 in 1996 (95%CI:6.63-10.53) to 1.83 in 2015 (95%CI:1.18-2.70) for females.

Conclusions and Relevance
Victorian workers' compensation administrative data indicate a fivefold decrease in accepted occupational contact dermatitis claims from 1991-2013. The declining rate of accepted OCD claims may indicate changes in workplace exposures or improvements in workplace prevention practices over time. However, these results need to be regarded with caution, as they are influenced by the eligibility criteria of the workers' compensation scheme, as well as underlying workers' compensation claims behaviour.

CHANGES TO WORKPLACE EXPOSURE STANDARDS.

Jackii Shepherd
Safe Work Australia

ABSTRACT

Workplace exposure standards should be an integral part of a hazardous chemical risk management strategy. To be effective they should reflect current toxicological knowledge and be consistent with the approach of protecting against adverse effects to health. In consideration of this, and acknowledging that Australia's list of standards may no longer be based on the most up-to-date evidence, Safe Work Australia in partnership with Golder Associates has conducted a review of the chemicals listed in the *Workplace Exposure Standards for Airborne Contaminants.* This review has integrated national and international standard setting documentation with current knowledge of Australian chemical use patterns to recommend changes to the listing of chemicals and to the exposure standards themselves. This lecture will highlight the processes used in evaluating exposure standards, the issues faced and how they were managed, an overview of the outcomes and the very important next steps.

THE HEALTH AND EXPOSURE OF MIGRANT WORKERS.

Alison Reid
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ABSTRACT

Migrants are an increasingly important source of workers for many countries with shrinking birth rates and ageing populations. The largest driver of migration is work and economic opportunity. Today, there is an estimated 150 million international migrant workers, seventy five percent of whom migrate to high income countries. The migrant workforce is mixed, containing young unskilled workers, as well as highly skilled workers and, increasingly, females. The majority work in services (including domestic service), manufacturing, construction and agriculture.

The international literature shows that migrant workers experience more work-related injuries and fatalities than native-born populations. There has been little examination of specific risk factors but the specific risk factors but it may be related to their working in the more hazardous industries or being assigned more hazardous tasks, as well as a reluctance to report hazards if they are working in precarious jobs and/or a lack of safety training. Even less is known about exposure to other work hazards, e.g. occupational carcinogens or psychosocial risk factors and whether that varies with that of their native-born counterparts.

Drawing on the findings from the international literature and studies comparing exposure to carcinogens and psychosocial hazards between migrant and native-born workers in Australia, I will examine why and how migrant workers are vulnerable to adverse working conditions and how this impacts on their occupational health and safety.

EVOLVING DEFINITIONS OF EXPOSURE: UNDERSTANDING PRECARITY AS A WORK-RELATED RISK IN THE NEW ECONOMY.

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USA Department of Epidemiology, University of Washington, USA

ABSTRACT

The organization of work is undergoing rapid change making our traditional definitions and methods of exposure assessment less effective in understanding work-related risks. Non-standard employment arrangements and increasing disparities in income compel an increasing focus on the health of working populations, rather than individual diseases or conditions. Many of the terms used to describe the context of work have overlapping attributes, their lack of clear conceptual definition hampers our ability to explain the apparent health risks.

This paper describes the various concepts associated with precarious work and suggests that precarity requires integration of concepts of work organization with worker vulnerability. By doing so, we can better understand the relationships between job content, working conditions and power dynamics within the workplace and its social context. Using a multidimensional typological approach to understand work related risks helps to overcome the limitations of characterizing work organization or social determinants on single dimensional characteristics, and offers a new framework for exposure assessment and for understanding the health implications of precarious work.

Responding to the changing nature of work organization, the vulnerability of working populations, and the shift in relevant health risks, the Annals of Work Exposures and Health has adopted a wider conception of exposure, including its assessment, measurement, and control. While challenging to the classical approach to occupational hygiene, this transformation is necessary to address the major work-related risks to health in the new economy.

EMERGENCY PLANNING AND PREPARATION.

Jane Canestra
MBBS FACEM MPH

ABSTRACT

Emergencies confront all communities. The resilience of communities is dependent on effective risk identification, adequate risk controls and mitigation, effective response to dynamic threats, and recognition of potential consequences and appropriate steps to minimise negative consequences. Emergency management must have community at the centre, in partnership at all levels of government, across agencies, and with the private sector. Relationships are pivotal to the process and need to be reflected in the systems, organisations, and documents essential to emergency planning and preparedness.

Discussion of recent major incidents will be used to describe critical challenges, vital lessons, and essential partnerships underpinning current preparedness arrangements, with a particular emphasis on health.

INTERNATIONAL BEST PRACTICE IN THE PREVENTION OF ILLNESS AND DISEASE IN TUNNEL CONSTRUCTION WORKERS.

Kate Cole
Ventia, Kingsgrove

ABSTRACT

Each year, over 250 workers in Australia die from an injury sustained at work, while over 2,000 workers will die from a work-related illness. Construction is a priority industry for work health and safety, with controlling exposures to disease-causing hazards identified as an area requiring improvement.

Tunnel construction workers have an increased risk of developing many diseases compared to those in the general construction industry including silicosis, chronic obstructive pulmonary disease, adverse respiratory symptoms, and double the rate of lung function decline than heavy smokers, asthma, general airflow limitation, and lung cancer.

Australian tunnelling has reached a new chapter, tunnelling further in the next seven-years than we have in more than the past two decades. Tunnel construction represents a key part of building Australia's necessary infrastructure and services, and is complimented by world-class feats of engineering. However, the delivery of such world class infrastructure should not be at the expense of the health of thousands of workers who will support these great projects.

This paper will highlight international best practice in illness and disease prevention from the UK, USA.
Norway and Switzerland. Drawing from existing best practice frameworks, eight elements were reviewed to understand approaches taken internationally, which included Leadership, Engagement and Collaboration, Training and Awareness, Standards, Health in Design, Program Health Risk Management, Targeted Health Risk Management, and Sustainability.

This research was funded by the Winston Churchill Memorial Trust as part of a Winston Churchill Fellowship with the aim of investigating practical best practice approaches to ultimately preserve the health of the thousands of Australians who work in the tunnelling industry.

HOW WELL IS GHS BEING IMPLEMENTED.

Meagan McCool[1] & Lance Islip[2]
[1]Safework NSW, [2]University of NSW

ABSTRACT from Scientific Committee

The impending implementation of the GHS (Globally Harmonised System for Classification and Labelling of Chemicals) under WHS legislation in Australia from January 2017 raised trepidation among some sectors of the chemical industry and many small businesses. Meagan McCool from SafeWork NSW's Hazardous Chemicals directorate will present how the regulator's multi-stream GHS Project helped address those concerns and tackled some interesting chemical labelling issues. Lance Islip from the Universities Chemical Safety Group will share the journey of how a network was born when faced with the daunting challenge of relabelling thousands of laboratory chemicals. The panel discussion is bound to provide much food for thought for hygienists and other allied professionals on how they can effectively apply the GHS in preventing workers' health risks from chemical exposures.

ABSTRACT Lance Islip

The early time post the introduction of the GHS in 2011 was spent working out the impact on University resources. Of key interest was exactly how many containers were we going to need to relabel and potentially reclassify. With 65,000 containers in use we knew we had a problem and 5 years of transition wasn't long enough. Since then we have put GHS into all of our laboratory based training courses, chemical procedures and guidelines and continued spreading the word through workplace networks. We have discovered the benefits of the GHS with easier labelling for decanted products and the pitfalls it has had on recognising if containers are correctly stored. NSW Universities formed a coalition to open a dialogue with SafeWork NSW to open their eyes to the scale of the problems our sector would face and we worked well together to be part of a sensible resolution to the re-labelling issue. We still face challenges re-labelling and sourcing SDS's for very old materials which researchers must retain and finding easy to use label creation systems. We have discovered that the same material can be classified multiple ways by different manufacturers and where indeed is the source of truth? Our high turnover of personnel is a problem for retaining knowledge but it helps us improve our training programs and to find how best to keep it simple.

DEBATE: EXPOSURE TO CHEMICALS IS BEST REGULATED BY INDUSTRY.

Deborah Vallance[1], Carolyn Davis[2], Regulator: Shelley Rowett[3]

[1]AMWU National OHS Coordinator, [2]Director WHS and Workers Comp from ACCI, [3]Chief Adviser Work Environment, SafeWork SA

ABSTRACTS

Carolyn Davis states that the Australian Chamber of Commerce and Industry (ACCI) is the only national organisation that connects business of all sizes, from all sectors of the economy in every state and territory, to advocate policies that benefit business, employers, employees and the community. The ACCI network represents in excess of 300,000 private enterprises engaging over four million employees or contractors, of which 85 per cent are small and medium businesses. ACCI represents the broad interests of the private sector rather than individual businesses or narrow sectional interests. Further information about the ACCI and its member network can be found on http://acci.asn.au/. The AACI forms a vital link between business and the Australian Government, regulatory authorities and the community. The Chamber strives to make Australia a great place to do business in order to improve standards of living for all and represents Australian business in international forums. The ACCIencourages entrepreneurship and innovation to achieve prosperity, economic growth and jobs.

From the Regulator's perspective (Shelly Rowett) states Australia has Lord Robens' style regulations which are in essence 'self-regulation' – workplaces have a legal duty to comply with principles of conduct (goal-setting duties) via the Act, supported via the Regulations and have a detailed requirements i.e. on what is expected in the many Codes of Practice (developed in open tripartite consultation). In the utopia of compliance this supported by guidance would be all that is required. But workplaces generally need a reason to implement regulations (that they see as a cost) so the regulations also have penalties and safety regulators in each state are empowered to ensure workplace compliance. Should workplaces be left to it? (is the topic of this debate) Case history would suggest not, but there are also issues with regulation in a scientific area and perhaps possibilities for better outcomes in the long term via other cooperative business mechanisms.

Deborah Vallance contends that in the context of performance based H&S laws, the role of government in establishing minimum standards is a political argument.

- Reduction of "red tape" is the mantra of corporate and government sectors – at all levels.
- To speak against such "reduction" leads to counter allegations of "putting workers lives at risk".
- If precedents are any indicator, neither industry nor government can be relied upon to promulgate best practice.

CONCURRENT ABSTRACTS AND PAPERS

IS OCCUPATIONAL EXPOSURE TO PESTICIDES ASSOCIATED WITH COPD?

Geza Benke[1], Alif SM[2], Dharmage SC[2,3], Dennekamp M[1,4], Burgess JA[2], Perret JL[2,5], Lodge CJ[2], Morrison S [6], Johns DP [7], Giles GG,[2,3,8], Gurrin LC[2,3], Thomas PS[9], Hopper JL[2], Wood-Baker R[7], Thompson BR[10], Feather IH[11,12], Vermeulen R[13], Kromhout H[13], Walters EH[1,2,7], Abramson MJ[1], Matheson MC[2]

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ABSTRACT

Objective

To investigate the association of occupational exposure to pesticides and risk of chronic obstructive pulmonary disease (COPD).

Methods

Spirometry was performed and the work histories were collected of participants aged in their mid-forties (N=1,335) in the Tasmanian Longitudinal Health Study (TAHS). Analysis was undertaken using the ALOHA plus Job Exposure Matrix to assign occupational pesticide exposure. Fixed airflow obstruction was defined for post-bronchodilator FEV1/FVC <70% and lower limit of normal. Chronic bronchitis and other symptoms were also investigated using multivariable regression.

Results

Ever exposure to pesticides (relative risk [RR]=1.74, 95%CI 1.00 to 3.07) and herbicides (RR=2.09, 95%CI 1.18 to 3.70) were associated with fixed airflow obstruction for FEV1/FVC<70%. Similar results were found for chronic bronchitis and other symptoms.

Conclusion

Pesticides and herbicides are associated with clinical features that are consistent with COPD in this sample of middle aged Australians.

THE COAL WORKERS' PNEUMOCONIOSIS CRISIS IN AUSTRALIA AND THE ROLE OF OCCUPATIONAL HYGIENISTS IN DEVELOPING PREVENTION AND MINIMISATION STRATEGIES GOING FORWARD.

Lucy Bochenek
Special Counsel, Clyde & Co.

SESSION CANCELLED

ABSTRACT

More than 30 years after it was believed to have been eradicated, the re-emergence of coal workers' pneumoconiosis (CWP) in Australia has become one of the most significant occupational health and safety crises of our time. The Queensland Parliament's ongoing inquiry into the re-identification of CWP has revealed the shortcomings of authorities, regulators and mine operators in relation to dust exposure standards, monitoring of exposure levels and their handling of workers with confirmed cases of CWP. In addition, the parliamentary inquiry has also criticised the practices of health professionals charged with monitoring the health of coal workers in relation to the diagnosis and treatment of the disease. In March 2017, the inquiry stated its intention to make significant and wide-ranging recommendations in relation to the framework for protecting the health and welfare of coal workers in Queensland, although it is likely to have ramifications across the whole of Australia. This represents an opportunity for occupational hygienists to influence public policy as well as assisting mine operators in meeting their occupational health and safety duties. This paper will look at the ways in which occupational hygiene professionals can engage with this process, including consulting with others in the profession to develop guidance models, analysing global best practice programs (in particular from the United States of America) and working with mine operators to identify new technologies and practices for the prevention and minimisation of dust exposure.

INTRODUCTION

After the Queensland Coal Board published the Rathus and Abrahams Report in 1984 confirming 75 cases (or suspected cases) of CWP, a regime was put in place to eliminate CWP from Queensland mines, including requiring mine operators to undertake mandatory health surveillance and dust sampling measures. Other states and territories in Australian enacted similar legislation. For the 31 years until 2015, there were no cases of CWP reported. It was assumed that the disease had been eradicated. However, as the number of confirmed cases of CWP continues to rise, it now appears the disease was never eradicated, but rather only held back by a series of regulations and safety standards; with doctors misdiagnosing sufferers, believing the claims of the coal mining regulator that the disease had been eliminated. As of the end of May 2017, 21 cases of CWP had been diagnosed in Queensland.

The crisis prompted the Queensland government to initiate a parliamentary inquiry, seeking insight from, but not limited to, coal mine workers, the medical profession, the regulator (the Department of Natural Resources and Mines (DNRM)), the mining industry and occupational hygienists. This paper will consider the main recommendations made so far by the Queensland Parliament's Coal Workers' Pneumoconiosis Select Committee (Select Committee) and the resulting legislative changes such as the amendments already made to the Coal Mining Safety Health and Regulation 2001 (Qld). It will also discuss how occupational hygienists can play a significant role in the prevention and minimisation of dust exposure in Australian mines into the future.

What is Coal Workers' Pneumoconiosis?

CWP, commonly known as Black Lung Disease, is a type of occupational pneumoconiosis which is solely caused by chronic inhalation of coal dust particles. The risk of developing CWP is directly related to the extent and duration of exposure to coal dust. There is no cure and treatment of CWP consists of managing the symptoms, which

include shortness of breath and a severe cough. Where exposure continues, CWP can develop into progressive massive fibrosis, causing major damage to the lungs and the heart.

The effects of the disease on a person's life are drastic. Some of the workers who made submissions to the Select Committee report very low quality of mental and physical health. Workers reported not being able to walk around the house or play with their grandchildren, as well as the stress of contemplating death whenever they have pneumonia, a recurring effect of CWP. The disease is unfortunately complex to diagnose because its symptoms are similar to a range of other pulmonary diseases such as pneumonia or other types of pneumoconiosis. As such, while an early diagnosis could help better manage the illness by most importantly being removed from coal dust exposure, the failure to diagnose early symptoms results in worsening conditions.

The disease has a long latency period which often results in medical practitioners failing to link the symptoms to the disease. The Australian Institute of Occupational Hygienists submitted that it was impossible to ascertain an accurate number of cases of CWP at any period in time because of that long latency period, leading to poor data on which to base decisions for policy making in the field. While there is no cure for CWP, treatment consists of symptoms management which is easier when the symptoms are at early stages.

The Issues Raised by the Parliamentary Inquiry

The Select Committee's parliamentary inquiry is still ongoing. However, in a report published in May 2017, the Select Committee made 68 recommendations to assist in tackling the crisis.

Lack of Enforcement

The parliamentary inquiry found that because of the absence of identified cases since 1984, the mining industry switched its risk management focus to immediate threats (such as collapse, explosions and incidents resulting in immediate injuries) instead of long term risks such as CWP. The Inquiry's investigation showed that little was done in the field of regulation of dust exposure as strict guidelines were never established.

Additionally, the parliamentary inquiry raised the problems associated with the self-regulation regime for health monitoring by mine operators that had historically been in place. The schemes put in place for the purpose of coal workers' protection, such as the Coal Mine Workers Health Scheme and the Health Surveillance Unit, have been internally run by private mining companies. Under the impression that the disease had been eradicated, the mine operators failed to adequately enforce and monitor the effectiveness of the current regulations and further address the health risks caused by coal dust.

The Select Committee highlighted the conflict the current legislative regime has created by placing the burden of managing workers' health on private companies which, at the same time, seek profit maximisation. While the combination of both objectives is not always incompatible, the Select Committee suggested that an independent body should instead be responsible for overseeing compliance with the health monitoring systems of mining companies.

Failures of the Coal Mine Workers' Health Scheme and Medical Professionals

The Select Committee report also heavily criticised the current Coal Mine Workers' Health Scheme through which workers' health is monitored. Prior to January 2017, the decision for a worker to receive a medical routine check, including an X-ray, was at the discretion of the employer. Any Nominated Medical Advisor (NMA), responsible for medical matters within the company, was not required to have any particular experience or training in the field of occupational medicine or mining risks. This, combined with the pre-existing difficulties raised in diagnosing CWP, was determined to be unconducive to an effective risk aversion measure. For example, a worker who was formally diagnosed with CWP in 2016 described to the Select Committee that CWP was actually visible on his 2006

chest X-ray which failed to be properly assessed by a NMA. Accordingly, he was left undiagnosed for almost a decade.

As a result of the first 2 CWP diagnoses in 2015, the Queensland Government made substantive changes to the Coal Mine Workers' Health Scheme in requiring that health assessment be held every 5 years and that the person conducting the assessment is qualified to perform it. In mid-2017, the DNRM published a consultation paper with further reforms, particularly in relation to the qualifications of NMAs. The proposed amendments require NMAs to have qualifications and experience in the field in occupational medicine and particularly coal mining. In addition, the DNRM would be providing an additional qualification in order to achieve conformity in the quality of the health assessment provided to workers. While this measure remains at a consultation paper stage, it shows that the government is willing to re-assess and adapt the Coal Mine Workers' Health Scheme to deal with the current crisis.

Ineffective Dust Sampling

The third main issue raised in the report by the Select Committee related to the compliance with regulations regarding dust sampling. It was not until January 2017 that an exposure standard was established. Prior to this time, mine operators were required to conduct dust monitoring to ensure that the coal dust was at an 'acceptable level' at their mines. In addition, the mining companies did not have to report any of their dust monitoring assessments to an authority such as the regulator, DNRM. No accountability mechanism was in place, leaving companies to establish risk levels at their own discretion.

The recent amendments to the Coal Mining Safety Health and Regulation 2001 (Qld), made in the Mining Safety and Health Legislation (Coal Workers' Pneumoconiosis and Other Matters) Amendment Regulation 2016 (Qld), have now established an exposure standard and made it compulsory for dust control monitoring to be conducted every two weeks. More importantly, mining companies are required to report to the DNRM if their results are above the prescribed standard. These new requirements should help with strengthening the accountability process and ensuring compliance throughout the Queensland mining industry.

Independent Body

The main recommendation of the Select Committee is to create an independent body, the Mine Safety and Health Authority (MSHA) to be placed in charge of the implementation, supervision and enforcement of health and safety schemes throughout Queensland. The body would be responsible for all aspects of workers health including the approval of NMAs, setting standards, coal dust monitoring and mine inspections.

Under this re-organisation, the Safety in Mines and Research Station (SIMTARS) would dissolve from the DNRM and be administratively relocated within MSHA. Establishing the independent authority would mean decisions made in relation to mining safety and health are removed from the political pressures and biases inherent within a governmental department. Further, mining companies would no longer be required to 'self-regulate', reducing the perceived conflict of interests between profit, health and safety.

The Role of Occupational Hygienists

Occupational hygienists ought to be major players in the effective implementation of the new regime for managing the risks associated with CWP in Queensland. The previous legislation neglected to acknowledge the advantages of utilising experienced professionals, resulting in legislation that has failed to adequately address the risks and flawed implementation of control measures, leading to the health emergency we find ourselves in today. Although the skills of occupational hygienists have been used by some mining companies through SIMTARS and other private firms, those companies have historically not been required to use the services of occupational hygienists to assess their facilities for health risks.

With the advent of the parliamentary inquiry and the resulting changes to legislation (and other recommendations) this is set to change. Further it is likely that other states in Australia will follow Queensland's lead, either in the form of new legislation or best practice, so the potential opportunities for occupational hygienists are significant.

Development of Dust Monitoring Programs

The DNRM has recently published Recognised Standard 14: Monitoring Respirable Dust in Coal Mines, a standard made under the Coal Mining Safety and Health Act 1999 (Qld). Clause 14.2 of this Recognised Standard states:

A person who has a recognised competency as a certified occupational hygienist, or an equivalent competency under an international certification scheme (e.g. certified industrial hygienist), must review the adequacy of and endorse the coal mine's respirable dust monitoring program, and specifically:

- establish similar exposure groups (SEG);
- develop a respirable dust sampling plan that is representative of worker numbers, workers, shiftwork, tasks performed and conditions at the mine;
- estimate exposure of a SEG using descriptive statistics; and
- submit their review of the respirable dust monitoring program to the site senior executive.

Recognised Standards provide ways of achieving an acceptable standard of risk for people working in coal mines. Operators can manage the risk in a different way, but must be able to show that the method used is at least equivalent to the method in the recognised standard. They are admissible in proceedings against a mine operator that is alleged to have contravened an obligation under the legislation. What this means is, in Queensland, a mine operator's coal mine respirable dust monitoring program must be reviewed and endorsed by a certified occupational hygienist (unless a mine operator can show it adopted a different approach to reviewing and endorsing its dust monitoring program that achieved a level of risk equal to or better than having an occupational hygienist review and endorse it). Further, individuals who carry out dust sampling must have completed a SIMTARS-delivered training package (or a recognised equivalent competency).

Occupational hygienists now have what is essentially a legislated role in Queensland to assist mine operators develop best practice CWP and other respirable dust prevention and minimisation strategies, including conducting baseline dust surveys and characterisations. In order to remain effective, these plans will have to be reviewed and updated at regular intervals, which will require the assistance of occupational hygienists.

Assisting with the Introduction of New Technologies

Occupational hygienists can and must play a key role in assisting mine operators control the risks associated with respirable coal dust. One way that this can be done is by assisting with the introduction of new dust monitoring technologies in mines.

The parliamentary inquiry heard considerable evidence relating to the flaws associated with the current technique of respirable dust monitoring based on gravimetrical testing. The current gravimetrical method only provides feedback well after the exposure has occurred. The need for real-time monitoring was expressed throughout the Select Committee's hearings, for example many mine operators stated their desire to employ personal dust monitors such as the Thermo Scientific PDM3700 (which is used to great effect in the United States of America). Although mine operators desperately want to use this technology, it is yet to be certified for use in Australian mines due to not meeting either Australian Standards for intrinsic safety, the minimum measurements for accuracy or because they are cost prohibitive. Further, no real-time systems presently available on the market can distinguish between different types of respirable dust (i.e. diesel particles vs. silica vs. coal particles).

The Queensland Government recently launched a challenge for stakeholders to develop an affordable personal dust monitoring device that will provide real-time data to workers regarding their exposure levels to respirable dust, consistent with Australian Standards. Successful applicants will receive funding to research, develop and test their ideas and the final winning applicant(s) will potentially secure a contract with the Queensland Government to roll out their technology.

Mine operators are keen to invest their considerable resources in these new technologies, which will provide enormous benefits to the health of their workforce as well as long-term cost savings in the form of reduced workers compensation liabilities, increased productivity and reduced shutdown times due to exposure limit breaches. These new technologies will be used in Australia – and soon.

The introduction of real-time dust monitoring will mean increased sampling activities and, likely, increased corrective actions to address any breaches of exposure standards. The potential opportunity here for occupational hygienists cannot be underestimated with mining companies needing assistance to interpret data and develop systems plans to deal with the data that is being produced to ensure they meet their duties under the Coal Mining Safety and Health Act 1999 (Qld) as well as equivalent legislation in other Australian jurisdictions.

Further, an increased amount of data will provide occupational hygienists with the opportunity to undertake benchmarking exercises amongst the mining industry, which, up to now, have been lacking. Occupational hygienists have the unique ability to collaborate with their fellow hygienists in the mining industry without being constrained by the commercial competitive considerations that mining companies operate under (which often leads to a lack of information-sharing within the industry). Occupational hygienists can take the forefront in analysing data from various workplaces in order to determine what is best practice in terms of dust mitigation and to develop guidelines and models to deal with the risk. Such guidance has, up until now, been non-existent.

In rolling out these new technologies, and indeed for any new programs associated with health surveillance, occupational hygienists should also assist in preparing communication strategies with the workforce to meaningfully describe how and why these systems are being used and the benefits associated with them.

Influencing Public Policy

In its submission to the Select Committee, the Australian Institute of Occupational Hygienists raised concerns in relation to the current exposure standards in Australia, health surveillance mechanisms and dust monitoring practices. The legislative changes in Queensland in the past year have gone some way in addressing these concerns. However, as the goal of health and safety is always to continually improve performance, more can always be done.

The evidence before the parliamentary inquiry, including that given by a number of experts from the United States of America, demonstrated that the United States has a more advanced approach for managing the risks associated with CWP. The United States Mine Safety and Health Administration (MSHA) is responsible for the development of a respirable coal dust rule that has been progressively put into effect in the mining industry since mid-2014, and which appears better adapted to deal with tackling CWP incidence. The United States' prescribed occupational exposure limit (OEL) for respirable coal mine dust is 1.5mg/m3 and for workers who have evidence of the development of CWP, this is lowered to 0.5 mg/m^3.

By contrast the OELs in Australia, which are supposed to take into account the feasibility and cost effectiveness of control measures in relation to risks, are 3 mg/m^3 in Queensland and 2.5 mg/m^3 in New South Wales. Additionally, United States regulations prescribe a much higher rate of control for the personnel conducting the coal dust testing, with a certification required to be updated every 3 years.

Given their crucial role in developing and monitoring dust levels in mines, occupational hygienists must be active participants in influencing policy in Australia in relation to these matters. If a lower OEL is required to eliminate or minimise as far as possible the risks associated with CWP, occupational hygienists will be the profession that provides the research, data and analysis needed to accomplish this, including potentially collaborating with colleagues in the United States and other countries with large coal mining industries. Conducting gap analyses with legislative regimes and incidence rates in the United States and South Africa could also provide support to any policy changes to ensure Australia has in place a best practice regime.

Further, thought should be given to whether the learnings obtained from the re-emergence of CWP and the required legislative changes should be adapted to deal with other similar emerging health issues in the mining industry, such as the inhalation of silica and diesel particles.

CONCLUSION

The crisis associated with the re-emergence of CWP has highlighted the important role that occupational hygienists play, and must continue to play, in the management of CWP and other respirable dust risks in the Australian mining industry. The recent legislative changes as well as the recommendations of the Select Committee in Queensland show an intention to include health professionals in the development, implementation and supervision of the new legislative regime to ensure better health management. The opportunities for occupational hygienists to influence public policy in relation to dust management and assist in the introduction of new dust monitoring technologies are considerable. Most importantly, the skills and expertise of occupational hygienists will greatly benefit the coal mining workforce who have been let down by a system based on self-regulation and who require, and deserve, the assistance of competent professionals.

EXPOSURE TO LOW-QUARTZ MINERAL DUST AT HARD ROCK QUARRIES: IS THERE A RISK OF COPD?

Christopher A Aebi[1], Linda A Apthorpe[2] and Jane L Whitelaw[2]
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ABSTRACT

Aim: The objective of this project was to establish whether workers at hard rock quarries are being potentially exposed to low/no quartz mineral dusts at levels which could pose a risk to developing Chronic Obstructive Pulmonary Disease (COPD). Methods: Airborne dust monitoring was conducted at 20 different hard rock quarries over a 2-year period between April 2014 and February 2016, as part of an occupational hygiene monitoring program for respirable dust and quartz. 14 SEGs were monitored during both normal crushing operations, and during maintenance shut-downs, with combination of paired RD/ID sampling and traditional respirable dust and quartz sampling. Results & Conclusions: Maintenance workers generally were found to have highly variable RD exposures, whereas other plant operators had much lower airborne RD exposures and therefore, lower risk of health effects. In some cases, RD/ID ratios were used to calculate projected ID exposures, allowing the identification of a new set of workers potentially at risk to COPD, and requiring dust controls. Workers at low/no quartz mineral quarries can be monitored for exposures to ID or RD, depending on their established RD/ID ratios, as compared against the respective WES's. Paired RD+ID personal monitoring should continue for all SEGs so as to establish more statistically rigorous RD/ID ratios for each group. Further study should be conducted on the relevance of measuring respirable dust exposures for determining COPD, when recent studies have shown the thoracic dust fraction to be a better predictor of COPD risk.

TOLUENE EXPOSURE IN BELT SPLICERS: A CORRELATION OF AIR SAMPLING, PASSIVE AND ACTIVE, AND BIOLOGICAL MONITORING OF WORKER EXPOSURE.

Sar Mcfadden, Linda A Apthorpe, Jane L Whitelaw
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ABSTRACT

This study examined correlations between active and passive air sampling with urinary biological monitoring of Belt Splicers exposure to toluene. Solvents containing 60-70% toluene are regularly used in Belt Splicing, where the two edges of conveyor belts are brought together in a plaited fashion for strength and ease of movement across conveyor rollers. This unique group of workers are using solvents on a weekly turnaround schedule. Correlation studies over the last 20 years have all used passive sample badges for sampling convenience, and relied on the diffusion of air across the sample media as opposed to volume controlled pumped sampling. Belt Spicers at a major processing facility using the solvents, were monitored using both active sampling (i.e. using sorbent tube) and passive dose badge sampling. Urine samples were also collected on the same day at end of shift for analysis. Another integral part of the study was the correlation of the appropriate biomarkers for urine in the analysis methodology. At present, hippuric acid and o-cresol are the metabolites of choice. Several studies, particularly those published by Inoue et al in 2002, 2004 & 2008, have refuted the use of these metabolites as reliable, except where high level results occur in toluene exposure. They have argued that low levels of toluene, and lifestyle effects such as smoking and soda drink consumption, significantly effect hippuric acid and/or o-cresol. Benzylmercapturic acid (BMA) has been offered as a metabolite of choice, with correlations to higher pick-up rates as a biological marker. Testsafe Laboratory has purchased the equipment to include BMA as a method for toluene analysis which, if available will be included in the correlations.

HEAVY METALS, ARSENIC AND COBALT: USING AIR AND BIOLOGICAL SAMPLING TO IMPROVE WORKER HEALTH.

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University of Wollongong

ABSTRACT

Of concern is worker exposure to heavy metals, arsenic and cobalt in the processing and refining of copper-uranium-gold ore at a South Australian mine. Processing and refining of the ore body results in the accumulation and concentration of heavy metals in downstream processes such as electrorefining, electrowinning and gold processing. Both arsenic and cobalt exposure are associated with health effects including respiratory disorders (Agency for Toxic Substances and Disease Registry (ATSDR) 2007 & 2004). The International Agency for Research on Cancer (IARC) classified arsenic as a human carcinogen and cobalt as a possible human carcinogen (IARC 2012 & 2006). The aim of this study was to comprehensively evaluate the exposure risks to arsenic and cobalt, from all routes of entry (inhalation, dermal absorption and ingestion) for workers conducting tasks in the refining process. Personal airborne contaminant monitoring was conducted for arsenic trioxide dust and cobalt in accordance with Australian Standard 3640 for sampling and gravimetric determination of inhalable dust (Standards Australia 2009) and results directly compared to Australian Exposure Standards (Safe Work Australia 2017). In conjunction with airborne monitoring, biological monitoring for arsenic species and cobalt in urine samples was carried out to correlate airborne exposures with recommended biological exposure indices (BEIs) (American Conference of Governmental Industrial Hygienists (ACGIH) 2012). Results from air and biological monitoring were statistically analysed to determine exposure risk and effectiveness of current controls. Where worker exposures were not adequately controlled areas for improvement were identified and recommendations provided to reduce exposures to ensure improved worker health outcomes.

BIOLOGICAL MONITORING TO ASSESS ISOCYANATES EXPOSURE IN THE NSW MOTOR VEHICLE REPAIR INDUSTRY

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ABSTRACT

Urethane products that contain isocyanates are extensively used in the motor vehicle repair (MVR) industry and other industries such as furniture and cabinet making as two-pack spray paints, clears and adhesives. Attention has been refocused on isocyanate containing chemicals, particularly paints, as an alarming paper from the UK's Health and Safety Executive (HSE) stated that spray painters in the MVR industry had a propensity to develop industrial asthma at a rate 80 times higher than the general public. To track workers exposure to isocyanates a modified method for the analysis of isocyanate derived diamines in urine was developed using Ultra-High Performance Liquid Chromatography-Tandem Mass Spectrometry. Internal quality control and external quality assurance programs have been extensively applied to ensure accurate and reliable results of biological monitoring. The analytical method was applied to urine samples collected from 196 spray painters who worked mainly in 78 MVR shops in 54 New South Wales (NSW) towns and suburbs and were potentially exposed to isocyanates.

The main finding of the study was that 2.6% of the spray painters surveyed in the MVR industry in NSW handling isocyanate containing paints showed exposure to isocyanates with 1.0% being excessively exposed, with exposures up to more than twice the current HSE Biological Monitoring Guidance Value (BMGV) of 1 µmol/mol creatinine. These findings indicate that isocyanate exposure was occurring in the NSW motor vehicle repair industry. These findings were different with previous occupational biological studies that showed higher isocyanate exposure levels. This can be explained by the increasing use of water based paints in the industry resulting in lower than expected isocyanate metabolite levels detected in this study. The eventual use of isocyanate free final coat clear lacquers will undoubtedly improve the health of spray painters in the motor vehicle body repair industry and eliminate any inadvertent isocyanate exposures to others in the industry. The development of new biomarkers of isocyanate oligomer derived triamines should be incorporated in the assessment of isocyanate exposure in the MVR industry to provide a more complete picture of isocyanate exposure.

INTRODUCTION

Isocyanates are extensively used in the automotive industry and in the manufacture and application of two pack polyurethane paints, clears and some adhesives. The most commonly used isocyanates are hexamethylene diisocyanate (HDI), toluene diisocyanate (TDI) and methylene diphenyl diisocyanate (MDI). HDI and MDI are used as hardeners in two-part polyurethane products. In automotive paints, the hardener is typically based on HDI; in spray-on truck bed linings, the hardener is mostly MDI. Also, TDI and MDI are used in the manufacture of polyurethane foams, floor coverings and adhesives. Because of the well-known asthma related health problems [McDonald 2005, Stokes 2015], the percentage of free monomeric isocyanate in urethane paint hardeners has dropped dramatically. Now paints containing HDI have often much less than 1% free monomeric HDI with the majority of the hardener being polymeric HDI [Cocker 2007]. Currently in NSW, standardised respiratory function tests are the only means of detecting if a worker has had excessive exposure to isocyanates. Such respiratory tests are time consuming, need expert interpretation and often do not give sufficient advance health warning but only confirm the presence of disease. The development of the urine test was an effort to try and identify and control exposure before symptoms arise [Skarping 1994, Williams 1999] and can be used to assess the efficacy of personal protective equipment and individual work practices [Cocker 2007, 2011].

In 2008, a modified method for the analysis of isocyanates derived diamines in urine to assess the exposure of spray painters employed in the MVR industry was developed at SafeWork NSW laboratory. This was used in a preliminary study to determine the practicability of using urine metabolites to biologically monitor isocyanate exposures at various MVR shops in Western Australia between 2009 and 2012 [Hu 2014]. The results revealed

that measurable biological uptake had occurred, with 9% of spray painters' urine being in excess of the BMGV of 1 µmol HDA/mol creatinine.

In June 2013, the Australian automotive industry had 11,867 automotive body, paint and interior repair businesses. Aggregate employment within the industry is estimated at 361,187 for 2012/13 [Bletsos 2014]. NSW has the largest number of automobile body, paint and interior repair businesses (3609), followed by Victoria (3048), Queensland (2524) and Western Australia (1387). Isocyanates are called up in Schedule 14 of the NSW Work Health Safety Regulations 2011, as a hazardous chemical that requires health monitoring if there is a significant risk of exposure, with urine testing recommended as an option by Safe Work Australia [Safe Work Australia 2013]. In 2015, SafeWork NSW launched a campaign, named "High Consequence, Low Frequency" Program. It is designed to identify high risk industries and activities, and provide tailored safety advice and assistance. One of the activities was to conduct biological monitoring for spray painters in the MVR industry in NSW.

The aim of this study was to use the latest technology of Ultra-High Performance Liquid Chromatography-Tandem Mass Spectrometry (UPLC-MS/MS) to analyse urine samples from spray painters working in the NSW motor vehicle repair industry to determine their exposure to isocyanates. It also evaluated what types of control measures were being used and their effectiveness in protecting the spray painters from exposure to these hazardous paint chemicals.

METHODS

Participations of car smash repair shops and spray painters

Isocyanate exposure was evaluated in 78 MVR shops from 54 towns and suburbs across all 6 regions of NSW. The geographic areas of this occupational hygiene survey are shown in Figure 1. The east coast regions, Sydney, Southern, Northern, *etc*. of NSW were most prominently represented in the survey. The 78 MVR shops were randomly selected by SafeWork NSW Inspectors who had been extensively briefed on the project by the SafeWork NSW Hygiene & Toxicology Team that led the project.

The spray painters assessed in this survey used a variety of respirators, from positive pressure air supplied respirators with a dedicated air hose as is recommended in the Australian Standards (AS/NZS 4114.1:2003 & AS/NZS 4114.1:2003) to single or double cartridge respirators with or without inbuilt face visor and everything in between. There were varying levels of compliance with the relevant Australian Standards and approximately 800 improvement notices were issued on a range of work health & safety issues. However, only 3 prohibition notices were issued and were not for spray booths but for plant and electrical issues. The main areas for which improvement notices were issued included electrical, plant, spray booth maintenance, personal protective equipment, dangerous goods storage and chemical registers.

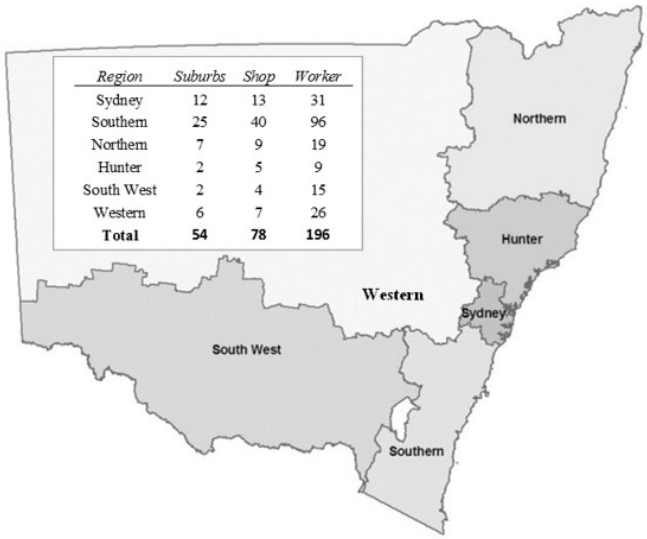

Figure 1. Geographic area of selected MVR shops in NSW.

Biological monitoring and analysis

Urine samples were collected at the end of the work shift from the workers who had read, agreed and completed a Consent Form to provide the urine samples. In this study the other isocyanate derived diamines, methylenediphenyl diamine (MDA), 2,4-toluene diamine (2,4-TDA) and 2,6-toluene diamine (2,6-TDA) released by hydrolysis of conjugates in urine samples collected at the end of the exposure were also measured to provide a more complete picture of isocyanate exposure or lack thereof. The work-up procedure of the urine samples was performed using a modified version of the protocol developed by Skarping et al. [1994] using Liquid chromatography with mass spectrometry (LC-MS) and Williams et al. [1999] using Gas chromatography with mass spectrometry (GC-MS). The analysis was performed using UPLC-MS/MS in this study [Hu, 2014]. An ACQUITY UPLC system with a Waters Quattro Premier XE triple quadrupole mass spectrometer was used for the analysis. The liquid chromatography column used was ACQUITY UPLC BEH C18 with 1.7 µm particle size, 2.1 mm internal diameter and 150 mm length. The analytes were identified by two characteristic Multiple Reaction Monitoring (MRM) transitions in a specific ion ratio occurring at a particular retention time. The confidence interval of the ion ratio was ± 20% and ± 5% for the retention time. Quantification was performed by internal standard calibration using deuterated analogues of the isocyanate derived amines.

Internal quality control checks for MDA have been performed routinely using a commercially available ClinChek-Control (Ref: 8922). The above modified method has participated periodically (twice a year) in the German External Quality Assessment Scheme (G-EQUAS), an Intercomparison Program since 2014 for toxicological analyses in biological materials from Institute and Outpatient Clinic for Occupational, Social and Environmental Medicine of the University of Erlangen-Nuremberg, Germany. Since Round 56 (October 2015) three more diamine metabolites, 2,4-TDA, 2,6-TDA and HDA have been added in the checklist. This analysis for biological monitoring on isocyanates in urine is also a National Association of Testing Authorities Australia (NATA) accredited method.

The creatinine in the urine was determined using a Roche Cobas Mira Plus system [Jaffe 1886]. The concentrations of isocyanates in urine are therefore reported in relation to the amount of creatinine in most occasions.

RESULTS

The biological monitoring method used for the analysis of four diamine metabolites in urine samples by UPLC-MS/MS at the laboratory was performed using a modified version of the protocol [Skarping 1994 and Williams 1999]. For the purpose of assessing the exposure to isocyanates LOQ was at 0.5 µg/L in urine for each four diamine metabolites. This level is comparable with previously reported analytical methods for the determination of

isocyanates in urine [Gaines 2010 and Williams 1999]. It is found that the method has good precision (< 6.3%) and trueness (< 4.5%) for the quantification of isocyanate derived amines in urine. The mean relative recoveries for the aromatic diamines 2,4-TDA and 2,6-TDA and MDA were between 101.2 and 119.3%. The mean relative recovery for the aliphatic diamine, HDA, was between 95.8 and 100%. The above recoveries were in agreement with similar results previously reported [Flack 2010].

The routine sample analyses of MDA were performed against two commercially available ClinChek-Control at different concentration levels. All the results for the above internal quality control samples were within the tolerance ranges. The method successfully participated in the Intercomparison program from Round 48 (October 2014) to recent Round 57 (March 2016) for toxicological analyses in biological materials of G-EQUAS. An example of satisfactory performance for Round 57 for 4 isocyanates derived metabolites is given in Table 1.

A total of 191 urine samples from 78 MVR shops across 54 suburbs and towns in NSW were analysed for HDA, MDA, 2,4-TDA and 2,6-TDA concentrations. The percentages of detectable concentrations are 1.6% for HDA, 0.5% for both MDA and 2,4-TDA as shown in Table 2. None of 191 urine samples had detectable 2,6-TDA concentration. Further, among these detectable results, 0.5% of 191 urine samples had HDA concentration equal to the BMGV of 1.0 µmol HDA/mol creatinine while 0.5% of the urine samples had 2,4-TDA concentration of 2.4 µmol/mol creatinine, exceeding the BMGV of 1.0 µmol 2,4-TDA/mol creatinine.

Table 1. The isocyanates derived metabolites results from the participation of G-EQUAS Round 57 (March 2016).

Metabolite	Controls	Lab results	Reference results	Tolerance range
		µg/L		
HDA	1	3.32	3.11	2.18 – 4.04
	2	7.58	7.20	5.97 – 8.43
MDA	1	4.58	5.69	4.01 – 7.37
	2	25.3	23.48	17.93 – 29.03
2,4-TDA	1	3.21	3.65	2.24 – 5.06
	2	14.25	13.50	9.78 – 17.22
2,6-TDA	1	3.45	3.17	2.30 – 4.04
	2	11.00	9.76	7.87 – 11.65

Table 2. Results of isocyanates derived metabolites in worker urine.

	HDA	MDA	2,4-TDA	2,6-TDA
No of total sample	191	191	191	191
No of samples ≥ LOQ	3	1	1	0
Samples (%) ≥ LOQ	1.6	0.5	0.5	0
No of Samples ≥ BMGV	1	0	1	0
Samples (%) ≥ BMGV	0.5	0	0.5	0

DISCUSSION

Analytical methods, internal quality control and external quality assurance

The latest chromatographic technologies (UPLC-MS/MS) were used in developing the biological monitoring method for the analysis of four isocyanate derived diamines in urine samples. The analytical columns used in the method had very small particle size (<2 µm) giving narrow chromatographic peaks with an average peak width of 0.2 min. This gave higher sensitivity and good separation of the four amines in a relative short run time (10 minutes) comparing with the previous methods [Skarping 1994, Williams 1999]. An example of satisfied performance for Round 57 of G-EQUAS in Table 1 demonstrates the analytical method is accurate and reliable for the biological monitoring of the four diamines in urine samples. In general, UPLC-MS/MS is extremely sensitive and selective technique when comparing it to GC-MS [Williams 1999]. UPLC-MS/MS provides improved identification and is easier to use. It also makes it possible to detect large isocyanate oligomer metabolites that GC-MS is not able to detect.

Attaining reliable results from biological samples is not an easy task. The low analyte levels often require complex sample treatment procedures that have to be carried out with a high degree of precision to allow reliable assessment of exposure. For example, the detection of isocyanate derived diamines in urine for isocyanate metabolites requires the detection level at µg/L of urine because their BMGV is at this low level, respectively. An approach widely applied today to achieve, maintain and document the quality of work of a biological monitoring

laboratory is the adoption of a quality control program [Schaller 2002]. Internal quality control and external quality assurance are important parts of quality management. One of the most popular external quality assurance systems for chemical substances and their metabolites is run by the Institute and Outpatient Clinic for Occupational, Social and Environmental Medicine at the University of Erlangen Nuremberg, Germany. Previously, only one of the isocyanate metabolites, MDA, was on this checklist but in 2015 2,4-TDA, 2,6-TDA and HDA have been added.

Biological monitoring results

The state of NSW has the largest number of automobile body, paint and interior repair businesses (Bletsos 2014). The selection of the MVR shops was taken mainly from the Sydney metropolitan and the southern parts of NSW. These MVR shops were selected by SafeWork NSW Inspectors who had been extensively briefed on the project by the SafeWork NSW Hygiene & Toxicology Team who led the project. The other regions also participated but to a lesser extent (Figure 1).

Biological monitoring for isocyanate derived diamines in urine is a simple, non-invasive and direct measure of the effectiveness of exposure controls (Williams 1999). When control measures involve a mix of options, especially where these involve PPE and correct methods of working, biological monitoring is often the only practical method of checking that exposure is being adequately controlled. As such, it is a recommended occupational hygiene technique in the WHS Regulations "Hazardous Chemicals Requiring Health Monitoring - Schedule 14" (Safe Work Australia 2013).

A key learning that came from this project was the Australian Standards 4114.1 and 4114.2 called for positive pressure spray booths which is in contrast to British, European and American Standards that require negative pressure spray booths. Unfortunately, the Australian booths unless totally airtight, will leak sprayed paints into the immediate environment around the spray booth, thus causing potential exposure to workers in the vicinity.

The restrictions that are placed on the paint mixing room with respect to ventilation and electrical safety are as severe. A survey that was done on 10 paint mixing areas showed that although the solvent vapours were quite often strong they never approached the lower explosive limit. However, it is suggested that electrical switches for equipment leads in paint mixing rooms be elevated well above the mixing table to avoid the heavier than air solvent vapours. Also, electrical equipment such as scales and colour matching machines be raised above the bench on non-flammable plinths to avoid the possibility of contact if there is a major solvent spill on the mixing bench.

Of the 191 spray painters who submitted urine samples only five were found to contain isocyanate metabolites and of these only two were at or above the BMGV of 1 µmol/mol creatinine. Biological monitoring results from this study show 2.6 % of urine results had detectable concentration of isocyanate derived diamines (Table 2) which were lower than had been in previous studies done by other research groups. One of them showed that HDA was detected in urine of about 25% of the spray painters in which the analytical method had 10.5 µmol HDA/mol creatinine (Pronk 2006). Another was from HSE SHAD program (6%) [Jones 2013], and other was from a survey (9 %) done a few years ago in Western Australia by the SafeWork NSW and WorkSafe WA [Hu 2014]. However, the current study results with lower detectable concentration of isocyanate derived diamines must be interpreted with caution. As the analytical method used has been vigorously ensured by internal quality control and an external quality assurance programs, a few worthwhile considerations are addressed below.

It is noted that the MVR shops that participated the survey had a flexible working environment. As a result, there were part-time spray painters as well as full-time painters who often worked less hours on spray painting job. It was found that the short initial half-life of HDA means that the urine sample only represents exposure over the past 2 – 4 hours [Williams 1999]. What possibly happened was that part-time sprayers or sprayers working less hours may have been exposed but metabolite concentrations were too low and too quickly excreted to show that an exposure had occurred. Although the sampling instructions were given to the employers and sprayers to provide urine samples at the end of a spraying session, there was no guarantee that all sprayers were compliant.

Currently, the applications of paint pointers in the Australian MVR shops are 30% of water based paints, 52% of solvent based paints, and 18% mixture of both (Street 2017). The trend in the industry in the world is to use water based paints [Liao 2015] and it is possible that the only exposure the spray painter gets to isocyanates is in the final coat of clear lacquer (which still has isocyanates) that is sprayed over the water based paint. Currently, there is much research being undertaken in the industry to make the final clear coat isocyanate free. Quite a number of the MVR shops visited in this survey were using water based paints and a number were using both. This could also explain some of the discrepancies in the urine isocyanate metabolite results.

The current studies involved exposure to the isocyanate monomer but in many workplaces there are exposures to oligomer or polymeric isocyanates. Around the world, the majority of regulations only cover the monomer, but both the monomer and the oligomers should be measured, particularly in relation to worker-related illnesses [Bello 2004]. This is particularly important with exposure to HDI in two-pack paints used in motor vehicle repair where free monomeric HDI is much less than 1% and the remainder is polymeric HDI, uretidone, biuret, isocyanurate [Rosenberg 1986, Fent 2008]. The structure of one of the HDI oligomers, HDI biuret is shown in Figure 2. More HDI oligomers were detected than HDI monomer in the air sampling studies in the MVR shops [Fent 2009]. As current biological monitoring of HDI exposure has been limited to the hydrolysis product of HDI monomer, HDA, the determination of metabolites of HDI oligomers are believed to be a more realistic exposure assessment with MVR spray painters [Robbins 2013]. An example of the molecular structures of HDI biuret and its corresponding metabolite, HDI biuret triamine is demonstrated in Figure 2.

A preliminary study has demonstrated [Robbins 2013] the triamine metabolite of isocyanurate in urine can be quantitated in the exposed workers using this extraction procedure and UPLC-MSMS analysis. In the past, HDI monomer metabolite have been analyzed using derivatization. The new UPLC-MSMS method requires less preparation time, no derivatization and detects large HDI oligomer metabolites that the GC-MS method cannot detect. This study provides evidence that biological monitoring of HDI oligomer exposure in the workplace can be performed and that assessment of exposure-dose relationship and assessment of adverse health risks due to isocyanurate exposure are reasonable in future studies.

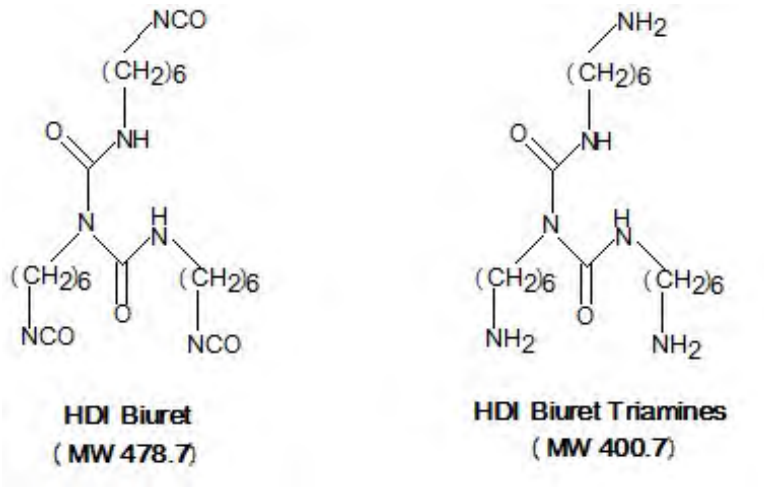

Figure 2. Molecular structure of HDI biuret and its corresponding metabolite, HDI biuret triamine.

CONCLUSIONS

Isocyanates have been extensively used in industry particularly in two-pack spray paints, polyurethane and adhesives. They are highly reactive chemicals and can cause respiratory sensitisation and asthma. More recently, isocyanate derived diamines in a worker's urine have been used to assess exposure. This study presents a highly sensitive and specific Ultra-High Performance Liquid Chromatography-Tandem Mass Spectrometry method for the determination of the isocyanate derived diamines. The method has been fully validated and has a low limit of quantitation of 0.2 µmol isocyanate derived diamine/mol creatinine. Internal quality control and external

quality assurance programs have been extensively applied to ensure accurate and reliable results of biological monitoring.

The analytical method was applied to urine samples collected from up to 191 spray painters who worked in 78 MVR shops in 54 suburbs and towns in NSW and were potentially exposed to isocyanates. This analysis was carried out using well validated analytical methods. It was found that both biological monitoring results had lower detectable concentrations of isocyanates in urine of the spray painters. The survey results indicate that isocyanates exposures were occurring in the NSW motor vehicle repair industry.

The increasing use of water based paints in the industry may be responsible for the lower than expected isocyanate levels that were detected in this study. The eventual use of isocyanate free final coat clear lacquers will improve the health of spray painters in the motor vehicle body repair industry and eliminate any inadvertent isocyanate exposures to others in the industry. The development of new biomarkers, namely isocyanate oligomer derived triamines should be incorporated in the assessment of isocyanate exposure in the MVR industry to provide a more complete picture of isocyanate exposure. A rewrite of the Australian Standards (AS/NZS 4114.1:2003 & AS/NZS 4114.1:2003) should also be considered to bring it into line with the US, UK and European spray booth standards that require negative pressure spray booths and other necessary amendments.

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Disclaimer
The views and opinions expressed in this paper are of the authors and do not represent the views of SafeWork NSW. This paper is in preparation for the 2017 AIOH conference proceedings, and is partially based on the authors' paper accepted for publication in *Annals of Work Exposures and Health* (formerly *Annals of Occupational Hygiene*), 2017, which is in press.

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CAMPAIGNING TO RAISE AWARENESS OF OCCUPATIONAL HYGIENE - WHERE DO YOU START? LESSONS FROM THE BREATHE FREELY INITIATIVE.

Mike Slater
Diamond Environmental Ltd. and BOHS Past President

ABSTRACT

Since its launch on April 28th 2015, the British Occupational Hygiene Society (BOHS) led Breathe Freely initiative has achieved significant success in raising awareness of the high incidence of deaths and ill health due to lung disease in the construction industry and in effecting action. Through the campaign, BOHS has provided employers with practical solutions to help them to implement effective exposure controls, including a range of free guidance materials, produced by BOHS members in collaboration with construction industry representatives. This information has been disseminated through a series of well-attended open events around the country, webinars and construction industry forums and by accepting a large number of invitations to speak at various meetings and events. Building on the success of the construction campaign, the initiative has now been extended into the manufacturing sector. The second phase of the campaign, initially focusing on welding, was launched on 25 May 2017.

The Breathe Freely initiative was a new departure for BOHS in that it was the first campaign the Society had delivered. It has presented a number of challenges on how to reach out to stakeholders and communicate a complex message in an accessible way to a general audience. The lessons learned during the preparation, planning and delivery of the campaign will be discussed. These have included how to set realistic objectives and priorities, work with partners, identify and engage with stakeholders and develop relevant, accessible messages and materials.

RISKS AND BENEFITS OF VIRTUAL REALITY WITHIN A MULTI-SITE ORGANISATION.

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ABSTRACT

Virtual reality (VR) has become a popular medium used by gamers and training organisations for immersing a person in a digital space, creating an experience in which the person can interact with objects and other people. As this technology has become more prevalent and more affordable, VR has become well-established in industrial workplaces. In particular, research has provided a strong basis for the implementation of VR for training purposes. For employees in high-risk occupations, such as working at heights, in confined spaced or in radioactive environments, VR offers a safe and realistic means of training without putting people at risk. While the use of VR in OSH training has garnered limited attention from researchers, it has the potential to revolutionise the way organisations train those who work 'in the field'. Drawing on literature derived from academic sources and interviews from top-level management in a large corporate establishment, this paper discusses the potential for VR to be used for OSH training within a multi-site organisation.

INTRODUCTION

Multi-site organisations face a range of challenges in delivering equivalent training across different locations. In circumstances where employees potentially encounter a range of occupational safety and health risks, it is imperative that training is effective and consistent, embodying best practice and developing key skills and competencies that the employee will internalise to keep themselves and their co-workers safe. Traditional tick-a-box online safety programs rarely include the compelling experiential component that persuade an employee that this could be a life or death, health or injury matter. Similarly, seminars and workshops can be more engaging, but are also more distracting as a result of social interactions and the sense that the training is a holiday from everyday workforce realities. Virtual reality-delivered occupational safety and health training offers clear benefits in these circumstances.

Where an employer has managed to develop or source an appropriate suite of virtual reality experiences to meet its occupational safety and health needs, these can be combined into a compelling worker-focused experience. Not only does this technology offer the potential of an immersive experience for the OSH trainee, there is also the possibility that they will be able to interact with other trainees co-located or in different premises, to have a shared engagement with the educational encounter. The capacity of virtual reality (VR) to reduce the salience of everyday life and propel the user into a totally different psycho-emotional setting creates the opportunity for rich, deep learning. The new understandings forged in the process of this engagement can inform a heightened awareness when faced with real challenges in an occupational setting. A further benefit of the use of virtual reality is that it appeals to the very generation of young workers that is most prone to act first and think later when it comes to taking risks with the aim of getting the job done. Thus, the training is delivered to those that most need it in a way that they are most likely to be able to use it.

Virtual reality-based training does have its risks, however. As the technology develops and becomes an increasingly desirable leisure activity, with multi-sensory capacity including the manipulation of objects in virtual spaces, and kinesthetic and special awareness insinuated into virtual environments such as the surface of the moon or a Mayan temple, so the standard and quality of VR experiences becomes more critical. A worker who is a VR fan in their leisure time, may find the VR-delivered OSH experience amateurish or clunky. Further it may be necessary, in terms of compliance, to engage the VR-trained worker with a conventional questionnaire or follow-up survey which confirms that the desired take-outs and teaching messages have been absorbed and internalised. Such reinforcement of the compliance elements of OSH training may compromise the free-flowing, engaging experience of the VR-delivered encounter. These possible risks should not dissuade organisations from aiming to realise the benefits. When it comes to VR-delivered OSH training, there is huge potential with both worker and organisational benefit.

Virtual Reality

Defined by Bryson (1996) as the "use of computers and human-computer interfaces to create the effect of a three-dimensional world containing interactive objects with a strong sense of three-dimensional presence", VR is a way for humans to interact with computers and extremely complex data in real-time simulations of the world (Kizil and Joy, 2001). Once the domain of computer gaming enthusiasts, VR has found applications in a range of fields, including medicine, aviation and the military (Filigenzi et al., 2000, Rose et al., 2000). An immersive virtual environment (VE) engages a person's senses and gives the feeling of being within the simulation. This environment typically provides a three-dimensional (3D) representation of a virtual environment (Sacks et al., 2013), allows a user to interact with objects and the environment through the use of external input devices such as the Dataglove (Mantovani et al., 2003), tracks a user's progress, and allows evaluation of an experience (Filigenzi et al., 2000, Sacks et al., 2013). These features combine to "form a uniquely engaging experience" (Kizil and Joy, 2001).

Whilst virtual reality is a type of simulator, it provides a completely different level of experience to the user. A simulation is a computer program which does not need to be interactive. The environments are generally abstract or mathematical models that give insight into natural and social systems such as the modelling of cognitive processes in psychology (Brey, 2008). A simulation is generally viewed on a flat screen with little or no input from the trainee (Kizil and Joy, 2001). In contrast, VR is an immersive, interactive system which provides sensory feedback (including tactile and positioning) alongside engagement in real-world models and situations. VR is generally experienced through the use of a head-mounted display and the user's input is accessed through external devices such as the Dataglove or Datasuit (Brey, 2008).

To date, VR has been adopted and used in a variety of industries and settings. One of the first areas to adopt this training system was the medical community. Many studies have strengthened the case for the use of VR in medical scenarios, from emergency room situations, to high risk patients and complex surgery (Mantovani et al., 2003). The army and navy have implemented VR within their combat training to train officers in ship manoeuvres, soldiers for the battlefield, and to enhance resilience in high-stress environments (Tichon and Burgess-Limerick, 2011). Emergency services, pilots, drivers, console operators, divers, therapy and rehabilitation experts and even the Hubble Space Telescope Ground Control team have incorporated VR into their training systems (Rose et al., 2000, Filigenzi et al., 2000, Sacks et al., 2013, Tichon and Burgess-Limerick, 2011, Mantovani et al., 2003). Whilst VR has been implemented in some areas of OSH training, it has generally been restricted to large organisations with sizable workforces. One reason for this might well be that justifying the use of VR to improve safety is difficult without quantification (Kizil and Joy, 2001).

What Can VR do for Safety?

Inadequate, poor quality and insufficient training is often cited as the cause of accidents, injuries and fatalities (Filigenzi et al., 2000). The ability of workers to identify the hazards, assess, rectify and respond to risks and avoid harm is an essential skill that is generally acquired through training and experience. An employer can take all reasonably practicable precautions to ensure worker safety, but it is the decisions around the ways employees work that determine whether or not they engage in safe behaviours, and thus their level of risk (Sacks et al., 2013). Training regulations may have been enacted by the employer, however the tools used to train employees are often not as effective as they could be (Filigenzi et al., 2000). Low engagement training methods such as lectures, videos and demonstrations are common practice in many workplaces, yet have been shown to be less effective than high engagement methods. It has been proven that VR training users have a high level of engagement and alertness, and these types of training programs are more effective than classroom training (Sacks et al., 2013). The knowledge and skills that are acquired through the use of VR training transfer to real world activities in a "more meaningful and realistic way" than conventional training methods (Filigenzi et al., 2000). Recent studies have shown that there is clear scientific evidence of a positive transfer of both spatial skills and procedural learning from virtual to real-world environments (Rose et al., 2000).

The mining and construction industries' uses of VR include accident reconstruction, hazard identification, site walk-throughs and training (Kizil and Joy, 2001, Filigenzi et al., 2000, Stothard et al., 2004, Sacks et al., 2013). Kizil and Joy (2001) state that:

> Virtual reality provides the best tools for accident reconstruction, training and hazard identification by immersing the trainee in an environment as close to real world as possible…the difference between the conventional and VR training is that VR immerses the trainees in realistic, functional simulations of workplace and equipment and they demonstrate mastery of skills through performance of tasks in multiple scenarios (p. 569)

Virtual site walkthroughs allow a trainee to gain a general familiarity with the environment in which they will be working. It gives the trainee the opportunity to familiarise themselves with potential risks and hazards, as well as emergency exits, escape routes and emergency procedures (Rose et al., 2000). Following on from this, hazard walkthroughs can be developed using the virtual site, or another made-up environment, to increase awareness of risks and hazards that may be present in a workplace. This may be done in one of two ways. Firstly, hazards can be highlighted to the trainee as they walk around the virtual site or, secondly, the employee must identify hazards as they tour the virtual workplace, completing a virtual workplace inspection. The employee then re-tours the virtual workplace and any risks or hazards that were missed are highlighted (Kizil and Joy, 2001). These walkthroughs can be modified depending on the type of job or workplace that the trainee will be working in.

Virtual reality has also been used to translate the technical results of accident investigations for the workforce in a format that is stimulating and engaging. While accident investigations can often pinpoint the exact cause of an incident, the results of the investigation are often poorly communicated to the workforce (Kizil and Joy, 2001). Results may be presented in a text-based report that is difficult to understand and absorb. Virtual reality offers the organisation the opportunity to reconstruct the accident or incident, thereby giving a trainee an understanding of how and why it happened, how it could have been prevented, and if or how injuries or fatalities could have been avoided (Kizil and Joy, 2001). A person is far more likely to understand and absorb the safety implications of an incident if they are given the chance to experience it themselves, without the risk of injury (Filigenzi et al., 2000). It is only through effective OSH training, where employees recognise and assess hazards and risk, and implement appropriate controls, that these incidents can be minimised and/or avoided.

Virtual reality has the capacity to train employees in a safe, flexible, adaptable, modifiable and assessable environment. Not only does VR provide a safe environment, it can also provide access to high cost, high risk or inaccessible equipment, locations and situations which would be difficult or impossible to access or use in a training environment (Kizil and Joy, 2001). In particular, virtual environments are highly effective for training people in high risk tasks and situations. One such example is a worksite that stores and handles radioactive materials. Lack of hands-on training, or the training of employees in the correct safe handling procedures in a real-world environment, poses significant risk to the health and safety of not only the trainee, but also the trainer and other persons in the immediate area. Working at heights and in confined spaces are two further examples of high risk environments which can pose a threat to a person's safety whilst training. VR offers a realistic and engaging alternative training for these, and many other high-risk tasks and environments. Trainees can safety experience these situations, and the consequences of their decisions and actions, without inflicting harm to themselves or others (Sacks et al., 2013). These simulations are easily modified and adapted to an individual's level of skill or experience, extending the breadth of information and knowledge that can be gained from this resource. All employees are trained using the same information, in the same manner, creating an inclusive safety culture where employees are all equal. These simulations can be recorded, tracked and assessed by trainers either by pausing the VE during training, or independently evaluated post-training, with feedback given to participants both within and outside the VE (Kizil and Joy, 2001).

Benefits and Limitations of VR Training

Literature on the benefits of VR for training is abundant, yet the implementation of VR as a training resource has been inconsistent. The literature indicates a far larger number of potential benefits than of limitations, yet the costs of effective VR training and the skills required to develop therapeutic virtual environments appear to inhibit

its use by a number of occupational sectors. Even so, within a training context, VR offers the opportunity to drop in and out of the virtual environment, to pause training for discussion, to rehearse sequences, and to give instant feedback (Filigenzi et al., 2000, Sacks et al., 2013). Because of its real-time and real-world characteristics, the employee's learning journey is track-able and assessable eliciting task performance that enhances the learning process engendering higher levels of alertness and attention (Sacks et al., 2013). These characteristics underpin the effectiveness of the experience.

Because virtual environments can be encountered in repeat experiences, but also modified to provide new challenges, employees can experience the consequences of their actions without risk, and learn how to avoid or handle mistakes without damage to equipment or injury to others (Tichon and Burgess-Limerick, 2011, Mantovani et al., 2003). Training is no longer dictated by the amount of time an expert has to engage with the training experience, but is instead linked to the opportunity that the trainee has to spend time in the virtual high-risk environment (Kizil and Joy, 2001). VR-delivered experiences can reduce the cost of training. Workers who might otherwise spend time in dangerous and restricted environments can be safety trained in a VR lab. The encounter can be designed to highlight hazards for the new trainee navigating the experience for the first time or to highlight items missed when offering refresher courses or just-in-time skill reinforcement. The links between VR training and online gaming can motivate younger workers to engage with perfect scores on ladder boards, or as part of collaborative teams, and the adaptability of digitally-delivered experiences allows customisable outcomes and delivery options (Kizil and Joy, 2001).

The confounding disadvantages of VR training that have the capacity to deter employers from engaging with these technologies include a fear of complexity and uncertainty about the quality of outcomes, alongside the potential cost of developing effective training materials and virtual sites. Currently, the main disadvantage of VR lies in the costs of developing training materials and virtual sites (Sacks et al., 2013). Whilst the implementation cost may be high, Stothard et al. (2004) argue that VR is becoming increasingly accessible due to the decreasing costs associated with sophisticated computer hardware and software. The authors state that "VR-based training is an affordable technology", however this is in reference to coal mining operations. Fox et al. note that VR is often perceived as cost-prohibitive, however the costs of implementing VR are decreasing. Kizil and Joy (2001) argue that the cost of VR technology to train mining workers dramatically reduces the overall cost of training and also reduces losses in revenue due to stoppages. They claim that the money invested in implementing VR training would (in a mining context) be recovered in a short period of time.

One of the concerning possible side effects is that if VR is too good, an employee might see all equivalent engagement, including the reality of the risky environment, as a safe space which will forgive mistakes. Another concern lies in the patterned or conditioned responses that can be embedded into an individual's responses to certain events or situations. One particular example of an incident caused by conditioned, patterned responses resulting from a training environment, is that of the KLM-Pan Am Tenerife disaster in 1977. On 27th March 1977, two Boeing 747 passenger jets collided on the runway at the Los Rodeos airport in Tenerife. Investigations revealed that the principal cause of this tragedy was the captain of the KLM flight proceeding to take off without clearance (Weick, 1990). In-depth research has since revealed that conditioned and patterned communication and responses learnt within a training environment were fundamentally responsible for the miscommunication that led to the pilot proceeding to taxi down the runway towards take-off. As stated by Weick (1990), "stress can produce regression to first learned responses". The KLM captain was the Head of the Flight Training Department, an experienced trainer, and had not flown on regular routes for twelve weeks prior to the incident.

> Although the captain had flown for many years on European and intercontinental routes, he had been an instructor for more than 10 years, which relatively diminished his familiarity with route flying. Moreover, on simulated flights, which are so customary in flying instruction, the training pilot normally assumes the role of controller: that is, he issues take-off clearances. In many cases, no communications whatsoever are used in simulated flights, and for this reason take-off takes place without clearance (Aviation Week, 1978, p. 121).

The pilot, placed in a stressful situation due to external circumstances beyond his control, reverted to the conditioned patterns that he was familiar with whilst training new pilots. This is a topic that must be addressed in relation to VR training programs in high risk situations. This is particularly the case in environments where there is the risk of injury or death to people, or damage to expensive equipment or fragile sites.

In addition to these concerns, there is also the risk of physical side effects to VR training participants, such as disorientation, nausea, headaches and (in extreme cases) vomiting (Nichols and Patel, 2002).

Case Study

Many articles cite the use of VR as a training resource in the mining and construction industries, as well as oil and gas, and emergency services, yet large organisations with high-risk characteristics, such as utility and manufacturing organisations, have failed to incorporate VR when establishing training programs for their employees. This case study is based on a large Australian Government Organisation (AGO) with multiple departments. The AGO is seeking to enrich their OSH training by incorporating VR in their introductory and ongoing training programs. With a sizable mobile workforce, including a large number of contractors from a multitude of subsidiary and specialist organisations, safety training has become a complex and cumbersome exercise. Relying mainly on online training courses, and the internal training programs of contractor organisations, senior management are preparing to invest a considerable amount of time, money and energy in implementing a virtual reality training program that can used by employees at any location, at any time.

With an office based in the CBD, multiple AGO-owned sites, and various urban and rural locations, the organisation needs to be able to tailor their training programs for high, medium and low risk work and environments. Whilst the most common risk faced by employees is driving a car, the gambit that they're faced with ranges from working at heights, confined spaces, emergency situations, manual handling, heat, vibration, biological and chemical hazards, noise, and infectious diseases. Employee responsibilities can range from customer service, to monitoring, maintenance and compliance checks of sites and equipment, to installations, engineering and manufacturing. With a diverse workforce comprised of high school, TAFE and university educated employees, OSH training needs to encompass a broad range of topics and competencies.

Whilst the organisation has a range of health and safety training programs available, senior management agree that OSH could be "done better" (Lyndsey, OSH and Compliance Area Manager, AGO). Online training, workshops and seminars have low engagement with workers, and do not engender the motivation to sign up for, or seek out training for further development. The interactivity of virtual reality offers the organisation a way to connect with trainees and to enhance the learning process in a way that opens the door for further discussion about OSH issues.

This forward thinking came about after the AGO's OSH and compliance general manager, Adam, visited a site in Singapore that had implemented VR hazard walkthroughs in their training program. Adam was invited to experience the VE of this particular site, where he was tasked with identifying possible risks and hazards. Once the walkthrough was finished, the VE was played again, highlighting the risks and hazards that he had not identified. For Adam, this encounter was a powerful reminder that a personal experience was far more thought provoking and impactful than words on a screen. The management team were quick to buy into this opportunity.

> I think there's some smarter ways to do it like through VR or augmented reality, we can actually experience… so how do you how you change behaviour? You get people to actually believe in it and how do you get belief? You experience it. (Lyndsey, OSH and Compliance Area Manager, AGO)
>
> You've got so much more flexibility in that environment. (Adam, OSH and Compliance General Manager, AGO)

Whilst still in the early stages of this project, the AGO has already invested significant resources into researching an appropriate iteration of VR OSH training that can be effectively integrated into their existing training programs, adding value and amplifying impact.

> Yeah, I mean at the moment we're just trying to decide where. So, we've engaged a consultant to help us build the 3-d footage. They said 'you want to do it on a…good real site with real people'. (Adam, OSH and Compliance General Manager, AGO)

> We're looking at delivering training through that medium. But really, we're very much at the start of that journey… definitely it engages you and it's more interactive (Jasmine, OSH Interpreter, AGO)

The point of difference here, however, is the intended deployment and continued use of the VR training application. The AGO is developing the VR training environment with the intention (at a later stage) of deploying the training on smartphones for use in the field. Rather than a trainee having to travel to a set location to engage in training, the person will have the ability to train at any time, in any place, via their smartphone, a downloadable app and a set of VR goggles.

> Given that giving them the iPhone and the goggles, and they can walk on one of our sites, because we can render that in virtual reality, and then have them see what 'good' looks like from a fall-from-heights perspective, you know, put your harness on, clip on, go up inside your elevator and work platform, do your job. But then also see what bad looks like, which is when your phone rings and you forget to flip on your elevates, the thing tips over and of course in the real world…yeah you can fall and it can scare the bejesus out of you and see how that [feels]. (Adam, OSH and Compliance General Manager, AGO)

Feasibility investigations, and planning, continue, but it seems clear that Adam's experience for himself, of the power of VR training, has won hearts and minds in this particular organisation.

DISCUSSION

The literature, and interviews with one particular organisation, indicate that when OSH managers experience virtual reality in their training schemes they are motivated to continue using it. At present, the academic investigation is mainly focussed on the benefits to be delivered to workers and employers from using VR training when compared to text-based alternatives. As this sector of the training market matures, however, it is likely that there will be greater focus on the risks of life-like simulations as indicated in the KLM-Pan Am Tenerife disaster. In the meantime, it seems evident that the benefits far outweigh the risks and the major reason why VR is not universally used in OSH training is its perceived cost and complexity. As virtual reality becomes cheaper and more ubiquitous, and increasingly available to consumers as a leisure-time activity, so the barriers to adoption by motivated employers will decrease. What remains crucial is that new users of VR OSH training tools, and new market sectors who may be middle or late adopters of VR, need to build in continuous research and evaluation of the effectiveness of their training delivery so as to best realise the potential of these technologies.

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MANAGING HEALTH HAZARDS AT THE DESIGN STAGE – A CHALLENGE FOR OCCUPATIONAL HYGIENISTS.

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ABSTRACT

Industry is faced with a plethora of health, safety and environmental hazards and risks; systematic and effective risk management is therefore vital for industry's social licence to operate, resulting in the development and implementation of Health, Safety and Environment management systems. Risk management is the core of such systems, the crucial element of which is control, since the goal is to eliminate or reduce HSE risks to acceptable levels. The Hierarchy of Controls is a model of control strategies arranged in order of effectiveness but despite being well known and accepted, lower order control strategies are commonly used in the workplace rather than the higher order ones. The design stage of projects is the most opportune time to implement higher order controls, particularly for health considerations, which relative to safety and environmental matters are poorly managed during design, construction and operational phases of a project. Information and resources for Health Management in Design are available but there are challenges to its successful implementation in industry, and these are examined. By virtue of their training and expertise, Occupational Hygienists are well equipped to meet these challenges and are urged to take up the challenge to champion Health Management in Design, and thereby leave a legacy of better health outcomes to those people working in the operations.

INTRODUCTION

My career spans the better part of half a century; I spent around twenty years as an analytical chemist before transitioning to Occupational Hygiene (OH), which happened almost by accident following post-graduate study in OH that I undertook to improve my knowledge in the discipline in order to apply to the laboratory and associated work, such as sampling.

Given my background in chemistry then, it's not surprising making OH measurements (i.e. the OH principle of 'evaluation') was of most interest to me during the initial phase of my OH career. However, in time I focussed increasingly on the OH principle of 'control': after all, controlling a hazard or risk is fundamental to protecting the worker health, i.e. the ultimate goal. At the same time, I became concerned about how much the lower order Hierarchy of Control elements of the (i.e. Administration and PPE) are relied upon for managing OH (and indeed, safety) hazards and risks. However, implementing the higher order control elements (i.e. 'Elimination', 'Substitution' and 'Engineering') is difficult to do retrospectively in an operating facility and hence, the best opportunity to do so is at the design stage, i.e. 'designing out' health hazards. Consequently, I became am a keen advocate of designing out health hazards, a process that I will refer to as Health Management in Design (HMiD).

In this paper I will look at potential barriers to HMiD and with reference to my experience in the O&G industry (and with emphasis on noise management), discuss how Occupational Hygienists are ideally suited to champion HMiD to overcome these barriers and thereby leave a legacy in which health hazards and associated risk have been eliminated or reduced to levels that are as low as reasonably practicable (ALARP).

Risk Management and the Hierarchy of Control

Industry is potentially impacted by a plethora of health (H) and safety (S) hazards and risks, so it is understandable that 'Effective systematic management of risks improves worker health and safety, as well as productivity' (Safe Work Australia, 2017a). Environmental (E) considerations are also very significant and are subject to stringent regulation, at both Federal and State levels. Therefore, in order for industry to maintain its social licence to operate (Australian Government, Department of Industry and Resources, 2017) systematic and effective HSE risk

management is of vital importance. To meet this challenge, a range of management systems (MS) for HSE have been developed, either as discrete H&S or integrated HSE MS.

Risk management is the heart of a HSE MS and comprises the main elements of: identify hazards; assess risks, and; control risks. An example of the risk management process is provided in Figure 1a, where an additional element, 'Review control measures' (Step 4) is included to form a quality cycle.

Figure 1: Risk Management Process
Source: Safe Work Australia, 2017a, Figure 1

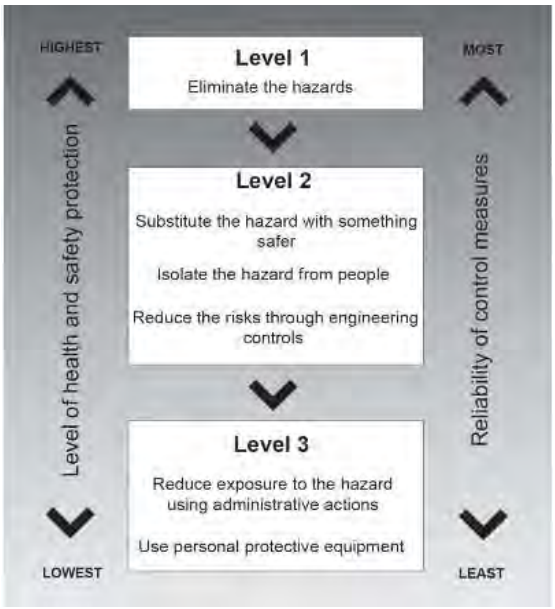

Figure 2: A Representation of the Hierarchy of Control *Source: Safe Work Australia, 2017a, Figure 2*

The elements of the risk management process are inter-connected and whilst they are all important, the crucial one is control, since ultimately the goal is to eliminate or reduce HSE risks to levels that are regarded as acceptable, normally ALARP. A number of control strategies can be used for this purpose, some of which are more effective than others, generally as follows: Elimination; Substitution; Engineering; Administration, and; Personal Protective Equipment (PPE). This then constitutes a preferred order of control strategies known as the 'Hierarchy of Control' (HoC) (Safe Work Australia, 2017a). An example of a HoC model is shown in Figure 2.

A Dearth of Higher Order Control Strategies

Although the HoC is a very well-known, understood and accepted construct, it is frequently found that the lower order control strategies of Administration and PPE are those most likely to have been implemented in the workplace: for example, in the case of noise exposure, the provision of PPE in the form of personal hearing protection (PHP) as a control is commonplace and often the only exposure control measure used (Safe Work Australia, 2010b, p.18) yet it has been estimated that 28% of the Australian working population is exposed to noise in excess of the national exposure standard of 85 dB(A)($L_{Aeq,8h}$) (Safe Work Australia, 2010a).

A significant reason for this situation is that implementation of noise control at the design stage of equipment and processes is not considered in a systematic manner, despite the means for controlling noise having been long known about (Safe Work Australia, 2010b, p.17, Corbett and Whitelaw, 2016, p.44); based on my experience of

having worked on or being closely associated with, a number of O&G development projects noise is not the only health hazard that is inadequately considered during the design stage.

If the HoC is a very well-known, understood and accepted construct, why then aren't the higher order control strategies implemented? There are many and varied reasons and it is not the intention or within the scope of this paper to attempt or to identify and discuss them all; I will therefore focus on some that are connected to HMiD and which I believe Occupational Hygienists are uniquely qualified to influence positively, namely:

- The silent 'H' in HSE
- The cost of implementing higher order controls
- Lack of knowledge of higher order controls strategies
- Organisational factors, such as:
    - Management commitment
    - The composition of project design and HSE teams
    - A project cultural mindset

The Silent 'H' in HSE

Despite the existence of HSE MS, it is generally the case that industry focuses more on addressing the S (such as fire and explosion) and E matters (such as pollution and greenhouse gas emissions) than on H matters. S and E matters are indeed very important but so is H and it is a commonly held view that 'good health is good business' (for example, Health and Safety Executive (UK), 2000, Australian Government, Department of Health, 2013, Kirkright, S., 2014).

The reasons for the silent 'H' include: the consequences of exposure to health hazards are chronic in nature, so they are not 'seen' until sometime in the future; health management is not generally well understood by both management and workforce alike and perceived as difficult, and; individuals' lifestyle choices and genetics can cloud the cause and effect relationship between exposure to a health hazard and the consequence of it. Consequently, H is often considered as the silent 'H' in HSE (for example, Keech, J., 2001) and the phenomenon is encountered during the design, construction, as well as the operations phases.

Cost and Technical Difficulty of Implementing Higher Order Controls

There is a general perception that implementing higher order controls for noise exposure is costly, despite evidence to the contrary (Safe Work Australia, 2010a). Additionally, it is also often technically difficult to 'retrofit' higher order controls in an operational facility (this applies to other health hazards as well as noise). As a project progresses, the opportunity to implement higher order controls diminishes considerably whilst the cost of implementing such controls increases considerably (Chandran et al, 2011, p.212), as illustrated in Figure 3.

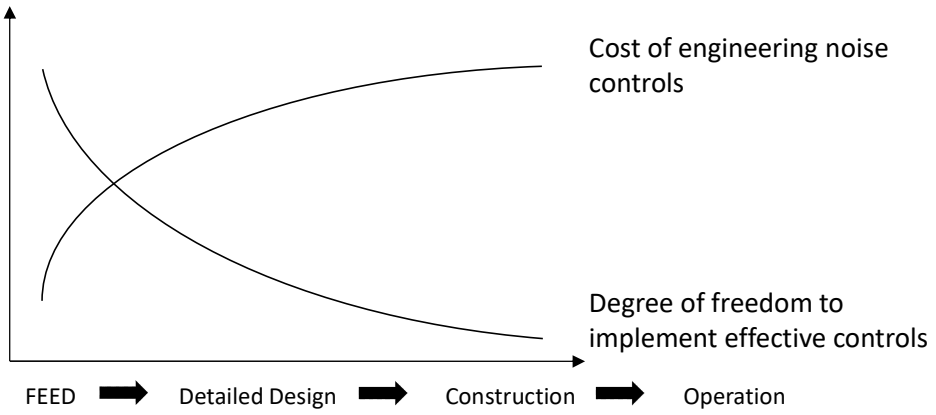

Figure 3: Cost of Noise Controls versus Degree of Freedom to Implement Them
Source: Chandran et al, 2011, p.214, Figure 1

Accordingly, the best time to implement the higher control strategies is during the design phase since the cost is much less and technically easier than during the operations phase. Whilst Figure 3 is specific to noise controls, a similar relationship would be expected to exist for other health hazards.

Lack of Knowledge of Control Strategies

As mentioned earlier, the means for controlling noise have been long known about; indeed, the means for controlling other categories of health hazards are also generally available.

There are also a number of schemes aimed at 'designing out' health and safety hazards during the course of the design development that are promoted internationally, for example:

- Within the United States of America (USA) the National Institute for Occupational Safety and Health (NIOSH) champions the 'Prevention through Design'(PtD) initiative, the mission of which is to 'prevent or reduce occupational injuries, illnesses, and fatalities through the inclusion of prevention considerations in all designs that impact workers'. The PtD initiative has been in in existence for some years and the PtD web site has a comprehensive suite of information available to support implementation (National Institute for Occupational Safety and Health, 2016).
- In the United Kingdom (UK), the Construction (Design and Management) Regulations 2015 (CDM Regulations) require construction designers to manage risks by applying the general principles of prevention. The CDM web page provides a range of information to support compliance with the CDM Regulations (Health and Safety Executive, 2015).
- Here in Australia, 'elimination of hazards at the design stage' was one of the 'national priorities' included in 'The National OHS Strategy 2002-2012' (Safe Work Australia, 2002) and is one of seven 'national Action areas' in the current 'Australian Work Health and Safety Strategy 2012-2022', where it is referred to as 'Healthy and Safe by Design' (Safe Work Australia, 2017c.). The Safe Work Australia 'Safe design' web page provides resources to address this nation Action area (Safe Work Australia 2017d.) whilst its 'Good work design' web page addresses health and safety issues at the design stage (Safe Work Australia 2017e.)

Systems for facilitating the integration of HMiD have also existed for some time. Within the Norwegian O&G industry, a range of 'NORSOK' Standards have been developed for the management of safety, as well as a range

of other technical areas related to O&G production. In relation to HMiD, NORSOK Standard S-002, Working Environment (NORSOK, 2004) applies to the design of new installations and modification or upgrading of existing installations for offshore drilling, production, and utilisation and pipeline transportation of petroleum, including accommodation units for such activities. It stipulates design requirements related to the working environment (WE) of petroleum installations as well as requirements regarding systematic management of WE issues in the project development and design process, with the purpose of ensuring that the design of the installation promotes the quality of the WE during the operational phase. In addition, Standard S-002 provides a range of guidance information to facilitate implementation. An example is Figure 4, which illustrates the typical timing of the various WE activities that are carried out relative to the various project phases (NORSOK, 2004, Figure G.2, p.43).

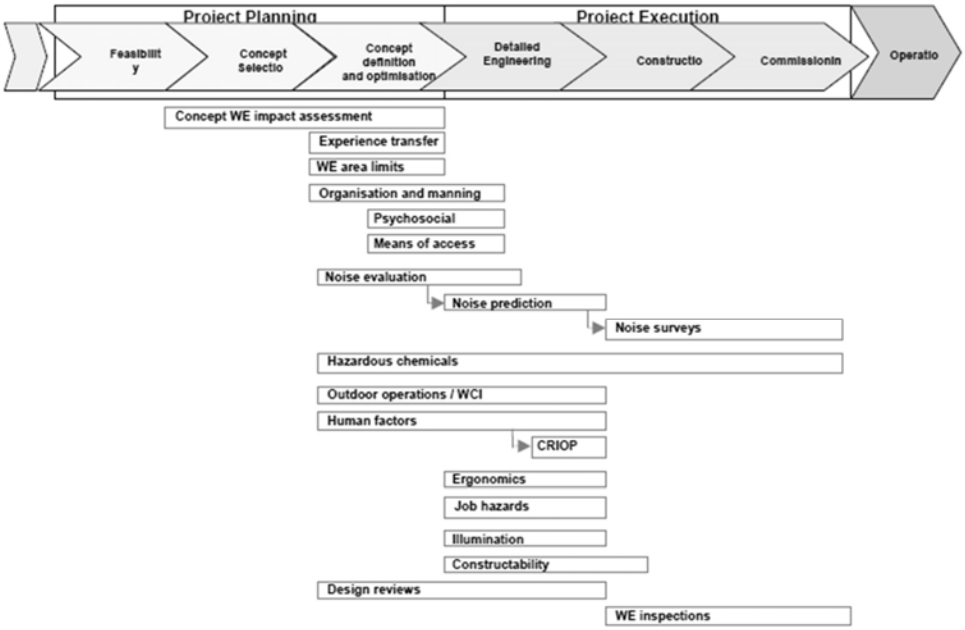

Figure 4: Typical Timing of Working Environment Activities Relative to Project Phases
Source: NORSOK, 2004, Figure G.2, p.43

Whilst there is an abundance of knowledge and resources available to support implementation of HMiD, a significant barrier to implementation is awareness and training in the field; hence, education is one of the four over-arching areas around which the NIOSH PtD initiative has been organised (National Institute for Occupational Safety and Health, 2010).

Organisational Factors

From my perspective, there are a number of organisational factors that serve as barriers to implementation of HMiD and these include:

- Management commitment – management commitment to HSE is of critical importance to the success of HSE management and as such, is a leading element in the various OHS and HSE management systems (MS) that exist: for example, the Australian/New Zealand Standard (AS/NZS) 4801 OHS MS includes 'Commitment and policy' as the first of five principles to facilitate continuous improvement (Standards Australia, 2001a, Standards Australia 2001b). In organisations where management is committed to HSE then the HSE MS is more likely to be effective, while the converse is also true (Safe Work Australia, 2010b, p.22). Since the HSE

MS should apply as much to projects as to operations, a failure to implement HMiD indicates there may be a problem with the organisations' management commitment.

- The composition of project design teams - within the O&G industry design teams are predominantly made up of discipline engineers and as a consequence OH expertise is lacking. Project HSE teams (both those of the contractor and the client) too, may not have OH representation. Such a lack of OH expertise could well mean that the risk management activities carried out during design phase (see below) may not consider H hazards and issues adequately.
- A 'project cultural mindset' – a mindset exists amongst personnel who work from project to project of 'we have always done it this way'; such a mindset is a barrier to continuous improvement in all aspects of project quality management, a component of which is HSE.

Project HSE Risk Management and the Principles of Occupational Hygiene

A range of risk management methodologies are used during the design phase, including the 'Hazard Identification' (HAZID) methodology, which is used extensively. HAZID involves the identification of hazards and other threats that could potentially impact HSE, as well as the system being designed, and the company's reputation. A HAZID study generally includes a qualitative assessment of the risk posed by the identified hazards (by means of a risk matrix, for example) taking into consideration the controls that will be in place, and prioritization of the risks that may require further treatment to reduce them to ALARP. HAZID is not generally a one-off exercise; rather, it is iterative, commensurate with the progress of the design (see Figure 3) so that a deeper understanding of the hazards is developed. This in turn facilitates a more accurate evaluation of the associated risk, allowing an informed decision on controls to be made. HAZID studies provide important HSE and other information to enable development decisions to be made at the earliest practicable opportunity.

Risk management is the essence of OH, being embodied in its definition as '…. the art and science dedicated to the anticipation, recognition, evaluation, communication and control of environmental stressors in, or arising from, the work place that may result in injury, illness, impairment, or affect the well-being of workers and members of the community' (Australian Institute of Occupational Hygienists, 2017). The principles of OH are consistent with the identification, assessment and control elements of the risk management approach (Safe Work Australia, 2017a), as represented in Figure 1.

The elements of identification, assessment and control that constitute HAZID then, are entirely consistent with the OH principles of anticipation, recognition, evaluation and control; therefore, the principles of OH are ideally suited to the design stage. Being trained in the application of the principles of OH, Occupational Hygienists are therefore ideally qualified to participate in and contribute effectively to the technical aspects of HMiD, for example: the development of Basis of Design (BOD) documentation for HMiD and lower level specification documents, such as equipment and accommodation noise specifications; attendance and participation in HAZID and other studies, and; provision of technical advice and support during the course of design, and possibly construction.

As well as technical skills and because of their importance to the advancement of the profession, the development of 'soft skills' is being promoted actively; for example, leadership and management (Australian Institute of Occupational Hygiene 2017b), and communication and training (American Industrial Hygiene Association, 2017); armed such skills, Occupational Hygienists are then able to address some of the reasons discussed above as to why HMiD is not implemented, namely: the silent 'H' in HSE; lack of knowledge of higher order controls strategies, and; organisational factors.

An Example of Successful HMiD Implementation (Noise Management)

An example of how HMiD can be implemented to arrive at an excellent outcome is the management of noise during the design and development of Chevron Australia's Wheatstone offshore production facility ('platform') described by Chandran et al, 2011. The range of noise management measures adopted by the project team included: engineering BOD documentation with particular noise management requirements; a Specifications for Noise Control document; a Front End Engineering and Design (FEED) Noise Management Plan; embedding of noise experts in the design team with ready access to OH expertise and support, and; a range of studies, ALARP workshops and vendor interactions, in which the noise experts and Occupational Hygienists participated. This approach was considered the best way to achieve a low noise WE and thereby meet the Chevron Australia's Australasia Business Unit requirements for noise management. I believe it also clearly demonstrates project management commitment to the matter.

The project team's approach resulted in a predicted reduction in noise exposures (as $L_{Aeq,8h}$) for operations personnel from an initial estimate of 93.3 dB(A) to 78.1 dB(A) and for staff conducting routine maintenance, from 88.3 dB(A) to 74.8 dB(A). As can be appreciated, this represents an immense reduction of sound energy and would lead to a WE in which reliance on the lower order controls would be virtually eliminated. This is a remarkable result especially considering the platform is a massive steel structure! However, design outcomes don't always translate to the operating WE for a range of reasons, hence noise studies are required during the operations phase.

The Wheatstone platform has been commissioned and is now operational (Chevron Australia Pty Ltd, 2017) and a noise survey has yet to be completed in the operational area of the facility. However, noise studies of personnel cabins within the accommodation area of the platform have been carried out. These show that noise levels of between approximately 27 to 33 dB(A) ($L_{Aeq,8h}$) have been achieved, compared with design specification of 40 dB(A) (Bence, T., 2017) and augers well for noise control outcomes for the platform WE. The legacy to the operations team in terms of hearing health will be enormous and one of which the project team and the Occupational Hygienists involved in the project can be justifiably proud. Figure 5 shows the Wheatstone platform.

Figure 5. The Wheatstone Platform
Source: Chevron Australia Pty Ltd, 2017

CONCLUSION

The know-how for HMiD is available but there are challenges to its successful implementation, which Occupational Hygienists are well equipped to meet. There are many opportunities for the OH profession to participate in HMiD, for example: individual Occupational Hygienists could seek to join project design or HSE teams or develop documentation within client organisations that facilitates implementation of HMiD; as a professional body, the AIOH could leverage off its good working relationship with Safe Work Australia and participate in the Good Work Design initiative (similar to the participation of the American Industrial Hygiene Association in the NIOSH PtD initiative). I wholeheartedly exhort Occupational Hygienists to take up the challenge and champion HMiD, and leave a legacy of better health outcomes to those working in the operations.

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LINKING EMISSIONS BASED MAINTENANCE OF DIESEL ENGINES WITH WORKER EXPOSURE – PROS AND CONS.

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ABSTRACT

Emissions based maintenance (EBM) of diesel engines is a significant and important control to reduce worker exposure in environments where other higher order controls cannot currently be utilised. However, the implementation of such a control requires strategic thinking, significant planning, ongoing training and support at all levels within the workplace. Influencing factors which can challenge success with implementation includes: additional job load, prioritising vehicle availability and movements, and competently measuring gases and diesel particulate matter. Therefore, a consistent approach to testing and maintenance is essential.

Once EBM has become part of accepted everyday work practices, then understanding and linking the resultant effect on worker exposures is a priority. A random sampling approach encompassing workers in a number of similar exposure groups, when implementing EBM gives a clear indication of the effectiveness and success of this control technique.

This paper provides specific information and examples on an implemented EBM program and the result this has had on worker exposure.

Communication with the workforce to inform them of progress and ongoing outcomes of both EBM and worker exposure ensures continuing proactive involvement and ongoing success of the program. In addition, there is a need to continually connect with all personnel within the operation so there is an understanding of extra time needed to test engines, the established benefits of the program and the attention to detail to make an EBM program work at an operational mine. At sites where this project has been conducted communication is vital and strategies utilised includes muster room television screens, toolbox talks, posters, emails and written forms to engage and involve all workers in the program.

ROBUST CONTROL OF DIESEL ENGINE PARTICULATE EMISSIONS IN UNDERGROUND COAL MINING.

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ABSTRACT

Australian Coal Association Research Program (ACARP) project C25073 was proposed by industry stakeholders seeking a solution that would both improve underground air quality and reduce the operational costs associated with currently implemented technology used to control diesel particulate emissions in the underground coal mining environment.

The need to protect workers from diesel particulate matter (DPM) has lead the underground coal mining industry to install disposable filter systems on their vehicles. While the disposable filters are efficient at removing significant amounts of DPM, the following major issues have arisen:

- High cost of operations; with disposable filters costing $250-300/each and need to be changed at least once per shift resulting in an estimated cost of up to $164M/year, in filters alone, to the NSW underground coal mining industry; and
- Improper installation, damaged seals and lack of installing a new filter when the old filter is removed means that workers are still being exposed to excessive amounts of DPM.

The ACARP project successfully demonstrated significant DPM emissions reduction comparable to the incumbent disposable technology on a proof-of-concept (PoC) wall-flow diesel particulate filter (DPF) system. It also demonstrated the ability to meet NSW MDG43 requirements for year 2020. The developed system provides satisfactory robustness as assessed using an industry representative test cycle representing operations of a Load Haul Dump (LHD) vehicle typical of that used by the Australian underground coal industry. It was noted in testing that the technology increased modal NO_2 formation, but was compliant over typical operational duty cycles.

One of the key benefits with the use of a wall-flow DPF system is its tamper-proof design, mitigating the risk of operating unfiltered diesel plant in poorly ventilated areas. Elimination of the need for continual replacement of disposable filters provides significant operational savings estimated to be up to 80% of the incumbent technology.

In addition to the above, the project also delivered a number of significant contributions to the knowledgebase of the Australian and international coal industry with regard to the characterisation of operations and control of emissions.

One of these contributions is to detail how the robustness of the after treatment solution can be maintained with both appropriate design and the use of embedded real-time, and near-real-time, monitoring technology.

INTRODUCTION

The project aimed to develop a wall-flow DPF type system to replace existing wet-element disposable filter systems used in typical LHD vehicles in underground coal operations.

The overall objectives were to:

- Prove a wall-flow DPF system could reduce Diesel Particulate Matter (DPM) emissions to a lower level than the current disposable filter systems;
- Prove that the wall-flow DPF system could be engineered to meet coal sector regulations such as explosion proofing, surface temperature and exhaust gas temperature limits;
- Prove that sufficient regeneration of the wall-flow DPF system would occur during typical operations so as to extend the interval between filter cleaning, thereby reducing maintenance costs. This was first verified on the engine dynamometer using the transient LHD test cycle developed by the project, and then later confirmed in the field at site tests.

After providing a summary of the results to show that the first two objectives were achieved, detail in this paper will focus on demonstrating how the third objective is achieved and monitored.

BACKGROUND

The LHD platform selected for demonstration was the Coaltram model, with an electronic Caterpillar C7 engine and coal sector approved Diesel Exhaust System (DES) satisfying industry mandated requirements for explosion protection.

The simplified system schematics in FIGURE 1 compare the layout of a typical conventional disposable wet-element exhaust filtration system to that of the wall-flow DPF system. With the conventional system, exhaust from the engine is cooled through a water-scrubber before being filtered through the disposable filter element. The disposable filter is typically a paper, or coated paper element (similar to an engine air intake filter), and traps the particulates in the exhaust stream. An oxidation-only catalyst is sometimes also included upstream to reduce gaseous pollutants such as carbon monoxide (CO) and unburnt hydrocarbons (HC).

Because of the disposable filter's construction, the exhaust gas has to be first significantly cooled; however, the cooling process does carryover substantial amounts of water both as liquid and in the form of saturated exhaust. This carryover water (and not the diesel particulates) can be a significant cause of premature filter blockage. Regular and early replacement of disposable filters is a substantial operating cost burden for the industry, further compounded by the costs of disposal and associated environmental handling. Whilst the current technology works to reduce particulates, the operational challenges can in instances lead to incorrectly fitted or operation without filters, resulting in a direct impact on ambient mine air quality during operations.

With the wall-flow DPF system, the wall-flow filter is installed before the wet exhaust scrubber since it requires heat for its effective operation. To satisfy tailpipe temperature requirements, the water scrubber is still required but is staged following the filter.

The wall-flow filter system technology discussed in this paper is detailed in FIGURE 2. The filter component is the second stage of the assembly and is a porous ceramic element where particulates are trapped as the exhaust passes through the structure. The combustion exhaust gas is forced to pass through the wall structure (hence the name wall-flow) because the cell structure of the substrate alternately blocks entry and exit flow channels. This wall-flow filtration method is understood to offer significant reduction in ultrafine particles compared to flow-through-filter (FTF) systems, such as metal monolith constructed substrates.

Approach to Development

The underground coal sector is highly regulated compared to other mining environments, both in Australia and internationally. The primary reasons for this superior regulatory oversight relates to the explosion risk posed by an ambient operating environment that may contain elevated methane levels and deposition of coal dust on equipment. A methane rich environment may be explosive, but can also affect the operation of diesel equipment which "breathes" this enriched air. However, it is the deposited coal dust that poses an immediate explosion risk at an ignition point well below that of ambient methane. Consequently, regulations are in place to limit the temperature of surfaces or other ignition sources to below 150 °C, with additional constraints placed on other ignition sources such as electrical equipment (for example Standards Australia, AS4871.xx and AS60079.xx).

The consequence of these regulations is that the coal mine itself cannot be used as a development environment for new equipment, as may be the case in other mining operations where these operational risks are not present.

Development of a robust wall-flow filter system required moving the early stage development activities away from the mine environment, yet replicating what is typical in mining operations. The off-line development of the wall-flow system was only possible through the use of a structured methodology to product and system development, coupled with the use of an advanced engine development facility at Orbital Australia Pty Ltd.

At the outset of the research project, detailed definition of the operation duty cycle of the machine needed to be undertaken. This could only be achieved with high-resolution characterisation of the operating LHD fleet. Replication of this characteristic duty cycle required the use of an engine development facility (see FIGURE 3)

capable of transient engine operation so that the cycle could be replicated in "real-time" – and not only as a simplification of steady speed and load points. Only in such an advanced development facility could the robustness of the system be assessed with instrumentation measuring emissions, temperatures and pressures at both nominal and elevated methane environments. Site work was only commissioned once the test data confirmed that the proof-of-concept system had been validated.

The process adopted whereby the core activities were undertaken off-line from the operational mining environment, but still retaining engagement with industry through frequent onsite testing and re-testing, allowed for a complex program to be executed in a safe and very fast timeframe.

Underground Coal Specific LHD Engine Test Cycles

FIGURE 4 shows two fleet based characterisations against the test profile mandated by the designated regulatory standard. The two fleet based characterisations similarly show engine idle accounts for approximately 50% of the LHD engine's operating time. This level of idle is far from best-in-class utilisation compared to other industry sectors using heavy duty diesel engines, including metalliferous (hard rock) underground mining, surface or pit mining, and on-road. This extended idle, coupled with less time spent at rated-torque or rated-power, results in a lower duty cycle than would otherwise be forecast from the use of regulatory standards.

FIGURE 5 shows the transient cycle compiled as a series of operational snippets measured second-by-second at the test site. These operational snippets characterised operation activities ranging from minutes to fractions of an hour. The overall idle fraction is similar to the long-term average and custom steady cycles discussed already. However, the transient segments better represent the working part of the machine's operations.

Accurate replication of the transient segments is critically important for thermal design where it takes time for components and chemistry to respond to changes in exhaust gas temperature and feed gas composition. Temperatures of the exhaust gas after the catalyst and DPF lag those of the input feed gas stream. There is also oxidation heat to be considered for the catalytic reactions whose efficiency is thermally dominated.

The regulatory framework also requires that the system be tested under conditions which may result in adverse performance of the DPF including loading of the substrate with soot at temperatures below the system's operating point and then monitoring the effects of oxidising this stored soot on post-DPF gas, substrate and system surface temperatures. Testing of system's performance under prescribed elevated methane conditions is also a regulatory requirement.

PROOF-OF-CONCEPT RESULTS

The research project was focused on defining the design characteristics of the proof-of-concept system that would not only reduce DPM by a substantial amount, but do so in a manner that was robust given the observed low exhaust feed gas temperature associated with the typical LHD's usage in the coal sector. Development was also focused on ensuring that the proposed proof-of-concept design would satisfy regulatory requirements for the surface temperature of any equipment used in underground coal operations.

The project evaluated a number of diesel particulate system configurations, with data from three of these to be reported in this section:

- 10.5" diameter diesel oxidation catalyst coupled to a filter substrate of the same diameter (system only includes standard housing components from on-road applications);
- 9.5" diameter diesel oxidation catalyst coupled to a filter substrate of the same diameter (system only includes standard housing components from on-road applications); and
- 9.5" diameter system (as above) with the pipework from the turbo flange and the DPF unit itself shrouded in insulation optimised to achieve a measured surface temperature of below 150 °C.

The insulated and uninsulated 9.5" system used the same core substrate components; eliminating this as a potential source of variation. Both the 10.5" and 9.5" systems used the same chemical formulation, cell density

and precious metal washcoat loading levels; the only difference being diameter of the substrate and the runtime hours (the 10.5" system had been run for a substantially longer duration than the 9.5" system).

Reduction in Particulate Emissions

Particulate emissions reported are measured as total particulates. This includes all the compounds deposited on the sampling filter paper and is different to NIOSH5040 methods which focus on the elemental carbon component. Total particulates, rather than speciation for elemental carbon, is used by engine and exhaust after treatment developers during lab based testing for a number of reasons, including single step sampling and analysis, rapid turnaround of results in-house, and improved repeatability of measurement. The measure of total particulates is valid in that all the sample is from the exhaust of the engine under test, unlike in a working mine environment where some particulates may be attributable to other sources unrelated to diesel exhaust and hence the use of EC allows for traceability to what is diesel sourced.

MDG43 standards apply to total particulate measurements. FIGURE 6 shows the diesel particulate reductions achieved with the insulated 9.5" DPF at the conclusion of the proof-of-concept project. Reductions of over 95% were achieved over both the regulatory stipulated cycles (NRSC and NRTC) and the fleet derived customised industry test cycles developed as part of this program of work. The DPM (or particle emission) performance of the wall-flow filter was seen to be insensitive to the duty cycle of engine; something which is not seen with earlier flow-through type diesel particulate filter systems. In all cases, the DPM reduction was such that the absolute level of measured particulates was clearly below the year 2020 limit set in MDG43, thereby providing not only capability to pass today's but also future regulated levels.

Gaseous Emissions

Gaseous emissions measured include the conventional globally reported compounds of carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x) and hydrocarbon (HC); but given the occupational implications of exhaust in the confined working environment, reportable compounds such as nitrogen monoxide (NO) and nitrogen dioxide (NO_2) were also sampled using a laboratory based Horiba gas analyser. All emissions were measured after the DPF, but prior to where the wet exhaust scrubber would normally be installed. Therefore, none of the effects of water absorption were accounted for in the measurements.

FIGURE 7 shows the gaseous compounds reported as a composite total (power normalised) using the weighting factors for individual test modes specified in the regulatory ISO 8178 non-road steady-state cycle (NRSC) standard. The graph shows how each of the three reported test systems performed comparatively.

As the catalyst and DPF washcoat chemistry is biased for oxidation performance, and the diesel exhaust is operated lean of stroichiometric for all modes within the test, compounds such as CO and HC are virtually eliminated from the tailpipe exhaust gas. NO_x emissions are not substantially affected by the choice of system. This is not unexpected given the oxidation bias of the system results in minimal chemical reduction of NO_x to N_2. Any variation shown can be considered "no change" given that the tests were completed over the course of the project's timeline.

Similarly, the NO_2 emissions can be considered to be similar for all three test systems. The observation to make is that NO_2 emissions account for 37-43% of the NO_x. This is a significant increase compared to non-catalysed exhaust which typically has an NO_2 proportion below 10%.

In both configurations, the NO_2 emissions from the 9.5" system were seen to be marginally higher than with the 10.5" system. The mechanisms for this are complex. The smaller volume 9.5" system has a reduced catalytic volume, and so the expectation would have been for a lower NO_2 result from this system. However, the 9.5" system also increases exhaust system back pressure, affecting the kinetics of the exhaust gases over the catalytic substrate which in turn changes the reactivity of the catalyst. Coupled with small changes in temperature and perhaps some improved reactivity because of differences in runtime history of the two substrates, it becomes apparent that differences in NO_2 formation cannot always be directly predicted with theory and experimental work is typically required.

SYSTEM ROBUSTNESS

The removal of stored particulates, predominantly carbon-based soot, would be a substantial challenge if temperature alone was used to facilitate oxidation into CO_2. Many modern-day wall-flow DPFs include a catalytic washcoat to assist in reducing the oxidation temperature of the trapped soot. This substantially lowers the exhaust feed gas temperature requirement from over 550 °C to typically 350-400 °C. Whilst better, this is still a substantial temperature for diesel engines to reach – compounded by the typically low duty cycle operation of an LHD in coal mining operations, with many LHDs spend more than 50% of their daily duty at idle.

To further lower the temperature required for soot oxidation, it was proposed to use technology which not only included a catalytic DPF, but also a pre-catalyst for preparation of the feed gas chemistry delivered to the DPF. The particular wall-flow technology used in this research work is proprietary to Johnson Matthey Catalysts Inc. and is effective in enabling oxidation of stored soot at temperatures as low as 250 °C (ref. Johnson Matthey website). The specific wall-flow technology tested was a part of the CCRT (catalytic continually regenerating trap) product family.

Whilst retention of exhaust heat for the purpose of improving wall-flow DPF performance is desirable, both the management of thermal loadings and exhaust gas composition chemistry were issues that required engineering solutions to be developed and are discussed in this paper.

Exhaust Back Pressure Stability

The robustness of a wall-flow DPF system can be characterised by a number of parameters, but the easiest tell-tale is whether the system reaches a stabilised pressure condition measured as the differential pressure across the system over a consistent test cycle regime. What this signifies is that the DPF system is storing and regenerating (oxidising) soot produced by the engine in a stabilised manner.

The basis of the testing undertaken to qualify stability was the custom developed transient cycle. The custom transient cycle exposes the DPF to significant periods of idle (non-regenerating periods to load the DPF with soot), typical periods where operational tasks may be undertaken (where the temperature and feed gas composition will provide increased soot rates, but may also provide the conditions suitable for oxidation of stored soot), and periods of idle between tasks, where the after treatment system is allowed to cool down and become inefficient (so as to be conservatively biased). The test cycle loops every 30 minutes, for a total duration of 100 hours. The use of a transient capable dynamometer facility not only allows the testing to be completed accurately, it also allows for each cycle repeat to be identical. The process is substantially automated including the acquisition of data – eliminating variations that can occur infield.

FIGURE 8 compares the performance of an insulated 10.5” system over cycles starting at 1 hour, 50 hours and 100 hours into the test, and at the end after the DPF is fully regenerated by a period of high load operation to burn-off any stored soot.

The data show that DPF back pressure has peaked and stabilised by the 50-hour point and maintains those conditions through to the 100-hour point. The burn-off is seen to be effective in restoring DPF performance to original pre-sooting conditions.

Demonstration of Thermal Control

Conventional practice in the underground coal sector is to use a water jacket around exhaust components as the means of reducing surface temperatures. The use of a water jacket poses compromises with regard to the implementation of a wall-flow DPF system. Firstly, the water jacket not only cools the surface of the pipe, it also cools the temperature of the exhaust feed gas. If the gas temperature upon exit from the engine’s turbo is already on the low side of optimal, it will only get lower with water-cooled pipework. Secondly, exhaust heat lost to the water system needs to be dissipated in the LHD’s radiator necessitating this to be larger than needed to cool just the engine.

Using a non-conducting insulation barrier around the exhaust pipework and DPF unit has benefits with regard to heat retention in the exhaust gas and minimisation of heat to the coolant circuit. Hotter exhausts may however increase the evaporation rate, and hence water consumption rate, of the wet exhaust scrubber.

The proof-of-concept design sought to evaluate and optimise the properties of the insulation barrier, with the ultimate goal of demonstrating that surface temperatures could be controlled with insulation as the primary measure. There may be locations and features where insulation is impractical and for these water-cooling may be a necessity.

Regulations prescribe that surface temperatures are not only controlled at nominal operating conditions, but also under adverse conditions of elevated ambient methane levels. Elevated ambient methane is combusted by the engine to produce more power and consequently higher exhaust temperatures. The equipment is generally fitted with methanometers which shut down the engine at ambient concentrations 1.25%; hence this is the capped test limit. However, 1.25% ambient methane in the intake air represents a significant excess fuel loading for the engine.

FIGURE 9 shows thermal images captured by a FLIR thermal camera. Whilst arguably not as accurate as thermocouple results (refer the ACARP project report), they provide a more complete impression of the overall level of thermal management achieved. The full-scale readings on the thermal images taken whilst the engine was operating at 1200rpm full-load (with no methane injection) indicate peak temperatures of between 98 and 125 °C, well below the mandated 150 °C limit.

Monitoring the Performance and Robustness of the System

Whilst testing results have shown that a DPF system can be designed to be inherently robust within prescribed operating boundaries, the use of embedded electronic sensors allows for the vigilant monitoring of both the operational input factors and performance output results.

Conventional sensors deployed to monitor DPF performance include temperature and pressure sensing. Pressure sensing is best done as a differential measurement across the DPF substrate rather than as a absolute reference. Temperature sensing includes both monitoring of gas conditions as well as external surfaces which must comply with stringent limits because of the ignitability of coal dust and ambient methane. The introduction of electronic sensing direct to high temperature exhaust is a new challenge area for DPF system integrators; one which has not been required previously as in the past it has been sufficient to sample at exhaust conditions post wet-scrubber where they are cooler.

The next level of system monitoring comes with the use of sensor technology which can measure exhaust emissions real-time, or near real-time. Technology to do this has reached maturity and has been progressively introduced into the automotive and heavy on-highway sectors over the last few years. For diesel engines, NO_x sensors are used to assess the variation in emissions both before and after the DPF after treatment system. These NO_x sensors utilise a development of the lambda sensor (relative air-fuel ratio sensor) technology which has been in service since the 1970's. This sensing technology has converged to virtually all manufacturers using a similar principle. NO_x sampling can be undertaken effectively in real-time, although specific algorithms and numerical processing is required to filter for stabilised readings and tuned to each application. PM sensing is comparatively new and a particular technology approach has yet to dominate. None of the currently available PM sensing technology is truly real time, with some requiring sampling periods of stabilised engine operation to work effectively.

Whether real-time, or near-real-time, the use of on-board embedded exhaust emissions sampling is set to provide a more rapid notification of changes to baseline performance than conventional periodic sampling and compliance checking which can be spaced days, weeks or months apart. The biggest challenge in implementing this real-time technology comes not from the sensing science; but the regulations around the use of non-conventional electronics in the highly regulated underground coal mining sector.

CONCLUSIONS

The proof-of-concept wall-flow DPF system developed by the research project demonstrated:

- DPM levels sufficiently low to pass the MDG43 year 2020 (0.025g/kWh) standards, including allowance for deterioration factors (DF);
- Gaseous emission levels sufficiently low to pass the MDG43 year 2020 standards for Carbon Monoxide (CO), Oxide of Nitrogen (NO_x), Nitrogen Oxide (NO) and Hydrocarbons (HC), including allowance for deterioration factors.
- DPM reductions of a similar order of magnitude to that achieved with conventional disposable wet-element systems for which the baseline engine was certified with;
- Robustness in the control of DPM as seen through sooting tests based on a developed light duty cycle which showed a stabilised exhaust back pressure for the system only a few kPa higher than the starting condition of an unloaded (soot free) DPF;

As is typical with the use of catalytic oxidation systems, there was an observed increase in NO_2 emissions as exhaust NO_x conversion was biased to NO_2 formation to assist with low temperature regeneration of any stored soot.

As part of the follow-on industrialisation work being undertaken as part of ACARP project C26070, embedded electronic sensor systems are being utilised to ensure that the system performance and robustness can be monitored for external influences that may affect the boundary conditions outside those normally encountered in typical operations.

ACKNOWLEDGEMENTS

Orbital would like to acknowledge ACARP (formerly the Australian Coal Association Research Program) for the funding provided to undertake this work program. ACARP is a unique and highly successful mining research program that has been running in Australia since it was established in 1992. It is 100% owned and funded by all Australian black coal producers through a levy of five cents per tonne paid on saleable coal. ACARP's research covers a wide range of important areas including all aspects of the production and utilisation of black coal including health, safety and the environment.

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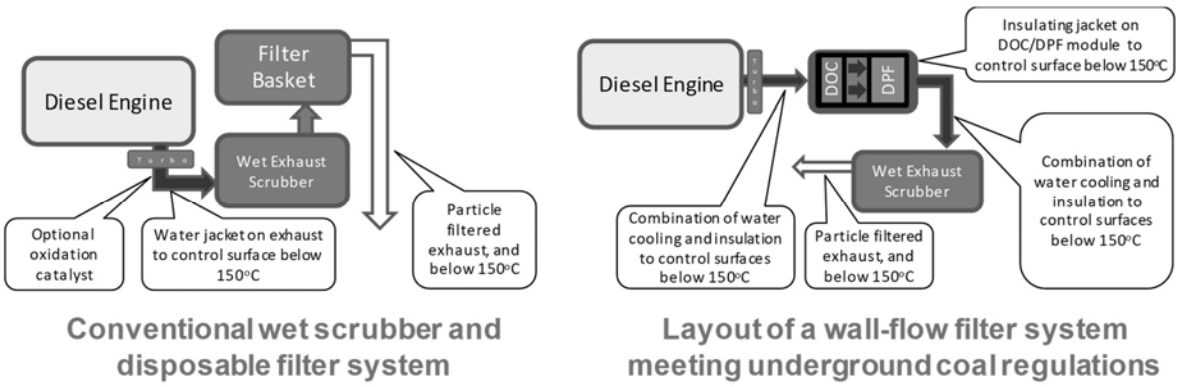

FIGURE 1 – COMPARISON OF CONVENTIONAL WET SCRUBBER, DISPOSABLE FILTER SYSTEM AND WALL-FLOW DPF SYSTEMS

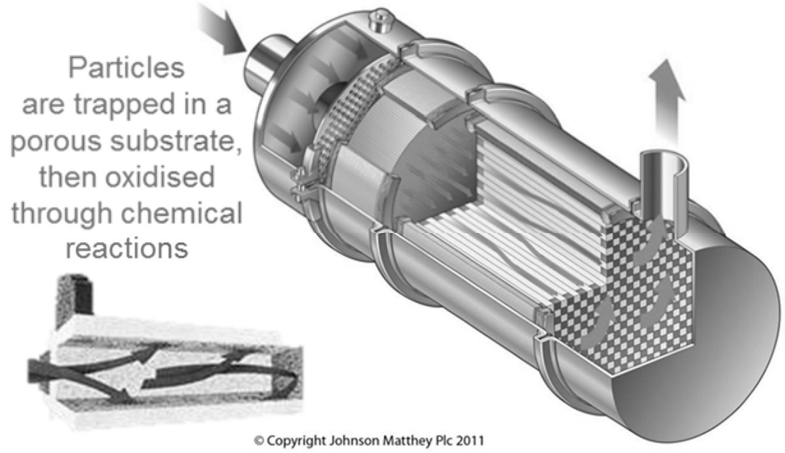

FIGURE 2 – OUTLINE OF HOW A WALL-FLOW DIESEL PARTICULATE FILTER WORKS

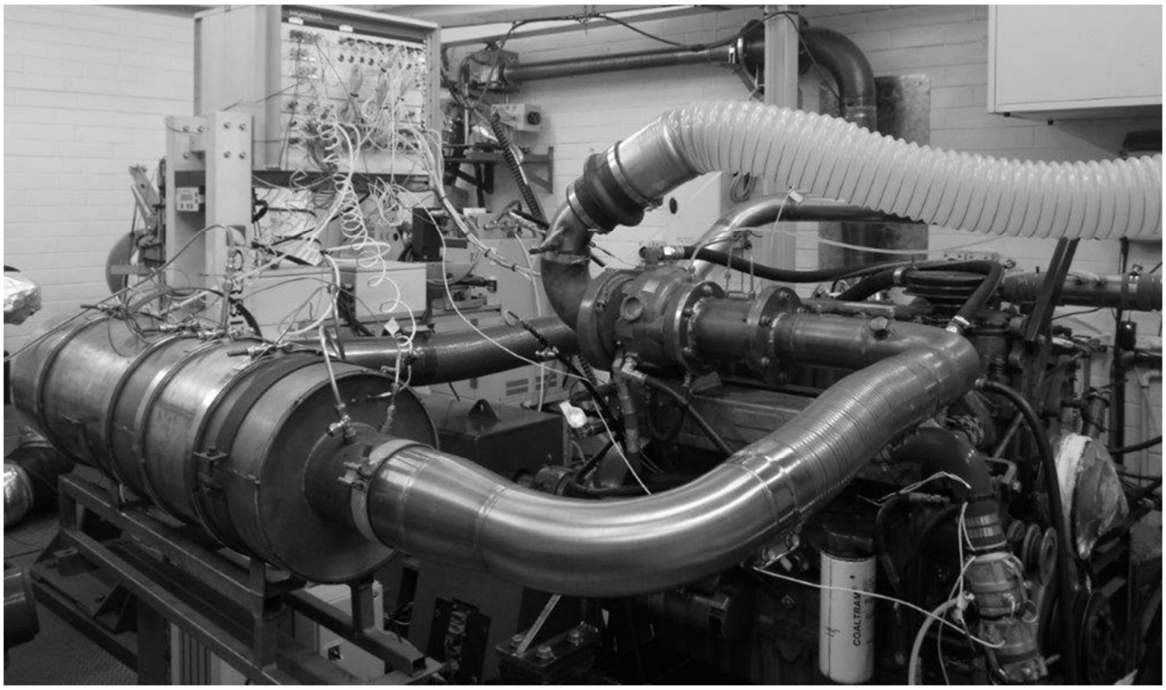

FIGURE 3 – INSTALLATION OF THE TEST ENGINE AND UNINSULATED WALL-FLOW DPF IN ORBITAL'S DEVELOPMENT FACILITY

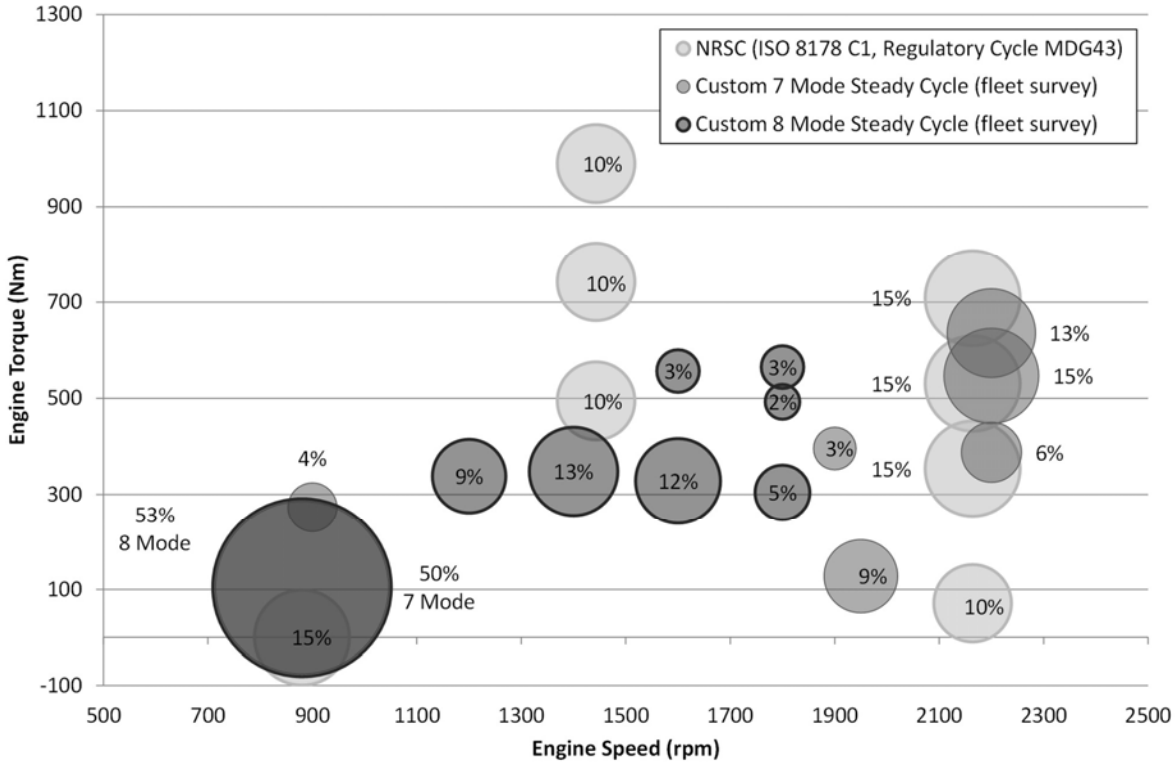

FIGURE 4 – COMPARISON OF REGULATORY AND FLEET BASED PROFILE OF LHD ENGINE OPERATION

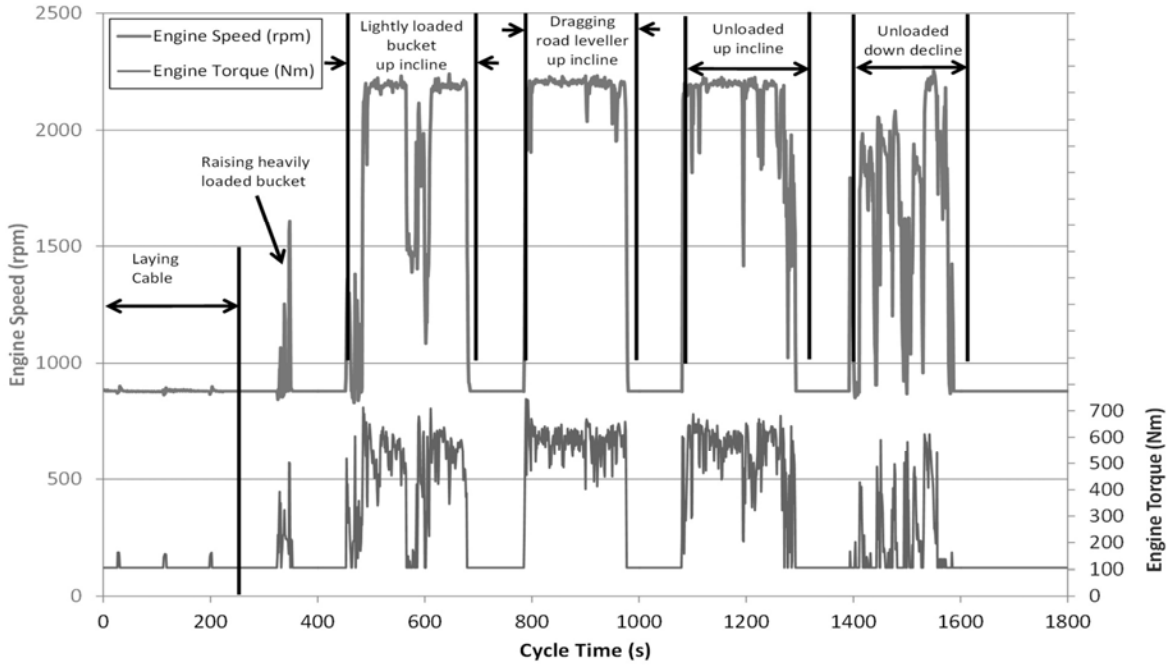

FIGURE 5 – DERIVED TRANSIENT CYCLE TO REPRESENT LHD OPERATIONS IN UNDERGROUND COAL MINING

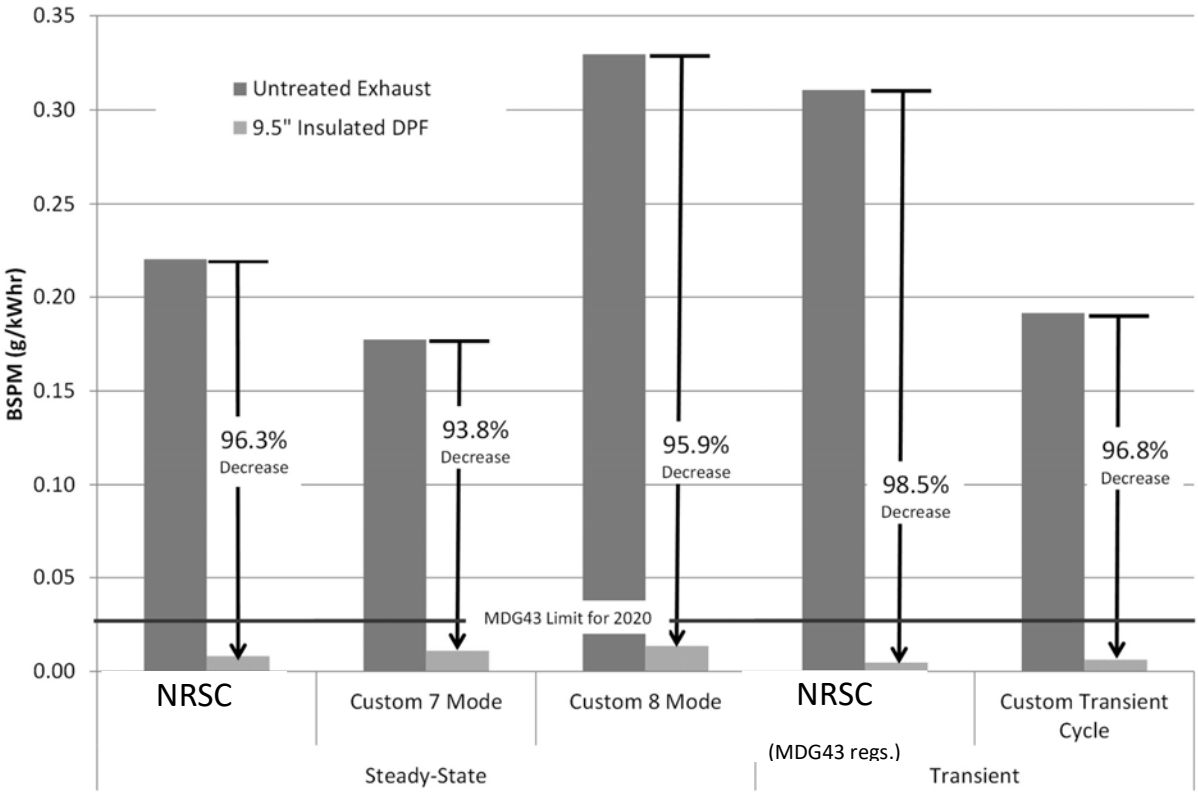

FIGURE 6 – COMPARISON OF TOTAL PM RESULTS OVER DIFFERENT TEST CYCLES (STEADY STATE AND TRANSIENT)

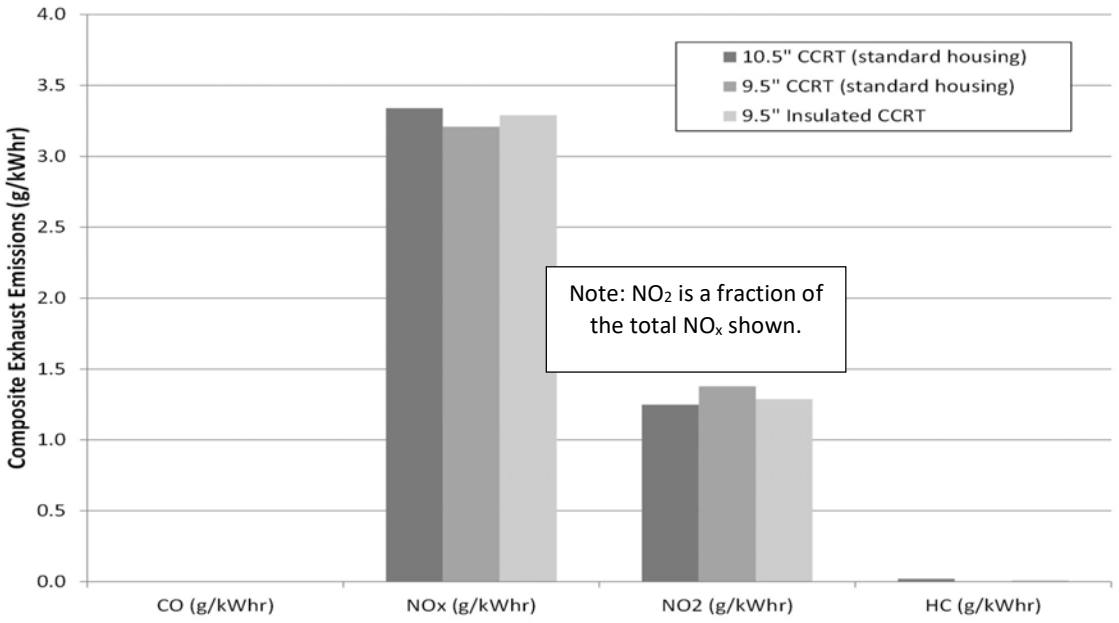

FIGURE 7 – COMPARISON OF COMPOSITE (NRSC WEIGHTED) REGULATORY GASEOUS EMISSIONS WITH CCRT OPTIONS

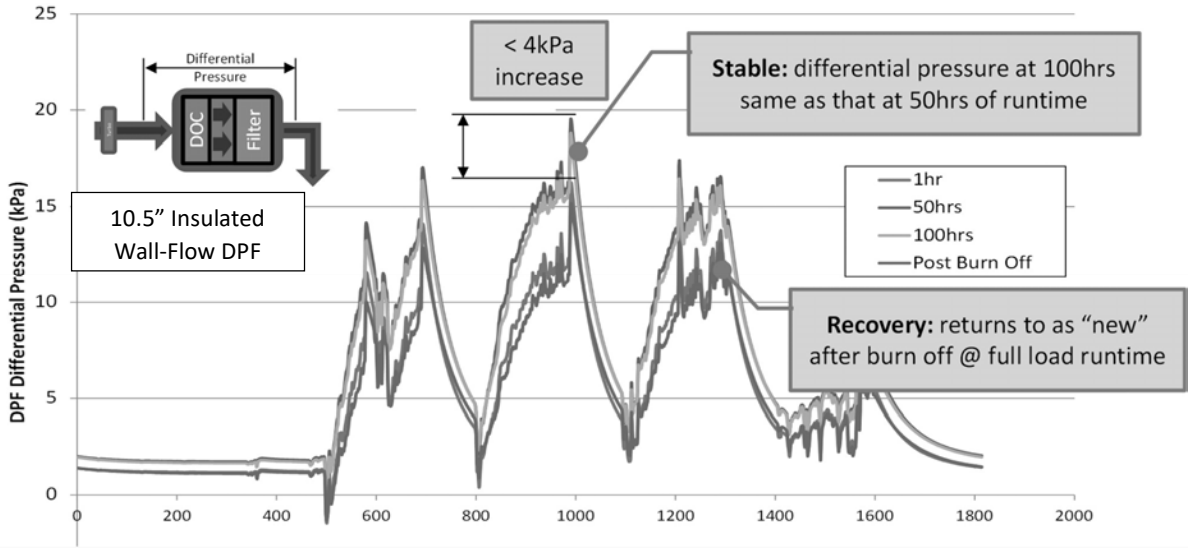

FIGURE 8 – COMPARISON OF DPF DIFFERENTIAL PRESSURE AND STABILISATION OVER INDUSTRY DEVELOPED TRANSIENT TEST

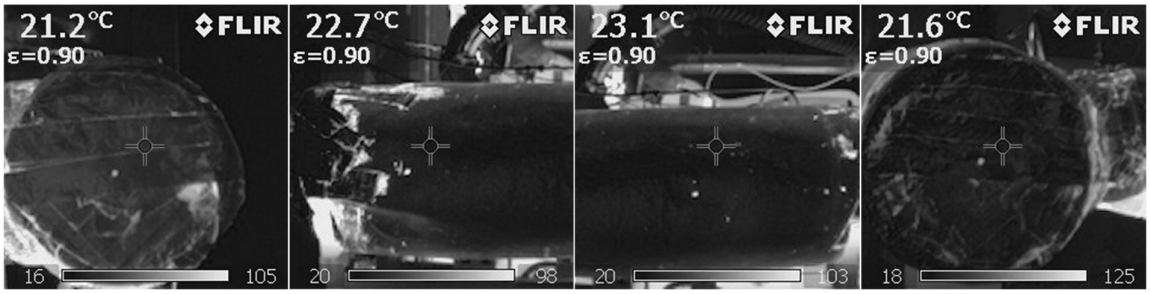

FIGURE 9 – FLIR THERMAL IMAGES FOR 9.5" INSULATED DPF AT 1200RPM FULL-LOAD FROM ENTRY (RIGHT) TO EXIT (LEFT)

POSITION PAPERS - THE SCIENCE AND MACHINATIONS OF THE OEL COMMITTEE WITH PARTICULAR REFERENCE TO DIESEL EXHAUST EMISSIONS AND RESPIRABLE COAL DUST.

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Beesknees Hygiene Pty Ltd

**The views expressed in the paper are the Author's views and not those of the AIOH or OEL Committee.*

ABSTRACT

The AIOH established the Exposure Standards Committee to provide expert guidance and comment to the exposure standards setting process at a State and National level and internationally where appropriate, through development of AIOH Position Papers, AIOH guidance publications or comment on relevant Standards, Regulations and Codes of Practice. The Committee's remit is to confirm that the exposure standards numbers, and Standards and Codes of Practice, are changed for valid occupational hygiene and scientific reasons.

On the face of it, easy; in practice, anything but. The development of the Position Papers for diesel exhaust emissions and respirable coal dust are used to highlight some of the issues, not only in the science but also in the presentation of the science.

For diesel exhaust emissions, the evidence is equivocal even for traditional diesel engines, the black smoke belching engines from before 1990. In the next 15 years the transformation in diesel engines was such that the emissions now bear no resemblance to those of the past. Yet there are those who present questionable evidence from pre-1990 in support of a standard for present day engines.

For respirable coal dust, there are two cohorts of miners whose health outcomes were studied over decades and for whom there is good exposure data. From the analysis of both cohorts, cases of 'black lung' and even progressive massive fibrosis are predicted to occur at well under the occupational exposure limits (OELs) used in Australia. Data from other cohorts supports that position.

INTRODUCTION

The AIOH established the Exposure Standards Committee to provide expert guidance and comment to the exposure standards setting process at a State and National level and internationally where appropriate, through development of AIOH Position Papers (PPs), AIOH guidance publications or comment on relevant Standards, Regulations and Codes of Practice. The Committee's remit is to confirm that the exposure standards numbers, and Standards and Codes of Practice, are changed for valid occupational hygiene and scientific reasons.

The AIOH is not a standards setting body. Through its Position Papers, the AIOH seeks to provide relevant information on substances of interest where there is uncertainty about existing Australian workplace exposure standards (WES). This is done through a review of the existing published, peer reviewed scientific literature. The PPs attempt to recommend a health-based exposure value that can be measured; that is, it is technically feasible to assess workplace exposures against the derived WES. It does not consider economic or engineering. As far as reasonably possible, the AIOH formulates a recommendation on the level of exposure that the typical worker can experience without adverse health effects. (AIOH website Accessed 23 July 2017)

Those available at July 2017 are shown below; updated DPM paper and a new Respirable Coal Dust PP are in press.

- Synthetic Mineral Fibres (SMF) and Occupational Health Issues (2016)
- Asbestos and its potential for Occupational Health Issues (2016)
- Nickel and its Compounds - Potential for Occupational Health Issues (2016)
- Adjustment of Workplace Exposure Standards for Extended Work Shifts (2016)
- Polycyclic Aromatic Hydrocarbons (PAHs) and Occupational Health Issues (2016)
- Sulphuric Acid Mist and Occupational Health Issues (2015)
- Dusts Not Otherwise Specified (DUST NOS) and Occupational Health Issues (2014)

- Diesel Particulate Matter and Occupational Health Issues (2013)
- Occupational Noise and its Potential for Health Issues (2012)
- Inorganic Lead and Occupational Health Issues (2009)
- Respirable Crystalline Silica and Occupational Health Issues (2009)

The OEL Committee is deliberately diverse, bringing together chemists, miners, consultants and government hygienists. Additionally, they have different interests and approaches. An example of how this plays out in the PPs relates to biological exposure monitoring; some committee members see biological exposure indices (BEIs) as an essential part of any PP, others will only reference a BEI where there is a clearly established health effect and some require relevance to the position being established.

On a very positive note the diversity allows the committee to tease out the many relevant aspects of papers from the literature that inform our PPs. The same diversity also brings different views on the assessment of tolerable risk. An example of this is in the use of safety factors. If there is evidence that a level of exposure does not cause a health effect, should we incorporate an additional factor and divide the scientifically derived occupational exposure limit (OEL) by 2 or 4 or 10? How is animal data translated to humans?

These differences result in robust discussion and we believe well discussed and reasoned outcomes, to derive PPs that the AIOH can defend and be proud of.

Like many voluntary organisations the AIOH OEL Committee relies on its members to give up their free time to work on the papers. Consequently, this may impact on the priority and selection of topics for the development of papers. Committee members who have a special interest and knowledge of a substance can develop a paper more easily than another member who must start from scratch. Generally, if a topic is important to a member it is important to their workplace and relevant in other workplaces. We see the same in the ACGIH where in my time as a hygienist the silica and manganese TLVs have been reviewed several times but the coal tar pitch volatiles TLV remains unchanged and of doubtful relevance.

The Process of Development

Once a topic is decided, the process starts. Are there relevant reviews by reputable standard setting bodies (e.g. SCOEL, ACGIH, NIOSH or UK HSE)? Read them. This identifies the key literature that has informed the current OELs and gives a sense of the relevance of the literature informing that OEL. Go to Pubmed and search the topic, search the authors who have published in the past, read the abstracts, identify the papers that appear relevant. Try to get copies of the papers. Many journals are freely available while others charge up to $20 or $30 for a copy of a paper.

Reading journal articles is time consuming and sometimes boring. Usually the paper needs to be read a couple of times to determine its contribution to the topic. The relevant points from the paper are noted for later collation into the draft PP. This is reviewed by the members of the committee and when satisfied the PP goes to Council and then to the Membership for final review prior to ratification.

To the Challenges

Several issues plague the hygiene literature. Lack of exposure data is common place. Hygiene is generally concerned with chronic effects which can take years to manifest. Epidemiologists employ a number of techniques to overcome this problem and most are fraught with danger. Examples include:

- length of tenure in a role can be used as a surrogate of relative exposure;
- a group of hygienists can assemble a job matrix and estimate exposure into the past based on current exposure and recollections of how contaminated the workplace atmosphere used to be;
- a surrogate for which measurement exists can be related to the agent of interest.

Length of tenure can possibly give us relative exposure but not actual exposure. Hygienists measure exposure because they know guessing is risky; to guess a history of exposure over half a century or more maybe the best we

have but great caution needs to be exercised. Surrogates are only useful if the surrogate has been measured accurately and the ratio of agent to surrogate is unchanged over the period of interest.

Sampling techniques change. Once dust was measured with a konometer, in millions of particles per cubic foot, now gravimetric analysis is used. Epidemiologists used a conversion factor to relate the two. Verma (1989) undertook side by side sampling with a cyclone and a konometer in gold and uranium mines. He found that the relationship varied with both the environment and the concentration of dust with the result that the generally used conversion factors were inaccurate.

Total dust and inhalable dust are not the same. Depending on particle size there are estimates (Tsai 1996) suggesting inhalable samplers can collect double that collected by total dust samplers.

Epidemiologists invariably express exposure data as geometric means (GMs). This measure has no relevance to the average exposure of workers. If geometric standard deviations (GSDs) are provided reasonable estimates of the actual exposure can be made. With a GSD greater than 3 the average exposure is about double the GM.

Presentation of the risks of health effects takes a plethora of forms and to even the experienced hygienist this can be challenging. Standard Mortality Ratio (SMR) is used for cohort studies and is the ratio of the prevalence of a health effect in a working population to that in the general population. The difference is attributed to workplace exposure. Odds ratios (OR) and risk ratios (RR) are also common metrics used and present the chance of an outcome with an exposure compared to that without the exposure. Or and RR are apparently similar but are not the same.

The consideration of confounding exposures is another vital aspect of an exposure response relationship. A confounder is an exposure or circumstance which can bring about the same health effect or mask the health effect under study. To be a confounder, two aspects must be satisfied:

- the exposure or circumstance must be able to cause or mask the health effect being considered; and
- exposure to the confounder must be related to exposure to the agent being considered.

Smoking causes lung cancer. If the question under consideration is whether diesel exhaust caused lung cancer, smoking is only a confounder if those with higher DPM exposure systematically smoke more or less than those with lower exposure.

Data Presentation

Data presented in the literature must be carefully scrutinised. The assumption must not be made that all is as it is portrayed. Two examples are from the work of Sir Richard Doll and Sir Austin Bradford Hill (1950, 1954) who investigated the large increase in the rate of lung cancer in Britain between the first and second World Wars.

In their first enquiry they looked at the smoking history of 649 men and 60 women who were admitted to 20 London hospitals with cancer of the lung and a control group who were admitted with cancer of other than the lung and respiratory tract.

In each case they present raw data. These are the numbers. Measures of statistical significance were included; but always the raw data. The other important point to consider is the effect size. A simple survey of a few hundred people was easily sufficient to identify smoking as the cause.

In a later survey (Doll and Hill 1954) they analysed the mortality of doctors in relation to their smoking habits. Again, we have raw data simply presented as deathrate per 1000 people. The increasing death rate from lung cancer with increasing tobacco consumption was clear providing strong evidence of a relationship. Tests of statistical significance were not conducted and Hill would later argue in many cases these are unnecessary and may be misleading.

TABLE IV.—*Proportion of Smokers and Non-smokers in Lung-carcinoma Patients and in Control Patients with Diseases Other Than Cancer*

Disease Group	No. of Non-smokers	No. of Smokers	Probability Test
Males:			
Lung-carcinoma patients (649)	2 (0·3%)	647	P (exact method) = 0·00000064
Control patients with diseases other than cancer (649) ..	27 (4·2%)	622	
Females:			
Lung-carcinoma patients (60)	19 (31·7%)	41	$\chi^2 = 5{\cdot}76$; n = 1 $0{\cdot}01 < P < 0{\cdot}02$
Control patients with diseases other than cancer (60) ..	32 (53·3%)	28	

The work of Doll and Hill is presented to show that data can be presented simply to demonstrate the point under consideration. Data on exposure and health outcome are presented and the point is clear. In our current studies that is seldom the case; authors rely on correlation coefficients and tests of statistical significance. As Hill (1964) observed

"Yet too often I suspect we waste a deal of time, we grasp the shadow and lose the substance, we weaken our capacity to interpret the data and to take reasonable decisions whatever the value of P. And far too often we deduce 'no difference' from 'no significant difference.' Like fire, the chi-squared test is an excellent servant and a bad master."

Exposure Assessment

In studies of diesel exhaust there is an ongoing problem with exposure data, i.e. there is none. This issue persists for practically every study of the effects of diesel exhaust and various techniques have been employed to fill this gap. The Diesel Exhaust in Miners Study (DEMS) related carbon monoxide (CO) to elemental carbon in diesel exhaust, while the Garshick study of truckers used the coefficient of haze and Steenland used miles travelled for trucker's exposures. In each case the AIOH OEL Committee must sift through the data presented to assess the validity.

DEMS relied on a series of measurements undertaken by the Mines Safety and Health Administration (MSHA) over the period 1976 to 2000 of gases in mines and tried to relate those measurements to respirable elemental carbon (REC). These measurements were almost all area measurements which were taken with colorimetric tubes. They are point-in-time measurements, not representative sampling. These tubes are known to be indicators of concentration but have errors of +/- 25% and these errors increase as the limit of detection (LOD) is approached. In the DEMS study all results were less than 5 ppm. Borak (2011) noted that the use of CO detector tubes at less than 5 ppm was not recommended.

Vermeulen (2010a) noted that the "*>6000 CO area measurements taken in the face area, which were used to develop the underground prediction models, had geometric mean air concentrations typically ranging from 1 to 2 parts per million (ppm) in 1975–1979, 1 to 3 ppm in the 1980s, and ≤1 ppm in the 1990s."*

Of the results available to DEMS about 35% were less than the LOD; the treatment of these results is critical. The preferred technique deal with <LOD results is to determine the distribution of the results which are greater than the LOD, then model the "less than" results assuming that the same distribution applies. This is what DEMS did. Vermeulen (2012b) for DEMS notes *"Natural log (Ln) transformation of the measurement data was used in the regression analyses, as the measurements were approximately log-normally distributed."*

In response, Crump (2012) noted that applying the Shapiro-Wilk test led to a firm rejection that the MSHA data were lognormal ($p = 6 \times 10–23$) and that the same was true of the DEMS data.

So the basis of this study upon which so much reliance has been placed is a set of CO measurements taken with measurement. It seems entirely plausible that the presentation of over one third of those results is flawed and it is the lower REC exposures which those CO results have been used to model which are the subject of so much recent speculation.

A further complication is the fact that CO was not the first choice gas for exposure modelling. The initial preference was to use CO_2. However, 70% of the CO_2 were less than the atmospheric background level of 375 ppm. They switched to CO and there is nothing to suggest that there was scrutiny of those CO results to see if they were similarly flawed.

With DEMS it must be borne in mind that all results were lagged 15 years so only exposure pre-1983 was considered. CO measurements were only available from 1976. For exposure prior to that engine horse power in the mine and mine ventilation were related to CO which was in turn related to DPM. This three stage reconstruction places further doubts on the exposure assessment.

Based on these and other questions on the exposure data the OEL Committee adopted a very cautious approach to the DEMS findings and preferred the review of Möhner and Wendt (2017)

Contrast the case of DPM with that of the assessment of coal dust exposure.

In Britain the known risk of disease in coal miners led to the establishment of the Pneumoconiosis Field Research (PFR) in the early 1950s which studied exposure to respirable coal mine dust and health outcomes. The Institute of Occupational Medicine (IOM) was established in 1969 to take over the research. In one of the most extensive studies of worker health ever conducted over 30,000 miners were followed over several decades from the 1950s to the 1980s.

Measurements of respirable coal dust exposure were undertaken at the time in the pits under study. In fact, that work lead to better systems of measurement with the development of the MRE 113 gravimetric dust sampler which remain relevant to this day. The amendments to the MSHA dust sampling rules for coal mines which became law in August 2016 require that dust be determined:

> *"…with an approved sampling device… …and then converting that concentration to an equivalent concentration as measured by the Mining Research Establishment (MRE) instrument."*

So, in the case of coal mine dust we have diseases known to be associated with exposure, miners being followed prospectively for 20, 30 or 40 years, a detailed health surveillance program run by well qualified people and detailed measurements of exposure.

Similar work was being undertaken in the USA with reports prepared by NIOSH in 1995 (NIOSH 1995) and an update in 2011 (CIB 64, 2011). NIOSH undertook the health surveillance while exposure data were from MSHA inspector sampling and coal mine operator data. Detailed exposure data is available although some have questioned the accuracy of the coal mine operator data.

Treatment of Smoking

The potential confounding effects of smoking on the development of lung cancer is a critical consideration for studies of exposure to DPM and is an important consideration for the development of chronic obstructive pulmonary disease (COPD) in coal miners.

In the DEMS case control study Silverman (2012) conducted a survey of smoking to control for this risk. Their results suggest that underground workers who do or formerly smoked more than a pack a day were 3 to 6 times less likely to develop lung cancer as a result of their smoking than surface workers who smoked the same amount.

The AIOH OEL Committee struggled with this. The results were compared to those from a substantial study of the incidence of cancer with smoking intensity by Lubin (2006). The OR for presented for surface only workers closely align with Lubin's findings which raises the possibility that the risk ascribed to DPM was in fact a result of understating the risk of smoking. This point has been made by reviewers including Gamble (2012).

Soutar and Hurley (1986) present results for COPD and coal dust exposure by smoking status. The data is simply presented in chart form and it is clear that smokers have a lower lung function than non-smokers, older workers have a lower lung function than younger workers and higher exposed workers have a lower lung function than low exposed workers. The effect is apparent at less than a 40-year working life at 1.5 mg/m^3.

The OEL Committee found this compelling.

Disease Assessment

Diesel Exhaust

The DEMS data was subject to a cohort study by Attfield (2012), a case control study Silverman (2012) and combined with the studies in meta-analyses by Vermeulen (2014). These have subsequently been reviewed along with a number of other studies. (Möhner & Wendt, 2017).

In the Attfield (2012) cohort review of the DEMS data, the finding was that, despite their much higher DE exposure intensity (75 times higher), the lung cancer risk for ever-underground workers was somewhat lower (only 64%) than that of surface-only workers (SMR 1.21 vs. 1.33). A positive exposure-response relationship was only seen when the (time-dependent) binary variable "work location" was included in the model *post hoc*. (Möhner & Wendt, 2017).

Attfield conducted a number of 'a posteriori' analyses whereby workers with tenure of less than 5 years were excluded and exposure was lagged 15 years with selection of the adjusting factors based on how the adjustment improved the data fit to the model of causality between REC and lung cancer.

The use of *a posteriori* analyses has been criticised by several reviewers including Gamble (2012). These are analyses which were not included in the original scope of the study with the concern being that such analyses should be used in hypothesis development rather than in risk assessment. Also criticised was the goodness-of-fit as a criterion to select the best lag to apply to the data. This should be based on biological plausibility. Such results should be confirmed by studies on other cohorts.

Even with those adjustments Attfield found the risk falls as exposure increases above the 80 to 160 µg/m^3.years. This is consistent with the work of Möhner (2013) who reassessed lung cancer risk associated with occupational exposure to DE in German potash miners. The re-analysis did not show any notable association between cumulative REC exposure and lung cancer risk.

In the DEMS case control study Silverman found a significant association between lung cancer and DPM. Several reviewers have questioned the application of smoking data as a confounder and the models used to draw the conclusions. Möhner and Wendt (2017) found a number of flaws and that at present, "the DEMS does not add evidence to an exposure–response relationship between DE and lung cancer."

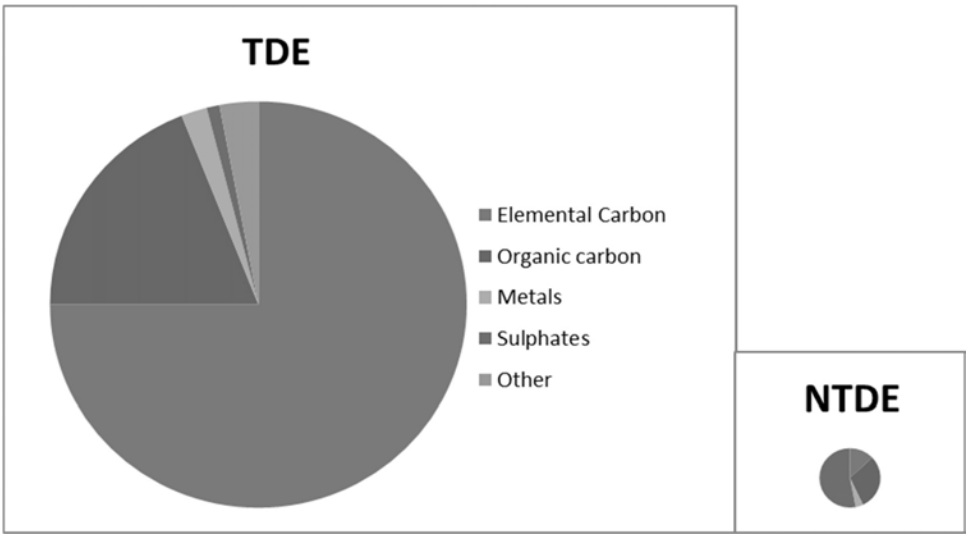
Möhner and Wendt (2017) suggest that an upper bound for the cumulative exposure of 2.5 mg/m^3-years respirable elemental carbon (REC) seems to be sufficient to prevent a detectable increase of lung cancer risk. This value they put as corresponding to an average annual exposure value of 0.05 mg/m^3 REC assuming a working life of 45 years.

Sun *et al* (2014) critically evaluated 42 cohort studies and 32 case-control studies from between 1970 to 2013 to examine the association between DE exposures and lung cancer. They conclude that epidemiological studies published to date do not allow a valid quantification of the association between DE and lung cancer, although such an association cannot be ruled out. They further note that causality of weak association is often difficult to establish, since it is susceptible to all forms of possible design bias.

The situation with respect to DPM exposure is not clear. Some studies such as DEMS claim to find a link; others such at the German Potash miners study find no link. The review by Sun suggests no dose response relationship but an elevated risk of perhaps 25% to 50% across all exposures but without the dose response attributing that to DPM is problematic.

One thing that is clear is that we are investigating a moving target. All the available research is focused on traditional diesel engines (TDE) and these are now largely museum pieces. Data presented by Khalek (2011) show that emissions of almost all polycyclic aromatic hydrocarbons (PAH) and nitro-PAH had been reduced by more than 95% in 2007 engines compared even to a 2000 technology engines which were already much cleaner than TDE. The concentration of all PAHs with more than four rings (except fluoranthene and pyrene which are not believed to be carcinogenic) including benzo-a-pyrene were not detectable in NTDE exhaust. We have moved on another decade and few working engines from the 20th century continue in use.

Hestergberg (2012) constructed the following figure from several data sources; the NTDE are actually 2007 model engines.



There has been one study conducted which investigated the carcinogenicity of exhaust from NTDE. A study by the Health Effects Institute McDonald (2015) on the effects of NTDE on rats found that NTDE exhaust "*did not induce tumors or pre-cancerous changes in the lung and did not increase tumors that were considered to be related to NTDE in any other tissue.*"

It is important to note that the level of particulate in NTDE exhaust is so low that the dose of exhaust particulate to which the rats in the HEI study were exposed, was limited by the maximum tolerated dose for NO_2 in the exhaust. This means that the dose was considerably less than in animal studies of TDE exhaust.

Respirable Coal Dust

The main assessment of the British study was funded by NIOSH and presented in a report prepared by Hurley and Maclaren (IOM Report No. TM/87/09). Estimates of individuals' cumulative exposures to respirable coalmine dust were derived from detailed work history records linked to results from an intensive program of environmental sampling. Radiographs were classified in accordance with the ILO scheme(s) by one or more doctors from the National Coal Board's panel of radiological specialists.

This study provides estimates of the prevalence of simple pneumoconiosis (CWSP) and of progressive massive fibrosis (PMF) in coalminers at various stages of a 40-year working life, the risks associated with work at dust concentrations of 2 mg/m3, and the sensitivity of these estimates to variations in the proportion of men who transfer to work at concentrations of 1 mg/m3 once CWSP category 1 or more is diagnosed.

The results showed for an ongoing exposure of 2 mg/m^3 the risk of any illness and the severity of that illness each increased with both the duration of exposure and of the coal rank. Based on their regression analyses, the

prevalence of PMF in long time miners exposed at 2 mg/m3 to higher rank coal was 1.84% or about 18 in each 1000 workers and fell to 0.71% or 7 in each 1000 workers for low rank coal.

The transfer to lower dust concentrations of men with simple pneumoconiosis had negligible effect on the estimated risks.

In the United States the NIOSH review published in 1995 and updated in 2011 described the risks associated with exposure to respirable coal dust. In summary, from this assessment the prevalence of CWP appears to increase from about 30 mg/m^3.years, while below that exposure the trend is less clear. At 80 mg/m^3.years (equivalent to 2 mg/m^3), the graph indicates the prevalence of CWP 1+ at about 13% for low rank coals rising to perhaps 21% for high rank coals. At 40 mg/m^3.years, the corresponding prevalence is 6 to 10%, however at this cumulative exposure high rank coal does not show as the highest risk, possibly suggesting that at this lower level of exposure, coal rank may not be so important.

In one of the few reports that did not relate to either the UK or USA cohorts, Tor et al (2010) report on the experience in Turkish coal mines with over 12000 workers including nearly 9000 underground. Exposures in the underground and on the surface averaged 1.66 mg/m^3 and 0.73 mg/m^3 respectively with the prevalence of pneumoconiosis ranging between 1.23 - 6.23 percent between 1985 and 2004. They found no cases of PMF.

The evidence for exposure to respirable coal dust is consistent across multiple cohorts on three continents. It is summarised in the following table which the AIOH OEL Committee found persuasive.

Author/cohort/average exposure		CWP 1	CWP 2+	PMF
Attfield/USA	1 mg/m^3	8	1	1.6
Attfield/USA	2 mg/m^3	17	4	5.1
Hurley/UK	1 mg/m^3	3.4	1.0	0.47
Hurley/UK	2 mg/m^3	7.75	2	1.2
Tor/Turkey	1 –2 mg/m^3	3	1.2	0

Table 1 Prevalence in % of CWP and PMF in Coal miners over a 40 year working life

The studies presented above all relate to current miners. In an earlier study, Maclaren and Soutar (1985) looked at the prevalence of PMF and CWP in both current miners and ex-miners. In this study a group of 1193 miners who had left the industry were followed up 11 years later.

They found that 98 of those men had developed progressive massive fibrosis. Increasing trends in incidence with lifetime dust exposure, age at follow up, and category of profusion of simple pneumoconiosis were apparent. This study is important as it clearly showed that PMF can develop after exposure ceases and that, while the status of CWP is important, workers with no apparent CWP are still at risk of developing PMF.

CONCLUSION

To summarise the OEL Committee findings a return to the start is informative. In 1964 Sir Austin Bradford Hill published an essay on causal effects. It is readily downloadable and I encourage you to do so. The question was how we establish causality. Bradford Hill arrived at nine tests which are applied to our present discussion.

The Bradford Hill Criteria applied to DPM and lung cancer, and Respirable Coal Dust and Pneumoconiosis; in the latter case at an exposure of say 1.0 mg/m^3. With DPM and lung cancer the association is equivocal, with Respirable Coal Dust and Pneumoconiosis the association is assured.

Criteria	DPM	Respirable Coal Dust
Strength of Association – how strong is the link. Think smoking and lung cancer or scrotal cancer and chimney sweeps	Weak	Very strong
Consistency – has the association been repeatedly shown in different times and places and with different people?	No	Yes
Specificity – Is the disease limited to specific workers and particular types of and sites of disease?	No	Yes
Temporality – which is the cart and which is the horse; did the disease occur a plausible amount of time after exposure?	Yes	Yes
Biological Gradient – Does the disease occur more often or become more severe as exposure increases?	No	Yes
Plausibility – is there a biologically plausible explanation for what we see?	Yes for TDE. Doubtful for NTDE	Yes
Coherence – the cause and effect interpretation should not interfere with the generally known natural history and biology of the disease?	Yes	Yes
Experiment – can we see a change due to experiment, if people are no longer exposed does the incidence of disease decrease?	Possibly	Yes
Analogy – are there other similar circumstances which suggest the possibility of the association?	Yes	Yes

The AIOH OEL Committee found the case for respirable coal dust to be compelling and that the OELs persisting in Australia were likely to lead to disease. An OEL in the order of 1 mg/m^3 is appropriate.

In the case of DPM the evidence is equivocal with almost all studies essentially redundant as the focus was on an agent, TDE exhaust, rare in today's workplaces; NTDE is vastly different. Only the animal study by McDonald looked at NTDE and that found no cancer. The AIOH OEL Committee adopted its approach from the review by Möhner, M & A Wendt (2017) which suggested that 0.05 mg/m^3 was protective of the possibility of lung cancer.

Over the years the nature of PPs has changed. Initially they were just that – Position Papers; this is the AIOH position on this topic. In more recent times there has been a much greater focus on ensuring the papers are a well-reasoned view based on a comprehensive review of the literature.

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WHY RISK ASSESSMENTS CANNOT BE REPLACED BY TOLERABILITY LIMITS IN RADIATION SAFETY.

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ABSTRACT

A fundamental principle of radiation safety across nuclear power & weapons, medical and high activity industrial sources is that radiation risk above the IAEA-recommended statutory dose limits is unacceptable, and all other radiation exposure needs to be optimised As Low As Reasonably Achievable (ALARA). Whilst the implementation of ALARA and the Linear No Threshold theory (LNT) is uncontested where radiation risks are significant, the principle can fail to return reasonably practical results in real life when risk can be considered trivial and material only marginally above prescribed definitions of radioactive material. Under these trivial or marginal conditions, field measurements that can be readily conducted with sampling and inspection against rule of thumb and unofficial tolerances, may also fail to correlate directly to exposure (risk). When management of radioactive risk is based solely on the conservative legislative definition of prescribed material and unofficial industry tolerances, it can be demonstrated that it may result in self-imposed regulatory control and management of little to no risk.

This paper discusses the detrimental health and safety outcomes of scaling down the high activity and high-risk approach to radiation safety when dealing with low concentration material. In trying to achieve ever smaller fractions of radiation doses to which workers are exposed, that are already considerably lower than conservative statutory limits, an operator can quickly reach the technical limits of what is reasonably practical and achievable. When considering the holistic risk exposure of an operation (time, financial, human), it is easy for an organisation to let the perceived risk associated with radiation hazards or an overly simplistic approach to radiation safety drive over-commitment on one hazard, depriving higher risk activities of necessary attention.

INTRODUCTION

From the original discovery of x-rays in 1895 by Roentgen (Goodman, 1995) and later of radioactive material (radioactivity) in 1896 by Henri Becquerel (Blaufox, 1996), professionals in radiation safety have found their niche in medicine, atomic weapons (ranging from kiloton fission weapons to the incredibly powerful megaton fusion devices), nuclear fuel generation and a number of mining and processing related industries (Eisenbud and Gesell, 1997, MacKenzie, 2000, Makhijani et al., 2000).

The breadth and depth of radiation physics and specifically radiation health is often greatly underestimated. It is frequently regarded as addressing a type of singular chemical or contaminant with its own MSDS such as silica dust or H2S, when in fact it is more accurately compared to the entire branch of organic chemistry and the vast range of effects that members of that branch can have on human health.

There is a huge variety in the combinations of isotopes, chemical matrices, environment and exposure pathways, and the radiobiological effects of each of these factors is different, so that a risk based approach was taken very early in the field of radiation protection.

The approach is based on the principles of radiation protection as recommended by the International Atomic Energy Agency (IAEA) (2006), central to which is that any exposure to radiation must be:

- justified (Principle 4)
- optimised (Principle 5)
- limited (Principle 6)
-

These principles, when combined, provide a framework which ensures that not only will people not be exposed above a certain exposure limit, as set by the statutory authority for the region, but that users of the radiation hazard must endeavour to achieve radiation exposure levels as low as reasonably achievable (ALARA), not just 'barely compliant' (Valentin, 2007).

Radiation exposure to humans is a measure of energy deposited in a person, organ or tissue, and from that, depending on a great many factors, the amount of damage done to that person, organ or tissue. Across Australia and in most regions of the world, the occupational radiation dose limits are as shown below.

TABLE 1 RADIATION EXPOSURE LIMITS (RADIATION HEALTH COMMITTEE, 2004)

1. an effective dose of 20 mSv per year averaged over five consecutive years;
2. an effective dose of 50 mSv in any single year;
3. an equivalent dose to the lens of the eye of 150 mSv in a year; and
4. an equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

A number of other useful limits such as annual limit of intake (ALI) and derived air concentration (DAC) exist for certain scenarios in specific applications (Department of Mines and Petroleum, 2010). They are all based on the premise that the resultant occupational radiation dose cannot exceed the limits as recommended by the IAEA.

Foundation of the Recommendations

As per most regulations, rules and recommendations, those around radiation safety were borne out of early incidents, public concerns and catastrophic events. From early x-ray technicians 'calibrating' equipment by exposing their owns hands until they were warm (Inkret et al., 1995), to the litigation in the 1920's and 1930's by the *Radium Girls (Clark, 1997)* and then battery of nuclear testing and bombing from the 1940's until today, the principles of radiation safety were built around scenarios concerning high dose rates in short periods of time (Advanced Research Workshop Atmospheric Nuclear Tests, 1998).

Radiation risk, at the deterministic health effect end of the spectrum where causality is clear, involves radiation doses in the order of 1 Sievert (Sv) (Mettler et al., 1997). It is generally accepted that a radiation exposure of 1 Sv over a 50-year career by a person designated a 'radiation worker', carries with it a 1 in 20 increased chance of shortened lifespan, due to radiation related illness or disease (Scientific Committee on the Effects of Atomic Radiation, 2009).

It should be noted that while exceeding the radiation exposure limits for members of the public and radiation workers is not permitted, these are administrative limits and actual harm to people or the environment is not documented until short -term exposures of several orders of magnitude greater than the limits occurs (Mettler et al., 1997).

In addition, the time span over which a worker receives a radiation dose affects the risk to worker health. Self-repair systems in the body can generally cope well with long term (decades) doses that cause damage however should the entire dose be received in a short period of time (minutes) the accumulative damage done may overwhelm the cellular repair systems and manifest as radiation sickness or diseases (Mettler et al., 1997).

Consequently, a method was developed for determining effects from radiation doses to workers that were below the deterministic effect threshold. That is to say, how is the risk scaled between 'normal' annual background doses of 1-2 mSv per annum, to significant doses of 200-300 mSv per annum (Mettler et al., 1997).

Table 2 shows the range of occupational, medical and background radiation exposures to members of public in Australia.

The adopted approach to this problem was the **Linear No Threshold** theory which states that all radiation exposure carries with it some level of risk (Mettler et al., 1997). It is based on the concept that if you halve the radiation exposure you halve the risk. Under such a regime, there is no control or mitigation strategy that reduces

the risk to zero. It leads to the often-cited stance that any radiation exposure to workers increases their probability of radiation exposure effects, even if that increase is negligible (Mettler et al., 1997).

TABLE 2: OCCUPATIONAL, MEDICAL AND BACKGROUND RADIATION EXPOSURES

Activity	Dose	Comment
Eating a banana	0.0001 mSv	Ingestion of K-40
Chest xray	0.05 mSv	Exposure to xrays
7-hour plane flight	0.07 mSv	Exposure to higher fraction of cosmic rays while at altitude
Annual dose to a person from food	0.4 mSv	Ingestion
Annual background – Aust	2 mSv	Cosmic, terrestrial gamma, radon and ingestion
Whole body CT scan	5 mSv	Exposure to a series of xrays
1 hr on the ground at Chernobyl	6 mSv	Exposure to nuclear fuel debris
Annual background – Ramsar, Iran	160 mSv	Increased exposure due to geology

(Lin, 2010, Bottollier-Depois et al., 2000, 2015)

Legislative Requirements

The Australian legislative landscape is divided into sometimes inconsistent sets of Acts which regulate radiation activities, the persons authorised to conduct these activities, and the statutory authorities who implement the legislation.

A review of these state and territory acts shows commonality with references to national codes of practice for medical, dental, industrial sources use and transport of radioactive material. These are all areas where the rules can be very definitive and the radiation risks to workers, members of the public and environment quantified.

Where the legislative framework is unclear or entirely silent is when radiation exposure risk combined with the radioactive material concentrations sits at levels far below those that the framework was written around. At the present time, a number of industries including mining, oil & gas and power (coal) generation are developing more sophisticated radiation inspection techniques for naturally occurring radioactive material (NORM) identified in their respective sectors, but finding little to no regulatory guidance regarding how to manage NORM to a responsible disposal solution.

In lieu of a threshold for specific activities (concentrations) of radioactive material that pose risk, many industries and consultants have adopted the threshold values published in the ARPANSA National Directory for Radiation Protection and IAEA SSR-6 Regulations for the Safe Transport of Radioactive Material 'Activity Limits and Classifications' (2012, 2014).

Detrimental H&S Outcomes

The threshold values define when a material or consignment becomes prescribed under legislation. While simple to implement and clear to make pass/fail assessments, this approach over simplifies the issue. It only considers the isotope and quantity and ignores factors such the types of radiation emitted and potential pathways of exposure to workers, members of the public and the environment.

The author recalls a number of scenarios where a waste product was bordering on the threshold value for exemption, and the question was asked, 'how the risk from radiation exposure changed as the specific activity increased from 0.9 decays per second (dps) per gram (g) to 1.0 dps/g', the threshold for exemption.

It can be demonstrated that the differentiation between material that is prescribed as radioactive material and material that poses actual tangible radiation exposure risk (i.e. it approaches or exceeds the exposure limits in Table 1 is no longer present with the use of threshold values not designed for risk assessment purposes.

The type of NORM present, other material it may be combined with and how it is handled can greatly influence the radiation risk. This issue can lead to two separate types of problems:

- overly cautious and restrictive management of material that is prescribed due to concentration, but low risk due to pathways; and

- lax management of material which has a low concentration and is not prescribed, but due to the physical form and handling of material, may have higher than expected risk.

Another approach commonly taken in the absence of specific guidance regarding the proper management of low level radioactive material, specifically NORM, is the adoption of established 'best practice' rules from one industry (such as mining) under the assumption they will also serve as best practice for a completely different industry (such as oil & gas). This method rarely identifies contributing factors such as different physical and chemical matrix, handling procedures and pathways to exposure of workers, members of the public and the environment.

Demonstrate

Headlines such as "BHP Kalgoorlie radiation claims quashed" (2010a) from 2010, highlight the perceived risk surrounding any radiation dose in the final statement:

> Sixty-nine radiation measurements were taken across the site and readings showed radiation levels averaged 0.11 microGrays per hour, which compares to typical background radiation levels of 0.08 microGrays per hour at the Kalgoorlie DMP office," he said.
>
> A residential garden in Roleystone measures 0.6 microGrays per hour due to the naturally occurring granite along the Stirling Range, five to six times higher than the site in Kalgoorlie-Boulder. (2010a)

The opinion that a radioactive material, specifically an artificially concentrated or treated one, can present no risk is rarely displayed in industry. This is even more the case if that industry in highly scrutinised by non-government organisations, community or media.

An example of the prescribed limit approach not giving an accurate assessment of risk would be the example of radium-226 and radium-228 isotopes in oil & gas NORM. In oil producing fields, as the water content for formation fluids increases and brings with it more dissolved salts such as radium to the surface, the production of NORM also increases. In this example, the radium isotopes are bound in a barium sulphate (Ba(Ra)SO4) solid matrix within the white scale formation (Crouch, 2012).

Assuming the scale was as a visible, insoluble sulphate layer within pipes at an average isotope concentration of 5 Bq/g Radium-226 and 50Bq/g Radium-228, the ARPANSA transport code of practice would identify this material, once removed from other production equipment, as prescribed solid radioactive waste which can only be transported within Australia as class 7 dangerous goods (2014).

Investigating this scenario further, it can be assumed this material would have particle sizes significantly larger than 5 microns (millionth of a metre) average mean aerodynamic diameter (AMAD) as it has not been milled or processed. For the sake of this worse-case scenario assume that both the Radium-226 and Radium-228 are exclusively in particles of 5-micron AMAD (Taylor, 1996).

Using conservative dose limits, we apply the member of the public annual limit of 1 mSv/yr (Mettler et al., 1997).

The following simplified scenario for that worker handling radium oil produced scale:

- Radium-226 and Radium-228 have concentrations of 5.0 Bq/g each
- prescribed exemption concentration for Radium-226 and Ra-228 is 10 Bq/g.
- all progeny isotope doses are included in the radium head-of-chain calculations
- breathing rate is 1.2 m3/hr (as per AS 3460)
- dust load in air is 1 mg/m3 which is highly unlikely if this was an actual scenario
- exposure time is 2000 hours per year which is also grossly overestimating the exposure time compared to an actual scenario
- dose conversion factor for Ra-226 and Ra-228 of 5 µm AMAD is $5.5x10^6$ and $36.1x10^6$ respectively (DMP, 2010)
- no correction has been made for PPE such as dust masks and respiratory protection

A person in the scenario above would receive, in theory, an inhaled dose of 500 µSv per annum. This exposure is comparable to that of one tenth of a typical medical computed tomography (CT) scan.

It can be seen from this example that the risk posed by radiation exposure of the material when it is at the prescribed limit is still significantly less than routine medical procedures. Given the low exposure risk, it is hard to argue that above a reasonable level of management and verification, controls akin to those required for nuclear facilities or high dose rate radiography is justified. It should be stated that this example did not consider other exposure pathways such as gamma exposure from the material.

A useful though unofficial dose risk comparison is the banana equivalent dose (BED) (Stahmer, 2016). As radon gas, medical x-rays and cosmic rays are not scenarios the general population knowingly have many experiences with, comparison to something considered mundane and of negligible risk is incredibly helpful in explaining risk due to radiation exposure.

The premise of the banana equivalent dose is that the ingestion of potassium-40, a naturally occurring radioactive isotope found in bananas, brazil nuts and other foods, exposes the consumer to a certain quantifiable amount of radiation exposure. This exposure is generally accepted to be 0.1 µSv per reference banana consumed. The annual background exposure each person receives is made of a number of sources as discussed above, one of which is the ingestion of radioisotopes in food and drink. This is also estimated to be approx.200 µSv per year in Australia (2015).

The scenario above which lead to a 486 µSv radiation exposure dose due to the inhaled radioactive dust from oil & gas NORM activities would be the same exposure as eating approximately 4860 bananas, or 13 bananas per day for a year. While the gastric impacts of eating 13 bananas per day for a year is outside the scope of this paper, if someone was to consider the risk from doing so, radiation exposure risk is unlikely to be considered significant.

The question can be asked; if we apply the Linear No Threshold model of radiation exposure to bananas or some threshold intake value of potassium-40, would it be practical to minimise the consumption of bananas based solely on the fact they contain low levels of NORM, or is it reasonable to assume the radiation exposure is negligible and focus time and resources on other more valuable social food and nutrition programs?

RECOMMENDATIONS

The issues discussed in this paper are becoming more common as industry looks for checklists and thresholds rather than detailed assessments of risk from radiation exposure. A common misconception is that a technician with a checklist based on a set of base assumptions, some past scenario that may not represent the current

situation, or a combination of both, can replace an experienced subject matter expert. It is the expertise of knowing the mechanics behind the hazards and risks, and how those risks compare to other risks that allow an operator to achieve best practice through an efficient tailored system, rather than a crude, brute force approach to compensate for a poor understanding of the hazard and risk.

It is not practical for any regulator in Australia to provide prescriptive guidance on every potential scenario that involves activities with radioactive material or the disposal of radioactive (NORM) waste as the topic has many permutations and does not align with the current risk based approach the regulation (2010b).

It is the opinion of the author that a national representative body can bridge the gap via programs that offer guidance providing a deeper understanding of the intent behind prescription limits of certain materials and, more importantly, when the prescription level is not to be used in place of a risk assessment.

The use of publicly available risk assessments (though not management plans) in this matter would also build a growing reference of detailed information regarding what a reasonably practical level of detail entails. It would showcase the various methods of assessing radiation risk and allow industry to 'know what they don't know' and what skill set and competencies are properly suited to managing a complex and commonly misinterpreted hazard.

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AWARENESS OF IONIZING RADIATION HAZARDS.

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ABSTRACT

A major challenge facing Occupational Hygienists is the expectation of being able to anticipate, recognise, evaluate and control an enormous range of hazards in diverse exposure situations. Radiological hazards are a category which can present in numerous forms with different exposure risks. As a Health Physicist, I investigate radiological hazards, assess exposures and advise upon suitable controls. In the interest of raising awareness, I will discuss occupational settings where known ionising radiation sources are in use and circumstances where hazards may not be inherent or obvious. Examples will include naturally occurring radioactive materials in mines, sealed sources for flow and level gauging in industrial processes, and unsealed solutions in research laboratories. These examples demonstrate the application of radiation safety legislation and guidelines, and emphasise how underlying radiation protection principles are based on safety assessments and risk management strategies comparable to other occupational hygiene hazards. Through enhancing awareness of the diversity of ionizing radiation sources and their application, there is greater potential for limiting occupational exposures.

INTRODUCTION

Health Physics is the applied science of radiation protection to facilitate safe applications of ionising radiation via anticipating, recognising, evaluating and controlling exposure hazards. Applications for ionising radiation evolve and are not always self-evident in workplaces. In general, where there is an awareness of the use of ionising radiation in a workplace and appropriate controls are in place, the likelihood of excessive exposure is usually very low. Excellent guidance on evaluating and controlling ionizing radiation hazards are available from Australia's state and federal regulators as well as international organisations in the form of standards, guides and codes of practice.

This paper seeks to promote awareness of applications of ionising radiation so that occupational hygienists anticipate and recognise potential hazards. To exemplify the variety of radiological occupational hygiene hazards, three categories of industries where ionising radiation is inherent are discussed. These are natural radionuclides in mineral exploitation, sealed anthropogenic sources in industrial gauging, and unsealed sources in radioisotope laboratories. For each category, the type of ionising radiation encountered and processes with potential for exposure to workers are discussed.

NATURALLY OCCURRING RADIOACTIVE MATERIALS

Naturally occurring radioactive materials (NORM) are substances, whether natural or process-enhanced that contain elevated concentrations of natural radioactivity. Fundamental radionuclides in NORM are potassium-40, uranium-238, thorium-232 and uranium-235. The three latter radioisotopes each have an associated decay chain of progeny radionuclides. The activity concentration of these natural radionuclides in commercially exploited minerals is often comparable to that in ordinary soil and rocks; however some mineral resources can contain naturally greater concentrations (International Atomic Energy Agency, 2006). Moreover, processing these minerals can significantly enhance the concentration of these natural radionuclides. For this reason, mining processes can result in the extraction, concentration and accumulation of NORM in products, by-products and waste streams (Australian Radiation Protection and Nuclear Safety Agency, 2008); thereby justifying radiation protection efforts to evaluate and control radiological hazards.

Evaluation of NORM materials should include measuring the activity concentration of key radionuclides and assessing the radiological dose to at-risk persons. An accurate, quantitative measurement of material activity concentrations generally requires assessment of samples at a suitable laboratory. Assessing the radiological dose

to at risk persons is based on combining exposure circumstances with the materials' radiological concentration information and factors for converting activity (units of Becquerel, Bq) to effective dose (units of Sieverts, Sv). Radiological exposure pathways to NORM can include external gamma radiation from close proximity to bulk quantities, and internal exposure to alpha and beta radiation from inhalation of aerosols, dusts and gases, or ingestion of particulates (International Atomic Energy Agency, 2006). Key examples of NORM in mineral industries include:

- Mining and milling of ores; in addition to uranium ore, the commercial exploitation of other metalliferous ore deposits can create NORM by-products and wastes due to uranium and thorium within ore materials (International Atomic Energy Agency, 2002).
- Oil and gas, where uranium and thorium progeny can be prevalent, such as radioisotopes of radium and lead inside pipelines (International Atomic Energy Agency, 2003b).
- Mineral sands, in particular monazite which is rich in thorium-232 and progeny, and zircon which contains uranium-238 and thorium-232 decay series' radionuclides (International Atomic Energy Agency, 2007, International Atomic Energy Agency, 2012b).
- Phosphate, where uranium-238 and thorium-232 decay series radionuclides are present in residues (International Atomic Energy Agency, 2013).
- Coal, where uranium-238 and thorium-232 decay series radionuclides are concentrated in residues from power stations, such as lead-210 and polonium-210 in fly ash (Australian Radiation Protection and Nuclear Safety Agency, 2008).
- Underground mining and enclosed workplaces with low ventilation rates, where elevated concentrations of radon isotopes and progeny can occur (International Atomic Energy Agency, 2003a, International Commission on Radiation Protection, 2015).

Case Study – Radon in Metalliferous Mines

An interesting component of NORM is radon-222 and radon-220 known, and herein referred to as radon and thoron respectively. Being gaseous, radon and thoron emanate from uranium and thorium bearing materials, namely the Earth's crust. The concentration of radon, thoron and their progeny can be an inhalation exposure hazard in enclosed spaces such as underground mines, if emanation rates are sufficient and ventilation is poor (International Commission on Radiation Protection, 2015). The World Health Organization (2009) attributes radon exposure as causative of 3 to 14% of all lung cancers; citing radon as the second greatest cause of lung cancer (smoking being the greatest) and calls for a reference level of 100 Bq/m^3 to minimize health hazards from indoor exposure (this reference level is relaxed to 300 Bq/m^3 under specific conditions). In Australia, current (albeit under review) recommended action levels are 200 Bq/m^3 for homes and 1000 Bq/m^3 for workplaces (Australian Radiation Protection and Nuclear Safety Agency, 2002). Typical occupational exposure to 1000 Bq/m^3 radon would result in approximately 10 mSv/y effective dose (International Atomic Energy Agency, 2014). In comparison, the worldwide average exposure to naturally occurring radiation sources, including radon and thoron, is 2.4 mSv/y (United Nations Scientific Committee on the Effects of Atomic Radiation, 2000). Evidently, radon, thoron and their progeny have the potential to contribute significantly to the radiological dose of workers in underground mines; which emphasises the importance of controls such as ventilation.

Our *Radiation and Nuclear Science* team has undertaken radon and thoron assessments throughout two underground mines within Queensland. One is a former silver mine, no longer operational, but maintained (including mechanical ventilation) for education purposes. Radon and thoron concentrations averaged over 3 months ranged from 30 to 300 Bq/m^3 and 30 to 900 Bq/m^3 throughout the mine respectively. The other mine

was formerly used to produce tungsten and molybdenum; it is currently maintained (natural ventilation only) with a view to resuming operations in the future. Three month average radon and thoron concentrations ranged from 30 to 700 Bq/m^3 and 30 to 2300 Bq/m^3 throughout the mine respectively. This illustrates the variability of radon and thoron concentrations throughout an underground metalliferous mine.

Case Study – Radium in Groundwater

Water treatment is also a process with potential for creating NORM residues. Groundwater can be enriched with radium as a result of natural radionuclides within the aquifer geology (Kleinschmidt et al., 2011). Groundwater treatment such as sedimentation, filtration, flocculation and aeration can substantially remove radium-bearing molecules, resulting in sludge with enhanced concentrations of natural radionuclides (Kleinschmidt and Akber, 2008). In Southeast Queensland there is a small water treatment facility that was used to augment a primary regional water supply. In the raw water our *Radiation and Nuclear Science* laboratory measured approximately 0.4 Bq/L radium-226 and 0.8 Bq/L radium-228. This constitutes groundwater enriched by radium that has leached from surrounding geology (Kleinschmidt et al., 2011). By comparison, local surface water contained <0.1 Bq/L of radium-226 and <0.1 Bq/L of radium-228. Treatment of the bore water created a waste sludge with approximately 2200 Bq/kg radium-226 and 4400 Bq/kg radium-228. The activity concentration of this sludge is significantly elevated compared with local soil concentrations of <50 Bq/kg radium-226 and <50 Bq/kg radium-228. On a mass ratio, radium from the bore water has been concentrated in the sludge by a factor of 5500. In this situation, appropriate controls include containment of the sludge to prevent leakage or leaching; keeping it wet to prevent generating dust, and appropriate disposal at intervals that prevent accumulating excessive quantities.

NUCLEAR GAUGING

Ionising radiation sources are routinely used for flow and level gauging throughout mines, paper mills, factories and oil and gas industries. They serve purposes such as non-invasive in-line process monitoring of fluids in pipes, fill levels of vessels, and thickness testing of products. The radiation source in fixed industrial gauges varies with application, and can be alpha, beta, gamma, X-ray or neutron radiation (Australian Radiation Protection and Nuclear Safety Agency, 2007). Industrial gauges are designed to collimate the radiation into a beam emitted in the direction of the material to be gauged, and attenuate or shield the radiation from being emitted in other directions. Dose rates from the collimated beam are generally sufficient to be a significant health hazard, therefore a suitable installation configuration is an important engineering control of these radiation sources. Akin to industrial gauging is the practice of density/moisture gauging albeit with portable gauges. These use gamma and neutron radiation for in-situ assessment of geology, concrete, asphalt and similar materials (Australian Radiation Protection and Nuclear Safety Agency, 2004). Gauges are typically manufactured to be robust and relatively self-shielding when switched off. When a gauge is turned 'off', the collimated beam is shielded by a shutter to minimise all radiation emissions, as appropriate when not in use or during relocation or maintenance. Alternatively, where a radiation source is electrically energised, switching 'off' is by de-energising the source. Despite the engineered controls of robust design and being able to switch and lock-off gauges, potential exposure incidents can arise, especially under harsh operating conditions or through inadequate maintenance and neglect. Below are three examples of when things have gone awry.

Case Study – Fixed Industrial Gauge Leak

At a mineral processing plant in Queensland, a routine inspection for recertification of a fixed radiation gauge containing caesium-137 identified anomalous elevated gamma dose rates on the floor beneath the gauge (Wratten, 2010). Subsequent investigations identified that vibrations in steel pipework to which the gauge was mounted wore-away the stainless steel encapsulation of the sealed radioactive source. In this manner, the source which was water soluble escaped the gauge housing and substantially contaminated the floor beneath. Additionally, small levels of contamination were detected several meters from the gauge and on lower levels of the facility, due to mobilisation and infiltration by moisture. Thankfully the process equipment was remotely

operated, meaning that worker occupancy and resulting exposures were low. Nevertheless a system shut-down and intensive decontamination process were undertaken (2010). In this instance, the process equipment was operating with excessive vibration, beyond the design limitations of the gauge's radioactive source encapsulation. At the time of this incident, this gauge was one of nine of the same type in use in similar configurations at the site. Consequently, the other gauges were assessed to confirm their integrity. In this situation, it is fortunate the radiation safety officer had the required recertification conducted in a timely manner, otherwise the failed gauge would have further leaked, the excessive equipment vibrations would not have been rectified, and another eight gauges would remain susceptible to leaking.

Case Study – Portable Density Gauge Incident

In February 2014, insufficient adherence to safeguards resulted in a borehole logging source used in Queensland's coal-seam gas industry being unshielded and exposing five workers, one of which sustained a significant burn to his leg (Hagemann, 2014, Queensland Health, 2017). This incident was the subject of a recent successful prosecution under Queensland's *Radiation Safety Act 1999* against a company providing services to a coal-seam gas company (Queensland Health, 2017). This incident illustrates the importance of organisations ensuring their contractors who utilise radiation sources not only adhere to work health and safety legislation, but also radiation safety legislation.

Case Study – Inadvertent Recycling of Industrial Gauge Radioactive Source

Improper tracking and disposal has resulted in occasions of industrial gauges being recycled as scrap metal whilst still containing their radioactive source, thereby creating contaminated scrap metal and subsequent products (Lubenau and Yusko, 1998, Ya-anant et al., 2011). Globally, this issue is being addressed through improvements in regulatory tracking of radioactive sources, as well as equipping scrap metal recycling facilities with portal radiation monitors to screen incoming loads (International Atomic Energy Agency, 2012a). In Queensland, a batch of stainless steel food mixing bowls for use in domestic kitchens and destined for a major grocery store retailer were detected during importation checks. Our *Radiation and Nuclear Science* laboratory analysed one set of these bowls and identified that in the set of 5 bowls (of various sizes), one contained approximately 40 kBq of cobalt-60 and the other four bowls contained trace activity levels. This demonstrates the potential for far reaching impacts when radioactive sources are orphaned from regulatory governance, such as tracking of ownership and disposal.

LABORATORIES

Radioisotope laboratories can be found in hospitals, universities, research and commercial organisations. They entail the handling of radioisotope solutions for a range of purposes associated with radiopharmaceuticals, radiolabelling, research and analysis. The type of handling of radioactive solutions can include production, storage, manipulation, dilution, use and disposal. The solutions routinely utilise alpha and beta emitting radioisotopes. Consequently, internal exposure is often the greatest hazard. Within radiolabelling, research and radiation measurement laboratories, a ready inventory of radioactive solutions may be ever-present for calibration purposes. These radionuclide solutions can vary significantly in terms of half-life, activity concentration and radiotoxicity. Within radiopharmaceutical laboratories, many of the radionuclides are short-lived, that is they have half-lives typically quoted in minutes or days. An advantage of short half-lives is that significant decay can occur prior to disposal and that surfaces inadvertently contaminated will return to normal. The disadvantage of rapidly decaying radioisotopes is that it is necessary to acquire and handle substantial activity levels so that they remain viable at the time of use. Consequently, the processes for controlling exposure during storing, dispensing, labelling, transporting and disposal of the radioisotopes are important. A valuable guide for evaluating and controlling radiation hazards in laboratories is Australian Standard AS2243.4-1998 Safety in Laboratories Part 4: Ionizing radiations (Standards Australia, 1998).

Case Study - Decommissioning Radioisotope Laboratories

The *Radiation and Nuclear Science* team has assessed radioisotope laboratories after cessation of their operations to ensure no radiological contamination remains that would be a health hazard or restrict future use of the facilities for other purposes. Our experiences include hospitals, universities, as well as state and federal government organisations. In most instances, negligible contamination was discovered. However, exceptions where radioactivity was identified are:

- Bottles of remaining stock radioisotope solutions in the back of storage cupboards.
- Obsolete benchtop analytical instruments with internal radiation sources.
- Contamination on bench, floor and drawer surfaces. Chemical cleaning often greatly reduced this contamination, though occasionally it was necessary to physically removal surface layers to achieve background radiation levels.
- Contamination of internal surfaces of air-conditioning ducts and within plumbing pipework such as sink traps. These were identified in laboratories where the air-handling and plumbing were inherently important to the radiation practices performed.

Through conducting these laboratory assessments, it became evident that radioisotope laboratories change and evolve in accordance with organisational needs. What was once a room for storing radioactive materials may become office space; or a researcher using radioactive solutions may exit the organisation leaving materials behind without anyone inheriting responsibility. In this situation where a laboratory undergoes a change or ceases to operate, it may be prudent to investigate if radiation hazards remain as a legacy of past activities.

CONCLUSION

Radioactivity is utilised in a wide range of workplace environments. In practice, radiation protection is a risk management process, applying controls to minimise exposure. The use of suitable controls is essential, because ionising radiation is a physical hazard which cannot be detected by the human sensory system (except under uncommonly high exposure rates). Like all physical hazards, the controls can include substitution, isolation, engineering, administrative, and personal protective equipment options. Simple administrative controls such as warning signs, trefoils and dangerous goods (class 7) labelling are often the catalyst for individuals recognising the hazard. Evidently exposures can occur simply due to an obscured or missing label. This emphasises the benefit of having a sound awareness of the types of radioactive sources and their applications, so that Occupational Hygienists and safety professionals are more likely to anticipate and recognise these hazards.

A number of situations where radioactivity is encountered have been discussed along with specific experiences of Health Physicists at the *Radiation and Nuclear Sciences* team within the Queensland Department of Health. Collectively these examples demonstrate the breadth of occupational settings where ionising radiation substances may be encountered and highlight how the presence of a radiation hazard may not be readily apparent. Therefore anticipating and recognising such hazards can be challenging, and whereupon the person responsible for this will need to facilitate evaluation and control of the hazards. Where a hazard has been identified, an important step in the risk management process is establishing what regulatory governance applies, as addressing these requirements will evoke important radiation protection controls and provide insights into documents and professionals who can guide occupational hygienists through the ambit of radiation protection.

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USE OF MOBILE PHONES AND LIGHT METER APPLICATIONS IN THE ASSESSMENT OF THE OCCUPATIONAL LIGHTING ENVIRONMENT.

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ABSTRACT

With the development of built-in smart sensors, smartphone users can do many things with only one portable device. Light meter applications measure illuminance and are offered free or at low cost. Like noise meter apps, it is tempting to use such devices for preliminary lighting surveys. However, there are few reports of studies evaluating such use, and none which have explored their potential use for assessment of blue light hazards.

This paper presents preliminary data on side by side measurements of illuminance and blue light hazard function (BLHF) -weighted illuminance with a range of smartphones, apps and light sources.

Phones with Android and Apple operating systems and two phone apps were compared alongside a professional lux meter on a workstation desk in a mock office, set up in a dark room. A blue light filter (Hoya B440) was used directly over the sensors for the BLHF-weighted value.

The values of the illuminance and blue weighted illuminance differed depending on distances and the types of light sources.

The rationale for the use of BLHF filters on photometric instrumentation for blue light hazard assessment has been described in the literature. Calibration factors for both naked and filtered sensors need to be established for specific phones and software. The limitations and variances of particular combinations also need to be understood. However, in principle, the use of a smartphone in preliminary lighting surveys may be feasible, and if so, guidance for their use may be developed.

INTRODUCTION

Carefully designed lighting can not only improve worker productivity, but can also reduce the risk of occupational injuries. However, lighting can adversely affect workers' health in terms of circadian rhythm and sleep disruption, psychological disturbance, eye fatigue or visual receptor impairment (AS/NZS 1680, 2008). Hence lighting in the workplace has a close relationship with the quality of working life and this can be assessed by multidisciplinary approaches. Lighting surveys are typically used to determine the quality or risk associated with the working environment. The surveys can be considered in two ways. One is direct observations in workers' environments - looking at tasks, durations of shifts, working conditions, types/numbers of light sources, etc. using AS/NZS 1680 criteria (Smith 1991) and the other is more subjective, from surveys and questionnaires about lighting quality from workers themselves. (Chung & Burnett 2000)

The evaluation of lighting conditions for task performance is complex due to the need to consider, *inter alia*, the visual task, associated directionality relative to light, and spatio-temporal variability in illuminance, luminance, and colour. (Chung & Burnett 2000)

In order to assess lighting conditions in the workplace, a variety of equipment can be used. These include photometers such as luminance meters or illuminance meters which can measure the intensity of light. A spectroradiometer can provide information on the spectral distribution of light impinging on work surfaces or the eye, but these devices are expensive, and are not generally used by hygienists or ergonomists.

The global mobile phone market has seen tremendous growth in recent years and it is estimated that 67% of the overall Australian population will be using a smartphone by 2018 (Statista 2017). With the popularity of mobile devices, various easy-to-use applications have been created. Initial applications using mobile sensors were available with separate attachable accessories on mobiles but with quickly evolving mobile technology, software/sensors have been developed to eliminate the need for such attachments. New mobile devices have various functions including; movement direction sensors (e.g. accelerometer, gyroscope and magnetometer), sound and light sensors (Liu 2013).

Many mobile apps using multifunctional sensors can be used in the occupational health field, for example, health monitoring or health surveillance using GPS apps or noise monitoring using noise meter apps (Hovila et al. 2005; Triantafyllidis et al. 2017).

Through these sophisticated technologies, many functions can be performed with just one mobile device. Liu (2013) suggested that a light sensor, which recognises light and supports camera features, could contribute to accurately measuring the light intensity.

Light meter applications work by manipulating light sensor hardware outputs. These apps typically display illuminance, based on software calibration factors. In principle, they may become very useful portable devices that can be used for preliminary evaluation of lighting problems in occupational settings.

Research Purpose and Questions

This study is focussed on the applicability of mobile phone light meter apps for measuring illuminance values in occupational settings, as an alternative for using lux/illuminance meters.

Using existing literature and results of illuminance and BLHF illuminance from tests in a mock-up workstation, it was intended to develop guidance for the use of such apps.

In order to develop a strategy for this outcome, the following questions were to be answered;

- Are the mobile phone apps and light sensors suitable for lighting surveys?
- What is the performance of light meter apps relative to a professional lux meter?
- Are there types of mobile phone apps that are more reliable than others?
- Could a blue light filter be used on a photometer to assess a blue light hazard?
- What is different between blue light-weighted and –unweighted illuminance for the various light sources?

1. Literature Review - Are the mobile phone apps and light sensors suitable for lighting surveys?

Goldschmidt and Pittner (2016) provided the initial data and ideas about the use of mobile apps for illuminance measurement. They measured the illuminance values from seven mobile apps in seven different types of mobile devices on a horizontal surface and set up three reference illuminances (100 lx, 500 lx and 1000 lx) using an illuminance meter (PRC Krochmann) under three different light sources. The range of deviations of the apps according to the reference illuminances in the predetermined lighting conditions were from 3% (the lowest) up to 113% (the highest) and the apps of Android and Windows phones showed the higher illuminance values than the reference illuminance and the other apps with iOS operating system indicated the lower illuminances than the references. In addition, four iPhone 5 mobiles showed different outcomes (all lower) under 3 different reference values. With one iPhone loaded with 2 different apps, again different outcomes (all lower) from each app were obtained (Goldschmidt & Pittner 2016).

In a larger and more recent study, Cerqueriar et al. (2018) examined the accuracy of 14 light meter apps using 138 mobile phones with three different operating systems (Android, iOS and Windows). They set up three different coloured light sources in a black chamber and designated four reference illuminance values (300 lx, 500 lx, 750 lx and 1000 lx) for comparison. The higher the illuminances from the reference light meter, the greater was the spread of data from the apps. Depending on colour temperature (2700 K, 4000 K and 6500 K), the brighter the light sources the smaller the differences in values of the illuminances measured. The authors noted that the applications with calibration functions showed significantly lower mean deviations - however, the range of deviations' ratios was still from 31.1 to 50.8%. (Cerqueira et al. 2018)

From both studies, it would be premature to think that smartphone light meter apps are capable of replacing existing lux meters for professional measurement.

Negar et al. (2014) showed variable outcomes from their new light intensity calculation app, Access Light, and reported this app could measure lux values comparable with a professional light meter. Johnson et al. (2015) stated that the error rates between Access Light and a professional light meter were only 0-5%.

ASSESSMENT METHODS

Workstation set-up

All tests were conducted in the mock office which was set up in a room which had no extraneous light, only light sources being the switchable fluorescent ceiling lamps (Figure 1(a)). The workstation was set up with typical equipment (including IT devices) from general office supplies. The height of the desk was 0.7m and the height of downlights to be tested was set up to be perpendicular to the desk and 1.9m from the desk. One spot in the centre of the workstation was designated to measure the illuminance and all tests using mobile apps and an illuminance meter were conducted in this fixed spot. (Figure 1)

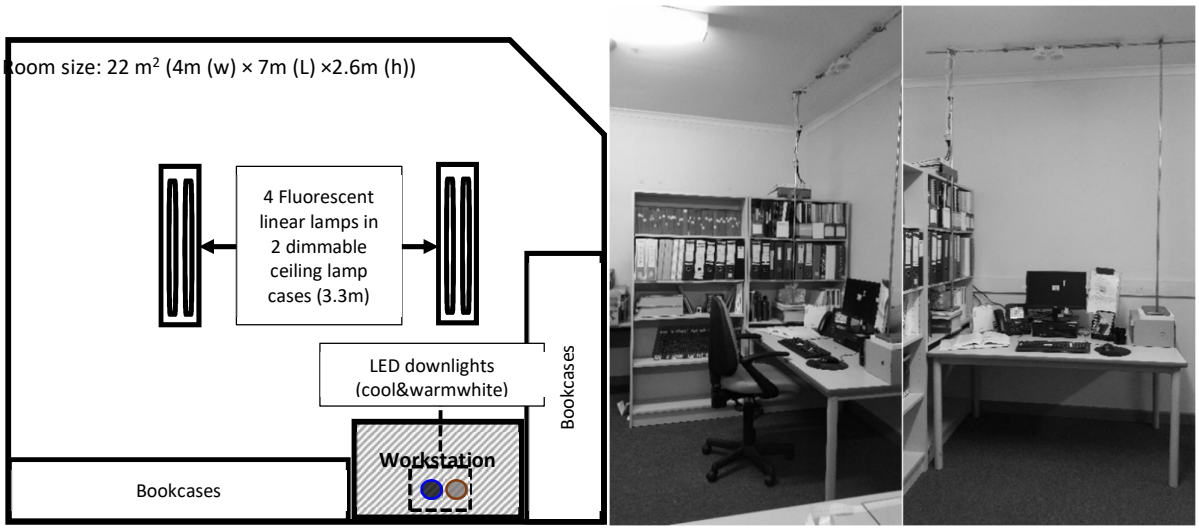

Figure 1. Simulated workstation in the office: Left to right (a) floor plan (b) & (c) pictures of the simulated workstation

Characteristics of the Light Sources

One DETA 12W cool-white (Model: DET492) and one warm-white (Model: DET490) LED were set up in the ceiling above the workstation. Two twin OSRAM 36W linear fluorescent tubes (Model: L36W/840) in two twin prismatic diffusers were used as luminaires for testing of background lighting (Table 1). All measurements were taken in the fixed spot location on the desk and all brand-new lamps excepting ceiling mounted fluorescent linear lamps, were used in the all tests.

A Specbos 1211 UV (JETI Germany, S/N: 2010143) spectroradiometer, with LiMeS software (Version 4.1.0m), was used to determine the characteristics (e.g. luminance, actual colour temperature or spectral radiance) of the light sources in the workstation.

Table 1. Emission characteristics of overhead light sources

Measuring equipment	Measurement	DETA 12W cool-white LED downlight/DET492	DETA 12W warm-white LED downlight/DET490	OSRAM 36W fluorescent linear tube/L36W/840
Spectroradiometer (Specbos 1211UV)	Luminance [cd/m^2]	75257	66451	6452
	CCT [K]	5672	3024	4062
	Blue-weighted radiance L_B [W/ m^2·sr]	56.5	22.4	3.3

Applications and Devices

Six smartphone devices and two tablet PCs were used for testing the illuminance (Table 2). Two free applications for two different operating systems were downloaded from each of the websites. An illuminance meter (Digital Lux Tester, National Company, BN-2000LTE, calibrated by the QUT Photometric Laboratory), was used as the reference device. (Figure 2)

Table 2. Types of hardware and software on mobile devices

Model	Operating system	Used applications/provider
Samsung Galaxy Note 4 Samsung Galaxy Note 3 Samsung Galaxy S5 Motorola Razr	Android	Light Meter/Trajkovski Labs
iPhone 4s iPhone 7 iPad mini iPad pro	iOS	LUX Light Meter/Nipakul Buttua

Figure 2. Mobile phone apps and illuminance meter. Left to right (a) light meter application for Android, (b) light meter application for iOS and (c) National lux tester

Measurement of Blue light Hazard Function (BLHF) -Weighted Illuminance

A luminance meter can emulate blue-weighted spectral radiance if appropriate blue filtering is used and correction factors determined with a spectroradiometer (Okuno 1988). However, use of blue filters on illuminance meters has not been reported in the literature. We sought to measure BLHF-irradiance using a professional lux meter and with mobile phones.

A blue filter (HOYA company, glass type: B440, 50×50mm) was used.

2. What is the performance of light meter apps relative to a professional lux meter?

Mobile light meter apps and the reference lux meter

Mobile device apps and a lux meter were used to measure lux in six different lighting conditions to compare illuminance values. Firstly, vertical illuminances of mobile apps and lux tester were measured at the workstation using two downlight LEDs with different colour temperature (cool-white and warm-white). Reference illuminance values from the lux meter were 148 lx under a cool-white LED and 125 lx under a warm-white LED. (see Figure 3a)

The range of the illuminance values of mobile apps was from 91 lx to 296 lx and the comparative results varied significantly, whether under cool- or warm-white LEDs.

Interestingly, iPhone and iPad installed iOS operating system have two light sensors in front and rear camera respectively and can detect illuminance with both sensors. However, a front light sensor produced significantly lower values than a rear sensor in a same mobile device.

To compare the difference between mobile light meter apps and the lux meter, the relative errors are reported. On average, the illuminance values under a cool-white LED were higher than under warm-white LED. Galaxy S5 and iPad pro rear camera showed the biggest disparity in the both light sources. (Figure 3a)

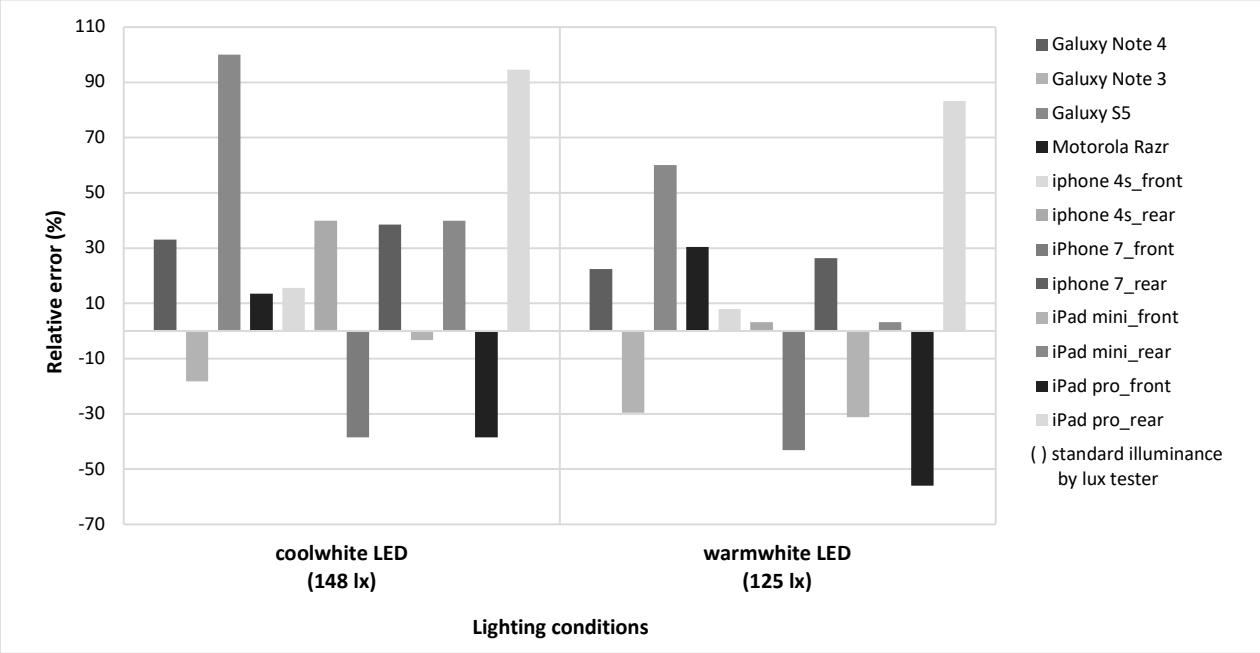

Figure 3a. Relative deviations from standard lux measurements for overhead sources

Two luminaires each with two linear fluorescent tubes, both with prismatic diffusers were fitted to the office ceiling, and were used to collect additional experimental data for assessing the illuminance values from multiple angles (see Figure 1a). The closer ceiling-mounted prismatic diffuser was located at around 2.2m distance and an angle of 35° away from the fixed measuring spot and the further one was located at around 4.5m distance and an angle of 55° away from the spot. The additional lighting conditions were; cool-white LED and four fluorescent lamps, warm-white LED and four fluorescents, four fluorescents only, and cool- and warm-white LEDs and four fluorescents.

The reference values from a lux meter were 276, 260, 147 and 417 lx and the range of the illuminance values of mobile apps were 180 to 371 lx, 148 to 371 lx, 60 to 143 lx and 310 to 585 lx respectively from the left of the lighting conditions. iPhones' and iPads' front sensor showed lower, but variable illuminance values than the rear sensors. The illuminance values based on colour temperature in the multiple angle from the mixed lighting conditions did not show a large difference and the values from the lux meter also showed 276 lx in cool-white LED and four fluorescents and 260 lx in warm-white LED and four fluorescents.

Unlike the results under vertical down-lighting LEDs, illuminance values from multiple angles were more variable for all mobile devices. One of the notable points is that under the non-vertical lighting condition using only the fluorescent lamps, all mobile apps showed significantly lower illuminance levels than the lux meter used (discussed later, regarding cosine correction). The range of values was from 71 to 143 lx and the relative errors of all mobile apps were high at the other errors in the non-vertical lighting conditions (Figure 3b).

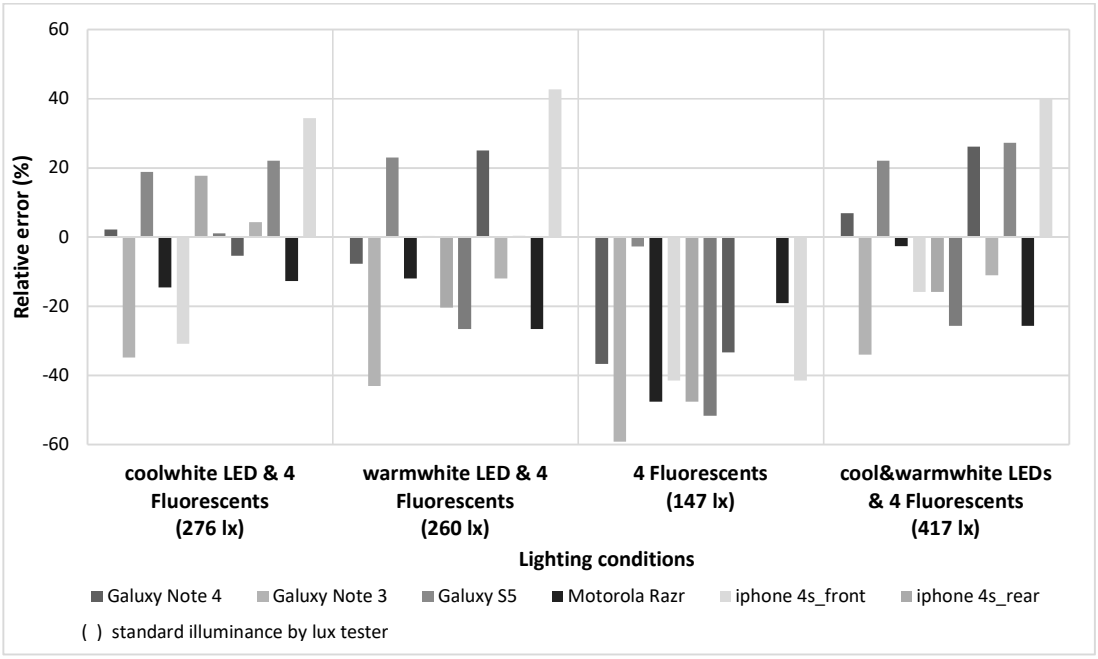

Figure 3b. Relative deviations from standard lux measurements for mixed sources

Comparison between the standard lux meter and mobile apps with a constant illuminance

Comparison of illuminance levels of each mobile app under the same reference illuminance, 320 lx (12W cool-white LED) downlight was set up. Each app showed different outcomes to the reference, 320 lx, and even iPhones' and iPads' front and rear cameras in the same smartphones showed significantly different outcomes. (Figure 4)

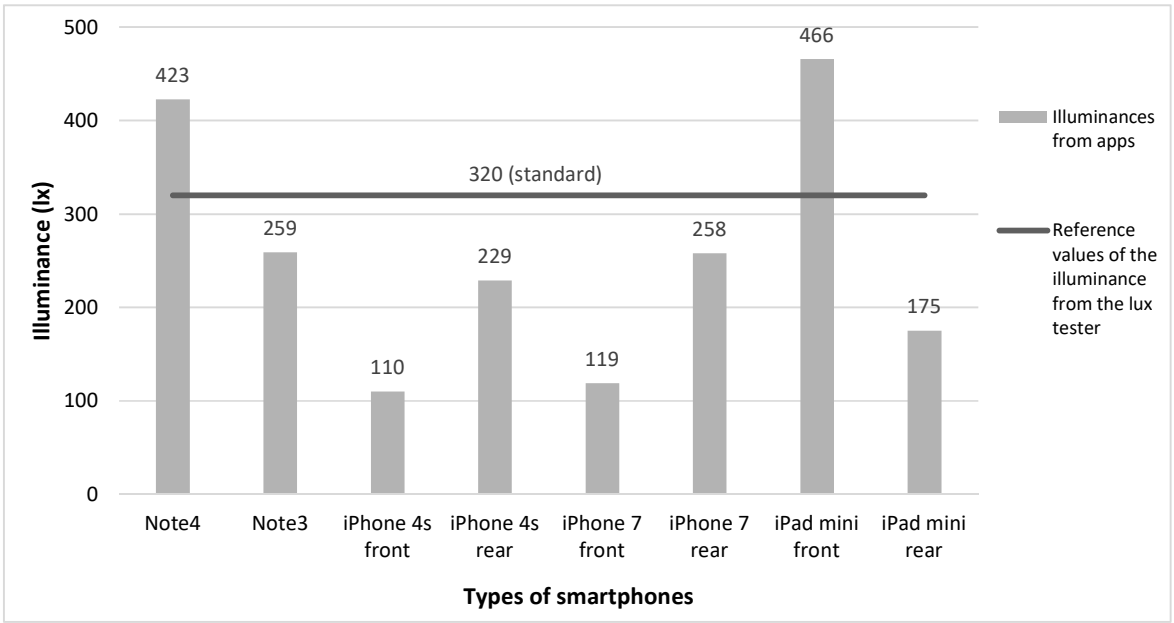

Figure 4. Comparison of smartphone illuminances at 320 lx

Other light sources

Two LED globes (Philips/14W cool- and 12W warm-white), a CFL twist blub (OSRAM/18W daylight/model No. 865) and two halogen globes (Mirabella/40W/pearl dimmable and OSRAM/28W natural light/clear) were used to measure and compare illuminance values in various lighting conditions.

Each mobile app showed different values in different light sources and the relative errors were different even in the same mobile depending on the light sources. (Figure 5) According to lighting power or colour temperature, most apps usually showed higher or lower values than the lux tester. The iPad 4s rear sensor showed a significantly larger deviation than others with a 28W Halogen globe.

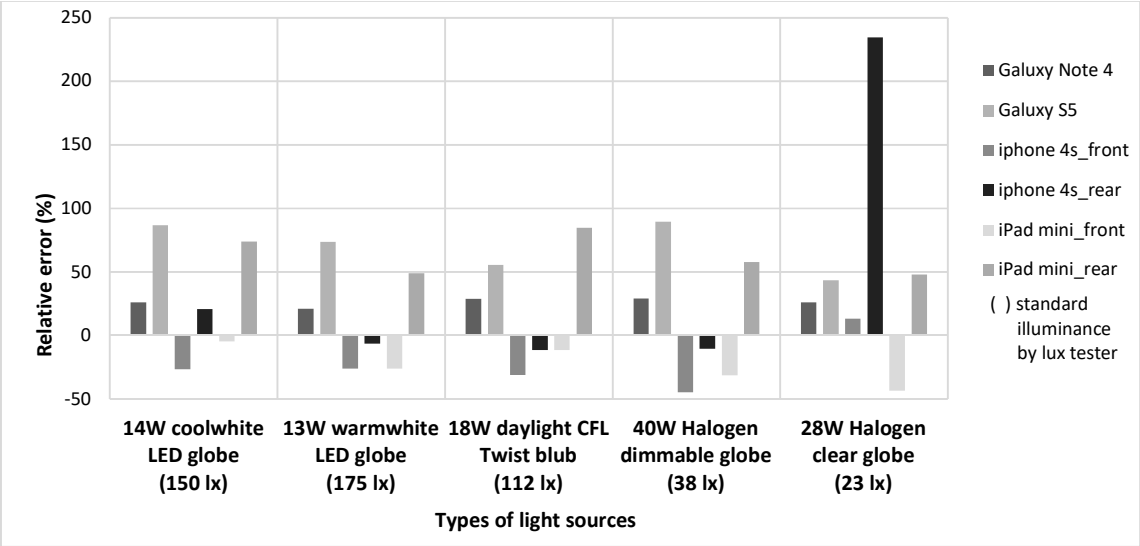

Figure 5. Other light sources mounted at 1.9m ceiling height

3. Are there types of mobile phone apps that are more reliable than others?

With all illuminance values, Table 3 is the ranking of the mobile devices in a list to identify which mobile phones are more reliable than others when compared with the lux meter. Galaxy Note 3 showed the lowest range of the deviation and iPhone 4s rear camera sensor showed the highest range of the deviation compared the reference illuminance values. As mentioned before, iPhones and iPads showed completely different illuminances between front and rear camera sensors and furthermore, there was inconsistency in iOS devices while Android phones showed more consistent illuminance values than the values from Galaxy Note 4, S5 and Motorola Razr which were always lower than the lux meter. However, Cerqueira et al. (2018) reported that same version mobiles (iPhone 5) with iOS system showed varying illuminance values under the same conditions and Goldschmidt and Pittner (2016) stated similar variation in results.

Table 3. The ranking of mobile devices compared with the lux meter (Under vertical illuminance)

Rank	Type of mobile devices	The range of deviation (%)	The range of absolute difference	Average of deviation (%)
1	Galaxy Note 3	-18 to -29	9	-9
2	Galaxy Note 4	21 to 33	11	18
2	iPad pro rear	83 to 94	11	29
4	Motorola Razr	13 to 30	17	7
5	iPad pro front	-56 to -38	18	-15
6	iPhone 7 front	-62 to -38	24	-20
7	iPhone 7 rear	-19 to 38	57	6
8	Galaxy S5	43 to 100	67	46
9	iPhone 4s front	-65 to 15	80	-13
10	iPad mini front	-43 to 45	88	-9
11	iPad mini rear	-45 to 84	129	28
12	iPhone 4s rear	-28 to 234	262	20

4. What is different between blue light-weighted and –unweighted illuminance for the various light sources?

The illuminance values from all mobile apps and the lux meter with a blue filter were low, typically 0 to 5 lx. The iPhone 4s rear and iPad mini front camera sensors showed the range of BLHF illuminance between 13 to 60 lx compared to the range of the illuminance values between 110 to 682 lx under vertical lighting directions. The BLHF illuminances from mobile apps and the lux meter with a blue filter were almost 100 times lower than the values without the filter. (Table 4)

Table 4. BLHF illuminance with a blue filter

	Light sources			
	12W LED daylight	14W LED Cool-white	13W LED Warm-white	42W Halogen Pearl
Rated Colour temperature (K)	5700	6500	3000	
Rated Lumens	9500	1400	1400	600
Measurement Distance (cm)	120	115	100	50

Table 4. BLHF illuminance with a blue filter (continued)

	Light sources							
	12W LED daylight		**14W LED Cool-white**		**13W LED Warm-white**		**42W Halogen Pearl**	
	Illuminance (lx)		Illuminance (lx)		Illuminance (lx)		Illuminance (lx)	
	without Blue filter	with Blue filter	without Blue filter	with Blue filter	without Blue filter	with Blue filter	without Blue filter	with Blue filter
Lux tester (Standard)	320	4	320	4	320	3	320	2
Samsung Note 3	259	5	216	4	397	3	203	4
Samsung Note 4	423	7	410	4	213	3	380	3
iPhone 7_front	119	1	119	1	-	-	-	-
iPhone 7_rear	258	4	320	4	-	-	-	-
iPhone 4s_front	110	0	143	0	-	-	-	-
iPhone 4s_rear	229	20	682	60	-	-	-	-
iPad mini_front	466	13	143	-	129	-	-	-
iPad mini_rear	175	13	261	-	261	-	-	-

DISCUSSION

Professional illuminance meters are cosine and colour corrected and can measure a wide range of illuminance from the angular incidence of light (Hovila et al. 2005). However, light sensors in mobile devices can only sense the direct light radiation upon the vertical surface of a mobile screen. Most studies have only measured the vertical illuminance of these sensors and compared their outcomes with typical lux meters. In our tests examining the illuminance values at various angles, mobile apps showed larger deviations from the lux meters under ceiling-mounted fluorescent linear lamps than under direct vertical illuminances, and the intensities of the illuminance including four ceiling mounted fluorescent lamps were lower than the levels under the only vertical illuminances. (Figures 3a & 3b)

According to Cerqueira et al.'s (2018) study, the higher the levels of the reference illuminance, the larger the deviations in values of the illuminance from mobile apps measured in a vertical direction. However, depending on types of light sources (e.g. brightness, colour temperature, etc.), the deviations varied in our study. (Figure 5)

From the results in Table 3, it appears that there might be reliable mobile apps or mobile devices which can be used to measure illuminance in the vertical direction. Galaxy Note 3 showed the lowest range of the relative error compared with the lux meter in the vertical illuminance. (Table 3) In situations where vertical illuminance is the significant source of lighting, certain mobile apps can provide useful measurements but when the lighting is from different angles, their reliability is poor.

Using Okuno's (1988) method for measuring blue light radiation with a colour filtered luminance meter, we attempted to determine whether the BLHF illuminance meaningful. Although the outcomes using the filter were significantly lower than the actual illuminance values (Table 4), we consider that there is some potential for determining the blue light hazard from the exposure to very bright blue light sources.

There are several portable dome-shaped diffusers (Lux for All or Lumu) that have been developed as attachments for mobile phones for measuring illuminance (Goldschmidt & Pittner, 2016). They were developed with the purpose of using a smartphone camera to take a high-quality picture as a DSLR camera. These tiny portable tools provide illuminance values and look similar to typical lux meters and thus may be used in the workplace instead of the larger professional lux meter or instead of general mobile light meter apps (Guinness 2015). However, in this study, we only focused on the use of mobile light meter apps and did not assess these other attachment devices.

The existing studies stated that different light meter apps in the same mobile phone can show significant variations, (Cerqueira et al. 2018; Goldschmidt & Pittner 2016). The results of this research support these outcomes.

CONCLUSIONS

The illuminance values determined by mobile phones/ apps and a professional lux meter under vertical illuminance and non-vertical illuminance situations were significantly different. The deviations can be explained in terms of hardware sensors that can be variable even for the same brand/model, and a lack of cosine and colour correction.

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OFFICE LIGHTING SURVEYS FOR THE 21ST CENTURY – REFOCUSSING ON THE EYE AND HEALTH.

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ABSTRACT

Current guidance on office lighting tends to be oriented towards illumination engineering, i.e. achieving a certain lighting environment. The selection of lamps and luminaires from a vast array of current lighting options often reflects architectural style and efficiency, rather than "healthy lighting". This paper explores the criteria for healthy lighting based on visual anatomy and physiology and characteristics of workers and tasks in office environments.

A primary consideration is characterisation of light sources in the occupational visual field, which is determined by the visual task. Another consideration is how, and for how long, the source(s) are imaged on the retina (especially the macula). Again, this depends on the visual requirements of the task. Indeed, directionality is much more important for lighting than other hazards such as noise. Such assessments are not possible with an integrating light measuring instrument such as a lux meter. Finally, in the cases of blue-rich sources, the assessment should be about radiometry rather than photometry.

The concept of healthy lighting is described and the types of instrumentation that might be needed to assess risk are outlined.

INTRODUCTION

There is a range of guidance material on the assessment of workplace lighting (Smith, 1991; AS/NZS 1680.1, 2006). Lighting surveys are typically used to determine the quality or risk associated with lighting in the working environment. The surveys can be quantitative and involve direct observations and measurement - looking at tasks, durations of shifts, working conditions and layout, types/numbers of light sources, etc. using AS/NZS 1680 criteria such as maintenance illuminance and luminance contrast. A complementary approach is more subjective, gathering data from interviews and questionnaires about lighting quality from workers themselves (Chung & Burnett 2000).

Most health and safety professionals would apply both approaches, aiming to understand and achieve "good quality" lighting as described in AS/NZS 1680.1 (2006). Here, there are three main considerations, namely safety, task performance and an "appropriate" visual environment. However, quoting from Veitch and Newsham (1995) 'Lighting quality may be the most-talked-about but least-understood concept in lighting research and lighting design'. What is currently missing is the notion of "healthy" lighting, and minimisation of health risks arising from certain forms of lighting. These health risks are diverse and arise primarily from light entering the eye, rather than skin. This paper explores the criteria for healthy lighting based on visual anatomy and physiology and characteristics of workers and tasks in office environments. It is limited to visible radiation i.e. light (380-780 nm), and has an emphasis on incoherent light sources arising from luminaires, computer display screens, windows and skylights.

Potential health impacts of exposure to light

The range of health impacts has recently been reviewed in the context of light emitting diodes (LEDs) (SCHEER 2017). These may be broadly classified as photothermal, photochemical, and disruption to circadian rhythm (for night workers). Psychological aspects of lighting (colour, intensity) are briefly mentioned in AS/NZ 1680 under

"comfort". Colours invoke a range of psychological and physiological response that may, in principle, induce or exacerbate adverse health effects (Kaiser 1984, Ab Jalil 2012). Photothermal effects (heating of ocular tissue by several degrees) would only arise with extremely intense sources which would not be present in offices. Photochemical damage to photoreceptor cells (the "blue light hazard" could potentially arise from certain LEDs and metal halide lamps, although the research to date has been limited, e.g. examining cell response, lamp emissions etc (ACGIH 2016, NakanishI-Ueda et al 2013, Necz et al 2014). Disruption to circadian rhythm is a complex area and it is thought that changes may be associated with poor sleep, cancer risks, metabolic health effects and cognitive function (James et al 2017, SCHEER 2017)). A secondary, but common effect in office-like environments, is asthenopia (fatigue, pain in or around the eyes, blurred vision, headache, and occasional double vision).

The flipside of exposure is susceptibility and in office environments, this includes older workers susceptible to age related macular degeneration and those workers with individual eye problems (e.g. evaporative dry eye (DE), aqueous-deficient DE, and gland dysfunctions), or wearing corrective lenses, certain cosmetics and diet (Wolkoff 2017).

Few of these potential health impacts are addressed or mentioned in the lighting standards. Indeed, the recommendations of AS/NZ 1680 "series presume that the occupants of the interior have normal or near normal vision" (with or without corrective lenses). Furthermore "it is more economical and efficient to ensure that the occupants have normal or near normal vision rather than to over-design the lighting system". One could infer from these statements that current guidance on office lighting tends to be oriented towards illumination engineering, i.e. achieving a certain lighting environment. The selection of lamps and luminaires from a vast array of current lighting options often reflects architectural style and efficiency, rather than "healthy lighting".

Are we measuring the important factor – light going into the eye?

Typical measurement of lighting conditions in the workplace is akin to determining what is available to go into the eye (including what is emitted from the lighting system and reflected), rather than what enters the eye. Illumination of the working plane or task may be poorly correlated with light projected on to the retina (Piccoli et al 2004, 2015) and therefore does not provide a direct metric for of any of the health effects, especially macular degeneration. For that purpose, we need to frame the measurements in the occupational visual field (OVF) (Piccoli et al 2004) rather than the visual field outlined in AS/NZ 1680, which refers to line of sight, task surroundings and "immediate" task surroundings. The OVF is determined by the visual tasks but also takes into consideration anatomy and physiology.

Another consideration is how, and for how long, the source(s) are imaged on the retina (especially the macula). Again, this depends on the visual requirements of the task. Indeed, directionality is much more important for lighting than other hazards such as noise. Such assessments are not possible with an integrating light measuring instrument such as a lux meter.
In the cases of blue-rich sources, the assessment should be about radiometry rather than photometry. (Table 1)

Table 1: Radiometric versus photometric units (from thorlabs.com)

QUANTITY	RADIOMETRIC	PHOTOMETRIC
Power	W	Lumen (lm) = cd·sr
Power Per Unit Area	W/m^2	Lux (lx) = $cd·sr/m^2$ = lm/m^2
Power Per Unit Solid Angle	W/sr	Candela (cd)
Power Per Unit Area Per Unit Solid Angle	$W/m^2·sr$	cd/m^2 = $lm/m^2·sr$ = nit

Overall, the most relevant measures are radiance ($W/m^2.sr$) and luminance (cd/m^2) rather than irradiance (w/m^2) and illuminance (lux). Nilsson (2009) explains it as follows: "The problem with illuminance is that it is an average measure of flux density. It does not distinguish a small strong light source from a large weak one. Such discrimination requires a directionally sensitive measurement, which is why luminance is preferred over illuminance for vision work".

Unfortunately, there is no simple relationship between radiometric and photometric units, even for monochromatic light.

What would healthy lighting look like and how would we assess it?

Designing a workplace to suit the worker and minimise health risks could be considered an aspect of ergophthalmology (Piccoli et al 2003). This can be differentiated from the principles of most lighting standards. Healthy lighting would be adjustable to take account of workforce susceptibility, with optimal task performance. With respect to circadian rhythm, night work would involve less blue in fixed lighting and display screens. Some manufacturers of smartphone and computer displays offer night light and night mode. F.lux (https://justgetflux.com/) is cross platform software that adjusts a display's colour temperature according to location and time of day. LED technology for fixed lighting, and desk lamps may accommodate variable output and colour temperature.

With respect to the blue light photochemical risk, key considerations are lamp selection and shielding, so as to avoid, for example, metal halide lamps in the OVF. An audit of light sources should reveal whether metal halide lamps are in the workplace.

The objective assessment of both colour temperature and the blue light hazard involves the use of a spectrometer or a spectroradiometer. Unfortunately, these are expensive and the use of a more commonly available luminance meter as a blue light radiometer has been described (Okuno 1988).

With regard to asthenopia risk assessment, both luminance and illuminance meters would be required, but with an emphasis on luminance ratios (Piccoli et al 2004). The use of smartphones and apps has been explored but these are not considered adequate mainly due to lack of colour and cosine correction (Cerqueira et al 2018). That said, understanding and recording complex lighting environment may be more easily recorded with mobile phone apps such as Google Street View.

CONCLUSIONS

The usual practices of lighting surveys do not address the variety of health risks associated with light entering into the eye. A more holistic approach is needed that goes beyond requirements of lighting standards and illumination engineering. Guidelines should be developed around the notions of healthy lighting and susceptible subpopulations of workers.

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IS THERE A SYNERGISTIC EFFECT OF EXPOSURE TO WELDING FUME AND NOISE ON NIHL?

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ABSTRACT

Literature indicates that ototoxic chemicals may have a synergistic effect in the presence of noise exposure on hearing. Accordingly, workers are more prone to hearing loss if exposed to both noise and ototoxic substances simultaneously. Animal studies have demonstrated that welding fume in conjunction with noise potentiates hearing loss. To investigate whether welding fume in conjunction with noise may have a similar effect on the hearing of welders, personal monitoring of noise as well as for welding fume and its constituents, was conducted during a range of welding tasks undertaken at a mechanical engineering company to determine the:

- Typical noise levels,
- Typical welding fume levels, including analysis of the metal constituents which are considered ototoxic;
- Potential synergistic effect of exposure to welding fume and noise on NIHL; and
- Necessary controls to protect workers from NIHL

Results to date for both welding fume and noise, both personal and static monitoring, have indicated that there were results that exceed the adjusted occupational exposure standards or their respective action levels. This indicated that further controls were needed to be implemented to reduce the exposures to as low as reasonably practicable.
Keywords: welding fume, metals, ototoxicity, noise, noise induced hearing loss (NIHL), synergistic.

INTRODUCTION

Research has indicated that ototoxic chemicals have a synergistic effect in the presence of noise exposure on hearing (Kovacic & Somanathan, 2008; European Agency for Safety and Health at Work (EU-OSHA), 2009; Australian Institute of Occupational Hygienists (AIOH), 2012; Nies, 2012; Cannizzaro et al., 2014; Safe Work Australia, 2015; Department of Mines, Industry Regulation and Safety, 2017). This means that workers are more prone to hearing loss if exposed to both noise and ototoxic substances simultaneously. Mirzaee, et al. (2007) exposed rabbits to noise or fumes alone or simultaneously and concluded that "welding fumes can potentate noise-induced hearing loss by further reducing the noise-related decrease in [outer hair cells] OHC function".

As a consequence various regulatory bodies are now recommending that noise exposure limits should be reduced for workers exposed to both noise and ototoxic agents as a precautionary measure.

BACKGROUND

The aim of this pilot project was to determine the levels of both welding fume and noise in a workplace and determine if there are any impacts on temporary hearing loss that may if not controlled progress to permanent hearing loss.

To meet this aim the project has the following research questions:

1. What does the literature indicate about the potential exposure to the ototoxins in welding fume in conjunction with noise exposure?
2. What are typical noise levels in an engineering workshop undertaking repairs to mining equipment?
3. What are typical welding fume exposure levels in an engineering workshop undertaking welding?
4. What impact does exposure to welding fume in conjunction to high noise levels have on workers hearing?

The driver for this research was based on animal studies which have demonstrated that welding fume in conjunction with noise potentiates hearing loss. To investigate whether welding fume in conjunction with noise

may have a similar effect on the hearing of welders, personal monitoring of noise as well as for welding fume and its constituents, was conducted during a range of welding tasks undertaken at a mechanical engineering company to determine the:

- Typical noise levels,
- Typical welding fume levels, including analysis of the metal constituents which are considered ototoxic;
- Potential synergistic effect of exposure to welding fume and noise on NIHL; and
- Necessary controls to protect workers from NIHL.

This study was conducted in a mechanical engineering workshop, where the organisation wanted to understand their Noise and Welding Fume exposure profiles in order to improve their controls where necessary. The mechanical engineering workshop refurbishes equipment for the mining and oil and gas industries which involves welding and fabrication processes which inevitably generate noise and welding fume. This workplace could be described as a "jobbing shop" where the tasks may vary from day to day, along with the amount of welding carried out. Noise is considered a significant hazard in mechanical engineering workshops and occurs in association with welding and other refurbishing and fabrication processes, all of which are known to generate high levels of noise. Dust and fume may be generated during welding, cutting, grinding and burning processes carried out at these workshops (Platcow and Lyndon, 2011).

The main type of welding carried out was Flux-cored Arc Welding (FCAW) which uses continuous wire feeds and utilizes an open arc self-shielded flux process. FCAW is applied for Hard facing which is the application of wear-resistant weld metals to a part's surface by means of welding to increase its wear resistance, and to restore worn-down surfaces (Pradeep, Ramesh, and Durga Prasad, 2010). Arc air gouging was conducted which causes molten metal to be ejected from the work-piece using an air jet. High currents (up to 2000A) and high air pressures (80 to 100 psi) are used which can be very noisy (Welding Institute, 2016). Typical noise exposures from Arc air gouging are reported to be between 100 – 115 dB(A) (Health and Safety Executive, n.d.). A substantial amount of carbon steel grinding was conducted in the preparation and finishing of the refurbishment process which is known to generate dust and fume.

POTENTIAL HEALTH IMPACTS

Noise

The main hazard attributed to high levels of noise exposure is detrimental effects on hearing (Groothoff, 2013). This can range from temporary to permanent hearing loss, or tinnitus. The hearing loss can occur from prolonged exposure to high noise levels such as between 85 and 90 dBA, or brief exposures to levels above 90 dBA, or sudden loud noises concentrated in the ear area.

Welding Fume

The health effects of welding contaminants are many and varied because the fumes can contain many different harmful substances. Health impacts associated with welding contaminants include short term and long-term effects, predominantly respiratory disorders (Australian Government, 2015). More recently the International Agency for Research on Cancer (IARC) has classified welding fumes as a Group 1 carcinogen (Guha et al., 2017). However, it is the ototoxicity (Mirzaee, et al., 2007; Salano, 2009) that is subject to this study.

Established Controls in the Engineering Workshop
Extraction ventilation was active both in the main workshop and robotic welding room.

Personal protective equipment (PPE) in the form of eye protection and hearing protection (Class 5) was worn by all operators in the workshop. 3M™ Speedglas™ Welding Helmets with an Adflo powered air respirator systems

were worn by those conducting welding; whilst the operator conducting gouging in the noise proof booth wore an air fed respirator, and ear plugs (Howard Leight, Max-1 Foam Class 5/SLC_{80}-26dB) as well as ear muffs (Honeywell, Howard Leight, Model Leightning L1N, SLC_{80}-30dB).

LITERATURE REVIEW

It is now well recognised that certain pharmaceutical products are ototoxic and can induced hearing loss (Schacht and Hawkins, 2006; Johnson and Morata, 2010; Bisht and Bis, 2011). However, ototoxicity in the occupational setting is a relatively new phenomenon that most people are unaware of (Sheikh, Williams and Collony, 2016).

Although an ototoxic agent is required to reach the cochlea via the bloodstream for its toxic effect on the cochlea's hair cells and auditory neurons (Roth and Salvi, 2016) the outcome - hearing impairment – is the same as excessive noise. Ototoxins are able to injure the inner ear by various mechanisms, with different ototoxins targeting specific cells, individual components of cells, or intracellular pathways (Cannizzaro et al., 2014; Roth and Salvi, 2016). The pathophysiological effects of both noise and ototoxic substances are considered to be sensorineural, as damage occurs due to impacts on cochlea sensory cells and nerve fibres (Morata, 2007; Themann, Suter and Stephenson, 2013). Cannizzaro et al. (2014) has identified that production of Reactive Oxygen Species (ROS) and reduced blood flow are important mechanisms shared by ototoxic substances and noise, and that in combination, the likely result is increased hearing loss.

Noise is present in most occupational settings and has been considered the cause of hearing impairment without consideration being given to other exposures (Campo, Morata, and Hong, 2013). Nies (2012) emphasises the fact that occupational exposure levels are based on the "critical effect" which is the most sensitive health effect caused by a toxic substance. Ototoxicity is seldom the "critical effect" and seems to be a phenomenon of higher exposure concentrations and therefore perhaps underestimated.

However, welding fume has been shown to potentate noise-induced hearing loss in animal experiments by Mirzaee et al. (2007), and in workers by Salano (2009), who noted that workers exposed to noise in conjunction with welding fume demonstrated an increased hearing loss in comparison with those exposed to noise only of the same intensity. Welding fume and noise are frequently encountered hazards in engineering workshops which are generated by welders during tasks associated with welding such as grinding and gouging (Welding Institute of Australia, 2013). It is the simultaneous exposure in environments such as mechanical engineering workshops that may present the greatest risk to hearing (Mifsud and Boyev, 2016).

Mounting epidemiological evidence is now indicating that an increased risk of NIHL may be attributed to exposure to solvents, metals and other chemical substances that interact with noise (Vyskocil et al., 2010). For example, Roth and Salvi (2016), found that divalent metals, such as cobalt, manganese, mercury, lead, and cadmium that may be present in welding fume are potentially ototoxic. Whilst Cannizzaro (2014) indicated that the ototoxins in welding fume include the metals arsenic, cadmium, cobalt, lead, mercury and manganese, and the gas carbon monoxide.

Welding fumes are a complex mixture of metal oxides and particulates, the composition of which varies depending on the type of welding process and materials being welded (e.g. steel, aluminium, titanium, nickel). The constituents of welding fume may include antimony, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, titanium, vanadium, zinc, silica and alkaline metal oxides, that may be generated in conjunction with several other hazardous atmospheric contaminants including carbon monoxide and phosgene (Li, Zhang, Lu, Wu and Zheng, 2004; Antonini, Santamaria, Jenkins, Albini and Lucchini, 2006). Of the metalloids, which are often formed for example, metal chlorides; lead, manganese, cadmium, mercury and cobalt these are suspected to be potentially ototoxicity (Nikolov, 1974; Sokas, Simmens, Sophar, Welch, and Liziewski, 1997; Ellingsen, 2006; Choi, Hu, Mukherjee, Miller and Park, 2012; Hoshino, Ferreira, Malm, Carvallo and Câmara, 2012;

Li, Ding, Salvi and Roth, 2015). In conclusion certain components of welding fume have been determined or suspected to be ototoxins.

Sheikh, Williams and Collony, (2016) recommend that noise exposure limits should be reduced for workers exposed to both noise and ototoxic agents as a precautionary measure. The AIOH (2012) advises, when occupational exposure to ototoxic chemicals exceeds 50% of the 8-hour TWA, that workers be included in a hearing conversation program including regular audiometric testing, regardless of whether respiratory protection is worn. In addition it is recommended that when potential exists for exposure to ototoxic chemicals in conjunction with noise exposure that the $L_{Aeq,8h}$ of 85 dB(A) for noise be reduced to 80 dB(A) or below, and the $L_{C,peak}$ of 140 dB(C) be reduced to 135(C) (AIOH, 2012). Exposure standards for chemicals and noise have not yet been altered to take account of increased risk to hearing. Until revised standards are established, Safe Work Australia (2015) recommended that the daily noise exposure of workers exposed to any of the substances listed in their Code of Practice Table A.1, which includes metals often detected in welding fume, be reduced to 80 dBA or below.

METHODOLOGY

Noise Monitoring

Noise was measured according to AS/NZS 1269.1:2005 "Occupational noise management - measurement and assessment of noise immission and exposure". Immission at the various locations throughout the workshop was conducted.

The personal noise monitoring was undertaken using Brüel and Kjær Model 4488 Dosimeters, calibrated with a B&K Type 4231, worn by each of the participants as specified in AS/NZS1269.1. General workplace noise levels were measured using a Brüel and Kjær Sound Level Meter Model 2250, using a ½ inch Brüel and Kjær Microphone Type 4189, and calibrated using a B&K Type 4231 calibrator. All sound level equipment comply with AS IEC 61672.1. All sound level equipment was independently calibrated as required by AS/NZS1269.1.

Personal dust, and noise, monitoring was undertaken on workers who were carrying out a range of activities, including Welding, Grinding, Gouging, Hard Facing; and Fabrication.

Area noise monitoring within the Main Workshop and the Robotic Welding Room was conducted on three separate dates (May, 2016, November 2016 and May 2017). On each occasion monitoring was conducted at locations along the central walkway of the Main Workshop at approximately 8 meter intervals at a height equivalent to a worker's ear.

The noise exposure standard in Australia, for an 8-hour work day is $L_{eq,\ 8hr}$ of 85 dBA and a peak level of 140 dBC. (Safe Work Australia, 2015) For the extended 9-hour shift, worked at the site monitored, the noise exposure standard remains the same as there is no adjustment needed for work shifts less than 10 hours.

Welding fume monitoring

At a preliminary survey, in May 2016, static (positional) monitoring was conducted to profile the potential welding fume exposures and the metal constituents of the fume. At the two subsequent surveys personal monitoring was conducted. The welding fume was measured in accordance with AS/NZS 3853. 1-2006 "Health and safety in welding and allied processes - Sampling of airborne particles and gases in the operators breathing zone - sampling of airborne particles". Sampling of airborne welding fume in the breathing zone of the operators was conducted.

AS/NZS 3853. 1-2006 requires inhalable dust samples be collected using IOM sampling heads loaded with PVC filters and attached to Airmet SKC AirChek 52 Pumps. Each inhalable dust (IOM) sampling head was located within the worker's breathing zone, connected to a sampling pump unit by flexible tubing worn on the belt of each operative. The SKC AirChek 52 pumps were calibrated at 2 L/min, using DryCal Defender 510. The filters were pre

and post weighed at ECU using a Mettler Microbalance Model Toledo XP6, then sent to the Safe Work NSW Testsafe Chemical Laboratory for metal content analysis, using Method XRF WCA 182. The Testsafe Method WCA 182 analyses for 16 metals which include: Arsenic, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Molybdenum, Nickel, Selenium, Tin, Titanium, Vanadium, Tungsten, Zinc.

Occupational Exposure Standards for Welding Fume
The occupational exposure standards for inhalable dust and welding fume were sourced from AIOH (2014) and Safe Work Australia, Hazardous Substances Information System (HCIS) (Safe Work Australia, 2016) respectively.

As the employees worked longer than 8-hour day, the exposure standard needs to be adjusted to ensure an equivalent level of protection. One of the most conservative formulas, the Brief and Scala Model (AIOH, 2010), was used to calculate a reduction factor to adjust exposure standards for a 9-hour work day schedule at this workshop.

Action levels are commonly used to trigger action prior to exposure standards being reached. Action levels are commonly set at 50% of the exposure standards. For example, the AIOH recommended exposure standard for inhalable dust for an eight-hour day is 5 mg/m^3. The adjusted workplace exposure standard for a 9-hour day is therefore 4.15 mg/m^3 with an action level of 2.07 mg/m^3.

A colour coding system, indicated below, is used to classify the results of both the welding fume and noise for ease of interpretation.

Real time dust monitoring
To determine the particle sizes of the airborne dust in the workshop in May 2017 TSI DRX DustTrak (Model 8533) was used in a number of areas of the workshops.

RESULTS
A noise level measure at the ear level of an operator undertaking gouging was measured to be 112 dB(A).

Table 1 – Results of Inhalable Dust and Personal Noise Exposures in May 2017

Job Type	Average Noise Exposure $L_{eq, A}$ dB(A)	Peak Noise Exposure dB(C)	Inhalable Dust Exposure mg/m^3
Exposure Standard	85	140	4.15
Welding and grinding carbon steel	90.3	136.6	5.28
Welding carbon steel	94.6	134.5	1.75
Gouging (all day)	112.2	143.5	6.40
Hard facing and grinding	94.9	143.5	13.38
Fabrication & welding	91.3	137.2	
Welding and grinding	91.9	137.4	0.01
Welding and hard facing	91.8	132.1	6.76
Exceeds the modified exposure standard			
Exceeds recommendation action limit			

Noise Monitoring

Area noise monitoring in the main workshop on 3 days showed the general levels varied from 73 to 108 dB(A), with the highest levels being measured closest to gouging operations, as follows:

- May 2016 - 78 – 108 dB(A)
- November 2016 - 73 – 88 dB(A)
- May 2017 - 76 – 88 dBA

Inside robotic welding room, the general levels varied from 85 to 93 dB(A), as follows:

- May 2016 - 85-87 dB(A)
- November 2016 - 91-93 dB(A)
- May 2017 - 85 dBA

The results of the personal noise monitoring, May 2017 are shown in Table 1.

Welding Fume Monitoring

In May 2016, five tasks were monitored for welding fume which included inhalable dust along with the concentration of 16 constituent Metals. The results shown in Table 2 highlight that manganese is an issue in hard facing operations and chromium in welding operations on that day.

Table 2 – Area (Positional) Monitoring - Preliminary Dust Survey in May 2016

Hard Facing	**Welding**
Inhalable dust = 8.6 mg/m^3	Inhalable dust = 8.3 mg/m^3
Manganese = 0.7 mg/m^3	Chromium = 0.4 mg/m^3

In November 2016, five operators were monitored for inhalable dust along with the concentration of 16 constituent Metals. The results shown in Table 3 highlight that chromium and iron and vanadium are an issue in hard facing, and only inhalable dust in general in flex core wire welding operations on that day.

Table 3: Results of the Personal Air Monitoring on November 2016 Above the Action Limit

Hard Facing & Grinding Operator 1	**Hard Facing & Grinding Operator 2**	**Flex Core Wire Welding**
Inhalable dust = 21.4 mg/m^3	Inhalable dust = 6.4 mg/m^3	Inhalable dust = 2.3 mg/m^3
Iron = 3.3 mg/m^3	Iron = 2.3 mg/m^3	
Chromium = 1.10 mg/m^3	Chromium = 0.23 mg/m3	
Vanadium = 0.02 g/m^3		

N.B Chromium VI below the exposure standard

In May 2016, six operators were monitored for welding fume including inhalable dust and 16 metals. The results shown in Table 4 highlight that chromium and iron are an issue in hard facing and grinding, and inhalable dust and chromium in welding and hard facing operations on that day.

Table 4: Results of the Personal Air Monitoring on May 2016 Above the Action Limit

Welding & Grinding carbon steel	**Gouging**	**Hard Facing & Grinding**	**Welding & Hard Facing**

Inhalable dust = 5.2 mg/m^3	Inhalable dust = 6.4 mg/m^3	Inhalable dust = 13.4 mg/m^3	Inhalable dust = 6.8 mg/m^3
		Iron = 4.8 mg/m^3	
		Chromium = 1.22 mg/m^3	Chromium = 0.54 mg/m^3

Established Controls in the Engineering Workshop

Extraction ventilation is installed both in the main workshop and robotic welding room, with additional extraction ventilation being installed after the November 2016 monitoring.

Personal protective equipment (PPE) used in the workshops include eye protection and hearing protection (Class 5) which was worn by all operators in the workshop. 3M™ Speedglas™ Welding Helmets with an Adflo powered air respirator systems were worn by those conducting welding; whilst the operator conducting gouging in the noise proof booth wore an air fed respirator, and ear plugs (Howard Leight, Max-1 Foam Class 5/SLC_{80}-26dB) as well as ear muffs (Honeywell, Howard Leight, Model Leightning L1N, SLC_{80}-30dB).

DISCUSSION

Noise Exposure

All the personal noise results (Table 1) were above the current noise exposure standard of $L_{eq,\ 8hr}$ of 85 dB(A). Whereas not all the area noise levels exceeded 85 dB(A). This is because the personal noise results give a better reflection of the actual exposure. It should be noted that all workers currently use Class 5 hearing protection such as Howard Leight, Max-1 Foam ear plugs. Operators wear both Class 5 Ear Plugs and Class 5 Ear muffs when undertaking the Gouging Operation, which is good considering the noise levels measured for an operator who worked a full shift and received a noise of an L_{eq} of 112 dB(A).

Welding Fume Monitoring

The results of both static (area) and personal monitoring indicate that for a range of tasks including, welding, grinding, gouging and hard facing, the inhalable dust concentrations on occasions can exceed the recommended adjusted occupational exposure standard. The chromium concentrations associated with these elevated dust levels particularly during Hard Facing have been shown to exceed or approach the occupational exposure standard; fortunately, the chromium VI species was not prevalent. In addition, the manganese, vanadium and iron, although they did not exceed the occupational exposure standard, they were above the action level. Figure 1

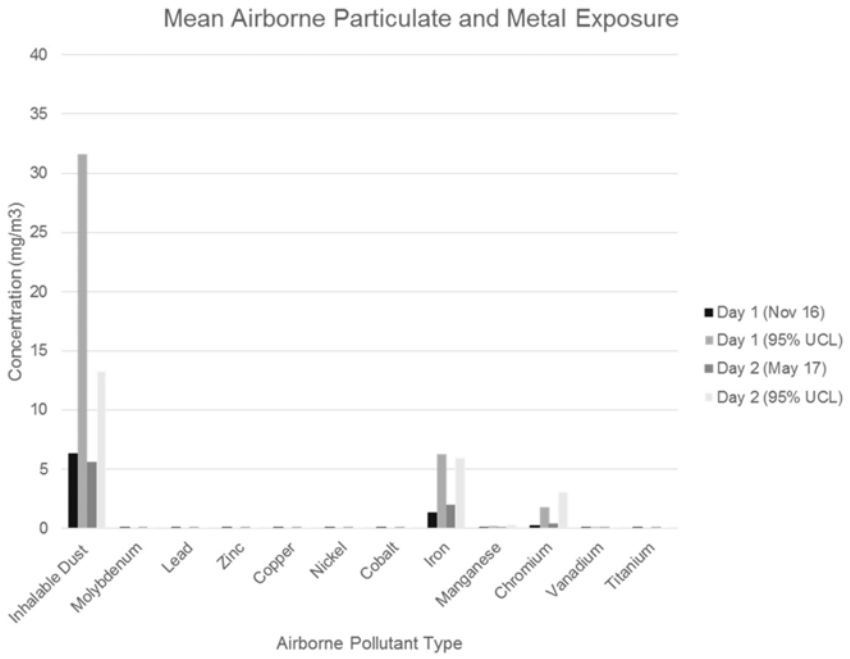


Figure 1: Welding Fume levels prior to and post installation of new extraction ventilation (N.B. Significantly more welding Activity on Day 2 – May 2017 with a larger 95% UCL, spread of the data)

To protect against inhalation exposures to welding fume at the concentrations measured all the operators in the engineering workshop must wear appropriate respiratory protective equipment and use the additional ventilation system that has been introduced, as a consequence of the initial monitoring results.

Potential for Ototoxicity

Chromium is considered to be ototoxic by Kim, et al. (2008). Manganese is considered ototoxic by Nikolov (1974) however, more recently Muthaiah, Chen, Ding, Salvi, and Roth (2016) conclude from their animal experiments that that manganese "in the presence or absence of noise had, at best, only a minor effect on hearing. Vanadium has been determined to have "mild neurological effects" but no evidence of an ototoxic effect (Agency for Toxic Substances and Disease Registry, 2012). It is important to note that noise in this instance is the predominant exposure and any ototoxic effect of any of the welding fume metal constituents may be masked.

Static monitoring following installation of additional ventilation

Static ambient work area monitoring, using an Aerosol Monitor (AM510), was conducted before and after installation of additional extraction ventilation, to determine if the ambient levels were reduced on the installation of the additional ventilation. However, the welding conditions varied significantly between the two days (Figure 2). During the initial monitoring (Day 1, November 2016) there were no tasks being conducted in close proximity i.e. within 5 metres of the monitor, and therefore constituted monitoring of the ambient workshop air. For the "after" (Day 2, May 2017) installation of the extraction ventilation, monitoring was conducted during the welding tasks, less than 2metres, which generated significant welding fumes. Despite the generation of more fume close to the monitor on the repeat sampling the results of the Static Ambient work area monitoring were very similar, indicating the efficiency of the extraction ventilation.

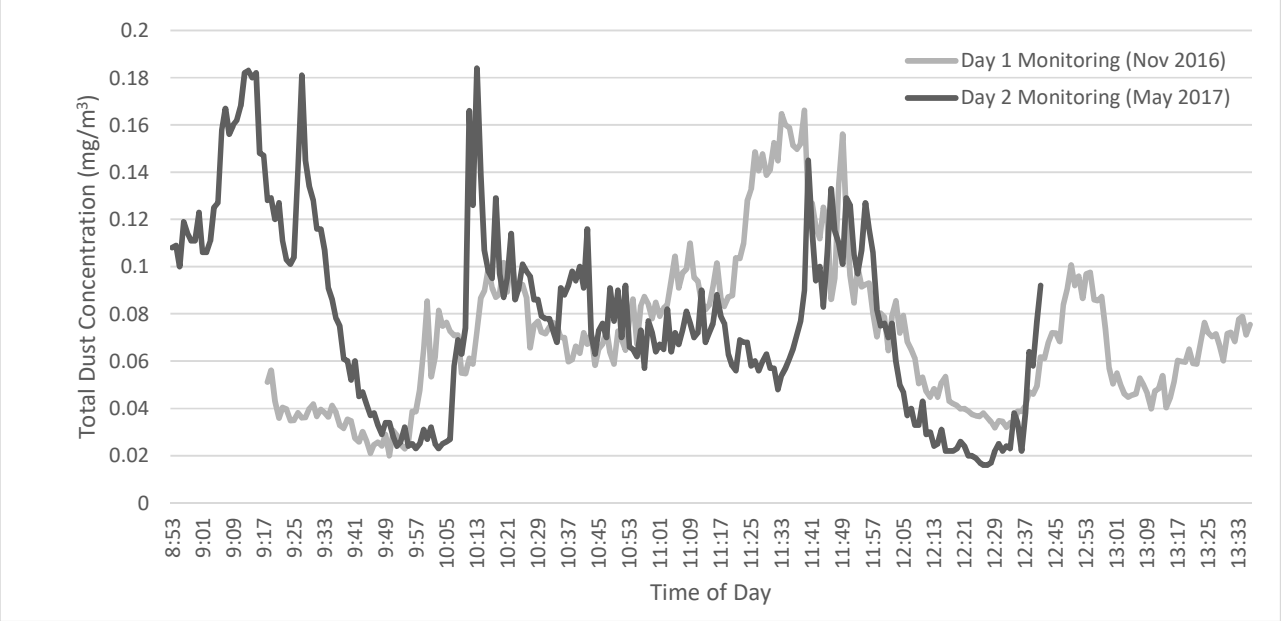
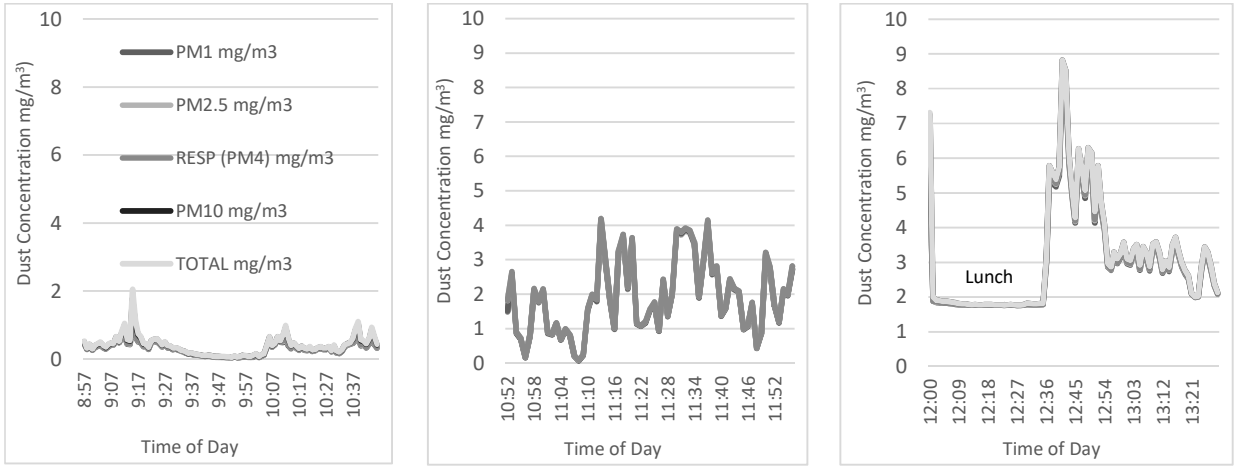


Figure 2: Total Particulate Levels Before and After Extraction System Installation

In May 2017 a TSI DRX DustTrak was used to determine what the particle sizes (Figure 3) are in the welding fumes in the workshop. The results of the monitoring show that the majority of the particles were less than 1µm which was expected, as they were generated as part of a fume.



General Welding in Main Workshop | Robotic Welding Room | Gouging in Booth

Figure 3: Particle sizes During Three Operations on the Workshop

CONCLUSION

The noise levels measured are typical of a large welding operation in an engineering workshop; and there were some exceedances for inhalable dust predominantly as welding fume, and the metal constituent chromium. In addition, vanadium and manganese concentrations were detected above their respective action levels. Appropriate PPE has always been worn to protect against these exposures, but additional local extraction ventilation (LEV) was introduce in response to this monitoring, which proved to be efficient.

It is important to note that noise is the predominant exposure and any ototoxic effect of any of the welding fume metal constituents may be masked.

In response to this monitoring strategy a hearing conversation program including regular audiometric testing has been introduced by the company as advised by the AIOH, when occupational exposure to ototoxic chemicals exceeds 50% of the 8-hour TWA.

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WELDING FUME EXPOSURE IN RAIL SETTINGS – RISK OBSERVATIONS AND TRIALLED CONTROLS

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ABSTRACT

Welding is a common industrial process—so common that up to two percent of the working population in industrialized countries has been engaged in some sort of welding (Liss 1996). Similarly, Antonini et al (2003) stated that approximately one million workers worldwide actively performed welding activities as part of the work duties. A vast array of methods and sources can be used for welding processes. These may include the use of gas flames, electric arcs, electric resistance, lasers, electron beams, friction, molten metal baths and ultrasound to name a few. As a result of these varied energy sources, welding can give rise to other hazards, therefore, precautions are required to avoid electrocution, fire and explosion, burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation (SWA 2012).

According to the Health and Safety Executive (2010), the fume given off by welding and allied processes is a varying mixture of airborne gases and very fine particles which if inhaled can cause ill health. Welding fumes have been classified as a possible human carcinogen (Group 2B) by the International Agency for Research on Cancer (IARC). Although this classification relates to stainless steel welding due to the fume compounds generated by the electrodes, i.e. Fe, Mn, Cr and Ni, this classification is not limited to stainless steel welding alone, rather, it encompasses all forms of welding.

The scope of this research presentation will be to focus on one type of welding process aluminothermic welding and its use in the rail industry. Aluminothermic welding has been is use for over 100 years and remains the most effective technique for site welding of hard steel rail sections. Despite the continued use of this form of welding process, it would also appear that control methods used to reduce personal worker exposure to welding fume have not changed in the past 100 years either. Therefore, the aim of this presentation is as follows:

Provide insight into the types of contaminants workers are being exposed too,

- The risks associated with those contaminants of concern,
- Insight into the observed cultural workplaces practices inhibiting change,
- The effectiveness of trialled controls,
- Provide insight into international advancements in protecting worker health in these settings, and
- Identifying areas of overall improvement in managing worker exposure whilst undertaking rail welding works.

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ASSURING ASBESTOS-FREE IN OVERSEAS-CONSTRUCTED INSTALLATIONS - BEST PRACTICE FROM PRELUDE FLNG.

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ABSTRACT

A glance at recent headlines in the Australian press shows that asbestos in new installations and materials is an ongoing problem for Australian industry. Worldwide, over 2 million tons of asbestos are produced every year and incorporated into common building materials while asbestos materials are still legal in many countries. In response, the Australian Border Force has implemented enhanced requirements for asbestos management in imported materials that can result in materials being held at the border for extended periods, potentially resulting in significant delays and cost impacts. To prevent this, a novel approach was developed to provide assurance that asbestos was not present in Shell's Prelude Floating Liquefied Natural Gas (FLNG) facility before it was imported into Australian waters. The approach involved categorization of materials according to material type and country of origin which resulted in several tiers of increasing asbestos risk. This classification was used to determine bulk sampling requirements; analysis was conducted by a NATA-accredited laboratory in Australia. The assurance program was monitored by an independently occupational hygienist who conducted his own surveys and sampling. In all, several hundred samples were taken and no asbestos was detected which led to the Australian Border Force allowing Prelude's import with no delays or restrictions. This approach can be used as a template for managing asbestos content risk in future for large installations or plants constructed overseas.

INTRODUCTION

Worldwide, over 2 million tons of asbestos are produced every year and incorporated into common building materials (USGS 2015). Although asbestos has been banned in 61 countries, the installation and use of asbestos materials is still legal in a large number of countries including the United States, China, Russia, Brazil and India (IBAS 2017). The interpretation of what is asbestos free also varies between countries; what is considered asbestos free in one country may not meet the criteria for this definition in another country. The addition of asbestos containing material may also be inadvertent in countries where the use of asbestos is legal. This can take place where non-asbestos containing materials are manufactured on the same manufacturing equipment as asbestos containing and adequate decontamination does not take place between batches of asbestos and non-asbestos containing materials (ABF 2016).

A glance at recent headlines in the Australian press shows that asbestos in new installations and imported materials is a serious problem for Australian industry.[1] In response, in 2016 the Australian Border Force implemented enhanced requirements for asbestos management in imported materials (ABF 2016).

Shell's Prelude floating liquefied natural gas (FLNG) facility was constructed in South Korea, although modules and components were sourced from several countries, including ones that have not banned the use of asbestos. Prelude was towed into Australian waters in July 2017 and was required to comply with all Australian Border Force (customs) requirements relating to imported materials. To avoid any potentially costly delays, it was therefore necessary to be able to provide assurance in advance to the Australian Border Force that Prelude FLNG does not

[1] See for example the following media reports - http://www.abc.net.au/news/2016-09-13/perth-hospital-asbestos-report-sparks-call-for-ban-on-imports/7840632 or http://www.abc.net.au/news/2016-06-09/asbestos-illegally-imported-from-china-provokes-anger/7498190 or http://www.themercury.com.au/news/national/asbestos-found-in-imported-childrens-crayons-marked-with-dora-the-explorer-and-peppa-pig/news-story/c3b112f047e9893b31721fc4dc1fb907 or http://www.dailymail.co.uk/news/article-4618458/Kids-quad-bikes-contain-asbestos-national-recall.html

contain asbestos. In addition, obtaining this assurance was considered important to satisfy other stakeholders, including the workplace regulator and NOPSEMA. This paper describes how this assurance program was designed and implemented, and offers suggestions for businesses planning future asbestos assurance programs for imported materials and installations.

Review of initial controls

Shell Health is the division of Shell responsible for supporting Shell assets and projects in identifying and managing health risks. From (2009 Shell Health provided support and assurance to the Prelude FLNG project, initially via the Shell Health Risk Assessment Process (HRA). The HRA process is a standardised method for identification, assessment and control of health hazards. A Design HRA was completed for Prelude in 2009. Subsequent to this initial HRA, a construction HRA was completed for Prelude in 2012, shortly after the cutting of the first Steel for the Project. This construction HRA identified the potential risk of the introduction of asbestos containing materials and assigned a remedial action plan (RAP) to the project of putting in place a quality assurance process to ensure the facility was asbestos free. The additional asbestos control barrier in the RAP was deemed necessary as the asbestos controls already in place for this project were not considered by Shell Health to be adequate to control this potential asbestos risk.

The controls already in place in the project before the construction HRA were as follows:

- The contract with the Engineering Production Construction and Installation (EPCI) contractor included a requirement that the installation be asbestos free. However, the contractor was not obliged to provide assurance that Prelude did not contain asbestos, apart from the provision of an “asbestos-free” certificate, which as discussed earlier has dubious value.
- Some materials and equipment for Prelude were being sourced from and/or constructed in countries that did not have bans on asbestos
- No material sampling and analysis for asbestos was being undertaken or was planned by the project or by the EPCI contractor

Shell Health concluded that it was unlikely that the controls in place in 2012 would provide sufficient assurance that Prelude was “asbestos-free”. It was recommended that an assurance program that included physical asbestos sampling and analysis should commence immediately.

Development of the Prelude Asbestos Assurance Program

The Asbestos assurance program was developed jointly by a number of internal Shell stakeholders. The overarching principals of the program were as follows:

- As the fit out of Prelude had already commenced, the program needed to provide assurance that materials, products, modules, equipment packages already installed on Prelude did not contain asbestos and also that materials yet to be installed on Prelude did not contain asbestos.
- Materials and equipment would have different asbestos risk profiles depending on material type and origin. Therefore, understanding the source location of materials and equipment and whether materials contained components known to potentially contain asbestos was critical.
- It was not possible or practical to sample and analyse all materials, components and equipment. Therefore, sampling would need to be determined using a risk based sampling program (discussed further below).
- Sampling would be conducted by personnel from the EPCI contractor
- Ad hoc sampling would also take place when project personnel identified items in the field suspected to contain asbestos

- Analysis would need to be conducted by a National Association of Testing Authorities (NATA) accredited laboratory due to uncertainties in asbestos content level of reporting in laboratories located in South Korea
- Linked to the previous point, this meant an import permit needed to be obtained from the Federal Minister of Employment to import potential asbestos into Australia for analysis, as well as the ok from the state regulator where the analysis would take place (in this case WorkSafe Victoria).
- Analysis would also be undertaken for refractory ceramic fibre (RCF) to comply with Shell requirements for the management of RCF
- Written assurance from all material manufacturers also needed to be obtained that materials were "asbestos free", so that assurance did not rely purely on sampling by the project
- The Assurance Program would need to be reviewed and audited by an independent third party (a Certified Occupational Hygienist) who would be able to access the facility and stores and conduct their own sampling and analysis, at regular intervals during the construction.
- A proactive approach of engaging with the Australian Border Force well before the completion of the program would be undertaken to ensure that the assurance program met their expectations and there were no "surprises" at the time of import

The estimation of asbestos content risk was based on location of source material and material type. See Tables One and Two for definitions of material and source country risk categories and Table 3 for sampling expectations for each combination. Wherever possible, all efforts were made to comply with the sampling expectations as per Table One although sometimes access to materials was simply not possible due to construction progress at the time the assurance project commenced.

Table 1 – Source country risk definitions

Source Country Risk	Description
Very low risk	Countries that have banned the import, export and use of asbestos, where the ban is robust and longer than five years.
Low risk	Countries that have banned the import, export and use of asbestos, where the ban is less than five years and / or limited information is available its effectiveness.
Intermediate risk	Countries that: • have a ban on asbestos that may not be effective; or • have not banned the import, export and use of asbestos; or • are still using chrysotile in commercial quantities.
High risk	Countries that have asbestos mining, exporting, importing, or manufacturing industries.
Uncertain provenance	When the provenance of materials or equipment cannot be verified

Table 2 – Material type risk definitions

Material Type Risk	Description
Very low risk	Homogeneous material with minimal potential to contain asbestos. Typical examples include: unpainted steel and other metals, glass, ceramics, common plastics.
Low risk	Certified, type approved product from a reputable international brand with certified composition.

Intermediate risk	Materials / products / applications that have typically contained asbestos or ACM on marine vessels (Lloyds Register Marine 2014)

Table 3 – Guide on sampling requirements

		Material Type Risk		
		Very low	**Low**	**Intermediate**
Source Country Risk	**Very low risk**	No sampling required	No sampling required	None
	Low risk	No sampling required	No sampling required	Some sampling required
	Intermediate risk	No sampling required	No sampling required	Extensive sampling required
	High risk	No sampling required	Some sampling required	Extensive sampling required
	Uncertain provenance	No sampling required	Some sampling required	Extensive sampling required

RESULTS and DISCUSSION

The assurance program ran for approximately 18 months from 2015 to 2016. The independent Certified Occupational Hygienist conducted 4 visits to the shipyard where Prelude was constructed. A total of 284 samples were collected using the framework described in Tables 1 - 3 and shipped to an Australian NATA accredited laboratory for analysis. A further 120 samples were collected by the Independent Certified Occupational Hygienist who conducted his own NATA-accredited analysis for asbestos. None of the samples contained asbestos, although 6 items containing RCF were identified. The independent certified occupational hygienist concluded that no confirmed asbestos materials were identified during sampling and surveillance inspections. In July 2017 Prelude was successfully imported into Australia with no delays from the Australian Border Force.

This approach represents a potential option for other companies engaged in the import of large installations or equipment that are constructed overseas. The advantages of the approach were the use of a risk based sampling approach, which focuses sampling on areas of highest risk, the use of an independent certified occupational hygienist to provide independent oversight and the analysis in Australia at a NATA accredited laboratory. The disadvantages were the need to obtain a permit to import samples into Australia, the cost of sampling, shipping and analysis, and the fact that the program was only able to be initiated after construction had commenced. In future, requirements for risk based sampling could be incorporated into EPCI contracts with the onus of proof resting with the contractor. This approach could also be considered for contracts with suppliers who source materials from overseas (e.g. supplier for construction projects) so that the principle contractor can have confidence that supply and outrage risks are being adequately mitigated.

CONCLUSIONS

The Prelude Asbestos Assurance Program was successful in its overarching aim to avoid asbestos-related holdups and issues associated with the import of Prelude FLNG into Australia. The approach focused on risk based sampling as the key demonstrator that the facility was asbestos free, along with the use of an independent Certified Occupational Hygienist to oversight the program. Given the increasing scrutiny by the Australian Border Force on asbestos in imported materials and installations, this represents one option for importers to consider adopting to demonstrate compliance and ensure imported materials and asbestos are asbestos free. Although not a cost-free

approach, it may be considered to be a worthwhile investment when the alternatives could be costly delays at the border or serious damage to a company's reputation.

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FIBRE MONITORING AT A PILBARA BASED IRON ORE MINE SITE.

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ABSTRACT

This paper describes an exposure scenario which occurred at a Pilbara based iron ore mine site between 2016 and 2017. A targeted sampling program was undertaken in late 2016 involving airborne fibre monitoring following a preliminary risk assessment and leader requests. Thirty-five personal fibre samples were collected between August 2016 and January 2017 across three Similar Exposure Groups (SEG's). A review of results showed low levels of airborne fibre therefore a risk based sample program was developed, communicated and implemented in 2017. A consultant hygienist with specific expertise in fibre exposure risk assessment was engaged to deliver fibre awareness training to key personnel onsite to assist with managing risk perception of exposure to low concentrations of airborne fibres.

INTRODUCTION

Naturally occurring fibrous minerals occurring in at Pilbara based mine sites is managed in accordance with Department of Mines and Petroleum (DMP) guideline (DMP, 2015a). Pilbara based iron ore mine sites have potential to encounter fibrous minerals throughout exploration drilling, survey work, blast-hole drilling, waste removal and mining operations (load and haul). The geology is well understood in the Pilbara region and at this particular iron ore mining operation. The site selected for this project has a documented management plan (namely the "site Fibrous Minerals Management Plan") which details classification of pit locations based on the potential for fibrous mineral occurrence. The management plan requires any person that enters these classified areas must have a range of appropriate controls in place, from engineering to the use of respiratory protection.

A monitoring program for airborne fibres was implemented between August 2016 and January 2017 at a Pilbara based mine site following a preliminary risk assessment, worker and leader requests as they commence operating in a location with the potential for fibrous mineral occurrence ('designated area'). There was an expectation for personal and area monitoring to occur daily which would aim to assess the risk of naturally occurring asbestos exposure to workers in the designated areas. This expectation for increased monitoring was not aligned to the site Fibrous Minerals Management Plan objectives. The similar exposure groups included in the monitoring were Heavy Mobile Equipment (HME) operators (SEG 1), Drillers in a closed cabin (SEG 2) and Blast crew personnel (SEG 3). See section 4 for information on SEG determination. Results were recorded in a database and expressed as a percent of the adjusted Occupational Exposure Limit (OEL) as per internal product group reporting requirements.

In March 2017 a review of the recent personal fibre data for SEG 1 (n= 14, UCL^{95}= 6.24%), SEG 2 (n= 14, UCL^{95}= 35.22%) and SEG 3 (n= 7, UCL^{95}= 3.74%) was undertaken to better understand the exposure profile and inform suitable controls. The monitoring data confirmed exposures to airborne fibres are currently controlled. A risk based monitoring program for airborne fibres at this site was developed.

The risk based sampling program aligned to the DMP's legislative requirements. In March 2017 the changes to the airborne fibre monitoring program were communicated to leaders and workers. The plan shall be implemented throughout 2017 as part of a routine risk based hygiene management program.

LITERATURE REVIEW

Chemical Structure and Morphology

Asbestos is a silicate mineral fibre found naturally in the environment. Asbestos fibres form fibrous crystal bundles and show high tensile strength, thermal and chemical resistance and low electrical conductivity. As a result of these desired properties the mineral was used extensively in commercial applications like textiles, insulation, ship

building and brake lining mechanics (Levya, 2009). Legislative control of asbestos exposure occurred in 1931 in Great Britain, followed by the USA in 1971 (Lazarus & Philip, 2011).

The two primary classes of asbestos are serpentine and amphibole. Serpentine fibres have a wave-like strand structure. Amphibole fibres are rigid, durable and needle-like. Amphibole fibres can accumulate in the pulmonary compartment and are not cleared effectively (Kamp & Weitzman, 1999) which can impact on human health.

Amphibole fibres such as crocidolite are considered potent carcinogens (Hansell, 2008) and are straighter than chrysotile fibres (AIOH, 2016a). The most commonly used asbestos fibres include chrysotile, amosite and crocidolite (Lazarus & Philip, 2011).

The Australian occupational exposure limit for all asbestos fibres is 0.1f/mL (NOHSC, 1995), however there is no safe threshold level for exposure to carcinogens (Siemiatycki et al., 2004).

Risk of Developing Asbestos-Related Disease

Toxic effects of asbestos exposure are dependent on the dose and the time since initial exposure (Kamp & Weitzman, 1999). There is a latency period of approximately 20 to 30 years before asbestos-related diseases become apparent (Lazarus & Philip, 2011).

The risk of developing asbestos related disease is therefore based on the size and shape of asbestiform fibres present, the inhaled concentration and the duration of exposure (AIOH, 2016a).

Background rates of asbestos-related diseases exist among unexposed Australian population (AIOH, 2016a). The WA Department of Health (DOH), describe background or ambient levels of exposure as containing up to 200 fibres/1000L of air (DOH).

Toxic Effects on the Lung Caused by Asbestos

Asbestos can cause progressive lung diseases such as asbestosis, pleural plaques and malignant tumours like mesothelioma (Kamp & Weitzman, 1999). Despite the asbestos industry in western countries being relatively well regulated, there are still new cases of asbestos-related diseases being diagnosed (Lazarus & Philip, 2011). The most common clinical diagnoses of abnormalities are described below.

Benign asbestos pleural effusion

This pleural abnormality can be found in subjects within the first 20 years following exposure (Greillier & Astoul, 2008). Most cases are asymptomatic which could mean the overall incidence is underestimated. In symptomatic BAPE there may be fever, cough, pain and loss of breath (Greillier & Astoul, 2008).

Pleural plaques

Following heavy asbestos exposure, the prevalence of benign asbestos pleural effusion (BAPE) ranged from 7.2% – 14.3%. In low exposure work groups this ranged from 0% to 4%. This suggests a dose-response relationship (King, Mayes & Dorsey, 2011).

Pleural plaques are characteristic of asbestos exposure. Pleural plaques are identifiable as discrete fibrotic lesions occurring on the parietal pleura. They consist of collagen and may contain asbestos fibres (Greillier & Astoul, 2008). This condition is asymptomatic and there is a weak association between pleural plaques and impairment to lung function.

Pleural plaques are not associated with development of malignancies. Like BAPE, pleural plaques are a marker of asbestos exposure, a significant risk factor of mesothelioma and lung cancer (Greillier & Astoul, 2008).

Progressive pulmonary fibrosis (Asbestosis)

Asbestosis is associated with fibrosis and development of cancer (Gardiner & Harrington, 2005). Alveolar epithelial cells are responsible for the initiation, promotion and progression of fibrosis in the lungs (Lazarus & Philip, 2011). In asbestosis patients, FVC and total lung volume decreases which is characteristic of restrictive lung disease (Lazarus & Philip, 2011).

Malignant pleural Mesothelioma (aggressive tumour)

Mesothelioma is a primary malignancy of the pleura. This is a rapidly growing tumour. The disease is more common in males than females, and aged between 50 to 70 years of age. Subjects present with chest pain and shortness of breath. The pain is initially caused by excessive nociception (Grellier & Astoul, 2008).

Mesothelioma cases have also been recognised for many years in families of asbestos workers. The cause of these cases is linked to workers returning home with fibre contaminated clothing and hair (Hansell, 2008).

Regulation of asbestiform minerals in WA mining

Asbestiform minerals are commonly found in WA and may occur as veins. Iron ore mining operations may experience amphibole minerals as a result of the banded iron formations present in the geology of the region (Department of Mines and Petroleum, 2015a).

In WA mining operations fibrous minerals shall be managed in accordance with the Department of Mines and Petroleum (DMP) guideline for management of fibrous minerals (DMP, 2015a). Managing this hazard includes identification of the presence of fibrous minerals, control of fibres and dust at the source through dust suppression, management of contaminated material including transport and disposal, development of specific procedures, audits and risk based air monitoring to verify controls are working effectively (DMP, 2015a).

Risk based hygiene management program

The DMP had previously enforced a CONTAM quota for this mine site to implement on a quarterly basis. From 2015 the DMP's CONTAM quotas were discontinued and replaced with a risk based hygiene management program (DMP, 2015b) covering the following elements:

- Characterisation of the workplace
- Establish Similar Exposure Groups (SEG's)
- Risk assess exposures
- Determine number of employees to sample
- Develop a results strategy
- Health hazard control
- Re-assessments
- Quota proposal

The program is developed by this mine site and submitted to DMP for endorsement on an annual basis.

Methodology

Similar Exposure Groups (SEG's)

Mining operations roles have been categorised into Similar Exposure Groups (SEGs). The SEGs which formed part of this data review are described in Table 1 and has been based on similarity of tasks, activities and work location. There are a variety of rosters worked at this site with the most common roster being a 2 weeks on, 1 week off

cycle with 12 hour days. This involves 7 days, 7 nights and then 7 off. SEG 1 works an average of 56 hours per week. SEG 2 works an average of 42 hours per week and SEG 3 an average of 48 hours per week.

Table 1: Similar Exposure Groups

SEG No.	Activity	Description of tasks	Average headcount	Average hours per week
SEG 1	Heavy Mobile Equipment (HME) operator	Operating heavy mobile equipment including load and haul, waste removal, pit road maintenance.	250	56
SEG 2	Drill operator (closed cabin)	Blast hole drill operator	20	42
SEG 3	Blast crew	Staff involved in blasting operations (staking, priming, AN facility, clearing shots)	30	48

Fibre sampling methodology

Sampling methodology for airborne fibres was in accordance with National Occupational Health and Safety Commission (NOHSC) Guidance Note (2005). A variation to this guidance note was required due to the DMP's definition of a fibre being any object with an aspect ratio greater than 3:1, a length greater than 5µm and a width less than 1µm (DMP, 2015a, Appendix 7).

Airborne fibre samples were collected using AirChek 52 sampling pumps and membrane filter (25mm diameter, mixed esters of cellulose, 0.8µm pore size, printed grids) set in an asbestos cowl sample head (SKC part number 225-326) and pre-loaded by a NATA accredited laboratory in Perth, WA. The samples were calibrated to a flow rate of approximately 1.5 L/min ± 150mL to ensure sufficient volume and prevent dust overload due to the operating environment.

The analytical method used was the membrane filter method based on NOHSC (2005) and with adjustment for DMP's fibre ratio. Fibre counts were conducted by the same WA based laboratory and analytical reports were provided. The following details were used by the laboratory during fibre counting:

- Effective Filter Area: 368.9845 mm^2
- Graticule Area: 0.007854 mm^2
- Fields: 100

The lab was requested to perform Scanning Electron Microscopy (SEM) for a selection of samples where fibre counts were unusually high. This was to provide additional information when reviewing results to determine nature of fibres (organic or asbestiform).

Occupational Exposure standards

The time-weighted average (TWA) in-air exposure standard or occupational exposure limit (OEL) is the concentration of a substance that most people can be exposed to over a normal 8-hour workday, for a 40-hour work week. For shifts greater than 8 hours or unusual shifts, the OEL should be adjusted in accordance with OEL guidelines and exposures should be kept "as low as reasonably practicable".

Table 2: A list of in-air asbestos OELs as recommended by the ACGIH, Safe Work Australia, UK HSE and US OSHA (for all asbestos types)

ACGIH TLV	Australian WES (Safe Work Australia)	UK HSE WEL	US OSHA PEL
0.1 f/mL	0.1 f/mL	0.1 f/mL	0.1 f/mL

The mine site has accepted the Australian Workplace Exposure Standard (WES) for asbestos (all types) being 0.1 f/mL.

All data was entered into an electronic database used by the mine site to store and manage occupational hygiene monitoring results. The database automatically converts the result to a percentage of the adjusted OEL.

Adjustment of Exposure Standards

It becomes necessary to account for longer working hours to ensure worker health is protected. AIOH reviewed the common methods for adjusting exposure standards (AIOH, 2016b) including Brief and Scala, OSHA, Pharmacokinetic and Quebec models. There are many guidelines across Australian jurisdictions which can lead to inconsistencies in adjusting exposure standards. The AIOH recommends a single model based on the Quebec model. The DMP revised their approach to adjusting exposure standards and in 2016 adopted the Quebec model (DMP, 2016).

This mine site adjusts for extended shifts utilising the Quebec model.

Use of the AIOH WES Adjustment tool (AIOH, 2013) shows Asbestos as a category 3 substance (cumulative toxicant) and therefore a person working 12 hours / day, 56 hours /week would have an adjusted TWA OEL from 0.1 f/mL down to 0.07 f/mL (adjusted OEL). To compare exposures across different roster types we have used a percent of the adjusted OEL.

Existing data August 2016 to January 2017 were entered into the IHSTAT program (American Industrial Hygiene Association, 2013) for analysis. Results were assessed against the published occupational exposure limit (OEL) from Safe Work Australia, as listed in Table 2.

IHSTAT plotted the data in date order to permit assessment of SEG homogeneity. To determine the distribution fit the W-test result was compared to 1 and the closest fit was used.

The 95% upper confidence limit (UCL^{95}) and mean variance unbiased estimate (MVUE) has been used for comparison with the adjusted OEL and to determine non-conforming SEG's, uncertain exposures and conforming exposures.

Risk Based Hygiene Sample Plan

A risk based hygiene sample plan was developed in 2017 after review of existing recent personal exposure monitoring results from the initial program outline above. The sample plan is based on activities completed by SEG 1, SEG 2 and SEG 3. A minimum of 6 personal samples is proposed for fibres in each SEG to allow for statistical analysis through IHSTAT program. The sample plan is provided in Table 3.

When designing this risk based plan consideration was given to the National Institute for Occupational Safety and Health (NIOSH) guideline for determining minimum sample sizes (NIOSH, 1977). The proposed sample size was lower than the guideline values as it became possible to combine previous sample results for SEG 1 and 2 to

complete statistical analysis and the preliminary assessments for each SEG indicated low risk of airborne fibre exposure.

Table 3: Risk based sample plan 2017

SEG No.	Activity	Agent	Minimum sample size
SEG 1	HME operation	Fibres	6
SEG 2	Drill operator (closed cabin)	Fibres	10
SEG 3	Blast crew	Fibres	6

Workforce Presentations

The mine site engaged an independent Occupational Hygiene consultant (Certified Occupational Hygienist) to deliver fibre awareness training. The presentation duration was 20 minutes and included:

- Fibre hazard information
- The risk of developing asbestos related disease from low levels of exposure
- Exposure monitoring program objectives
- Summary of exposure results by SEG
- Risk based sample program
- Management of fibrous minerals and hierarchy of controls
- Department of mines guideline

RESULTS

Statistical analysis through use of the IHSTAT tool showed personal fibre samples for SEG 1 (n = 14) and SEG 2 (n = 14) were the only datasets found to have a lognormal distribution. SEG 3 (n = 7) dataset fit both a lognormal and normal distribution. IHSTAT outputs are summarised in Table 4.

Table 4: Summary of SEG 1, SEG 2 and SEG 3 exposure results (current and historical data combined) from IHSTAT analysis of fibre results

SEG	Number of samples	Mean as a percent of the adjusted OEL	Geometric Standard Deviation (GSD)	Current OEL (TWA, 8 hr)	Reduction factor	Adjusted OEL (TWA, 12 hr)	Distribution fit (Lognormal, Both, Normal, Neither)	UCL^{95} as a percent of the adjusted OEL	MVUE as a percent of the adjusted OEL	Percent of samples above the adjusted OEL (%)
SEG 1 HME Operators	14	2.78	2.59	0.1 f/mL	0.71	0.07 f/mL	Lognormal	6.24	2.94	0
SEG 2 Drill Operators	14	9.92	3.71	0.1 f/mL	0.71	0.07 f/mL	Lognormal	35.22	9.63	0
SEG 3 Blast crew	7	2.48	2.55	0.1 f/mL	0.71	0.07 f/mL	Both (Normal,	3.74	2.59	0

							W-test=0.845)			

SEG 1 and SEG 3 dataset's GSD were below 3 therefore confidence in this data and the conclusions with regard to potential exposures is possible because of the number of samples obtained, a low GSD, a low mean sample concentration (all mean sample results were below 5% off the adjusted OEL).

SEG 2 had a GSD greater than 3 and the highest UCL95 (UCL95 = 35% of the adjusted OEL) of all the datasets.

Figure 1 shows all results graphed as a percent of the adjusted OEL. Across all SEG's, all of the samples collected were below the adjusted OEL of 0.07f/mL.

Figure 2 shows the number of samples collected by roster type worked for all SEG's combined.

Figure 3 shows two data points which appear to be higher than the rest of the data and could be considered potential outliers. Despite these potential outliers, confidence in this data and the conclusions with regard to potential exposures is possible because of the number of samples obtained and a low mean sample concentration (mean is less than 10% of the adjusted OEL).

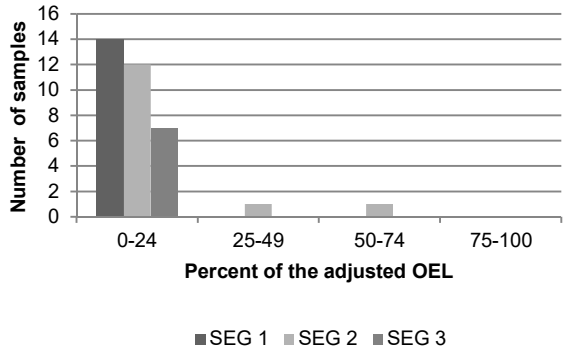

Figure 1: Percentage of samples collected in relation to a percent of the adjusted OEL

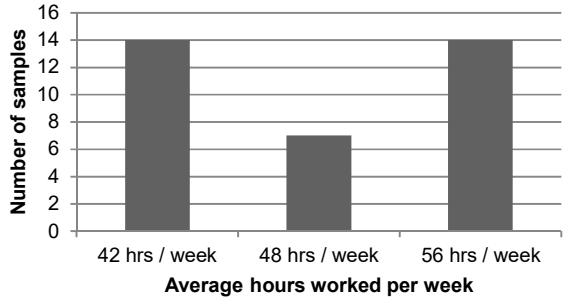

Figure 2: Number of samples based on length of rosters for SEG 1, SEG 2 and SEG 3 combined

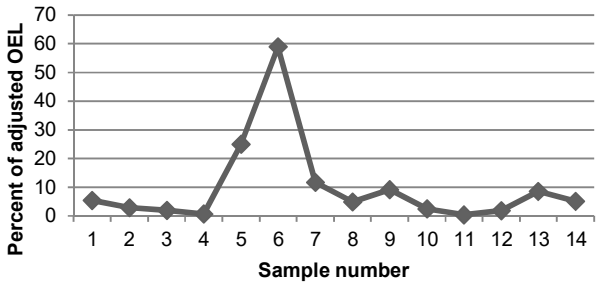

Figure 3: Sequential data plot from IHSTAT analysis of SEG 2

Fibre counts for sample 5 (25 fibres) and sample 6 (91 fibres) appeared as potential outliers (see fibre 3). SEM analysis of these select samples confirmed 4 fibres (sample 5) and 2 fibres (sample 6) were asbestiform mineral (crocidolite). The majority of fibres present were confirmed as inorganic fibres such as clay and iron oxide.

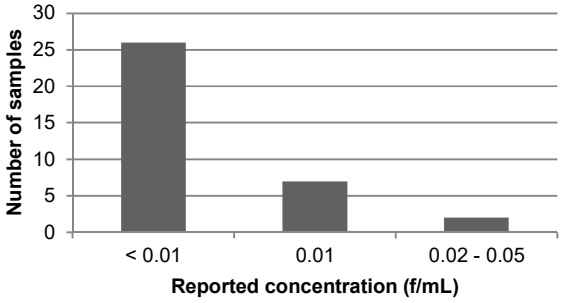

Figure 4: Number of samples by reported concentration for SEG 1, SEG 2 and SEG 3 combined

Ninety-four percent of samples were equal to or less than the analytical method limit of reporting.

DISCUSSION

Sample analysis was conducted using IHSTAT for personal fibre samples obtained between August 2016 and January 2017 for HME Operators, Drill Operators and Blast Crew personnel.

SEG 1 (n = 14) and SEG 3 (n = 7) results were all below 25% of the adjusted OEL indicating exposures are controlled.

SEG 2 dataset had a large GSD (GSD >3). Potential causes of a large GSD for fibres in this instance could be due to environmental dust and the presence of organic and inorganic fibres in the samples and is discussed further below.

SEG 2 also had the highest UCL95 (UCL95 = 35% of the adjusted OEL). When plotted sequentially in date order, the dataset shows two data points which appear to be higher than the rest of the data and could be considered potential outliers. As there was no justification to remove these outliers we continued to analyse the data with sample 5 and sample 6 included. Despite these potential outliers, some conclusions can be drawn from this data that would tend to indicate majority of samples have a low sample concentration (mean is less than 10% of the adjusted OEL) and confirmation of fibre mineralogy through SEM analysis whereby majority of fibres present were inorganic. Further investigation would be recommended to clarify if there is a particular cause for these higher results.

Only 2 samples collected as part of this project returned results that were greater than the analytical method limit of reporting.

Exposure data for fibres collected and reviewed during this project indicates that atmospheric exposure to fibres is currently controlled. This is due to the current conservative work practices employed by the company at this Pilbara based mine site, which involve geological classification of area's with potential to host asbestiform minerals, use of dust suppression, pressurised and filtered HME and drill cabins, vehicle and personal decontamination.

As a result of the current low exposures, a risk based sampling program as described in table 3 was developed and shall be implemented throughout 2017.

To communicate this change an awareness training presentation was developed which included the risk of developing asbestos related disease from low levels of exposure, summary of exposure results by SEG and the changes to a risk based sampling program. Questions raised by attendees of the training centered around adherence to site procedures. All queries were followed up with the Hygiene Superintendent.

There are benefits and potential disadvantages when engaging third party to deliver presentations on risk perception of asbestos. The following benefits were identified as part of this project:

- Subject matter expert experienced in fibre exposure monitoring and analysis
- Independence from the company
- Considered to be credible when presenting to workforce
- Ability to manage potential emotive responses from workforce
- Support for leaders and site Hygiene team with technical queries

Potential disadvantages of engaging a third party to deliver fibre awareness training could be:

- Perception that the company has reduced ownership of the messaging
- Perception that workers are less likely to ask questions if they have not formed a relationship with the presenter

CONCLUSION

Monitoring results for HME operators, Drill Operators and Blast Crew for airborne fibres were analysed using IHSTAT. There was sufficient data to complete analysis using IHSTAT however due to 2 potential outliers in SEG 2 data the risk based sample plan for 2017 will target 10 additional fibre samples and investigation into the contributing factors for these higher results.

Exposure data for fibres collected and reviewed during this project indicates that atmospheric exposure to fibres are currently controlled and therefore a risk based sampling plan is reasonable and continues to align with regulatory guidelines and internal company standards.

RECOMMENDATIONS

The findings from this project has identified a number of recommendations that include:

- continue to implement the risk based fibre sampling program (table 3) throughout 2017;
- analysis of SEG 2 data should continue with the additional samples obtained as part of the risk based sampling program and investigation of contributing factors to sample 5 and sample 6;

- improved documentation with regards to recording relevant tasks, locations and environmental conditions as accurately as possible during occupational exposure sampling for determination of SEG characterisation and analysis of exposures;
- whilst active work is undertaken in designated areas, an annual campaign should be run to ensure workers and leaders have completed fibre awareness training;
- fibre awareness training should be kept up to date with recent data;
- complete a gap analysis of the site procedures for managing fibrous minerals to ensure all stakeholders fully understand their responsibilities;
- review of existing data for other occupations such as field work, geologists and dewatering crews;
- continue to align site procedures with the DMP's guideline for management of fibrous minerals (DMP, 2015a); and
- continue to ensure workers who require the use of a P2 respirator are clean shaven and fit tested for that respirator in accordance with AS/NZS 1715:2009 (Standards Australia, 2009).

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VALIDATING ACM CHECK: AN INNOVATIVE SOLUTION FOR IDENTIFYING ASBESTOS-CONTAINING MATERIAL AROUND THE HOME.

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Curtin University

ABSTRACT

Aim

To validate the accuracy of ACM Check, a mobile phone application designed to identify and assess the condition of asbestos-containing materials (ACMs) located inside and outside of Western Australian (WA) homes.

Methods

A two-stage cross-sectional study; (1) 40 participants completed ACM Check on their pre-1990 constructed home in metropolitan Perth, WA, and (2) an on-site asbestos inspection conducted by an experienced Environmental Consultant. Cohen's kappa coefficient compared the results obtained from ACM Check with those of the Consultant.

Results

The 40 houses sampled were built between 1898 and 1988 with a median year of 1966. Of these, 38 (95%) properties were identified as having one or more 'possible' or 'likely' ACMs present by both ACM Check and the Environmental Consultant. A total of 91 materials were categorised as 'likely' to contain asbestos by ACM Check whilst a total of 93 materials were considered to be 'likely' ACM by the Environmental Consultant. Overall, the two methods showed perfect agreement regarding the identification of any (1 or more) ACM located outside the home, $K = 1.00$, $p < .005$, and moderate agreement for identification of any ACM located inside, $K = .593$, $p < .005$.

Conclusions

ACM Check is a free, easy-to-use and reliable tool that can be used by community members to identify in situ ACMs in Western Australian residential settings. Its method can potentially be modified for implementation in other countries or used as the basis for the assessment of other occupational or environmental–related hazards.

WORKPLACE HYGIENE AND LEAD RISK WORK CONTROLS IN RADIATOR REPAIR AND E-WASTE RECYCLING WORKPLACES IN NSW.

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ABSTRACT

Aim To assess workplace health and safety and worker exposure to lead in radiator repair and E-waste recycling workplaces.

Method Fifty-one lead risk workplaces were visited and assessed for lead contamination and worker exposure. Forty-four radiator repair and seven electronic waste (E-waste) recycling workplaces where lead risk work was conducted were verified against a checklist for regulatory compliance with health and safety. A total of 186 wipe samples were taken to assess surface lead contamination from thirty-two radiator repairers and forty-eight samples were taken from five E-waste recycling workplaces. Biological monitoring records for blood lead levels were assessed for any exceedance with legal exposure limits.

Results and Discussion Ninety three percent of the lead risk workers' Blood Lead Levels (BLL) were below the work health and safety regulatory limits of 10µg/dL (0.48µmol/L) for females of reproductive capacity and below 30µg/dL (1.45µmol/L) for others. A BLL above the legal removal limit of 50µg/dL (2.42µmol/L) was noted in one male worker who had been removed from lead risk work. The results of surface wipe samples from radiator repair workplaces ranged from 0.05µg/cm² to 392µg/cm² and for the E-waste workplaces they ranged from 0.05µg/cm^2 to 3.85µg/cm^2. Fifty per cent of the radiator repair workplaces had non-compliance issues in relation to PPE, hygiene practices and health monitoring records. Around 20% of non-compliance issues were in relation to ventilation, signage and laundering. Similar issues were identified in E-waste recycling workplaces. Specific recommendations given to both industries were to improve the use and storage of appropriate PPE, to enhance ventilation controls and to increase the frequency of health monitoring to prevent excessive exposure. The observed blood tests taken from 2010 to 2017 showed a reduction of the geometric mean by 85% in the blood lead levels among the workers in the radiator repair industry.

Conclusion This workplace assessment raised awareness and knowledge among workers and employers of the health impacts of workplace hygiene and helped them to reduce the exposure levels by implementing lead risk work controls.

INTRODUCTION

Lead is a cumulative poison and it affects almost every organ and system in the body regardless of whether it is inhaled or ingested. The International Agency for Research on Cancer (IARC) has classified inorganic lead compounds as Group 2A a probable human carcinogen (IARC, 2006).

World Health Organization (WHO) has identified lead as one of the top ten chemicals of major public health concern that requires action globally to protect the health of workers, children and women of reproductive age (World Health Organisation, 2016). Lead exposure has been associated with increased risks of several cancers, particularly meningioma, brain cancer and kidney cancer (Liao, et al., 2016). Work related cancer in Great Britain due to occupational exposure to inorganic lead has been linked to brain, lung and stomach cancers (Rushton, et al., 2012). Associations have been found between inorganic lead exposure and liver or esophageal cancer and reported a slightly increased overall mortality in a cohort of workers exposed to lead in Australia (Gwini, et al., 2012).

Occupations where workers are exposed to lead are radiator repair; waste recycling; lead smelting; refineries; foundries; leaded glass works; lead chemical works; paints and pigments manufacturing; metal works and welding; firing ranges; lead mining; newspaper printing; pipe cutting; construction and demolition works; gun and ammunition making and plumbing work and in *industries requiring flame soldering of lead solder* (IARC, 2006).

The Australian work exposures study on lead and lead compounds estimated the prevalence of work-related exposure to lead occurs commonly when performing tasks like soldering, preparing surfaces for painting or machining metalwork (Driscoll, 2014).

The radiator repair industry and the E-waste recyclers were selected to assess the level of exposure occurring in NSW as the workers were considered to be at a high risk of being exposed to excessive amounts of lead fumes and dust.

Lead Risk Work and Work Health and Safety Regulation 2011

The *NSW Work Health and Safety Regulation 2011* defines the work process as a lead risk work that involves the handling of lead that is likely to cause the lead level in a worker's blood to exceed:

- 10 µg/dL (0.48 µmol/L) for a female of reproductive capacity
- 30 µg/dL (1.45 µmol/L) for all other workers.

A review is underway by Safe Work Australia to evaluate the existing occupational exposure limits for blood lead levels. Under the Regulation the employer is required to provide regular health monitoring including biological monitoring to detect early of any elevated blood lead levels or signs of adverse health effects so as to proactively implement timely remedial and preventative actions to minimise further harmful exposures to workers.

METHODS

This study evaluated forty-four radiator repair workshops from March 2012 to April 2013 and seven E-waste recycling workplaces in NSW from May 2014 to April 2017. The workplaces were verified for regulatory compliance and the workers assessed for the level of exposure to lead. The study also investigated the effectiveness of the control measures implemented at the workplaces to reduce the workers' exposure to the lead.

Radiator Repair Work Process

Radiator repair requires the damaged radiators to be repaired by removing both end tanks of the radiator by desoldering the tanks, releasing lead fumes and particles. The radiator tanks are then cleaned by abrasive blasting or some other abrasive cleaning technique. The cleaned tanks are then resoldered to new radiator cores after which they are then leak tested in a water bath under air pressure. The restored radiator is then given a finishing coat of paint and presented for resale.

E-waste Recycling Process

E-waste is the term used to describe discarded computers, office electronic equipment, electronic entertainment devices, mobile phones, television sets, refrigerators and assorted white goods. This study investigated the recycling of precious metals used in the manufacture of Cathode Ray Tubes (CRTs) from old TVs and computer monitors. These CRTs contain large amounts of metallic lead in the form of leaded glass and other heavy metals including cadmium, mercury and tin. The recycling process involves the disassembling of the all the TVs and monitors by manually removing the plastic case, the metal chassis, yoke, IC Boards, electronic gun and metal strap from the unit. All of these parts contain different materials that are removed and sorted into separate bins to undergo their own recycling process. The leaded glass is recycled via a lead smelting process so it can be used to make new CRT monitors or related products. The glass contains approximately 20% lead. The workers involved in dismantling CRTs are therefore at risk of lead exposure. Work activities such as handling, processing, repairing,

maintenance, storage, disposal of lead that exposes workers and any other person to lead is defined in the regulation as lead risk work and is therefore under the jurisdiction of the *NSW Work Health and Safety Regulation 2011.*

Exposure Assessment

An occupational hygiene assessment was undertaken to assess the exposure of the workers to lead from both industries. This included the review of the past biological monitoring test results for blood lead; the determination surface contamination for lead and an extensive review of the workplace safe work processes. This included discussions with workers and supervisors; identification of the workers most likely to be exposed to lead; assessment of the existing control measures, including local exhaust and personal protective equipment; inspection of any administrative controls such as rosters and job rotation, workers training records and equipment maintenance records; assessment of the current contamination containment and management processes. The workers were also interviewed to assess their knowledge of the potential health effects of lead exposure.

Surface Contamination Monitoring

Surface contamination monitoring was undertaken in different locations in the workplaces using water impregnated cellulose paper swabs known as *Ghost Wipes* ™ swabs obtained from SKC Pty Ltd. The sampling locations were selected to identify the contamination of lead dust outside the lead process area as required in the Clause 396 of the legislation. The samples were collected by wiping a 10 x 10 cm area with the *Ghost Wipes* ™ in an overlapping "S" pattern using gloved fingertips. The swab was then folded and the unexposed area was used to wipe the same area in an "S" pattern in the opposite direction. Any curved surfaces that were sampled an estimate of the surface area was made. From the radiator repair workplaces 186 surface wipe samples were taken from 32 worksites. Sampling locations were categorized into one of seven exposure areas based on tasks performed in those areas. They included work benches within the workshop (away from the lead process area) where hand tools and PPE were stored, workers change rooms, lunch room, administration/office areas. From the E-Waste recycling workplaces 51 surface wipe samples were taken from the two largest worksites visited.

Biological Monitoring

An employer under WHS Regulation 2011 (Cl 405-418) have obligations of providing suitable health monitoring when workers undertake lead risk work in the workplace. At the time of visiting the site where available, previous and current health monitoring records were verified for regulatory compliance. Three E-waste recyclers provided blood lead level monitoring records for the period 2012-2014 and as follow-up 2015-17 records were obtained from the same recyclers to determine the workplace impacts of our assessments visits.

Chemical Analysis

The chemical analysis of the *Ghost Wipes* ™ for lead was performed by using the Inductively Coupled Plasma Mass Spectrometry (ICPMS) technique. The *Ghost Wipes* ™ samples initially underwent an acid digestion then diluted and analysed by ICPMS. The blood samples test results were obtained from the employer's health monitoring records having been analysed by the local health provider's pathology laboratory.

Instrumentation

An Agilent ICPMS 7500ce instrument was used for the analysis of the *Ghost Wipes* ™. The instrument was equipped with a Burgener Teflon Mira Mist Nebulizer. The analysis used an ICPMS multi-element standard solution and a Rhodium internal standard CertiPUR grade obtained from Merck Pty Ltd.

Biological Exposure Standards

The *WHS Regulations* 2011 mandates a Biological Exposure Limit (BEL) for determining the work as lead risk work

- 30 µg/dL (1·45 µmol/L) for females not of reproductive capacity and all males
- 10 µg/dL (0·48 µmol/L) for females of reproductive capacity.

The worker must be removed from that job if the level of lead in the blood exceeds

- 50 µg/dL (2·41 µmol/L) for females not of reproductive capacity and all males
- 20 µg/dL (0·97 µmol/L) for females of reproductive capacity or
- 15 µg/dL (0·72 µmol/L) for females who are pregnant or breast feeding,

Surface Contamination Clearance Levels

There is no assigned occupational exposure level for lead dust contamination. AS 4361.2 *Guide to lead paint management Part 2 Residential and commercial buildings* recommends lead clearance levels after lead paint management activities of 0.1 µg/cm^2 for interior floors, 0.5 µg/cm^2 for interior window sills and 0.8 µg/cm^2 for exterior surfaces.

RESULTS

Site visits were conducted as part of a SafeWork NSW *High Risks Verification Program* on the exposure to lead in NSW.

Radiator Repair

Forty-four radiator repair workplaces were randomly selected across NSW for this study. These workplaces had a workforce ranging between 1 - 5 workers who were directly involved in radiator repairs.

The analysis of 186 surface contamination samples for lead was carried out at 32 workplaces with 27 (84%) workplaces showing positive contamination results. The test results ranged from 0.05 µg/cm^2 to 392 µg/cm^2 with a geometric mean (GM) 0.36 µg/cm^2 and a geometric standard deviation (GSD) 12.6. The test results of the surface contamination of all 32 workplaces are illustrated in Fig 1.

In one case, where obviously high level contamination was found in the surface samples taken from a worker's inside parts of the motor vehicle that includes the seat cover, foot rest and steering wheel. This presumably led to workers taking lead residues into their homes on their work clothes, skin, and hair. The analysis of these samples prompted the worker to take extra care to limit the transfer of contamination away from the lead process area.

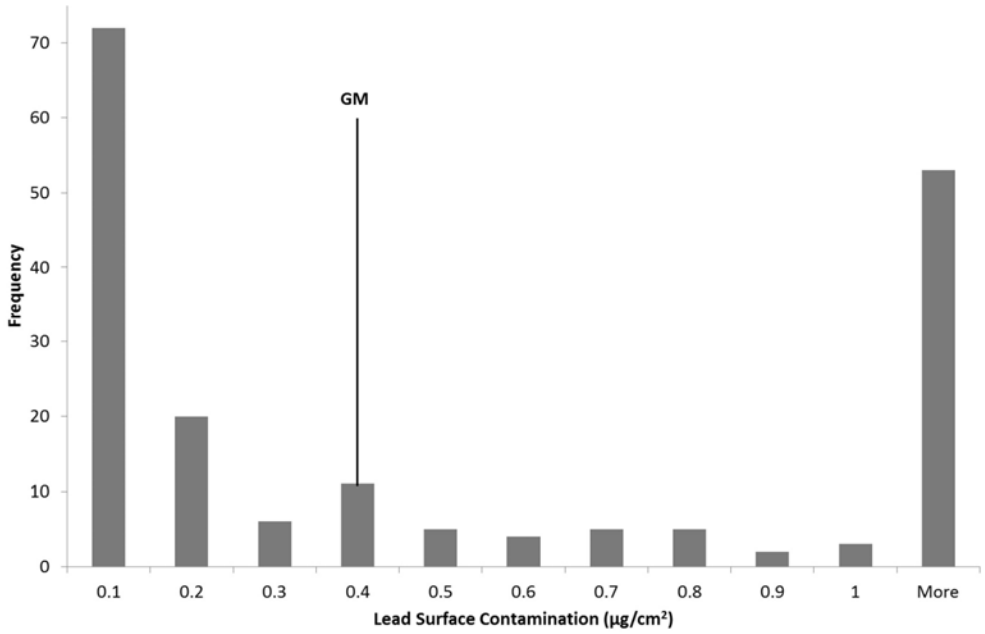

Figure 1. *Histogram of 186 surface contamination samples for lead from 32 radiator repair workplaces in NSW showing a GM of 0.36 µg/cm² with a GSD of 12.6*

The test results of biological monitoring of blood lead of 42 employees were reviewed from April 2010 to April 2013. Of the 42 employees; 32 (76%) were male; 4 (10%) were female and 6 (14%) were female of child bearing age. There were 191 blood samples taken over that period and 4 (2.1%) sample was over the BEL of 30 µg/dL and 19 (10%) were above the BEL of 10 µg/dL with the remaining 171 under the 10 µg/dL limit. All females of child bearing age were below the BEL of 10 µg/dL. In one instance a male worker returned a blood lead level of 61.9 µg/dL, which was above the legal levels of 50 µg/dL. He was promptly removed from lead risk work. The worker was a new employee and had only been working at the company for less than a month. No pre-employment test of his blood lead level was performed. Shortly after returning the high blood lead result he left the company. Being a new worker and returning such a high test result tends to indicate that training in safe lead work may have been inadequate. The test results show a GM of 3.9 µg/dL and GSD of 2.25. The test results of all blood lead analysis are shown in Fig 2.

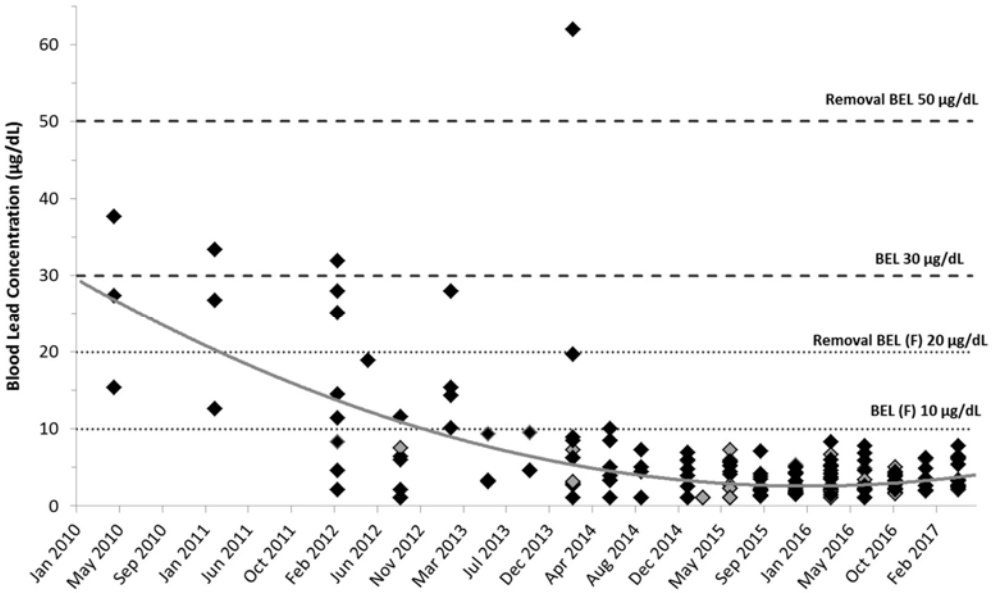

Figure 2. *Blood lead test results from 42 radiator repair employees from April 2010 to April 2017 showing a GM of 3.9 µg/dL and GSD of 2.25. Black diamond points are male and female workers. Grey diamond points are females of child bearing age. Dashed line indicates the BEL at 30 µg/dL and the removal BEL at 50 µg/dL of male and female workers. The dotted line indicates the BEL for females of child bearing age at 10 µg/dL and the removal level at 20 µg/dL.*

In twenty-four workplaces appropriate health monitoring as per *WHS Regulation 2011* was not undertaken correctly. Of these, eight workplaces did not have a program of health monitoring in place at all. The non-compliance with the regulation was due to:

a) Being unaware of their legal requirements under the WHS Regulation
b) Blood lead monitoring was not carried out by a registered medical practitioner,
c) The frequency of testing blood lead levels was not maintained or

d) The employer did not carry out health monitoring as the test results in the past were below the BELs and therefore did not consider their work as lead risk work.

A total of 56 major issues were identified during the visits to the radiator repairers' workplaces. The main issues were that the health monitoring program was not in place; that the employer had not lodged a notification of lead risk work occurring at the workplace; that the personal protective equipment program was not in place; that cleaning methods were unsatisfactory; signage was not visible or displayed; that the laundry process was inadequate; and that the ventilation was inadequate or not present. Some of the other issues found were that lead contamination was noticed outside of lead process area; that the labelling of hazardous substances was not adequately carried out; and a hazardous substances register was not available; pressure vessels were not registered; that plant maintenance was not adequate; that guard railing was missing; that risk assessments were not completed; that electrical testing and tagging was not compliant; and that supervision of the workers was seen to be in adequate. These issues are listed in Table 1 with the number of times identified in the workplaces.

Table 1 Major compliance issues (%) identified in relation to workplace health and safety in radiator repairers' workplaces. In brackets gives the percentage each group has to the total of issues.

Issues	***No***
Hygiene (23%)	
Cleaning methods unsatisfactory or not present	6
Laundry process not adequate	4
Contamination outside of lead process area	3
Total	**13**

Risk Control (20%)	
PPE program not in place	6
Ventilation not adequate or not present	4
Guard railing missing	1
Total	**11**

Issues	***No***
Regulatory Compliance (50%)	
Health monitoring not in place	8
Notification not lodged	8
LRW signage not visible or displayed	4
Labelling of hazardous substance to standard	3
SDS	2
Hazardous substance register not available	1
Risk assessment not completed	1
Supervision of workers	1
Total	**28**

Administration (7%)	
Pressure vessel not registered	2
Plant maintenance not adequate	1
Electrical testing and tagging – not compliant	1
Total	**4**

It is evident from the results that lack of health monitoring, non-notification of lead risk work, PPE not in use, and poor hygiene and cleaning practice accounted for approximately 50% of the issues. Use of ventilation, signage and laundering accounted for another 21%. Together these issues accounted for 76% of that total.

Two hundred and ten (210) issues that were identified as partial compliance or where the controls implemented needed improvement are listed in Table 2.

It was also noted that this industry employed young workers who were not adequately trained and lacked the understanding of the risks associated with the use of lead solder. It was evident from the site visits and interaction with the workers that the employers did not provide adequate information and advice to minimise lead exposure of these young workers and their families.

Table 2 Partial compliance issues (%) identified in radiator repairers' workplaces where the controls implemented needed improvement. In brackets gives the percentage each group has to the total of issues.

Issues	***No***
Hygiene (12%)	
Laundering inadequate	7
Maintain clean lunch room inadequate	5
Restrict lead contamination	5
Dedicated lead process area	4
Change room facility	3
Housekeeping inadequate	3
Clean shaven policy	2
Lead exposure during laundering	1
Smoking	1
Total	**31**

Risk Control (25%)	
PPE related issues	26
Respirators	9
Storage of PPE	8
HEPA vacuum inadequate	6
Ventilation inadequate	6
Contaminated PPE storage	2
PPE filter replacement inadequate	2
Ignition Source	1
Solder with less lead content	1
Machine guarding inadequate	1
Impervious flooring	1
Total	**63**

Issues	***No***
Regulatory Compliance (35%)	
Health monitoring related issues	25
SDS not available	17
Lead risk work signage not displayed	14
Safe work method statement for lead process	10
Notification inadequate	7
Chemical related (SDS, labels)	8
LPG cylinder security inadequate	2
SOP for entering and exiting Lead process area	2
Spray booth	2
BLL copy not available	1
Consultation inadequate	1
Total	**89**

Administration and other (28%)	
Electrical Equipment not tested	9
Fire extinguishers	5
Pressure vessel	5
Inspector interaction	4
Maintenance schedule for exhaust	4
Lead waste disposal inadequate	2
Vehicle hoist inspection	2
Pit maintenance inadequate	1
Others (admin related issues)	39
Total	**71**

E-Waste Recycling

Seven E-waste recyclers were visited in NSW. The workplaces had 1 – 3 workers who were directly in the lead risk work involved in CRT disassembling. To determine the amount of lead in E-waste 16 samples of dust from the crushed recycled E-waste were analysed for their lead content. It was found that the samples contained up to 6%

lead. Surface contamination samples (*n* = 42) were also taken from the seven workplaces with all workplaces returning positive test results. The surface contamination samples showed test results that ranged from <0.05 to 3.85 µg/cm^2 with a GM of 0.09 µg/cm^2 and a GSD of 1.92. The test results of the surface contamination of seven E-waste workplaces are illustrated in Fig 3.

Biological monitoring by the analysis of blood lead samples of 38 employees from May 2014 to April 2017 were reviewed. Of the 38 employees; 36 (95%) were male with two (5%) females of child bearing age. There were 112 blood samples tests results obtained over that period and no test result showed a level above the BEL of 30 µg/dL and only one sample was above the BEL of 10 µg/dL, the remaining 111 samples were below the 10 µg/dL limit. The test results showed a GM of 0.90 µg/dL and a GSD of 2.28. The test results of the blood lead analysis are shown in Fig 4.

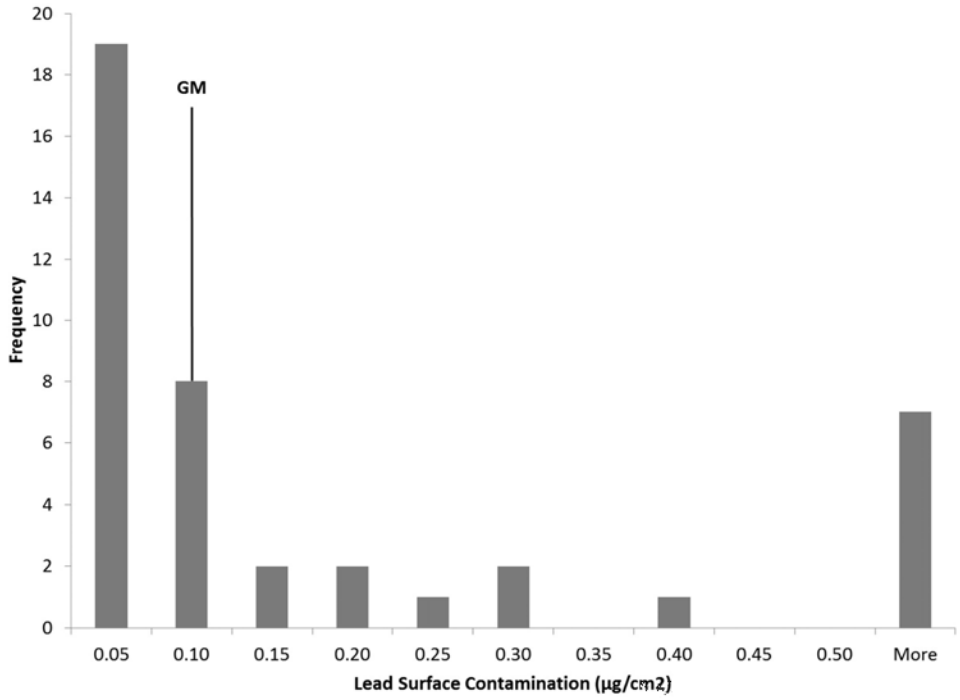

Figure 3. *Histogram of 42 surface contamination samples for lead from seven E-waste recycling workplaces in NSW showing a GM of 0.09 µg/cm^2 with a GSD of 1.92*

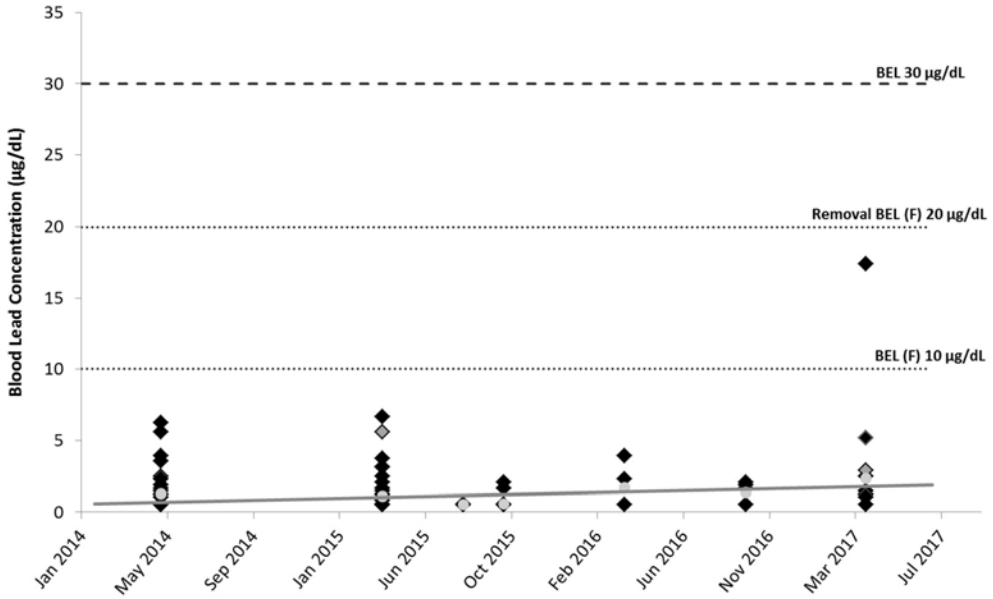

Figure 4. *Blood lead test results from 38 workers from seven E-waste recycling workplaces from May 2014 to April 2017 showing a GM of 0.09 µg/dL and GSD of 2.28. Black diamond points are male workers. Grey diamond points are females of child bearing age. Dashed line indicates the BEL at 30 µg/dL and the dotted line indicates the BEL for females of child bearing age at 10 µg/dL.*

Of the 38 workers who were assessed during the visits 3 had never undergone health monitoring previously during their lead risk work. In four E-waste recycling workplaces a health monitoring program was not in place, as they didn't identify their work as lead risk work and the employers were unaware of their regulatory obligations.

Other occupational hygiene issues across the industry included problems with PPE (20%); poor hygiene and housekeeping practices (20%); the absence of adequate signage (25%); poor ventilation; unsatisfactory laundry processes.

Poor personal hygiene was noted to be lacking in almost every workplace visited. Workers did not have adequate knowledge and understanding of the use of PPE, they lacked an understanding of the proper disposal of overcoats and other garments, and the washing of hands and nails were inadequate.

All seven workplaces visited were provided with a number of recommendations and areas of improvement including:

1) To correctly use, care and maintain PPE
2) To monitor the blood lead levels of female workers
3) To have a separate lead processing area
4) To improve housekeeping
5) To improve the cleanliness of lunch room and staff access areas
6) To prevent the transportation of lead contamination on the clothing of workers to their residences
7) To differentiate between work and street cloths i.e. establishing proper laundering facilities

DISCUSSION

This health and safety study was conducted as part of a regulatory program to verify the level of exposure to lead in the radiator repair industry and the E-waste recycling industry.

The results of these two projects demonstrate the importance of surface contamination sampling and biological monitoring as useful tools to determine the level of exposure to this hazardous chemical.

The radiator repair industry showed surface contamination with a GM 4 times higher than that found in the E-waste recyclers plants. This was reflected in the blood lead levels found in each industry with the radiator repair industry showing a GM 4 times higher again. The radiator repair industry showed a decline in blood lead levels over time with a GM 25.1 µg/dL in April 2010 to a GM 3.77 µg/dL in April 2017. While we would like to attribute the improvements made by this intervention as contributing to this decline, we also acknowledge that the workload in this industry has declined over this period as well and further improvements in controls are still warranted.

Practical advice and assistance has been given to the employers to help them to understand how to meet their regulatory obligations. The knowledge and awareness of the employers and their staff to the health hazards of lead was improved by this project.

Twenty percent of workplaces visited did not have a health monitoring program in place and 13% of them did not follow the right procedures for monitoring. The worker who was removed from lead risk work because of a high blood lead level above the legal limit was new to lead work and had never had a blood lead test taken before. Whenever a high blood lead level was returned, the worker was removed from lead risk work and was under the health monitoring program until that time when the worker's blood lead level returned to normal. It was emphasized to the employer that the health monitoring of the workers involved in the repair process needs to be improved and that adequate records need to be kept; that the regulator needs to be notified of lead risk work in workplaces using lead solders; that personal hygiene practices needs improvement to reduce potential exposure through dermal exposure and subsequent ingestion when eating drinking and smoking in the workplace. It was suggested that training in the use, handling and storage as well as appropriate training in the use of PPE and good hygiene practices would improve individual work practices and reduce the worker's exposure to lead.

The surface contamination samples revealed that further improvements were needed in a number of areas and provided information to the employers on the contamination levels and the need to improve housekeeping in a number of locations. This sampling also revealed that the laundering and the other cleaning practices were of concern and that there was a high risk of cross contamination. The workers that were interviewed were not aware that their work clothes were contaminated with lead dust and that they were unknowingly transporting lead to other areas in the workplace, contaminating their work colleague's clothes, PPE and work areas. They were equally unaware that they were transporting it home. Advice was provided to both the employers and workers on the risks associated with cross contamination as well as health risks to their family especially young children and pregnant woman.

Signage was inadequate in 10% of workplaces visited. Advice was given on the need to provide information to other workers and visitors of the possibility of becoming exposed to this hazardous substance.

Hygiene and cleaning practices also needed attention. It was observed that 20% of the workplaces had adequate facilities available for the workers but these facilities were not used. Employers were given information relating to the implementation and of good hygiene practices and the need to train and monitor their workers on these practices. Workers were also given similar information. Action in the form of Notices and agreed actions were taken to remedy the breaches.

Even though the majority of workers were aware of the risk involved in the repair using lead solders, they tended to ignore the hazards and complete the task of repairs without appropriate controls. This assessment brought this issue to the forefront, and provided information, advice and raised awareness of the employer and the workers on the risks of lead work.

Workplaces which had systems in place to manage the risk of exposure were able to review their systems and implement adequate changes, particularly to manage secondary contamination for the families of their workers.

Biological monitoring indicated personal exposure to lead with some workers exceeding the SafeWork NSW recommended BLL. Surface contamination monitoring results suggested workers' exposure is likely to have occurred through contact with skin. The surface contamination detected in work areas should be addressed. From observation of tasks and other verification information gathered during the workplace visits, improving work practices and reducing surface contamination would have a significant effect on reducing the exposure to this dangerous substance.

CONCLUSION

This study was undertaken as part of a regulatory verification program. It showed that lead exposure levels of both the radiator repair and E-waste industries are both below the BEL of blood lead. The main areas of concern were that a significant number of workplaces visited did not have a health monitoring program in place and that the regulative authority had not been notified that lead risk work was being performed. The incorrect use, care and maintenance of PPE were also of concern and the cleanliness of the workers and housekeeping in the workplace was lacking. The assessments have significantly raised the knowledge and awareness within the industry, regarding the high risks associated with lead exposure and the controls that need to be put in place to adequately manage the risks.

ACKNOWLEDGEMENT

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DEMONSTRATION OF THE EASE OF USE AND LOW DETECTION LIMITS OF A DRY FILTER SAMPLER FOR DETERMINATION OF VAPOUR PHASE AND PARTICULATE ISOCYANATE DERIVATIVES IN AIR.

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INTRODUCTION

Isocyanates are a main component in the production of polyurethane (PUR) materials. Exposure to isocyanates puts workers at risk for respiratory disorders and occupational asthma. Current glass impinger and filter cassette sampling methods presents several challenges to the investigator and analytical laboratory such as sample collection efficiency; selectivity and sensitivity; availability of certified reference materials; and shipping compliance issues.

The unique design and ease of use of the dry filter sampling device presents several advantages over existing devices such as the collection of both vapour phase and particulate isocyanates in one device; reliability – fast derivatization reactions into stable derivatives; complete derivatization of particles; sampling for greater than eight hours; no field handling of solvents or field desorption; and low detection limits.

The dry sampling device will derivatize both the isocyanate monomers and oligomers. The aromatic monomers include toluene diisocyanates-2,4-TDI and 2,6-TDI; 4,4'-diisocyanate-diphenylmethane (MDI); phenyl isocyanate (PhI). Aliphatic monomers include isophorone diisocyanate (IPDI), 4,4'-methylene bis-(cyclohexyl isocyanate) (HMDI); 1,6-hexamethylene diisocyanate (HDI); propyl isocyanate (PIC), ethyl isocyanate (EIC); methyl isocyanate (MIC) and isocyanic acid (ICA). Selective determination of the urea derivatives is performed using LC/MS or LC/MS/MS.

A practical workplace application of the dry sampling device during the automotive two-part clear coat process will be demonstrated.

Dry Filter Sampling Device Design

The dry sampler is comprised of two parts, a denuder and a filter cassette (figure 1). The filter media inside the sampler is impregnated with a mixture of dibutylamine (DBA) and acetic acid according to ISO 17734-1. During sampling, the isocyanates quickly react with DBA to form stable isocyanate-urea derivatives.

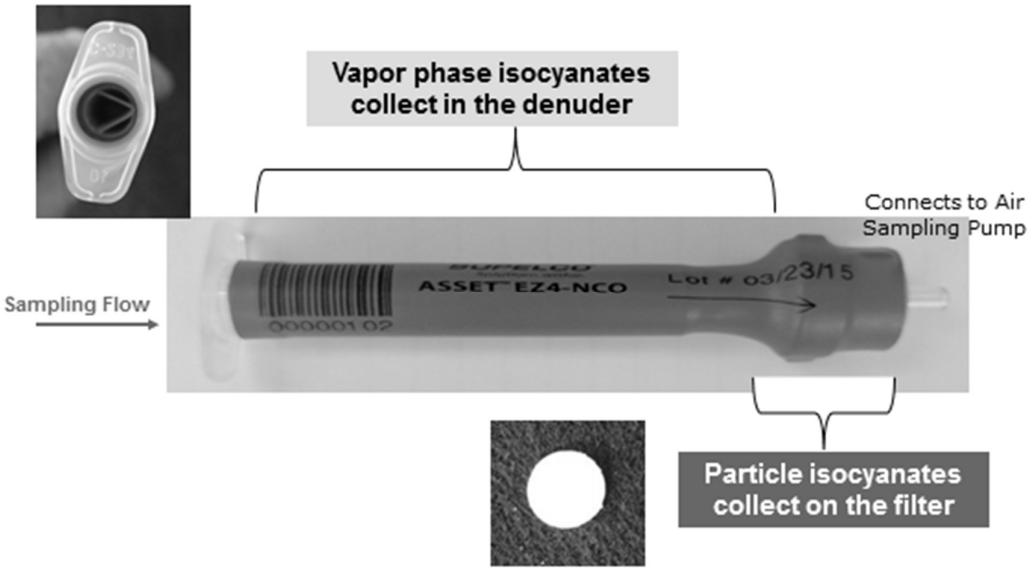
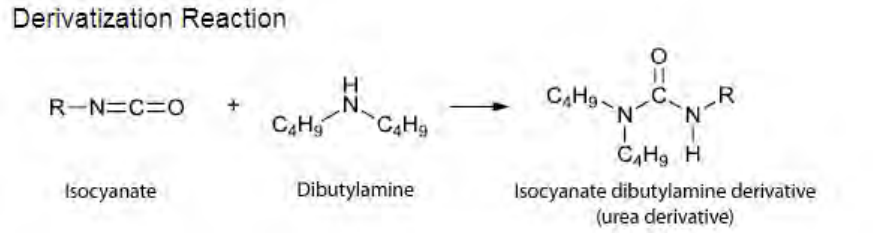


Figure 1: Dry Sampling device components



The DBA-derivatives are very stable and derivatization occurs during air sampling and does not require the use of additional liquids and reagents. The special sampler design ensures that both the vapour phase and particulate isocyanates are captured and derivatized during sampling. The volatility of the dibutylamine (DBA) is fundamental to the design. As air travels through the denuder, fresh DBA is released and carried to the filter. This dynamic process assures complete derivatization of the isocyanate particles collected on the filter.

Table 1: Advantages and Disadvantages of Dibutylamine Reagent

Advantages	Disadvantages
• DBA reacts quickly with isocyanates • Forms stable urea derivatives • No special storage conditions • No field extraction • Can be analysed up to 4 weeks after sampling event • Easy to ship internationally • DBA completely evaporates during sample preparation • For analysis, fully supported by certified reference materials (CRM) for isocyanate monomers and oligomers	• For analysis, DBA does not contain a UV chromophore, so it does not enhance the HPLC-UV response of the isocyanates.

Comparison to Common Isocyanate Devices

There are basically two other types of isocyanate sampling devices which contain derivatizing reagents such as 1-(2-pyridyl)piperazine (1,2-PP) or 1-(2-Methoxyphenyl)piperazine (1,2-MP, 1,2-MOPP). Several methods such as OSHA 42/47 employ the use of a 37 mm cassette with an impregnated filter to derivatize the isocyanates. The other type uses an impinger filled with a liquid solution of derivatizing agent made up in toluene, and a 37 mm filter cassette attached at the outlet of the impinger, such as NIOSH isocyanate methods.

The challenges associated with using the 37-mm cassette sampling device is that this type of sampler requires the Industrial Hygienist to take the cassette apart in the field, and place one of it's filters into a derivatizing solution containing toluene. Since toluene is flammable, this can create both regulatory and shipping problems. The other issue is keeping track of both parts of the sampler, so they can be analyzed together at the laboratory.

With impinger sampling, the air is drawn through the liquid derivatization media into the glass impinger and the isocyanates react with the solution. After sampling the media must be transferred into a clean vial to be shipped back to the laboratory. Because impingers are typically made of glass due to chemical compatibility; glass may break in the field or leak, causing the worker to be exposed to the liquid media solution, and to the solvent vapours given off by the solution.

By comparison, the dry sampler requires little preparation after sampling. Once sampling is completed, the Industrial Hygienist simply installs the caps on both ends, and places them into a clean bag. Since dibutylamine is stable, the dry samplers do not require refrigeration and immediate shipment to the laboratory. It is recommended the samplers arrive at the laboratory within four weeks of sampling. They are also non-hazardous to ship. Other common devices must be analysed within 48-72 hours after sampling.

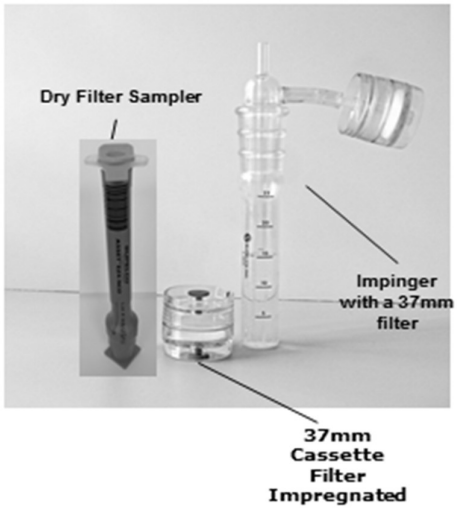


Figure 2: Comparison of common isocyanate sampling devices

Collecting the Air Sample with the Dry Sampler

The dry sampler has a recommended flow rate of 200 mL/min and a range from 100 – 850 mL/min. Because this is a filter sampling device, there is low backpressure across the device, <9 inches of water at 200 mL/min, and is suitable for most sampling pumps. However, because this sampler also collects particles, backpressure can increase during sampling. In order to ensure a stable flow rate during sampling, it is recommended to use an air sampling pump that compensates for standard temperature and pressure. After sampling, it is recommended to recheck the flow rate and record the average flow rate on the laboratory paperwork to be sent to the laboratory with the samplers.

The dry sampler has a high capacity and can sample from five minutes to eight hours. One single sampler can be used to sample for Short-Term Exposure Limits (STEL) for 15 minutes or an entire eight-hour shift for true time-weighted average (TWA) exposure measurements.

When taking personal samples, the dry sampling device can be oriented on the worker in the up or down position, secured with a lapel clip in the breathing zone. The up position is preferred for sampling gases and vapours. It is recommended to orient the sampler downward when sampling in environments where a large particle load is expected.

Practical Application – Automotive Clear Coat Process

Experimental

The clear coat was obtained at an automotive supply store. The three components of the coating (clear coat, activator, and thinner) were mixed together per the manufacturer's instructions. A High Volume Low Pressure

(HVLP) spray gun was used to apply the coating to a car hood in a ventilated spray booth. The person who performed the spraying was wearing a respirator with an organic vapour cartridge to minimize possible isocyanate exposure. Samplers were placed on the person in the breathing zone to study the personal exposure; and additional samplers were also placed inside the spray booth to measure the air concentration and to determine the identity of the isocyanate species (Figure 3).

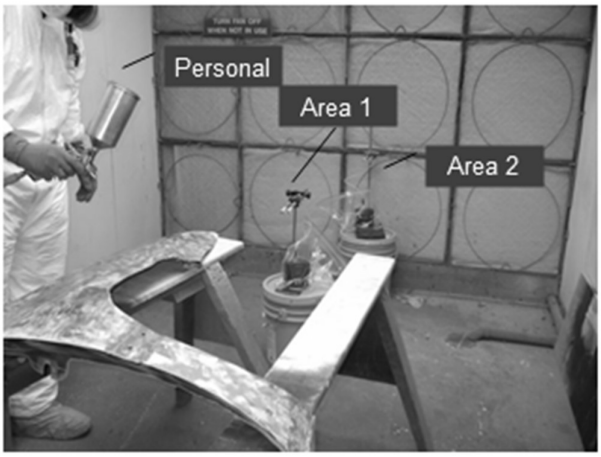


Figure 3: Dry sampler placement during clear coat study

The dry samplers were sampled at a flow rate of 100 mL/min, and the 37-mm cassette samplers with 1,2-PP reagent were collected at 1 L/min; simultaneously for 15 minutes. Quantitative analysis of the dry samplers was performed via LC-MS/MS method using DBA-isocyanate CRM standards and deuterated internal standards. Prior to the spraying experiment, the clear coat formulation was mixed and screened for isocyanates to find out which species of isocyanates should be the focus of the subsequent analysis. It was found that this particular clear coat contained 1,6-hexamethylene diisocyanate (HDI) and isophorone diisocyanate (IPDI), both monomer and polymeric compounds. So, the LC/MS/MS methods were set up to include these (Figure 4). Analysis of the 37-mm cassette samplers was performed by LC/UV using the available 1-(2-pyridyl)piperazine (1,2-PP) derivatized standards.

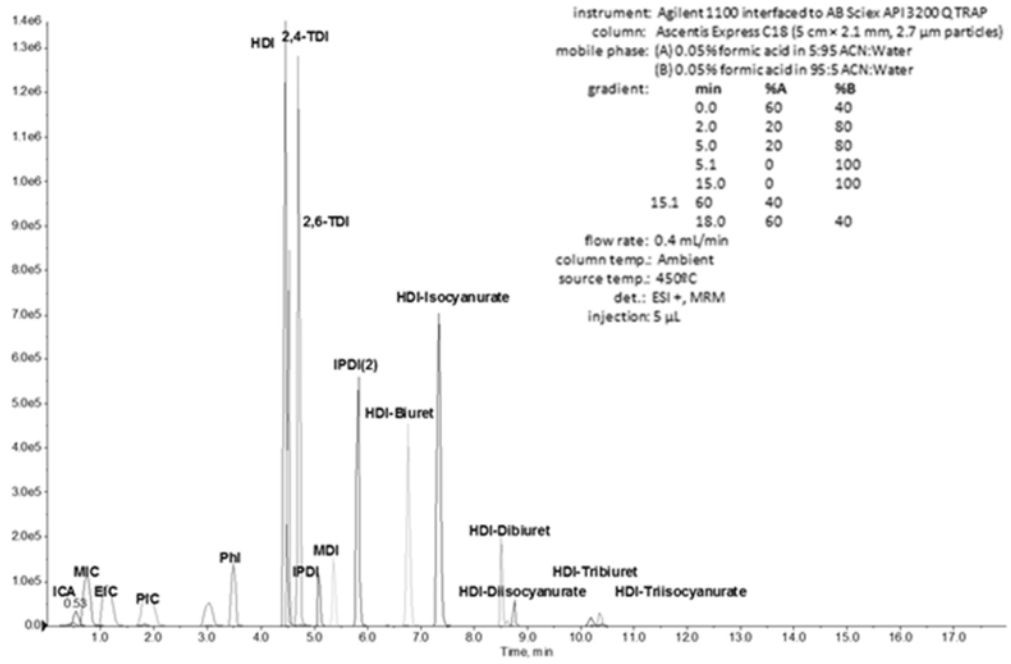


Figure 4: LC-MS/MS Chromatogram of isocyanates certified reference materials

RESULTS

Using dry samplers for isocyanates measurement

No monomeric isocyanates, HDI or IPDI, were detected in the personal samplers. Only polymeric (oligomer) HDI-Isocyanurate and IPDI-Isocyanurate were detected in the dry samplers located in the breathing zone. Two dry sampler samples were collected on each side of the spray painter's breathing zone. The isocyanate concentrations were higher from the samples collected on the left side. This may have occurred because the exhaust of the spray booth pulled the overspray across the spray painter's body from his right to his left side as shown in figure X. In the air of the spray booth, both monomeric and polymeric isocyanates compounds were identified and quantified. This data is graphically presented in Figure 5 for HDI and tabulated in Table 2.

Table 2: Area Sampler Measurements of HDI and IPDI Isocyanate Monomers

	Area 1 A (Low Volume)	**Area 1 B (High Volume)**	**% Diff**
Hexamethylene diisocyanate	30.9 µg/m^3	25.0 µg/m^3	21%
Isophorone diisocyanate 1	8.2 µg/m^3	9.0 µg/m^3	-9%
Isophorone diisocyanate 2	5.6 µg/m^3	4.6 µg/m^3	20%
	Area 2 A (Low Volume)	**Area 2 B (High Volume)**	**% Diff**
Hexamethylene diisocyanate	11.2 µg/m^3	11.7 µg/m^3	-4%

Isophorone diisocyanate 1	3.3 µg/m^3	3.8 µg/m^3	-14%
Isophorone diisocyanate 2	2.2 µg/m^3	2.0 µg/m^3	10%

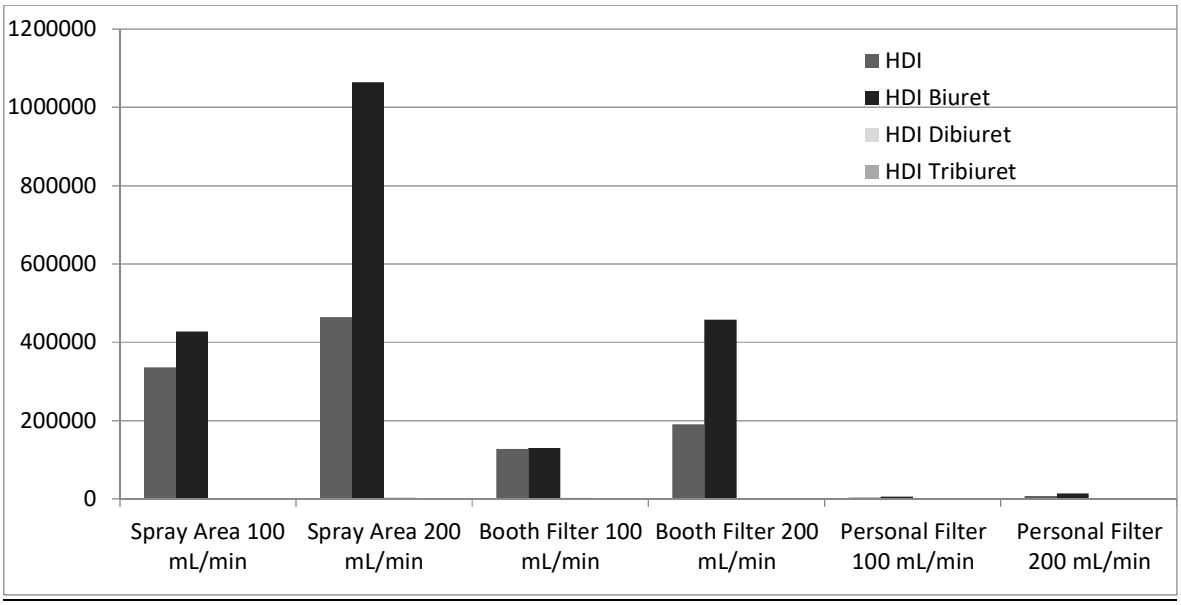


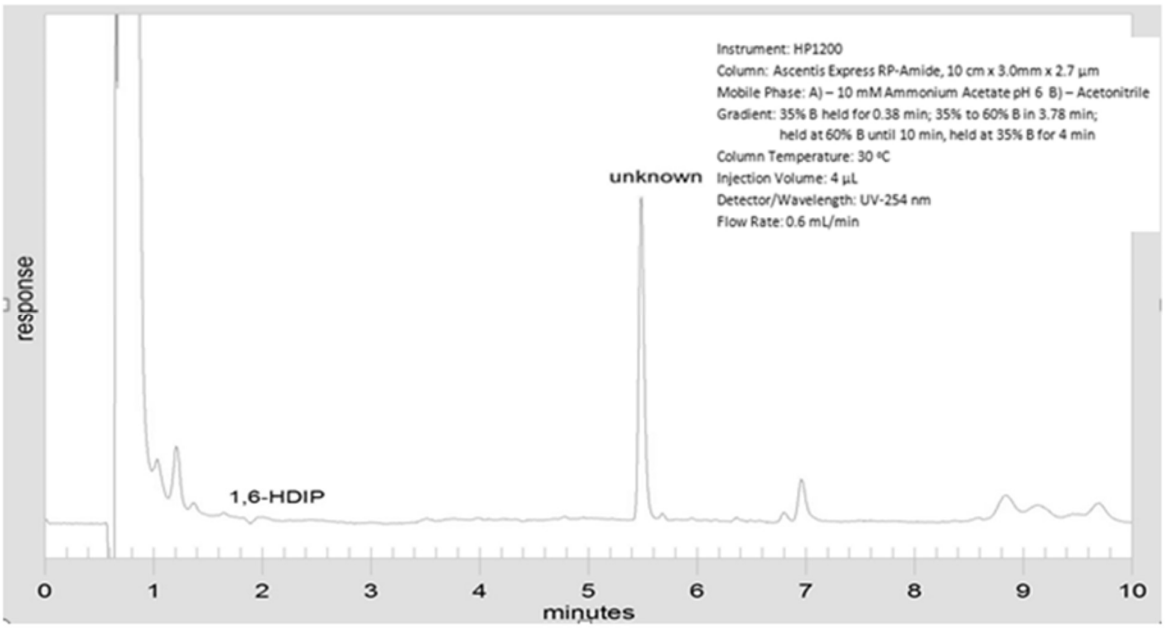
Figure 5: Relative Abundance of HDI Monomers and Oligomers in Collected Air Samples

Using 37-mm cassette samplers for isocyanates measurements

OSHA 42/47 methods are applicable only for the measurement of monomeric isocyanates: HDI, MDI and TDI. Only HDI was detected from the spray booth samples (Table 3), MDI and TDI were not detected but were excluded from measurements because they are not applicable to this study. No identification or quantitation for monomeric IPDI, or any of the polymeric isocyanates was possible because of the lack of available chemical standards and methods for the 1,2-PP derivatives. However, significant unknown peaks were observed in the chromatogram from the 37-mm samples which could not be identified by UV-VIS detection (Figure 6).

Table 3: Measurement of HDI monomers on 37-mm Cassette Sampler with 1,2-PP

Sample	**1,6-HDI Monomer (µg/m³)**
personal	ND<4.5
Area 1	6.3
Area 2	6.7



DISCUSSION

The dry sampler was able to capture and quantify both low and high concentrations of HDI and IPDI compounds from the air using a single dry sampler device. During the spray painting process, we discovered the air concentration of the polymeric species to be over an order of magnitude larger than the monomeric isocyanates. MRM transitions for HDI-Dibiuret, HDI-Tribiuret, HDI-Diisocyanurate, HDI-Triisocyanurate were for the doubly charged molecular ion (MHH)+. Recoveries for the derivatized oligomers fortified onto a sampler ranged from 88%-131%. Sufficient separation and resolution were obtained for the 6 oligomers and the analytical run time for all 17 compounds and their internal standards was less than 20 minutes.

Only polymeric isocyanates were detected in the breathing zone during the spray operation and these levels could pose an exposure risk to the spray painter. The OSHA 42/47 methodology was not suitable for measurement of these polymeric compounds. In addition, the comparison of quantitative results for HDI monomers detected in the spray booth showed the OSHA method underestimated the HDI concentration by five times the level compared to these obtained by the dry sampler.

CONCLUSIONS

Dry samplers were successfully used to measure the air concentrations of both monomeric and polymeric isocyanates while spray painting an automotive clear coat. Since the design of the dry sampler is dry compared to an impinger filled with a liquid, it makes it both convenient and easy to use. The LC/MS/MS analysis detected and confirmed the identity of all the isocyanate compounds contained in the clear coat mixture, and the use of deuterated internal standards provided accurate quantitation. The predominant species detected in this field study using the dry samplers were HDI-isocyanurate AND IPDI-isocyanurate. The dry sampler along with the robust analytical method provides safety professionals the ability to assess the real personal exposure from a complex mixture of isocyanates that make up the automotive clear coat finish.

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MANAGEMENT OF HAZARDOUS CYTOTOXIC MEDICINES IN THE HEALTHCARE INDUSTRY.

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Monash Health

ABSTRACT

Hazardous cytotoxic medicines are increasingly being used, stored and handled throughout the healthcare industry. They are an integral part of many disciplines and are used at varying stages of a patient's relationship with a healthcare service.

There are many challenges that the healthcare industry faces with managing the health and safety of staff who are potentially exposed to these medicines. This paper discusses how one organisation has engaged with multiple stakeholders to develop a system of work for the entire journey of cytotoxic medicine.

BACKGROUND

Creating a system of work to minimise the risk of exposure to all staff is challenging for many reasons:

- Inconsistent information from regulatory bodies
- Lack of systematic management of OHS risks associated with hazardous cytotoxic medicines
- Various sources of information that have varying degrees of staff safety identified
- Inconsistent identification and delivery of training
- Patient confidentiality concerns around identifying hazards
- Bodily fluids are classified as hazardous cytotoxic medicines for 2 – 7 days following administration to a patient
- Limited knowledge of staff in regards to the correct use of risk controls in particular PPE
- New areas/tasks of use are not systematically identified
- Multiple departments interact with medications, patients, bodily fluids and waste

INVESTIGATION

Due to a number of incidents being raised outside of clinical areas an investigation was conducted into what systems were in place to manage the safe use of hazardous cytotoxic medicines. This identified a number of systematic gaps which were anticipated in the non-clinical setting but were unexpected in the clinical setting. The findings were that an organisational system of work was required for the Safe Management of Hazardous Cytotoxic Medications.

BUILDING THE SYSTEM

It was determined that the system of work would be owned by the Occupational Health and Safety Department but would require consultation with multiple areas from across the business. A working party was created to initially develop the system and related procedures.

Key areas that were discussed and required significant investigation were:

- Definition of what medications were included in the term hazardous cytotoxic medicines
- What PPE is required for tasks?
- What higher level controls are required?
- What processes are required for cleaning surfaces and equipment?
- What are the requirements for health monitoring and who should provide guidance?
- Who needs to be trained to what level?
- How should the risks be managed during transportation of medication and patients?

- How are risks identified by all staff members?

A procedure and other related documents were created that provide a system of work for all staff members around the safe management of hazardous cytotoxic medicines.

FUTURE STEPS

The procedure and related documents are in the process of being approved. Within a large healthcare service this is a complex process. As this topic is interlinked with clinical services there are multiple governance committees that need to approve these processes prior to the final approval by the Executive Committee.

Through the working party a number of improvement opportunities have been identified in regards to the current processes and equipment currently being used. These are currently being consulted across multiple departments and will require approval by multiple governance committees as well.

Other medicines which may be posing a health risk to staff have been identified such as Monoclonal Antibodies and Antibiotics. Further investigation into these topics has started and will follow a similar process that was utilised for the creation of the system of work for hazardous cytotoxic medicines.

The working party has improved cross departmental communication around this topic and has proved to be an invaluable source of information sharing and relationship building.

SUMMARY OF STUDIES EXAMINING NOISE EFFECTS ON COGNITIVE PERFORMANCE.

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ABSTRACT

Most countries have exposure standards limiting noise levels in the workplace to protect individuals from excessive noise, ie $L_{Aeq,8hr}$ of 85dBA. Although not legislated, there are guidelines for acceptable noise levels for various work environments (eg AS/NZS 2107). These take into consideration the task, and ensure the noise is not too intrusive. For example the design sound level for an office, when it is ready for occupation, is 40-45 dBA. However many workers, particularly in transportation, are required to undertake complex and safety critical tasks in noise levels well above the acceptable level for comparable tasks performed in an office, but below the exposure standard for workplace noise. In the aviation context for example, the noise level in a commercial aircraft cabin can be as high as 80 dBA during cruise. Staff exposed to this noise are required to complete critical work tasks that utilise short-term and long-term memory. This paper will summarise findings from a number of studies investigating the effects of noise between 60 and 80 dBA on a range of cognitive tasks as well as between individuals based on language background. The findings on the interaction between noise, cognitive task, and native language background is discussed.

INTRODUCTION

Excessive noise in the workplace is widely acknowledged as a risk, leading to hearing damage. As a result, most countries around the world have legislated limits for noise exposure. In Australia, the limits for workplace noise exposure are $L_{Aeq,8h}$ of 85dBA or L_{Cpeak} of 140 dBC. When noise levels are found to be in excess of these values, noise mitigation is a requirement. Ideally this is achieved by noise reduction at the source, and as a last resort personal hearing protection for the exposed worker. Although not legislated, there are guidelines for design sound levels for various work environments (eg AS/NZS 2107, 2016). These acceptable levels take into consideration the nature of the task being undertaken and aim to ensure that the noise in the workplace is not intrusive and likely to affect that task. Thus, the acceptable noise levels in this standard for an office space are lower than for an area involving packing and dispatch. For example, the design sound level for a general office, when it is ready for occupation, is 40-45 dBA, whereas the guideline for public spaces is 40 to 50 dBA and a court room is 35 dBA.

There are many workers, especially in transportation who are required to complete tasks at least equal to, if not more challenging, than for an office worker. However, these tasks are undertaken in work areas well above the acceptable noise levels in offices but below the workplace noise exposure limits. In the cabin of a commercial aircraft, the background noise levels are typically at least 30 dB above the levels considered appropriate for office work, yet the crew are required to undertake complex cognitive tasks. In addition, many of these tasks are critical to the safety of passengers and other crew.

Studies on the effect of noise at various levels, which are below workplace noise exposure levels, on performance provide varied outcomes as many are directed to investigating just one aspect of performance. For example, the immediate effect of noise on high order cognitive skills such as memory and attention has been shown to adversely affect performance (Boman, Enmarker, & Hygge, 2005; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000). In contrast, the immediate effect of noise on low order cognitive skills such as reaction time appears to be negligible (Smith, 1989). There is the need to consider the effect of the noise on certain tasks for those who are non-native speakers. In one such study (Jang et al 2014) found the immediate effect of noise on performance for English second language speakers is more severe than their native English-speaking counterparts.

PERFORMANCE TESTING PROCEDURES

As the work environment under consideration was transportation and in particular aviation, these investigations used a noise source with similar characteristics. The noise that is common in transportation workplaces is generated by the engines and is typically broadband with an emphasis in the lower frequencies. During acceleration and deceleration, the noise level and spectrum can change but during cruise it is essentially constant. This is well represented by a 'white noise' broadband noise source. The level of the noise was varied between 65 and 80 dBA depending on the purpose of the test. A test performed in 'quiet', which was a quiet laboratory space around 40 dBA was consistently used for baseline performance.

The cognitive tests used aimed to investigate the effects on performance for short-term and long-term memory. One cognitive test common across the various investigations was a memory recall test particularly relevant to transportation/aviation work place. The memory recall test has been modelled on a safety brief and the recall of a safety briefing is essential in an emergency. The material for the test was similar in length to some aircraft safety briefing, 90 sec, and comprised information which was both factual and non-factual to avoid any bias in prior knowledge. After the briefing, each subject was provided with a written script that required recall of the correct number or word at 12 locations. An example of one of the sentences in the audio file relating to an Embraer 190 stated:

> *"it has a double-bubble fuselage design and according to the manufacturer this provides passengers with an extraordinary amount of personal space".*

The same sentence appeared in the written scrip, except with three options for one word (noted in bold).

> *"it has a double-bubble fuselage* **configuration/ design/ uncertain** *and according to the manufacturer this provides passengers with an extraordinary amount of personal space*".

Each participant needed to recall the correct word and were advised if they could not recall then to select uncertain.

The other tests that have been used aim to investigate other forms of memory. For example, the Mathematical Problem Solving task aimed at checking working memory, is based on the C-Span task developed by Salthouse and Babcock, (1991) and is designed to examine computations skills which are performed in working memory. Participants were provided with a series of two column mathematical problems to solve such as 34 + 27 (provided aurally) and once solved they typed their answer into the computer. All computation problems were additions. Answers were always two digits, and no two questions were the same.

Another working memory test was the Grammatical Reasoning Task (Baddeley, 1968) which is designed to examine the understanding of sentences of various levels of syntactic complexity. Hence, participants are presented a short sentence such as 'A follows B' and they are provided with an answer (e.g., BA) and their task is to state whether the answer provided is 'True' or 'False'. There are 64 possible combinations presented in six binary conditions: (1) Positive or Negative (e.g., A precedes B vs. A does not precede B), (2) Active or Passive (e.g., A follows B vs. A is followed by B), (3) True or False (e.g., A follows B), (4) Precedes or Follows (e.g., A precedes B vs. A follows B), (5) A or B mentioned first (e.g., A follows B vs. B follows A), (6) Letter pairing order of A & B (i.e., AB or BA). Participants were instructed to "Go as quickly as possible without making mistakes".

Yet another working memory test is the Letter Span Task (LSPAN) designed by Kane et al (2004) is derived from Daneman and Carpenter's (1980) original Reading Span test. In the Reading Span test, participants were presented a series of sentences and at the end of a predefined set were tasked to recall the last word of each sentence. In the Letter Span task, the participants were presented a single letter after each sentence, and were tasked to recall the series of letters after a set of sentences. In addition, some of the sentences were illogical (did not make sense), and participants had to decide if the sentence did or did not make sense.

FINDINGS

Over a number of different investigations, we have consistently identified an effect of noise on the memory recall test. For example, a recent test involved a series of cognitive tasks showed similar scores for both the condition 'quiet' and the condition with 55 dBA of noise (akin to an working office environment). When the noise condition was 65 dBA, there was a statistically significant reduction in the score. It is important to remember here that the memory recall test was based on a safety briefing and the recall of the details from such a briefing are critical in an emergency situation. For the same test conditions of noise there was only a very small degradation in numerical, linguistics and grammatical reasoning tests, and these were not statistically significant.

Another investigation used similar cognitive tests to try to determine the effect of long term exposure to noise typical of that in an aircraft cabin in cruise (Molesworth et al, 2014). Again, the baseline was the performance in the 'quiet' condition. The subjects were then exposed for 83 minutes at 80 dBA. During this time the subjects watched a silent animated video so that the only sound was the constant broadband noise. As there was an expectation of some degradation in performance, the subjects were divided randomly into three groups and one group were given the mitigation measure of active noise control headphones, another had no protection, while the third did not experience any noise i.e. quiet. Active noise control utilises sound 180 degrees out of phase with the incoming sound to provide 'cancellation'. They do not provide perfect cancellation, but they can provide reduction of noise particularly in the lower frequencies. In this investigation the active noise control headphones were similar to those promoted for comfort and did not include any other features to provide protection of hearing at higher frequencies. For those in quiet, the percentage difference in recall performance between the 'before' and 'after' showed an increase in performance score. Since the test scripts were different, this most likely indicates a learning effect for the test procedure. For those exposed to the noise there was a reduction in performance after the exposure to noise. For those provided with the noise cancelling headphones there was a small increase in performance score approximately half way between the other findings. So while the exposure to the noise led to a degradation in performance in the memory recall test, the noise cancelling headphones helped in part to mitigate this degradation.

As the effect of noise on memory recall had been shown to reduce recall performance over a number of studies it became clear that there would be a benefit if we could bench mark against a factor that also caused a degradation of performance and that is well understood in the community. The effect of alcohol on performance is one such factor that is well understood in the community and especially in regard to the limits for blood alcohol concentration (BAC) for driving ie a BAC of 0.05 is the legal limit for driving safely in Australia. The same memory recall test was used for these investigations (Molesworth et al 2014b). The results indicate that exposure to noise levels similar to those present during the taxi phase of flight at 65 dBA impairs performance to a level equivalent to that produced by alcohol intoxication of approximately 0.05 for non-native speakers and 0.10 for native speakers. In other words, native speaker need more alcohol to replicate the same detrimental effects of noise at 65 dBA than non-native speakers. This study also investigated the benefits of noise cancelling headphones as a potential mitigation measure. The use of active noise cancelation headphones were effective in mitigating these effects, especially for non-native English speakers.

CONCLUDING COMMENTS

It is well accepted that noise levels above 85 dBA present a risk of damage to hearing. The design guidelines for workspaces that require cognitively challenging tasks to be undertaken are typically below 50 dBA. There are many workers in transportation with safety critical tasks that are required to work for long time periods in noise levels between 50 dBA and 85dBA and in aviation is one of those where noise levels are typically around 80 dBA. Over a number of different investigations by the authors it has been demonstrated that there is little effect on cognitive tasks with noise levels below 60 dBA but above this noise level reductions in performance can be found.

Consistently, a detrimental effect has been found in the memory recall test and a greater effect for non-native speakers when compared with native language speakers. This is particularly concerning as memory recall of a safety procedure is especially important those with safety critical tasks in the transportation industry. It has been demonstrated that noise cancelling headphones can provide some mitigation of the effect when the noise source is broadband.

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OCCUPATIONAL HAZARDS IN THE EMERGING AUSTRALIAN CANNABIS INDUSTRY.

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ABSTRACT

There has been a rapid upscaling of the medicinal and recreational commercial cannabis industry in North America. In Australia, the reallocation of *Cannabis sativa* L. as a Schedule 8 controlled substance, when prepared or packed for human therapeutic use, has heralded the commencement of local medicinal cannabis industry. Eight medicinal *C. sativa* L. cultivation, and 4 manufacturer licenses have been issued by Office of Drug Control (ODC) to date. Additionally, 5 research licenses have been issued for cultivation and production. Past research has focused on the therapeutic and adverse health effects from deliberate consumption, with a comprehensive report entitled *The Health Effects of Cannabis and Cannabinoids* published by the National Academy of Science (2017). However, with the exception of respiratory disease the occupational health and safety research on the cultivation and manufacture of *C. sativa* L. for medicinal and industrial uses has been limited. Recent studies of the American recreational cannabis industry have indicated potential for repetitive strain and other musculoskeletal injuries associated with harvesting and trimming of marijuana, as well as elevated bioaerosol and delta-9-tetrahydrocannabinol (Δ9-THC) exposures via inhalation, dermal or ingestion routes. A collaborative project entitle Farm to Pharmacy is currently studying the potential health and safety concerns associated with the cultivation and manufacture of *C. sativa* L. in Australia. The intent is to collaborate with industry for the development of best practices guidelines. This paper critically reviews the current research for this rapidly evolving industry.

Keywords: Australia, medicinal cannabis, hazards, airborne exposure, bioaerosol

BACKGROUND

Leo Hollister observed in 1974 that "*The more one studies cannabis chemically, the more complicated it becomes*" (Hollister 1974, p. 3). These words, also expressed by Kinghorn, Flak, Gibbons and Kobayashi (2017), hold true not just for the phytochemistry and the botanical classification of *Cannabis sativa* L., but also the complexity associated with the reestablishment of commercial markets after their long hiatus restricted narcotic status of *C. sativa* L.. Medicinal cannabis and industrial hemp are both subspecies of *C. sativa* L. that has a myriad of uses both industrial and medicinal (Table 1). C. sativa L. belongs in the monotypic genus *Cannabis* L. of the family *Cannabaceae* (ITIS 2017; Kew Gardens 2017). The distinction between the two plants is based on their phytochemistry. More specifically the ratio of cannabidiol (CBD) to the psychoactive component tetrahydrocannabinol (THC), or based on the percentage of THC in the dried inflorescence and young plant structures. Using the ratio approach there are three predominant subspecies; the 'drug' type containing low CBD and high THC (>0.5%), the 'fibre' type with high CBD and low THC (<0.5%), and the 'hybrid' or 'intermediate' type with variable ratio of THC to CBD (Chandra, Lata, Khan, et al. 2017). In Australia, the permissible THC content for industrial hemp cultivation varies from 0.1% in Victoria, to 0.35% in Western Australia and 1.0% in all other States and the Australian Capital Territory (ACT). The 0.3% cut point for THC content of dry inflorescence or young infrastructure was a measure used to distinguish between two subspecies of *C. sativa* L. in the 1970's (Small 2017). However, 0.3% THC content has become a classification tool used to distinguish between hemp and drug type cannabis by regulatory agencies which has found its way into many legislative instruments including the Narcotics Drugs Act 1967, and the *Single Convention of Narcotic Drugs 1961 (as amended in 1972)*.

Table 1: Commercial Products Derived from Industrial Hemp (Adapted from Cole and Zurb, 2008)

Plant Component Used	Processing Method to Produce Final Product	Final Product
Seeds	Whole seed pressing and crushing	*Hemp Seed Oil:* – Industrial; paint, varnish, printing ink, solvents, putty and fuel. – Personal Hygiene; soap, shampoo, bath gel, cosmetics, body scrubs – Dietary; nutritional supplements *Seedcake* - Animal feed, food, beer and nutritional supplements.
	Hulling and crushing of seed meat and shell	*Meat* - Animal and human food *Shells* – flour
Leaves	Mulching	*Agriculture* –animal bedding, mulch, compost
Core (Shives/Hurd/Xylem)	Decortication of stalks	*Agriculture* – animal bedding, mulch, compost, growth medium. *Industrial* - particle/fibre board, cement blocks, insulation, stucco and mortar, paint, sealant and plastics. *Paper* - printer, specialty, newspaper, cardboard and packaging *Biofuel* – feedstock
Stalks and Bark(Phloem)	Decortication Retting	*Paper* - printer, specialty, newspaper, cardboard and packaging *Textiles* - apparel, fabric, handbags, carpeting, cordage hosiery and fine textile fibres. *Technical textiles* - rope, cordage, canvas, carpet backing, geotextile, horticultural textiles (shade cloth etc). *Industrial* - moulded products, agri-fibre composites, brake/clutch linings, caulking, insulation and fibreglass substitute.
Stalk with seeds	Extract Cell Fluid	Abrasive fluids
Entire Plant	Mulch and extract	Biofuel

Botany and Phytochemistry

Cannabis sativa L. is a highly variable, predominantly dioecious (male and female flowering plants), occasionally hermaphroditic, wind pollinated, herbaceous annual. Plants grow from 0.2 to 6.0 metres in height depending on growing conditions, with both male and female plants producing pollen. Male plants are typically tall and skinny, while females are more squat and dense (Chandra, Lata, Khan, et al. 2017; Pertwee 2014). The botanical classification of the *Cannabis* L. genus is highly controversial with two predominant schools of thought. The first is a monotypic, but highly polymorphic species, and the second a polytypic (multispecies) genus (Chandra, Lata, Khan, et al. 2017; Pertwee 2014; Small 2017). However, regardless of its current, and the future botanical classification, there are marked differences in desirable traits for its industrial and medicinal applications. Unfertilised female plants are cultivated for medicinal cannabis, and males produce superior hemp fibre. Fertilised plants are required for seed production in selective breeding programs, as well as hemp seed oil

manufacture. The phytocannabinoids are not distributed evenly through the plant, and can vary widely with the flowering portions (inflorescences) having the highest THC content (Potter 2014). THC is produced in secretory glands call trichromes, epidermal appendages on the inflorescences, leaves and bracts (specialised leaves) of female plants (Potter 2014; Small 2017). The female flowers themselves do not contain THC, rather it is the perigonal bracts surrounding the flowers that can be densely covered with the secretory trichomes (Figure 1) (Small 2017).

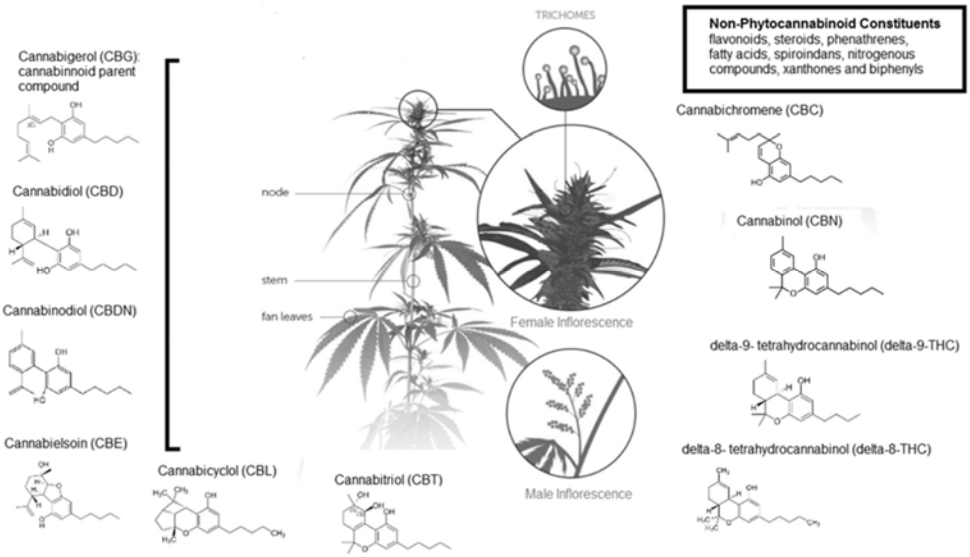

Figure 1: Phytocannabinoid Groups present in *Cannabis sativa* L.
(Adapted from Pertwee (2014) and Leafly (2017))

Male hemp plants are preferred to females because they produce better fibre (Small 2017), while the unpollenated female plants (*sinsemilla*, non-seed bearing) with their potential for high phytocannabinoid yields make them the obvious choice for medicinal and recreational growers. *Cannabis sativa* L. plants produce a myriad of chemical constituents including over 100 phytocannabinoids, and in excess of 500 non- cannabinoid compounds (ElSholy & Gul 2014; ElSohly et al. 2017). In Australia, commercial cannabinoid medicines such as Drobanol (synthetic THC) and Natiximols-Sativex (THC and cannabidiol) can be accessed through the Therapeutics Goods Administration's (TGA) special access scheme. Cannabinoid medicines are based on the isolated and/or synthetic THC and CBD. However, it is thought that the synergistic activity of the many phytocannabinoid and non-phytocannabinoid components, rather than a single component like THC or CBD, that imparts the therapeutic benefits for treating chronic and debilitating conditions such as multiple sclerosis, epilepsy and chronic pain relief (National Academies of Sciences & Medicine 2017). The pharmacological classification of *C. sativa* L. is controversial. Cannabinoids have been classified as a sedative-hypnotic, as well as mixed-stimulant depressant, mild hallucinogen or psychedelic (Small 2017). The plant derived chemical constituents referred to phytocannabinoid are classed as; Cannabigerols (CBG), Cannabidiols (CBD), Cannabinodiols (CBDN) Cannabielsoins (CBE), Canabicyclols (CBL), Cannabitriols (CBT), delta-8-tetrahydrocannabinols (Δ8-THC), delta-9-tetrahydrocannabinols (Δ9-THC), cannabinols (CBN) and Cannabichromenes (CBC) (Figure 2). Non-phytocannabinoid constituents include flavonoids, steroids, phenanthrenes, fatty acids, spiroindans, nitrogenous compounds, xanthones and biphenyls (ElSholy & Gul 2014). Phytocannabinoids are predominantly in their carboxylative state, and it is the application of light and heat during storage, or combustion, that transforms them to the neutral state (National Academies of Sciences & Medicine 2017) The precursor to THC and CBD is olivetolic acid (Figure 2).

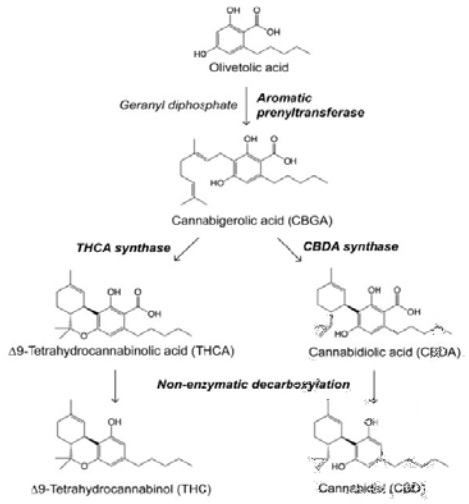

Figure 2: Synthesis Pathway for Δ^9-Tetrahydrocannabinol and Cannabidiol in *Cannabis sativa* L.
(National Academies of Sciences & Medicine 2017, p. 51)

Australian Perspective

The plant *C. sativa* L. first arrived in Australia on the First Fleet as a gift from Sir Joseph Banks (Jiggens 2012). Cannabis based medicines were available in Australia during the late 1800's and early 1900's. One of the most popular 'medicines' was Dr J. Collis Brown's Chlorodyne, a mixture of hash dissolved in chloroform and topped up with morphine (Freeman, 1864; Jiggens 2012; Rainford 2009). Cannabis also grew wild in scattered pockets of New South Wales early last century. Australia was a signatory to the 1925 Geneva Convention on Opium and Other Drugs which restricted the use of C. sativa L. to medical and scientific purposes only. In 1938, *C. sativa* L. was declared a noxious weed by the then Director of Agriculture Mr McDonald. Field officers instructed to eradicate every trace of the weed because "*its effect upon the nation could be disastrous if evil-intentioned persons attempted to make use of it*" ('Marihuana Drug is Banned' 1938). The 1960's and 1970's saw an increase in the use of *C. sativa* L. as a recreational drug. During this time Australia signed onto the international Single Convention of Narcotic Drugs in 1961. The intent of the Convention was to combat drug abuse by coordinated international action, and designated *C. sativa* L. as legal for medicinal purposes only. Other legal instruments of the period included the Australian Narcotic Drugs Act 1967, United National Convention on Psychotropic Substances (1971) and the amened Single Convention on Narcotic Drugs (1972). In the 1990's there was a softening of opinion towards *C. sativa* L. with greater recognition of its potential industrial applications. Tasmania amended its the Poisons Act 1971 in 1995 to allow for industrial hemp cultivation and/or manufacture, a move that was followed by all other States and the Australian Capital Territory (Table 2). The Northern Territory is currently the only state where cultivation of Industrial Hemp is not permitted. In 2016, Australia amended the Narcotics Drugs Act to permit licensed cultivation and manufacture of medicinal cannabis for clinical trials and scientific research. There is now discussion as to the removal of *C. sativa* L. from the single convention on narcotic drugs (pers. comm. 2017).

Table 2: Australian Legislative Instruments for Licensing of *Cannabis sativa* L. cultivation and Production

Product	Jurisdiction / Register	Legislation	Permitted THC Content in Industrial Hemp
Medicinal Cannabis	Commonwealth / *Office of Drug Control*	*Narcotics Drugs Act 1967*	Not Applicable
		Single Convention of Narcotic Drugs 1961 (as amended in 1972)	Not Applicable
	Therapeutic Goods Administration	*The Poisons Standard (SUSMP)*	Processed hemp fibre containing 0.1% or less of THC and hemp fibre products manufactured from such fibre. Hemp seed oil for purposes other than internal human therapeutic use containing 50 mg/kg or less of cannabinoids. When labelled "not for internal use" or "not to be taken".
Industrial Hemp	Australian Capital Territory / *Department of Environment and Heritage*	*Hemp Fibre Industry Facilitation Act 2004*	Must not exceed 1% THC in leaves and flower heads. Certified hemp seed must only be harvested from plants with no more than 0.5% THC in leaves and flowering heads.
	New South Wales / *Department of Primary Industries*	*Hemp Industry Act 2008*	Must not exceed 1% THC in leaves and flower heads. Certified hemp seed must only be harvested from plants with no more than 0.5% THC in leaves and flowering heads. Licensee must not supply hemp with THC content greater than 1%.
	Northern Territory / *Department of Primary Industry and Resources*	*Misuse of Drugs Act 2010*	Cultivation Not permitted. Exemptions exist for processed fibre hemp products, processed products made from hemp seeds as long as they are not whole, and hemp seed oil for external use containing less than 0.005% tetrahydrocannabinols
	Queensland / *Department of Agriculture and Fisheries*	*Drugs Misuse Act 1986:* *Part 5B Commercial production of industrial cannabis*	Commercial industrial Cannabis plants grown for seed or fibre must not exceed 1%THC under the Act, and may only be grown from seed certified to produce plants with no more than 0.5% THC.
	South Australia / *Office of Industrial Hemp and Medicinal Cannabis*	*Industrial Hemp Act 2017*	Has a concentration of THC in the leaves and flowering heads of not more than 1% and grown from certified seed.
	Victoria / *Department of Economic Development, Jobs, Transport*	*Drugs, Poisons and Controlled Substances Act 1981*	Cannabis may be cultivated from seed harvested from low-THC Cannabis, and may be sold or supplied when substantially free of flowering heads and leaves and containing no more than 0.1% THC. Low-THC Cannabis is defined as

Product	Jurisdiction / Register	Legislation	Permitted THC Content in Industrial Hemp
	and Resources (DEDJTR)		containing no more than 0.35% THC in the leaves and flowering heads.
		Drugs, Poisons and Controlled Substances (Industrial Hemp) Regulations 2008	Processed fibre products may contain a maximum of 0.1% THC, must not contain whole Cannabis seeds, and must not be in a form suitable for ingestion, smoking or inhalation. Processed seed products may contain no more than 0.001%THC and must not contain whole seeds
	Western Australia Department of Agriculture and Food	*Industrial Hemp Act 2004* *Industrial Hemp Regulations 2005.*	Industrial hemp is defined as Cannabis containing no more than 0.35% THC in the leaves and flowering heads. Industrial hemp seed is that which is certified as having been produced from industrial hemp or that which will produce industrial hemp when cultivated. Crops must be grown from approved seed sources

Cultivation & Manufacture

In Australia, the legal cultivation and manufacture of *C. sativa* L. can be undertaken as either a medicinal cannabis or industrial hemp crop. Medicinal cannabis is covered by two separate licenses, cultivation and manufacture, under the Narcotic Drugs Act 1964, issued by the ODC. Licenses to grow industrial hemp are managed by States and Territories. The commercial cultivation and manufacture of recreational cannabis remains illegal in Australia. The preferred cultivation approaches for medicinal cannabis and industrial hemp vary considerably due to the physical and chemical traits desired by the industry. Industrial hemp is traditionally a broadacre seasonal crop, while medicinal cannabis is grown either indoors under artificial light or in glasshouses with natural light (Potter 2014). Indoor cultivation is important for controlling environmental conditions that may affect the phytocannabinoid profile, enabling greater consistency and quality, as well as protection from crosspollination (contamination) by other commercial or illicit crops (Deloitte Access Economics 2016; Potter 2014; Small 2017).

Cannabis sativa L. cultivation may be undertaken from seed or clones. Seeds or nursery stock can be acquired from other licensed Australian cultivators, or brought from overseas with an import permit issued by the Department of Agriculture and Water Resources (Office of Drug Control 2017). Imported seed is subject to hot water treatment to eliminate any potential pathogens. Important considerations of cultivation include light intensity and duration, pest and disease management including moulds, cultivation model (hydroponic versus media based) and fertilising regime. The irradiance level (light intensity), as well as exposure duration for indoor and glasshouse crops can significantly influence the phytocannabinoid profile and yields, particularly the THC content (Chandra, Lata, ElSohly, et al. 2017; Potter 2014). The length of daylight, relative to the latitude where outdoor crops are grown also influences flower development and phytocannabinoid yield (Potter 2014). Application of pesticides and herbicides are generally avoided in pharmaceutical production (Potter 2014), and as undesirable in recreational cannabis markets. However, they may be applied in hemp production. Management of pests and diseases is typically addressed through good management practices including cultivation of pest resilient traits, mechanical ventilation systems for indoor production, use of quality disease-free growing media, cleaning and disinfection of grow rooms and creating open canopies where fresh air can freely circulate and

reduce potential for fungal proliferation such as *Botrytis cinerea*, *Penicillium* spp., *Fusarium* sp. and *Phytophora* sp. (Couch et al. 2017; Potter 2014; Walters et al. 2017).

Depending on the crop, as well as the size and girth plants, harvesting may be undertaken manually by hand (medicinal and recreational cannabis), or with heavy machinery such as combine harvesters (hemp). After harvesting, medicinal plants are dried to prevent bacterial spoilage by suspension outdoors on wire or lines, in specially designed rooms like tobacco barns, or in ovens (Couch et al. 2017; ElSohly et al. 2017). The female inflorescences are destemmed and manicured to remove the outer bracts with the lower THC content, and the remaining resinous floral tissue then undergoes a second refinement, may be referred to as garbling, to remove any undesirable plant material (Potter 2014). Female flowers may also be rubbed through size selective screens to separate small stems and seeds from final product (ElSohly et al. 2017). The flower material is then packaged in food grade quality polyethylene bags, and stored at either 18-20°C (short term) or -10°C (long term) prior to final processing (ElSohly et al. 2017). Automated processes have been developed for processing of *C. sativa* L. (Couch et al. 2017; ElSohly et al. 2017). Essential oils from *C. sativa* L. may be processed through carrier oil, solvent, super or sub-critical carbon dioxide (CO_2) or light hydrocarbon extraction processes. (Deloitte Access Economics 2016; Potter 2014)

Processing and manufacturing of industrial hemp requires a variety of mechanical, chemical and/or biological processes depending on the end product. The harvesting of hemp can be undertaken using traditional hay making equipment including rotary mowers and combined harvesters (Fike 2016). In fibre production, plants are traditionally field dried and then subject to retting process (microbial degradation) by either water submersion in water, paddock retting (dew or desiccation) or industrial processes (chemical or sonication) (Graham, Beltrame & Fitzgerald 1995). The retting process breaks down the bonds joining the bast (outer bark fibres) from the woody xylem core, which may also be referred to as shives (Fike 2016; Graham, Beltrame & Fitzgerald 1995; Small 2017). The remaining material is then baled and transferred to the end user for processing into cordage, textiles, building materials, boards and biofuels as depicted in Figure 2 (Graham, Beltrame & Fitzgerald 1995). For oil, seeds are pressed or crushed to produce oil, or hulled for seed meat and the hulls ground into flour (Fike 2016). Supercritical CO_2 may also be used for extraction for hemp oil. (Aladić et al. 2015)

Occupational Health and Safety

The indoor and outdoor cultivation models have their own inherent health and safety hazards which are not just associated with the growing environment, but also with the plant and its constituents. The anticipation of potential hazards needs to be extrapolated from similar industries including opioid cultivation and manufacture. In the United States, NIOSH has carried out a risk assessment on harvesting and processing of crops at a Californian outdoor organic recreational marijuana farm (Couch et al. 2017). Outdoor production of medicinal cannabis is unlikely to be pursued in Australia due to the strict licensing requirements, however the findings from the NIOSH study provide an indication of potential hazards encountered in the processing and manufacturing procedures.

Optimal growth conditions for *Cannabis sativa* L. are 21°C. to 32°C, with a relative humidity of 50% to 70% (Potter 2014; Small 2017) are, however, optimal conditions for microbial growth, making exposure to fungi and bacteria a potentially significant hazard for workers. Microbial hazards are especially a concern for indoor and glasshouse cultivation if ventilation systems are inefficient or unsuitable for the premises. Fungal spore concentrations from non-detect to >5400cfu/m^3 have been recorded for indoor illicit grow operations, with airborne mycoflora including potential pathogenic species such as *Cladosporium* sp., *Penicillium* sp., *Aspergillus* sp. and *Alternaria* sp.(Martyny et al. 2013) The processing of hemp fibres also involves potential for significant microbial and organic dusts exposures as is evidenced by the concentrations of organic dust, bacteria, fungi and endotoxin measured in hemp textile factories (Fishwick, Allan, Wright & Curran 2001; Mukherjee et al. 2004; Munshi & Chattoo 2008; Ribeiro et al. 2015), as well as the occurrence of adverse respiratory effects and diseases including allergic asthma

and byssinosis (Barbero & Flores 1967; Bouhuys et al. 1969; Bouhuys, Gilson & Schilling 1970; Bouhuys et al. 1967; Bouhuys & Van de Woestijne 1970; Bouhuys & Zuskin 1976; Chattopadhyay, Saiyed & Mukherjee 2003; El Ghawabi 1978; Fishwick, Allan, Wright, Barber, et al. 2001; Fishwick, Allan, Wright & Curran 2001; Gandevia & Milne 1965; Guyatt et al. 1973; Lai & Christiani 2013; Lopez Merino et al. 1973; Zuskin, E. & Bouhuys 1975; Zuskin, E et al. 1990; Zuskin, Eugenija et al. 1992; Zuskin, Eugenija, Mustajbegovic & Schachter 1994; Zuskin, E. & Valic 1971; Zuskin, E. et al. 1975). Exposure to cannabis seed has been associated with bronchial asthma and anaphylaxis (Stadtmauer et al. ; Vidal et al. 1991), and there have been cases of pulmonary aspergillosis associated with marijuana smoking (Chusid et al. 1975; Gargani, Bishop & Denning 2011; Kurup et al. 1983; Llamas, Hart & Schneider 1978). The *C. sativa* L. pollen may be wind dispersed over vast distances (Aboulaich et al. 2013; Choudhary et al. 2017; Freeman, GL 1983), and has been recognised a public health allergen of significance since last century (Maloney & Brodkey 1940). Exposure to *C. sativa* L. pollen can stimulate hypersensitivity responses including allergic asthma, rhinitis and conjunctivitis. In addition, IgE mediated cannabis allergy is reported to be on the rise (Basharat et al. 2011; Decuyper, I et al. 2015; Decuyper, II et al. 2017; Nayak et al. 2013). Enforcement and laboratory personal have reported cases of contact dermatitis associated with handling of *C. sativa* L. (Herzinger et al. 2007; Herzinger et al. 2011; Majmudar, Azam & Finch 2006; Rojas Pérez-Ezquerra et al. 2015; Williams, Thompstone & Wilkinson 2008)

To optimise yields, carbon dioxide may be added into the atmosphere of indoor grow operations. This procedure could potentially expose workers to oxygen deficient atmospheres if undertaken incorrectly, as well as the hazards associated with handling of compressed gases in the occupational environment. The exposure of the workers to the active ingredients of *C. sativa L.* is of concern. Air analysis could be undertaken to monitor for exposure to CBD, THC and a range of other plant terpenes. Biological monitoring could be used to monitor for levels of THC, 11-hydroxy-THC, 11-nor-9-carboxy-THC and CBD. Other chemical hazards that may be encountered during cultivation include the use of potentially corrosive and irritant rooting hormones such as naphthaleneacetic acid, indolebutyric acid for propagating clones and the herbicide 2, 4- dichlorophenoxyacetic acid for weed control a potential mutagen, as well as potentially corrosive and irritant disinfectants such as sodium chlorite used in cleaning indoor grow houses. The *C. sativa L*. are prone to the fungal disease powdery mildew which may require application of fungicides. Inorganic fertilizers for promoting plant growth and flower development are potential corrosive or irritant hazards, while organic fertilizers are a potential biological hazard. The extraction of volatile oils from *C. sativa* L. may also expose workers to potentially hazardous chemicals as well explosive atmospheres, especially use of solvent extraction methods using petroleum-ether (butane, hexane), naptha or ethanol.(Deloitte Access Economics 2016; Editorial 2014; HIDTA 2014) Supercritical CO_2 extraction of cannabis oil requires the application of pressure, heat and CO_2 which can create physical as well as asphyxiation hazards.(Busick 2016; Lucas et al. 2003) Physical hazards encountered in the workplace may include ergonomic and manual handling, electrical, heavy machinery, working at heights and noise induced hearing loss. Workers may also be susceptible to heat stress and other environmental hazards.

Californian recreational marijuana farm workers are concerned about physical hazards associated with the bud trimming and harvesting process. Other concerns included bioaerosol exposure (*B. cinerea*, *Actinobacteria* sp.) and widespread contamination of surfaces with THC (Couch et al. 2017). An earlier study of 30 illegal indoor cannabis grow operations undertaken in Colorado prior to recreational cannabis legalisation in 2013 identified potential health and safety concerns with power supply for lighting, carbon monoxide from CO_2 generators, and bioaerosols from microbial growth due to high humidity and poor indoor ventilation. (Martyny et al. 2013) Walters et al. (2017) in a study on worker health and wellbeing in the Colorado recreational marijuana industry and found that the workers were concerned about physical injury associated with the harvesting and manicuring of crops, and the limited amount of health and safety training that they received. However, conversely, the workers also expressed little interest in receiving health and safety training in spite of reporting health symptoms such as skin irritation, eye irritation and headache and dizziness associated with pesticide application (Walters et

al. 2017). The Colorado recreational marijuana industry has been collaborating with researchers and regulators for the development of health and safety guidelines for the industry. The guidelines provide a comprehensive review of biological, physical and chemical hazards associated with the Colorado cultivation and manufacture model for recreational marijuana including mould and sensitizers, pesticides, disinfectants, indoor air quality, compressed gasses and ergonomics. (Marijuana Occupational Health and Safety Work Group 2017)

CONCLUSION and RECOMMENDATIONS

There needs to be further consideration of the potential long term health effects to workers in the medicinal cannabis and industrial hemp industry in Australia. This review has indicated potential major occupational health issues, such as dermatitis, respiratory disease and physical injuries, for workers that should be addressed before the medicinal cannabis goes into full commerical production, as well as the upsizing of the industiral hemp cultivations. There are also knowledge gap regarding the potential long term effects associated with chronic exposure in the workplace to medicinal cannabis. It is recommended that collaboration similar to the Colorado Marijuana Occupational Health and Safety Work Group be developed to produce a best practices guideline relative to the Australian industry models, for medicinal cannabis and industrial hemp.

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DRUGGED AT WORK – RISK ASSESSMENT FAIL.

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ABSTRACT

This case study discusses a classic case of a risk assessment failure which unfortunately led to a legitimate workplace exposure to illicit drugs.

Risk assessments are an essential and effective tool widely used to protect workers from a diverse range of workplace hazards and to prevent disease. Under the NSW *Work Health and Safety 2011 Legislation*, employers are required to 'manage risks' to eliminate or reduce risks so far as is reasonably practical.

Therefore, the importance of carrying out risk assessments to identify and control hazards cannot be overstated, particularly when they are associated with workplace exposure to drugs such as pseudoephedrine and cocaine during genuine workplace activities.

Chemicals such as drugs can enter the body in many ways, and in this case exposure occurred due to: -

- High concentrations of illicit drugs were extremely likely due to the specific tasks undertaken by a worker and particular workplace scenario,
- Failure to assess risk for a task allowed exposure to cocaine and pseudoephedrine via inhalation, skin absorption and ingestion,
- No instructions or procedures were available for minimum clothing or PPE requirements for the task (the only form of 'respiratory protection' provided was a surgical mask)
- Existing ventilation was not utilised, and
- No special clean up or personal decontamination procedures were provided.

As a result, workplace exposure to drugs may lead to temporary (and potentially longer term) effects. Other serious long term ramifications related to employment status may also occur due to positive random workplace drug tests.

Therefore, it is essential thorough risk assessments are conducted where hazardous chemicals, including illicit drugs, may be present in order to prevent exposures and other potential social issues arising such as habituation and contamination extending outside of the workplace into the wider community.

INTRODUCTION

This interesting case study discusses the importance of carrying out risk assessments to identify and control hazards, particularly when they are associated with workplace exposure to illicit drugs such as cocaine and pseudoephedrine (and methamphetamine) during legitimate workplace activities.

Appropriate management of hazards and risks in the workplace is essential to ensure the health and safety of workers. Under the NSW *Work Health and Safety 2011 Legislation* (cl 35), employers are required to 'manage risks' to eliminate or reduce risks so far as is reasonably practical.

Risk assessments are an effective tool widely used to manage risks by protecting workers from a diverse range of workplace hazards and to prevent disease. When hazards are identified which may cause harm, control strategies must be employed in order to prevent exposure and any subsequent health effects which may arise.

Carrying out risk assessments is vital not only to protect the health of workers, preventing exposure to certain hazards may have other significant benefits such as ensuring employment status is sustained and compliance with employment contracts and organisational requirements.

Regarding this particular case study, it is unknown whether a risk assessment was carried out or not. However, the consequence of undertaking specific workplace activities which involved illicit drugs was that a worker was

exposed, and ramifications of that exposure unravelled after a random employee drug test was found to be positive. The worker was stood down based on the positive test and subsequently lost employment as a result.

It is proposed that if a formal risk assessment was undertaken by competent persons, worker exposure to potential illicit drugs would have been prevented as suitable control strategies would have been employed.

BACKGROUND

This case study is a classic case of a risk assessment failure which led to a legitimate workplace exposure to illicit drugs. The workplace in question has high integrity and respect within the community, however workplace practices during specific situations (which is not uncommon in the context of this workplace) inadvertently can expose workers to illicit drugs.

The specific activity was to determine if illicit drugs were present in various items in order to gather evidence to support prosecution of criminal activity. This task is known as 'deconstruction' and is carried out to reveal drugs or other contraband which may be hidden within various items. The personnel carrying out the activity are normally law enforcement personnel.

The employment conditions and organisational requirements for this workplace requires workers to undergo regular random drug tests to ensure they are not under the influence of illegal drugs during work or involved themselves in criminal activity. Positive personal drug tests are considered significant in the context of this specific workplace.

Therefore, due to the consequence of exposure to illicit drugs it is essential to carry out suitable risk assessments where exposure to these types of chemicals may occur to ensure workers are protected to prevent health effects, possible habituation and to support ongoing employment status.

CASE STUDY WORK ACTIVITIES – 'DECONSTRUCTION'

Deconstruction tasks are carried out to reveal contraband within various items. The contraband may be drugs, cash, stolen property etc., and the items may be cars, boats, furniture, or various other objects such as electrical or mechanical equipment.

Depending on the circumstances, deconstruction activities may take long periods of time (i.e. many hours over many days) in order to thoroughly and systematically work through the item to find concealed material. In the case of illicit drugs, they are usually found as a powder within a package (e.g. plastic wrapping).

Deconstruction activities carried out to reveal hidden drugs can involve a great deal of hard work as items are methodically broken apart using equipment/tools and physical force. Some of the tasks require the use of drills, hammers, saws and other tools to break apart the objects. As the object is broken down, at every stage it is possible to find packages of powdered material (suspected to be illicit drugs) or other contraband. At times, items are also banged down, tipped up and hammered to dislodge hidden packages and powder. Wire tools, spatulas and other implements can also be used to recover powder from the object and packages may break during the deconstruction work releasing powder into the work space to settle on horizontal surfaces and personnel.

Recovery of all packages and powder (even if spilt) is important as it may be used as evidence for prosecution. Therefore, brushing up dislodged powder from floors and other horizontal surfaces with dustpan and brush, and bagging recovered material into exhibit bags is required. The bags are weighed and labelled appropriately prior to sending for laboratory analysis.

At the completion of the deconstruction work, the work area must be cleaned and all materials gathered for suitable storage or disposal.

For this case study:

- The work was carried out in an internal environment where fume hoods were present in the room, however not utilised during deconstruction work;

- The worker was wearing their own clothing (i.e. no supplied uniform) during the work and no specific personal protective equipment (PPE) was worn (the only form of 'respiratory' protection available was a surgical type mask);
- Regarding the composition of the powder recovered from the items, it was later found to contain pseudoephedrine and cocaine.

Therefore, where legitimate workplace exposure to drugs (i.e. suspected to be illicit drugs) has the potential to occur, suitable protective programs and procedures must be implemented to ensure exposure is effectively controlled, in other words, a suitable risk assessment must be carried out to prevent exposure.

IMPACT OF EXPOSURE TO DRUGS

Prevention of worker exposure to agents which are restricted (i.e. listed as a Scheduled chemical on the Australian Government *Poisons Standard* 2017) is important, particularly for workers who may be exposed to chemicals such as pseudoephedrine and cocaine in their normal workplace duties.

There is substantial impact associated with the use of recreational/illicit drugs and substances in workplaces, hence the requirement for regular (and random) drug testing for workers in many organisations, including law enforcement agencies. In addition, many employment contracts prohibit the use of illicit drugs as it may impair workplace performance and decision making, and may indicate links to illegal/criminal activities.

Where the drug testing is in place, suitable procedures must be in place in order to handle the situation if positive tests are obtained. If this occurs, the scenario must be managed appropriately with due diligence and must consider the sensitivity of the situation. In these circumstances, employees must understand consequences of any positive test results and the process for any subsequent testing and formal investigations which are undertaken as a result.

Tests carried out can include biological monitoring in the form of urine testing (i.e. for short term exposure) and hair testing (for long term exposure) may also be required in some circumstances.

From the information provided above regarding deconstruction activities, it can be assumed the opportunity for exposure was extremely high. The worker central to this case study failed a random drugs test carried out after several days of deconstruction activities were undertaken. The positive tests identified cocaine (urine and hair test) and methamphetamine (hair test).

As a result of the positive tests, the worker was suspended from duties pending further investigation. The subsequent investigation carried out by the employer concluded that as the worker tested as 'positive', their employment was not reinstated. It is understood the possibility of legitimate workplace exposure to the specific drugs identified in both the recovered powder and biological tests carried out were not considered in the investigation undertaken by the employer, and the worker's employment was terminated.

CASE STUDY DRUG INFORMATION

The illicit drugs which are applicable to this particular case study are pseudoephedrine (and methamphetamine) and cocaine.

Some information is provided below for these chemicals.

- *Pseudoephedrine* is a decongestant drug formulation (typically pseudoephedrine hydrochloride or sulphate salts) which can be found in many over-the-counter preparations.
    - Pseudoephedrine is a Schedule 4 - Prescription Only Medicine, or Prescription Animal Remedy (Australian Government *Poisons Standard* 2017). The use or supply of which should be by or on the order of persons permitted by State or Territory legislation to prescribe, and should be available from a pharmacist on prescription.

- Pseudoephedrine can be used to make the stimulant and highly addictive drug, *methamphetamine*. Possession, sale, transport and production of methamphetamine is illegal in Australia.
- Routes of entry into the body for methamphetamine by drug users include snorting/sniffing/blowing (i.e. nasal insufflation), smoking, injection or eating. Depending on the route of entry, various factors differ such as: -
  - Uptake into the body, e.g. injecting incurs fastest effect
  - Duration of the stimulant effect (i.e. 'rush') is different, e.g. snorting gives longer effect duration than smoking or injecting
  - Overall adverse health effects, e.g. smoking damages lungs, and is more addictive than snorting or eating

- *Cocaine* is a stimulant drug which is can used for limited (and restricted) therapeutic applications. As an illegal recreational drug, it is a very addictive which give users energy and happy/euphoric feelings.
  - Cocaine is a Schedule 8 - Controlled Drug (Australian Government *Poisons Standard* 2017), i.e. a substance which should be available for use but require restriction of manufacture, supply, distribution, possession and use to reduce abuse, misuse and physical or psychological dependence.
  - Various salts of cocaine (e.g. hydrochloride, sulphate and nitrate) are available, with cocaine hydrochloride commonly used as a recreational drug as it is soluble in water.
  - Routes of entry into the body include: -
    - Snorting/sniffing/blowing (nasal insufflation), inhalation, smoking, skin & gum absorption, chewing & ingestion, injection, via mucous membranes such as eye, and as a suppository
    - Whilst not directly absorbed into or metabolised by the body, cocaine can also be absorbed into hair from direct contact with the chemical (i.e. from external contamination) (LeBeau, 2009) (absorption into hair would have no stimulant effect, however when tested, the hair can show a positive result which mimics that of a cocaine user)
  - For persons using the chemical as a stimulant recreational drug, body uptake of the chemical and duration of the 'high' are dependent on route of entry chosen. In terms of using the drug to induce a 'high, the least effective routes of entry include inhalation and ingestion.

RISK ASSESSMENTS

Codes of Practice provide practical guidance in achieving compliance with the NSW Work Health and Safety Legislation. Regarding risk assessments, the SafeWork Australia 2011 Code of Practice: *How to manage work health and safety risks* is applicable for persons with health and safety duties. The Legislation requires persons conducting a business or undertaking to "eliminate risks to health and safety so far as is reasonably practicable, and if it is not reasonably practicable to eliminate risks to health and safety – minimise those risks so far as is reasonably practicable" NSW *Work Health and Safety 2011 Legislation* (Cl 35).

When discussing hazard and risk, it is important to consider the meaning of these terms. From the SafeWork Australia (2011) document, a hazard has the potential to cause harm to a person, whereas risk is the possibility of harm occurring upon exposure to a hazard. Controlling risks is essential to eliminate impacts to the health and safety of workers, or if that cannot be achieved, the risks must be minimised so far as is reasonably practicable.

Management of risks is a step by step process known as a Risk Assessment. This process considers the nature of the hazard(s) and subsequent consequences, and employs strategies to eliminate or minimise health and safety risks by controlling exposure (SafeWork Australia, 2011).

A risk assessment must be carried out for all work tasks/activities which may lead to a risk to health upon exposure to a hazard.

From the SafeWork Australia (2011) document, the method involves 4 simple steps: -

1. *Identify Hazards:*
    a. **Recognise** any potential hazard (chemical, physical, biological, ergonomic, psychosocial) hazard which may cause harm to workers if exposed.
    b. During this phase, it is essential to consider all parts of a process, the work environment, and the actual tasks undertaken.
2. *Assess Risks:*
    a. Consideration must be given to the toxicity and significance of the hazard and any subsequent health effects.
    b. The pathways of exposure/routes of entry and the likelihood of exposure must be understood
    c. Determine the level or amount by **evaluating** the hazardous agent (as required) using measurement or assessment techniques.
    d. Consider and **evaluate** any existing controls in place
3. *Control Risks:*
    a. Determine and execute the most effective **control** measure for the particular situation
    b. Wherever possible elimination of the risk must be undertaken. If this is not possible, the risk must be minimised so far as is reasonably practicable.
    c. To **control** risk, apply the hierarchy of control ranking scheme to effectively control exposure (and risk).
4. *Review Control Measures:*
    a. To ensure that the control measures are effective as planned, a review must be carried out
    b. Review the entire risk assessment whenever;
        i. the process changes, or
        ii. the control measure is no longer is effective, or
        iii. new hazards or risks are identified

CASE STUDY RISK ASSESSMENT

For this case study, it is most unlikely that a risk assessment was carried out for the deconstruction activities conducted as worker exposures were not controlled. Information which could be used as part of a formal risk assessment for the scenario is provided.

Whilst chemicals such as pseudoephedrine and cocaine are normally considered as drugs, they are also listed as poisons in the Australian Government *Poisons Standard* (2017) and where workplace exposure to potential hazardous chemicals includes poisons, the carrying out of risk assessments is not excluded. Therefore, the Code of Practice for *How to manage work health and safety risks* must be used in order to manage health and safety risks which arise with hazardous chemicals that are restricted.

For this scenario, the various toxicological and other issues related to illicit drugs (i.e. potential adverse health effect, routes of entry, duration of exposure and dose) must be considered as part of the hazard identification and risk assessment process.

Therefore, whenever legitimate workplace exposure to drugs has the potential to occur, appropriate programs and procedures must be implemented to ensure exposure is effectively controlled, in other words, a suitable risk assessment must be carried out to prevent exposure.

Relating to this specific case study, a typical risk assessment for deconstruction activities would include some of the following information (for this case study, it is important to remember that at commencement of the deconstruction work, illicit material may or may not be found, and if found, the quantity and composition of any contraband present in the items is unlikely to be known).

a. HAZARD IDENTIFICATION

Hazard identification must include everything relating to the work processes undertaken including; tasks, activities, clean-up, storage, disposal and determine where controls must be implemented to ensure no adverse health effects occur for the persons conducting those tasks.

Regarding the deconstruction activities the potential for the presence of drugs, in powdered or tablet form was very high. Even if the exact composition of the recovered material is unknown at the time, consideration for the potential that the material could be positive for illicit drugs must be made, i.e. assume presence until otherwise confirmed.

Considerations for worker exposure includes:

- *Physical and chemical form*, e.g. powdered drugs can easily be made airborne for inhalation, absorbed through the skin (eyes and mucous membranes), and ingested (i.e. accidentally through poor personal hygiene)
- *Work activities* carried out which may lead to exposure, i.e. any activity which may lead to release of material in powder or tablet form and contact of that material with workers

b. ASSESS RISKS

Assessment of risk, i.e. likelihood of exposure must consider various factors such as listed below.

- *Toxicity and significance of the hazard*. Drugs are chemicals which are manufactured to treat or prevent disease or infection (i.e. medical benefit), or induce an effect on the body.
    - Where unknown substances may be encountered and consequences of that exposure are significant, exposures must be prevented
    - Illicit drugs include various substances which are restricted and/or forbidden by law due to various effects on the human body when taken. Pseudoephedrine (and methamphetamine) and cocaine are restricted substances and considered toxic/hazardous to heath (e.g. highly addictive, long term effects)
    - Exposure consequences of these chemicals are significant in terms of health effects and other ramifications such as employment status (particularly in the context of this workplace)
- *Routes of entry in the body.* Consider entry of the drug into the body via inhalation (normally the most significant route of entry into the body for many airborne contaminants), skin absorption (including mucous membranes and eyes), ingestion and injection.
    - Depending on the specific drug, there are multiple routes for these drugs to enter the body including nasal insufflation, smoking, injection, ingestion (i.e. gastrointestinal tract e.g. via mouth or suppositories), skin absorption, and via mucous membranes

- Regarding *evaluation* of the level or amount of exposure to the particular hazard, considering the effects and consequences of exposure to illicit drugs, evaluation is not considered to be so important as implementation of immediate and long term effective controls to prevent *any* exposure to illicit drugs (either confirmed or unconfirmed) at all times for law enforcement personnel. In addition, Exposure Standards are not applicable (or available) for chemicals such as pseudoephedrine or cocaine.
- For this case study, there were no controls to prevent exposure to potential illicit drugs in place during deconstruction activities (note: these activities involve hard physical work, the use of various tools and banging to remove packages of powder hidden with items).
    - The workers were involved in various activities which allowed uncontrolled spread of powdered material which was suspected at the time to be illegal drugs (presence of pseudoephedrine and cocaine was later confirmed by laboratory analysis)
    - Extraction ventilation (fume hood) was present in the space, however it was not utilised for deconstruction tasks
    - There were no procedures (i.e. work or decontamination procedures), training or personal protective equipment programs available to educate, prevent or control exposure to potential illicit drugs (or other chemicals) during deconstruction tasks. It is possible other hazards may also be present during deconstruction tasks such as noise, manual handling, ergonomics etc.
    - Even as a 'last resort' option in the hierarchy of controls, there were no specific or suitable personal protective equipment (PPE) employed or available for use during deconstruction activities such as skin protection (i.e. long sleeves and pants or disposable coveralls), hair protection (e.g. hairnets, snoods, hoods of coveralls), or respiratory protection (only 'surgical' type masks available) to prevent inhalation of powdered material. It should be noted that nitrile gloves were available and worn (however these gloves may not be suitable for preventing exposure to pseudoephedrine or cocaine during the specific activities undertaken)

c. CONTROL RISKS

In order to control any exposure to potential illicit drugs, various control measures applicable to the scenario must be employed. For the workplace in this case study, it should also incorporate an assumption that *any* chemicals found during deconstruction activities are hazardous (e.g. illicit drugs or other hazardous chemicals) until proven otherwise.

- Employ all suitable strategies available using the hierarchy of controls to prevent exposure, such as:
    - Elimination and substitution – unlikely to be achieved based on the nature of the tasks carried out and potential to uncover hidden substances of unknown composition (i.e. the purpose of the task is to 'find' hidden packages within items)
    - Isolation – isolate the activity and potential generation/release of chemicals from the worker to prevent exposure. Isolation may incorporate potentially dusty tasks being carried out inside a suitable enclosure/barrier which will block dust generated at the source from the worker
    - Engineering – employ the use of suitably designed, practical and effective local extraction ventilation systems and booths to capture any airborne material (e.g. gas, vapour, solid) generated during work deconstruction work to prevent exposure. Use of suitable HEPA vacuum cleaners and wet wiping for clean-up and housekeeping may also be useful
    - Administration – develop suitable standard operating procedures to prevent exposure; minimise dust generation using appropriate techniques and equipment, provide appropriate procedures for personal decontamination and personal hygiene; provision of suitable work uniforms/clothing

and laundry service to prevent potentially contaminated items being taken home; deliver targeted education and training to support all control measures utilised to prevent exposure

- PPE – employ suitable PPE to prevent inhalation (i.e. suitable respiratory protection which is commensurate with the level of risk and form of the hazard) and skin absorption by protection of hands, face, legs, arms, body and head with suitable level (and type) of material appropriate for the level of risk, and decontamination after use for any non-disposable items.

CONCLUSION

Effective management of risks to health in the workplace can only be achieved by a standard method whereby each hazard is identified, the risks for each hazard and work process are assessed, and the hazards are controlled to prevent exposure. When utilised and undertaken correctly, this step by step risk assessment procedure is an effective way to protect worker health and manage risks in the workplace.

Unfortunately for the worker in this case study, controls to prevent exposure to a substance suspected to be illicit drugs during genuine workplace activities were not in place. Based on the information available, it is likely the worker was exposed to significant quantities of pseudoephedrine and cocaine as a result of deconstruction activities which were carried out over several days of work. Therefore, it is most unlikely a risk assessment for deconstruction activities was conducted by the employer.

As a consequence of the workplace random drug testing which designed to provide compliance with employment conditions, a positive result was found for the worker. It is unlikely the employer considered the exposure to the drugs actually occurred during legitimate workplace tasks, i.e. from the deconstruction activities and ramifications of the positive drug test (after investigation by the employer) led to termination of employment for the worker.

For deconstruction activities, a risk assessment should consider issues such as:b-

- Likelihood of finding potentially hazardous chemicals (i.e. illicit drugs),
- An assumption that any material found could potentially be harmful until proven otherwise,
- Processes which may cause contact with potentially hazardous chemicals and workers (i.e. exposure), and routes of entry into the body,
- Consequence of exposure including health effects and subsequent effects such as habituation and employment status, and
- Practical and effective strategies to control and prevent exposure (i.e. using the hierarchy of controls)

The importance of carrying out risk assessments cannot be overstated and it is most likely that if a thorough risk assessment was undertaken, exposure to the illicit drugs would not have occurred for workers carrying out deconstruction activities as effective control strategies would have been employed.

Therefore, due to the consequence of exposure to illicit drugs it is essential comprehensive risk assessments are conducted *whenever any possible exposure* may occur for workers in order to protect worker health and minimise other potential social issues arising such as addiction and contamination extending outside of the workplace into the wider community.

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STATISTICAL EVALUATION OF NOISE DOSIMETRY SAMPLES ACROSS A WIDE RANGE OF SIMILAR EXPOSURE GROUPS.

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ABSTRACT

Personal noise dosimetry monitoring forms a crucial part of the noise exposure assessment for workplace personnel in defined Similar Exposure Groups. The Australian mining and Defence industries have among the highest levels of time lost and compensation paid in relation to occupational noise exposure and noise-induced health effects.

Over 1,000 personal noise dosimetry samples have been measured by Vipac Engineers & Scientists Ltd, spanning a 7-year period. Each dosimetry sample was assigned a Similar Exposure Group (SEG) and assessed against the noise exposure standard requirements. Consideration of extended work shift adjustments and exposure to ototoxic substances has enabled a more accurate assessment of SEG noise exposure.

A quantitative evaluation of the extensive dosimetry database involved assessing statistical measures such as Mean Adjusted $L_{Aeq,8hr}$ Levels per SEG (and over time); Range Maximum and Minimum; Upper and Lower Confidence Limits. This evidence-based information can provide an effective Exposure Risk Measure and Key Performance Indicator (KPI) for determining improvements both over time and within or across SEGs in workplaces.

Many example facilities have shown continual improvement in their average SEG dosimetry levels over time; whereas for others which have not, this may demonstrate a need for improved controls. This paper shows that noise dosimetry can be a key occupational hygiene process that provides vital information on the health monitoring of an employee, when assessed against their SEG, the noise exposure standard and the workplace or industry average noise exposure levels.

INTRODUCTION

Workplace hazards have long been part of everyday work life in many industries. Occupational noise is just one of these hazards. Health consequences can vary from person to person, short term and long-term hearing loss is the most common health risk associated with high noise exposure. Globally, and in Australia, companies are continually focusing on understanding the Work Health and Safety (WHS) risks associated with employment, and mitigating those risks 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.

Vipac Engineers and Scientists Ltd (Vipac), a medium sized engineering consultancy specialises in the measurement, assessment and control of occupational noise, has amassed an extensive noise dosimetry dataset from the mining and Defence industries. 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 SEGs. Extended work shift penalties were also evaluated to determine the level of impact the adjustment has on noise exposure. A further adjustment for exposure to ototoxic substances is also accounted for in some exposure groups, where applicable.

OBJECTIVES

The objectives of personal noise dosimetry allow 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 in both industries, it is neither feasible nor practical to measure every employee. 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.

HEALTH EFFECTS

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. 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 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.

CRITERIA and APPLICABLE REFERENCES

Several noise criteria references are applicable within industry. In Queensland, the Coal Mining Safety and Health Act 1999, and Regulation 2001 (3), provides the legislative framework that a coal mine is required to adhere. The Australian Defence industry is required to adhere to its own legislation as well as the Work Health and Safety Act 2011 (4). In summary, the acceptable noise exposure 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 (5) provides an adjustment for work shift durations of 10 hours or greater. This extended work shift adjustment is typically +1 dB(A) for workers who generally work between 10.5 and 12.5 hour shifts.

Guidance on Noise Dosimetry

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. A noise dosimeter is considered a common instrument for the measurement of noise exposure over a work period. There are shortcomings in using PSEMs which include, shouting and tapping of 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.

Ototoxic Substances

Hearing loss can be exacerbated through combined exposure to both noise and VOCs. Three major classes of ototoxic substances include: solvents, heavy metals and asphyxiates. Ototoxic substances can be present at a mine and within Defence. 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 (or potentially exposed to) a combination of high noise and ototoxic substances.

SIMILAR EXPOSURE GROUPS

The classification of workers into Similar Exposure Groups (SEGs) is important to enable accurate data assessment and review. A carefully though-out classification of employees allows an accurate risk profile to be created using noise dosimetry data. This also ensures that results can be compared between survey periods, where noise controls or administrative improvements have been implemented. The SEGs used for this assessment and comparison purposes are outlined in Table 1. Note that for privacy and security reasons, the Defence SEGs are identified as Units.

Table 1 Key Similar Exposure Groups

SEGs (Mining)	SEGs (Defence)
Production	Unit A
Maintenance	Unit B
CHPP	Unit C

METHODOLOGY

Noise dosimetry measurements are conducted as consistently as possible between sites and noise surveys, to ensure that all variables are limited as much as practically possible. Workers who are sampled for noise are informed of their requirements for wearing the dosimeters, and their cooperation is always appreciated. Where

data seems invalid, or tampered with, this data is excluded. Workers are often spoken to either during, or after a shift, to discuss work-activities, altercations or issues.

Instrumentation

The same Class 2 Quest Edge 5 Noise Dosimeters were utilised during measurement to ensure consistency. Field calibrations of 114 dB at 1 kHz were 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 noise dosimeters were fitted with a custom-made windscreen for added protection against knocks and wind/air-flow noise.

Measurement Duration

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 for the mining samples varied between 8 to 12 hours depending on the working shift length, and 6 to 8 hours for Defence personnel.

Extended Work Shifts

Extended work shifts greater than a typical 8 hour working day are prevalent within 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

MEASUREMENT RESULTS

Personal noise dosimetry samples from eight Australian coal mines and various Defence sites were measured over a 7-year period. 1330 valid samples were measured 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).

Workers in the mining industry can be exposed to a variety of noise sources, but the primary sources include: vehicle generated noise, hand-tools, alarms, and fixed plant. In Defence, noise exposure can include similar sources such as vehicle generated noise (in-cabin and external), and hand tools, but for some SEGS, also include weapons fire. All measurements used for the evaluation of mining and Defence samples are considered representative of typical SEG noise exposure.

SAMPLE SIZE

Where possible, a statistically relevant dataset was measured for each SEG, with recommended sample numbers derived using the NIOSH Occupational Exposure Sampling Strategy Manual (7). 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%.

A breakdown of noise dosimetry samples measured per SEG and the average SEG distribution found in the SEGs shown as a percentage is produced in Table 3.

Table 3 Breakdown of Noise Dosimetry Samples per SEG

	Prod.	Maint.	CHPP	Unit A	Unit B	Unit C
No. Noise Dosimetry Samples	368	177	70	109	164	442
SEG Distribution (Industry avg.)	60%	30%	10%	50%	25%	25%

Average Noise Level Summary (LAeq,8h)

Each of the 1330 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 4.

Table 4 Summary Table of $L_{Aeq,8h}$ Noise Data

	Prod.	Maint.	CHPP	Unit A	Unit B	Unit C
Minimum, dB(A)	64.4	66.7	79.9	72.1	58.8	66.8
Maximum, dB(A)	102.7	108.9	100.7	123.0	113.0	117.3
Mean, dB(A)	86.4	86.9	88.0	89.2	84.6	88.9
Samples above NES	232	106	61	69	84	262
% above NES	63	60	87	63	51	59

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.

From Figure 1, the mean 8-hour equivalent $L_{Aeq,8h}$ noise exposure level exceeded the noise exposure standard of 85 dB(A) for each SEG assessed, with exception to Unit B which was 0.4 dB(A) lower. The following conclusions are derived from the dataset:

- All mean 8-hour equivalent $L_{Aeq,8h}$ noise exposure levels exceed the criterion when considering ototoxic substance exposure, if applicable
- In mining, the CHPP SEG had the highest mean noise exposure level of 88 dB(A), 3 dB(A) higher than the NES
- In Defence, Unit A and C shared the highest mean noise exposure level of 89 dB(A), 4 dB(A) higher than the NES, and more than 4 dB(A) greater than Unit B
- More than half of all samples measured, in all SEGs, exceeded the NES

- The range of noise levels in Defence varies greatly when compared with the mining industry (i.e. difference between minimum and maximum). A variance of up to 42 dB(A) in mining, compared with 54 dB(A) in Defence.

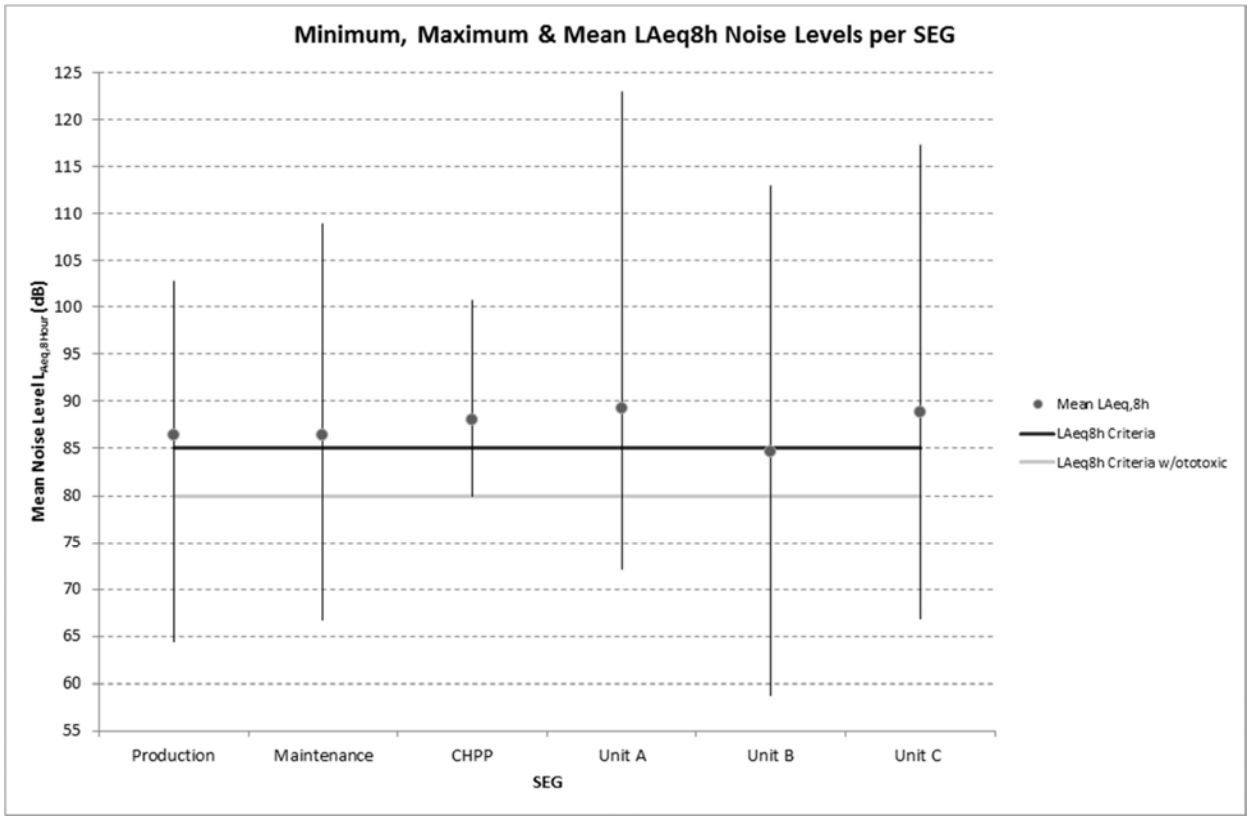

Figure 1 Normalised and Adjusted $L_{Aeq,8h}$ (mean, min & max)

Noise measurement results are useful in providing information on the average noise level exposure for workers in any noise environment, providing that the sample has not been interfered with. Depending on the results, they can be a useful indicator to rank the risks, and focus on detailed noise monitoring, with the primary goal of determining noise controls.

Engineering noise control is the primary and typically most beneficial way of noise reduction; however, it is not always feasible or practical. Removal of an employee from a high noise environment, PPE and administrative controls can also provide the desired effect of reducing the mean 8-hour equivalent $L_{Aeq,8h}$ noise exposure level.

Key Performance Indicators

An indicator of performance can be to show measurable improvement, or lack thereof, through a comparison of results. Conducting regular noise dosimetry within SEGs that have been identified as high risk, or exceeding the NES, provides a solid dataset for accurate data review, and comparison against future results. If noise reduction measures or behavioural changes have been implemented in a particular SEG, noise dosimetry, and physical inspections can show whether improvements have been made, and assist in determining whether controls have been effective.

When considering the effectiveness of noise control, each SEG in Defence was provided with noise reduction projects. Two noise surveys were conducted for each SEG; before noise controls and after noise controls. Noise dosimetry measurements in each SEG during each survey provided an opportunity to compare levels and determine whether measurable improvements were made. Table 5 provides a comparison of noise data on an example SEG (Unit A), noting that 2015 data was conducted prior to noise controls being implemented, and 2017 is post noise control implementation.

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

	Group 1 2015	Group 1 2017	Group 2 2015	Group 2 2017
Minimum, dB(A)	89.7	81.3	82.8	77.0
Maximum, dB(A)	93.9	97.7	92.3	87.2
Mean, dB(A)	92.3	88.3	87.4	81.2

Figure 2 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.

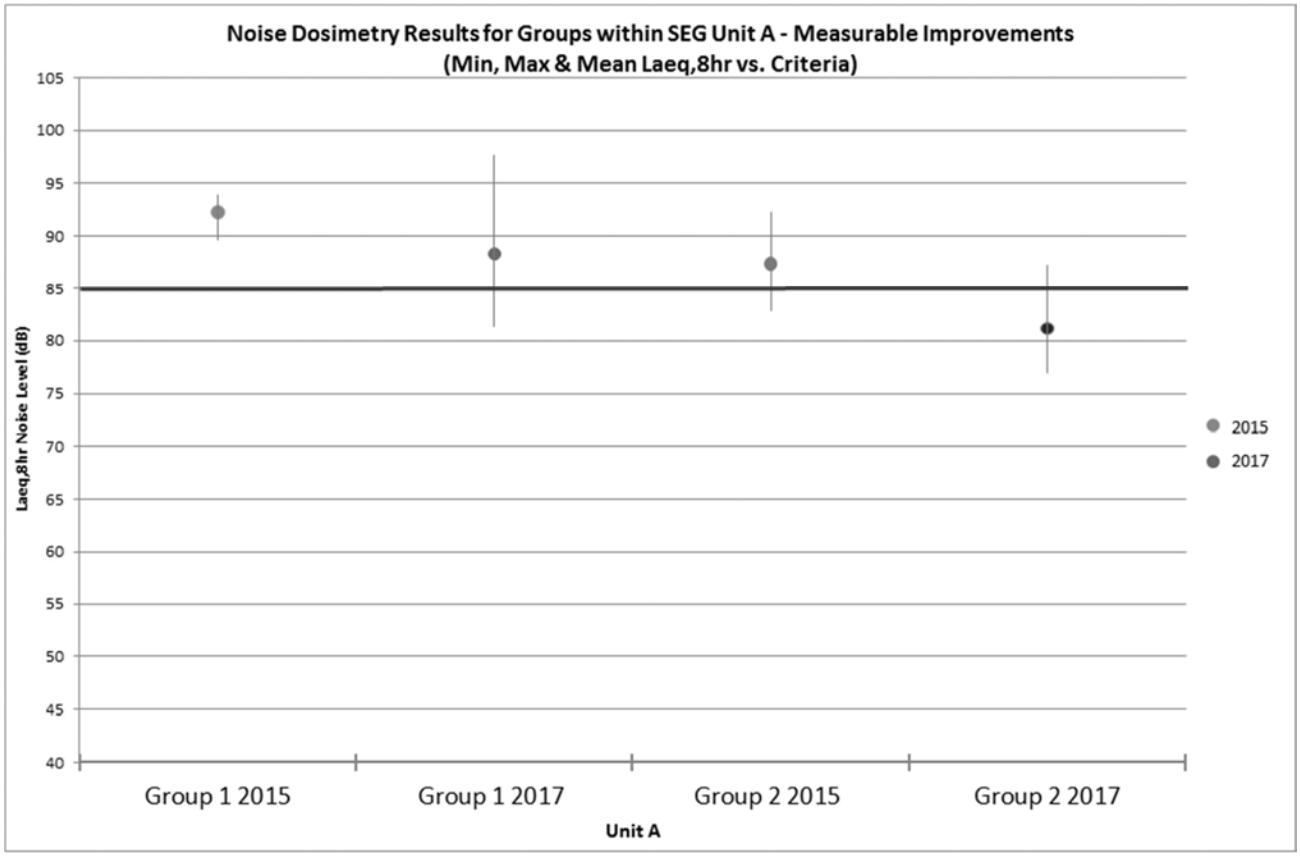

Figure 2 Mean $L_{Aeq,8h}$ noise level with the minimum and maximum levels for each SEG.

Two groups were measured within Unit A, the dosimetry data measured shows that average noise level exposure per shift reduced between the two noise surveys, with Group 2 measuring a reduction to below the NES. The data, along with detailed attended noise measurements supported the claim that noise reduction has occurred since noise controls were implemented, and thus noise controls were effective.

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 the two groups measured in the Unit A Similar Exposure Group in accordance with a ranking system derived by Vipac.

Table 6 Risk Ranking per SEG

Risk Ranking	Group 1 2015	Group 1 2017	Group 2 2015	Group 2 2017
% Low	11%	25%	0%	17%
% Medium	22%	50%	29%	67%
% High	67%	25%	71%	17%

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

- When assessing the number of samples rated as High Risk, a reduction of 42% and 54% occurred in Group 1 and Group 2 respectively
- This indicates that since noise controls were implemented, 25% of Group 1, and 17% of Group 2 workers are rated a high risk of developing health risks if their hearing is not protected during their work shift, down from 67% and 71% respectively
- 25% of workers were rated low risk in Group 1, up from 11%, and 17% of workers in Group 2, up from zero samples. This data shows improvement in reducing the average shift noise level exposure, and subsequent risk of health effects

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

NOISE CONTROLS

Where work areas have been identified as high risk, noise reduction measures using the hierarchy of controls 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.

Example noise controls implemented within the Unit A SEG, include:

- Installing Silencers on air hoses;
- Replacing older hand-tools with quieter equipment; and
- Installing a mobile acoustic screen inside workshops.

Other administrative control measures commonly applied in industry include: job rotation, changing work processes, limiting exposure times for high noise tasks, rest periods, limiting distances from noise hazards, limiting exposure to ototoxic substances and hand-arm vibration and equipment maintenance.

A measure of improvement noted on-site included the observation of HPD use and fitting. Improper fitting can mean that the HPD will not achieve the attenuation it is designed to provide, and 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.

It was noted that between noise surveys, the number of personnel observed to be wearing HPD and the correct type of HPD, had increased. This shows the on-going training that the SEG is exposed to on an annual basis, has assisted in maintaining awareness of noise within the work group.

CONCLUSIONS

High noise work environments are common within the mining and Defence industries. From a dataset of over 1200 noise dosimetry samples, average noise exposure levels have been determined for several Similar Exposure groups in each industry. This review has shown how noise dosimetry can be used to show measurable improvements in SEGs where noise control has been applied.

When considering adjusted mean noise exposure levels, all SEGs either exceeded or were within 1 dB(A) of the Noise Exposure Standard. Noise dosimetry sampling and follow up noise survey work confirms that:

1) High noise exposure exists in the Queensland Coal Mining industry and Defence, with exceedances to the NES common, without noise control implementation
2) A reduction in average noise exposure was achieved and proven, when noise sampling before and after the implementation of noise controls was conducted
3) A subsequent drop in high risk noise exposure in workers where noise controls have been implemented
4) Regular awareness training assists in maintaining noise in the forefront of employee routines

This follow-up review has confirmed that regular noise monitoring of workers and the implementation of targeted noise control are a significant priority for both mining and Defence industries to manage risk, and identify SEGs with high levels of noise exposure.

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DEMONSTRATION OF MEASURABLE IMPROVEMENTS FROM AN EVALUATION OF AN OCCUPATIONAL NOISE EXPOSURE REDUCTION PROJECT IN DEFENCE.

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ABSTRACT

A 7-year Noise Reduction Project for occupational noise has been developed and implemented across the Department of Defence. This project has been designed to address the widespread noise hazards in Defence workplaces and the identified deficiencies relating to noise management. This paper provides a quantitative evaluation of the program performance and real improvements demonstrated in noise management practices over time. An extensive evidence-based dataset was used to assess noise exposure and to inform effective noise control actions for Similar Exposure Groups (SEG) and workplace areas. This involved a systematic and coordinated approach with a range of stakeholders and best-practice noise survey assessments at representative Defence facilities. Tailored Noise Management Plans were developed, and some required actions related to common or widespread issues. A range of assessment methods were used to determine the current and improved status of noise exposure levels and noise controls. The measurement and comparison of statistical noise dosimetry samples, noise exposure levels in sections/areas, SEG exposure risk profiles and applied noise controls were analysed over program timelines. Key Performance Indicators (KPIs), developed to measure the level of noise management compliance and maturity, have been used over many years to provide robust improvement indicators. Many facilities have shown significant and continual improvement; for example, at a major Base over 90% of the Units have improved to a mostly or highly compliant level. Elements of this project may approach world's best-practice in the area of noise management and exposure reduction.

UNCOVERING THE CAUSES OF OCCUPATIONAL HEARING LOSS IN AUSTRALIA.

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ABSTRACT

Occupational noise exposure is the second most common cause of permanent hearing loss, after aging. Despite being largely preventable, noise exposure remains a major cause of hearing loss in Australia and a large proportion of the workforce still works in an environment with potentially damaging noise levels. In order to prevent occupational hearing loss, we need to first understand how many workers are exposed to excessive noise levels, the occupations that are most exposed and the workplace tasks associated with higher exposures. We conducted a cross sectional telephone survey of 5000 (2700 male and 2300 female) Australian workers. Participants were selected using random digit dialling and interviewed with the validated noise questionnaire software, OccIDEAS. They were asked about the tasks they performed during their last working day and the time spent on these tasks. OccIDEAS contains an extensive library of task-based noise exposures that were used to estimate the partial exposures for each task. These partial exposures were then summed to determine each participant's full shift noise exposure level (Laeq,8h). We found that 16% of respondents had an estimated LAeq,8h equal to or above the 85dB exposure limit; with a greater proportion of male workers (23%) exposed than female workers (7%). Eighty percent of those exposed over the limit were male. Prevalence rates and ear protection use varied between occupational groups. We found high proportions of exposed workers in a range of occupations including those involved with primary metal manufacturing, forestry, mining and mechanics. Exposure within occupational groups varied by tasks performed. This study identified the occupational groups most at risk of workplace noise exposure and the tasks that cause the most damage. This information is vital for the planning of interventions to protect workers' hearing.

WHAT'S THAT YOU SAY? USING THRESHOLD SHIFTS FOR HEARING CONSERVATION.

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University of Wollongong

ABSTRACT

Noise Induced Hearing loss (NIHL) is a debilitating condition with a severe effect on quality of life; however, it is entirely preventable. In 2014-15 there were 145 serious workers compensation claims for sound and pressure which resulted in a median time away from work of 6.2 weeks and a median cost of $12,800 (Safework Australia, 2017). This case study characterised noise exposure at a roller door manufacturing site, compared audiometric results between years for evidence of threshold shifts, and developed a hearing conservation program on site including fit testing for hearing protection and implementation of effective noise control techniques. Standard threshold shift (STS), i.e. a change in hearing threshold of 10 dB or more, is generally used as an identifier of a change in hearing which initiates further investigation; however, the use of this form of irreversible lag indicator is unsatisfactory due to the nature of NIHL. Temporary threshold shift (TTS), i.e. a change in hearing threshold that recovers to pre-exposure levels over time, has been regarded as a predictor for future hearing loss. Therefore, analysis of Threshold Shift (TS) via audiometric testing provided the basis to identify whether any employee (or employee group) has experienced TS and enabled employee engagement in the process. Individual fit testing of hearing protection further personalised the intervention strategy and provided an opportunity for education and training in controls designed to prevent NIHL.

IS YOUR RESPIRATOR MAKING YOU HOT UNDER THE COLLAR?

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University of Wollongong

ABSTRACT

Respiratory Protection is the last line of defence in control of exposures to hazardous substances, yet often the only viable choice in the workplace. For the past 40 years, Standards Australia (AS/NZS 1715 & 1716) have provided technical guidance in the design, selection and use of respirators, resulting in extensive improvements in their filtration and fit. Numerous qualitative studies have evaluated respirator comfort informing the new suite of ISO standards (ISO 16976), which provide guidance on Human Factors such as anthropology, ergonomics and performance as well as incorporating the individual's physiological response to the use of respirator. However, there is very limited workplace data on whether the use of Respiratory Protection actually impacts on the metabolic load of individuals. Standards Australia has advised their intention to adopt the ISO 16976:1-8 suite of standards with their next revision which will have ramifications for every workplace using respiratory protection. This study evaluated the physiological responses of Australian smelter workers in a sub-tropical climate to determine whether there was an additional burden from the use of negative pressure respirators in a hot and challenging work environment. Worker Breathing Rates were compared with Core Temperatures and Heart Rate during typical work activities to determine whether the use of respiratory protection contributed to an increased physiological burden, worker discomfort and hence increased health risks. This multidisciplinary approach connected human exercise physiology, occupational hygiene and medicine, to assist health and safety professionals across a range of industries better understand factors which need to be considered to ensure worker health is not compromised when utilizing respiratory protection. This research was part funded by the AIOH AES Professional Development Award 2015.

THE SINGLE TEMPERATURE STOP WORK CHALLENGE.

Dr Ross Di Corleto, Principal Adviser - Health Risk, Rio Tinto

Dr Ross Di Corleto is a noted Australian authority on the impact of heat in the workplace. He is a member of the Australian Institute of Occupational Hygienists (AIOH), he co-authored the AIOH booklet, 'Documentation of the Heat Stress guide Developed for Use in the Australian Environment'. Dr Di Corleto also publishes his own blog, The Thermal Environment, which includes a wealth of information and practical advice to help employers and employees recognise and control the dangers of working in high temperatures.

VALIDATION OF THE LASCAR SENSOR AS A TOOL TO ASSESS HEAT STRESS WHILE WEARING CHEMICAL SUITS.

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ABSTRACT

Chemical workers are often required to wear protective chemical suits while working outdoors in the heat. The purpose of this study was to quantify heat exposures by obtaining thermal data inside chemical suits. A secondary aim was to validate the effectiveness of Lascar sensors as a means to estimate wet bulb globe temperature (WBGT). Lascar thermal data loggers were used to collect personal (inside the suit) and positional thermal data. A conventional Quest Temp heat stress monitor was used to verify the accuracy of WBGT predictions made from Lascar data. It was concluded that ambient data could be used to predict thermal conditions inside a Simplair A.E. Tank Suit (C-suit) and that Lascar data loggers can be used to predict WBGT values from humidity and temperature data. The Lascar loggers are small and can be worn inside protective clothing.

INTRODUCTION

This study was carried out among maintenance and operations workers exposed to hydrofluoric acid (HF) at a Western Australian chemical manufacturing facility. Personnel at the plant are required to wear 'Respirex Simplair A.E. Tank Suit' chemical protective clothing (C-suits) that are connected to an external air supply. In addition to chemical hazards, workers are also exposed to heat stress which is exacerbated by the need to wear C-suits that hamper their ability to maintain thermoregulation. Quantifying the heat exposures of workers was deemed to be important in order to ensure that they are protected and that heat stress control measures are effective. This study evaluated the heat exposures experienced by workers wearing C-suits, determined the relationship between ambient temperatures and those experienced inside the C-suit and conducted validation trials of the Lascar data logger as an acceptable tool to estimate the wet bulb globe temperature (WBGT) index.

Evaporation is an essential part of the body's natural mechanism to maintain a constant core temperature. Personal protective clothing, particularly impervious C-suits, reduces the ability of the body to exchange heat with the environment through evaporation. Therefore, activities conducted while wearing C-suits, particularly in hot environments, places considerable physiological strain on the individual.[1] When the human body is unable to maintain its normal heat balance, individuals will experience physiological heat strain with symptoms of heat illness. In order of severity, these include; behavioural disorders; heat rash; heat cramps; fainting; heat exhaustion; and heat stroke, which is potentially fatal.[2] In addition to environmental factors, a number of personal factors that may affect an individual's physiological response under severely heat stressful conditions include age; gender; body fat composition; water and electrolyte balance; alcohol and drugs; acclimatisation and physical fitness.[3] When evaluating heat stress, it is necessary to consider environmental stressors, physical work load and protective clothing.

The index most commonly used to evaluate heat stress is the Wet Bulb Globe Temperature (WBGT) Index.[4] This index is determined through assessing four parameters; air temperature; water content in the air; radiant heat and; air speed. Adjustments for continuous work and clothing worn are applied once the WBGT value is calculated. Although numerous studies have reported on limitations of the WBGT, it remains the most commonly used tool, probably due to its simplicity.[5]

Convection, radiation and evaporation are identified as the key components of the body's cooling mechanisms, with evaporation being the most important.[6] Evaporation accounts for "25 percent of heat loss at rest and up to

95 percent during physical work" (O Connor J, Querrey K. 1993 p.36).[6] High humidity levels reduce the capacity of air to hold additional water vapour and because the air is saturated with water, evaporation is reduced, thus the body's key mechanism in achieving heat loss is hindered. Chemical work, in general, can be considered as "moderate work based on strength and flexibility demands" (O Connor J, Querrey K. 1993 p.37) and routine duties wouldn't normally result in metabolic heat loads which strain the body's cooling mechanism.[6,7] However when workers wear impermeable clothing, their ability to lose heat through sweating and evaporative heat loss is significantly reduced.

Environments within a chemical suit have been described as a "microenvironment" which may be as much as 5°C hotter than the external ambient temperature.[7] A study which evaluated the physiological responses of fire-fighters at varying air temperatures when wearing fully encapsulated protective clothing was conducted in Queensland, Australia. Three temperature parameters were tested which are representative of the local climate, 30°C, 35°C and 40°C. It was found that as the temperature increased the physiological responses of the fire-fighters significantly increased.[8] Micro-environmental conditions inside the suit hindered thermoregulatory functions, primarily evaporative cooling associated with sweating.[7,8]

Other studies found a difference of 6 to 10°C between the internal microclimate inside encapsulated protective clothing as compared to the ambient environment.[9] Relative humidity also increased rapidly inside the suit at higher temperatures.

METHODOLOGY

Study design

A longitudinal study was conducted at a chemical processing facility in Perth, Western Australia, where workers routinely wear C-suits.

Study population

The study population comprised of six maintenance and four operational personnel who are required to wear a chemical suit (C-suit) while performing routine tasks (n=10). One participant was female and nine were males, all were in good health and acclimatised to this unique work environment.

Methods

Maintenance and operations personnel were recruited through a voluntary participation program. All subjects were required to provide written informed consent prior to participating in the study, which was approved by the Human Research Ethics Committee of Edith Cowan University. Participants were requested to keep a log of time spent wearing the suit, thus allowing for the environmental data to be correlated with time spent working in the chemical suit.

Lascar thermal data-loggers were used to collect both personal and positional heat and humidity related data. The instruments were attached to lanyards worn around the neck inside the C-suit of the volunteers while others were placed in the external work environment.

A conventional Quest Temp heat stress monitor was used to verify the accuracy of WBGT predictions made from the external Lascar data-logger, using the equation;

$$WBGT(out) = 0.7 Wet\ Bulb + 0.2\ Globe\ Temperature + 0.1\ Dry\ Bulb.$$[12]

Data analysis

Data was downloaded from each of the Lascar instruments and Easy Log USB software was used to analyse the temperature and humidity data. Quest Temp software was used to download the WBGT data. Results were entered into a Microsoft Excel spreadsheet for further analysis.

RESULTS

Average readings for the 20 samples collected with the Lascar data loggers are summarised in Table 3. Since the Lascar instruments only measure temperature, humidity and dew point, an on-line tool was used to determine wet bulb temperature using the known values of temperature, humidity and atmospheric pressure.[10] Globe temperature was obtained from the Quest Temp monitor, thus allowing for the calculation of WBGT.

The data was analysed in two parts. Regression analysis of internal and ambient temperatures and humidity was conducted; and subsequently the predicted work/rest regime based on the WBGT threshold limit values was determined.[11]

Regression analysis

Lascar data-logger and WBGT

External Lascar data-logger and WBGT readings were analysed initially to verify the accuracy of predicted WBGT values based on the Lascar data. A preliminary test for the equality of variances indicates that the variances of the two groups were not statistically different F=0.87, p=0.45. Therefore, a two-sample t-test was performed that assumes equal variances. Using a significance level of 0.05, it was concluded that the lascar data and WBGT results are not statistically different (two-sided t-test, p=0.772). Having validated the conversion of temperature and humidity to WBGT, the Lascar data was used to evaluate the internal (C–Suit) and ambient temperatures.

Lascar data-logger temperature

A preliminary test for the equality of variances between internal C-suit and ambient temperature data indicates that the variances of the two groups were not statistically different F=0.59, p=0.22. Therefore, a two-sample t-test was performed that assumes equal variances. Using a significance level 0.05, it was concluded that the internal and ambient temperature results are not statistically different (two-sided t-test, p=0.24).

Since the alternative hypotheses was rejected a simple linear regression (SLR) was used to model the relationship between the internal C-suit temperature and ambient environmental temperature. The SLR model is based on a straight-line equation. Assumptions of regression modelling for the purpose of prediction include;

I. Linearity: A linear association between the dependent and independent variables.
II. Constant variance: There should be a constant variance across all the observations or errors.
III. Normality: Regression-analysis requires that the population under consideration be normally distributed and/or that the assumptions of equal variances between groups/conditions holds

TABLE 3 AVERAGE SAMPLE RESULTS FOR PERSONAL AND POSITIONAL MONITORING

					Lascar			WBGT						Pressure
Sample number	**Date**	**Sample Instrument**	**Sample Point**	**Minutes**	**Celsius (°C)**	**Humidity (%rh)**	**Dew Point (°C)**	**DryBulb (°C)**	**Globe (°C)**	**Humidity (%rh)**	**WBGT Out (°C)***	**WetBulb (°C)****	**Dew Point (°C)****	**Hectopascals (hPa)*****
TH001	8/2/16	Lascar	Personal	21	33	67	26	-	-	-	29	28	26	
TH004	8/2/16	Lascar	Personal	21	31	73	26	-	-	-	29	27	26	1019
TH002	8/2/16	Lascar	Positional	21	32	24	9	-	-	-	22	18	9	
TH008	8/2/16	Quest Temp	Positional	21	-	-	-	32	33	23	22	18	8	
TH005	12/2/16	Lascar	Personal	30	26	67	19	-	-	-	22	21	19	
TH006	12/2/16	Lascar	Personal	30	26	57	17	-	-	-	22	20	17	1017
TH007	12/2/16	Lascar	Positional	30	24	65	17	-	-	-	21	20	17	
TH009	12/2/16	Quest Temp	Positional	30	-	-	-	23	25	69	21	20	17	
TH010	24/2/16	Lascar	Personal	97	27	37	11	-	-	-	20	17	11	
TH011	24/2/16	Lascar	Personal	97	26	28	6	-	-	-	18	15	6	1019
TH012	24/2/16	Lascar	Positional	97	25	40	11	-	-	-	19	16	10	
TH013	24/2/16	Quest Temp	Positional	97	-	-	-	23	26	41	19	16	9	
TH014	5/4/16	Lascar	Personal	60	26	33	9	-	-	-	19	16	9	
TH015	5/4/16	Lascar	Personal	60	26	38	11	-	-	-	19	17	11	1025
TH016	5/4/16	Lascar	Positional	60	23	37	8	-	-	-	17	14	8	
TH017	5/4/16	Quest Temp	Positional	60	-	-	-	23	24	34	17	15	7	
TH018	6/4/16	Lascar	Personal	15	24	42	11	-	-	-	18	16	10	
TH019	6/4/16	Lascar	Personal	15	23	37	8	-	-	-	16	14	8	1029
TH020	6/4/16	Lascar	Positional	15	21	46	9	-	-	-	16	14	9	
TH021	6/4/16	Quest Temp	Positional	15	-	-	-	21	21	45	17	16	9	

* The following formula $WBGT(out) = 0.7Wet\ Bulb + 0.2\ Globe\ Temperature + 0.1\ Dry\ Bulb$ was used to calculate WBGT,[12]

** Wet Bulb and Dew Point were calculated using an online tool where temperature, humidity and atmospheric pressure were known,[10]

***Pressure (hPa) was obtained from the Bureau of Meteorology website for the respective of the time of day and location the samples were collected,[13]

I. Linearity

The Pearson Correlation Coefficient (r = 0.978) represents a strong positive linear relationship that was tested using a simple linear regression model. The Coefficient of Determination was (r^2=0.957). Thus, approximately 96% of the variation in effectiveness is explained by the linear regression model.

II. Constant Variance

The residual plot, Figure 1 shows an irregular scatter with no systematic pattern in the residuals; therefore, the homogeneity of variances assumption holds and the linear relationship describes the data well.

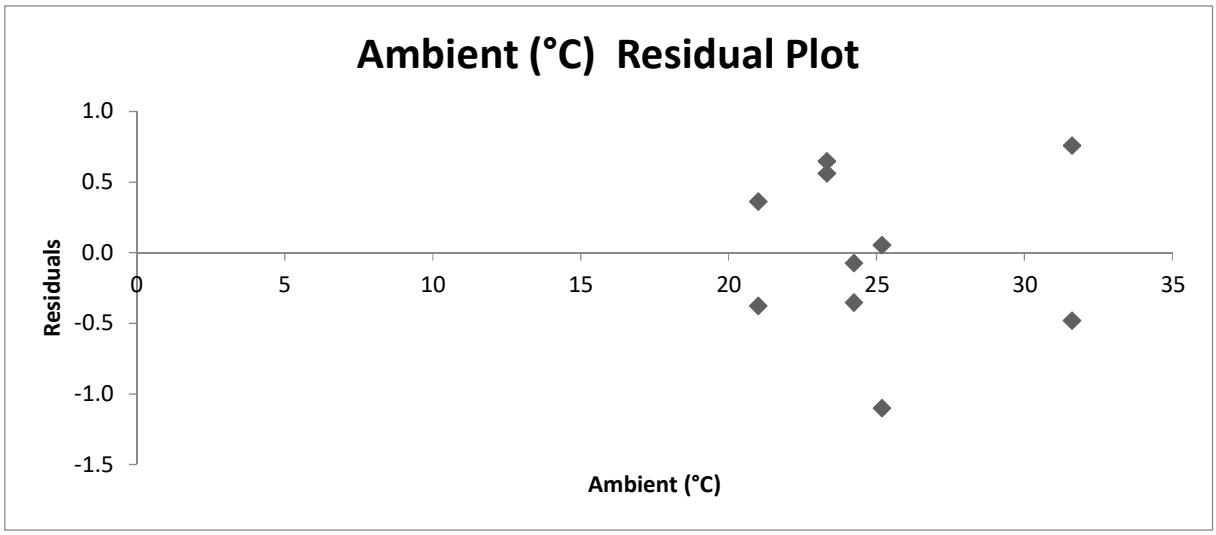

FIGURE 1 RESIDUAL PLOT

III. Normality

As the normal probability plot (Figure 2) resembles a straight line it can be concluded that the assumption of normality holds.

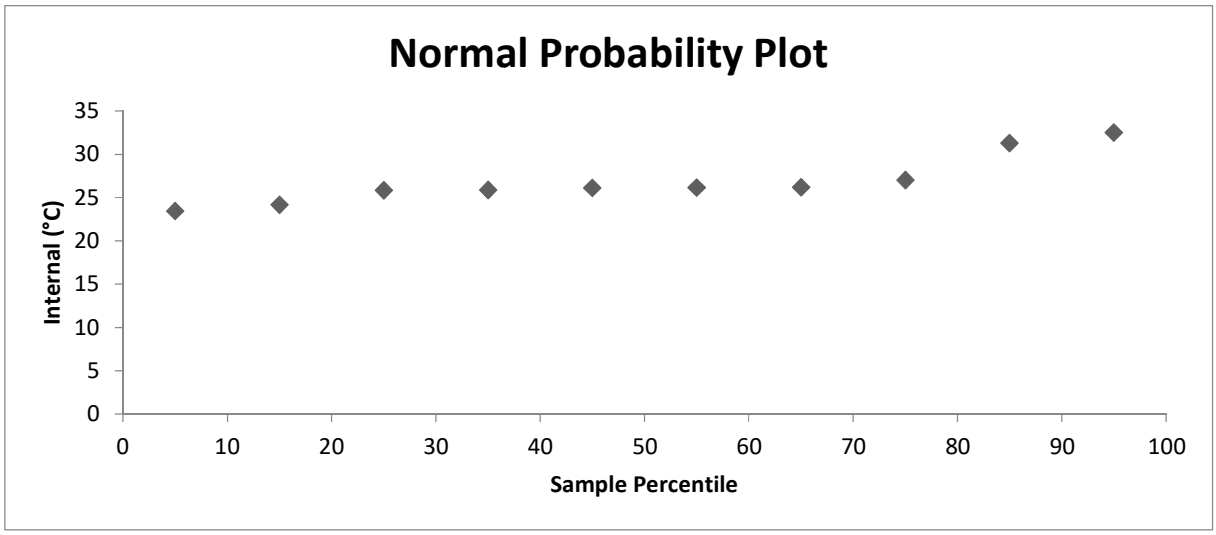

FIGURE 2 NORMAL PROBABILITY PLOT

The p-value generated by the F-test is less than 0.05 (9.18E-07) and hence the null hypothesis (β = 0) was rejected and it was concluded that linear regression is useful for estimation and prediction of temperatures in the C-suit.

Lascar data-logger humidity

Simple linear regression (SLR) was used to model the relationship between internal C-suit humidity and ambient humidity and as expected no linear relationship existed (r = 2.3). The p-value from the F-test was greater than 0.05 (0.997) and hence the null hypothesis ($\beta = 0$) was accepted and it was concluded that linear regression is not useful for estimation and prediction of humidity inside a C-suit.

Predicted work best regime

Atmospheric pressure for the time of day and location of data collection was obtained from the Bureau of Meteorology website.[13] Lascar data was used to determine wet bulb temperature and this allowed for the calculation of WBGT.[10] For the purposes of determining a work/rest regimen the work was classified as "moderate". [6,14]A further adjustment of 11°C was included to account for impervious clothing as recommended by the American Conference of Governmental Industrial Hygienists.[11]

DISCUSSION of RESULTS

This study examined the relationship between the thermal environments experienced inside a C-suit, and the external ambient environment. Studies have reported microenvironments to be as much as 5°C hotter than the external ambient temperature.[7] As shown in Figure 3, internal and external temperatures were well correlated and this study supported that finding. Temperatures inside the suits were higher than those measured externally, although to a lesser extent than reported elsewhere (mean = 2.6°C). This could be due to the shorter period of time spent in the suits.

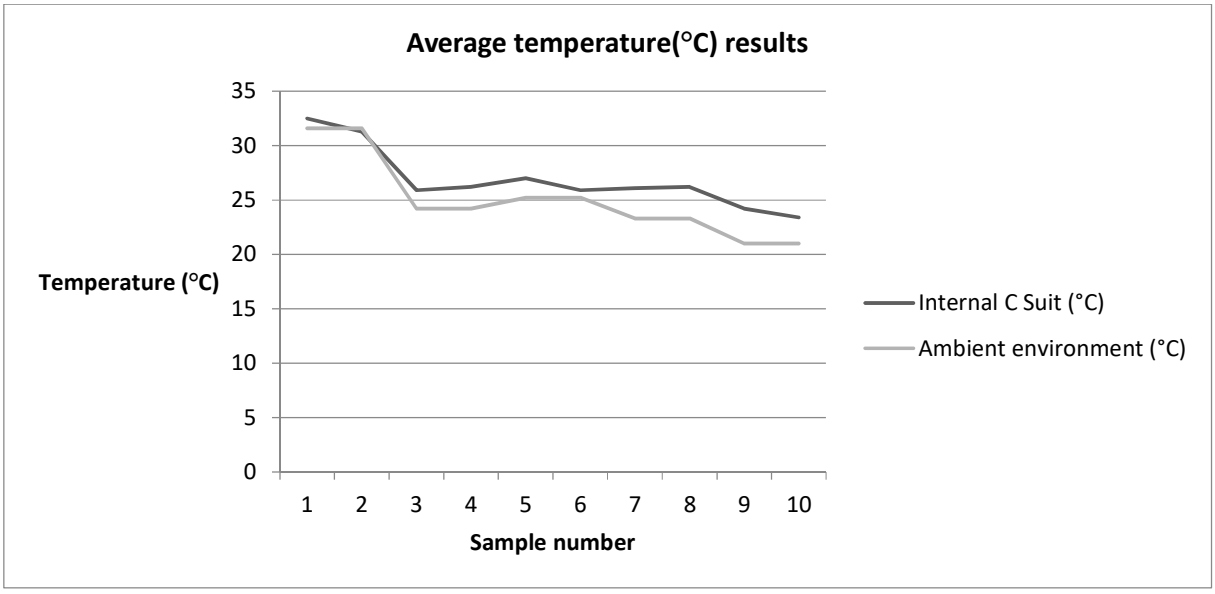

FIGURE 3 AVERAGE TEMPERATURE RESULTS

Traditional heat stress monitors are large and would be impractical to assess micro-climatic conditions inside impervious protective clothing. The Lascar data logger is much smaller and wearer friendly. The limitation of the Lascar instrument is the fact that it doesn't record globe or wet bulb temperature. However, wet bulb temperature can be calculated from the Lascar data and globe temperature can be measured externally. A strong correlation was established between Lascar (external) calculated WBGT and the results obtained from a Quest

Temp monitor in the same environment (two-sided t-test, p=0.945), however as expected there was no correlation between humidity inside and outside the C-suit.

Having established a Simple Linear Regression (SLR) model, predictions can be made as to the thermal condition inside the suit based on the ambient temperature. The model allows the user to predict temperature parameters only. To determine the WBGT value, a data logger is still required inside the suit to enable one to calculate wet bulb value and external monitor to measure globe temperature.

The predicted work/rest regime for these data, as prescribed by The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's), provides further support to the current body of knowledge that have found these TLV's to be overly protective. Applying the recommended work/rest ratios would be extremely resource intensive and not viable or practical in an Australian context.[15]

Table 4 shows the Work/Rest Regime required based on the WBGT values with the clothing adjustment factor and thermal risk assessment. More work needs to be done to develop a robust assessment tool to determine heat stress work/rest cycles that are more appropriate for use in Australia, particularly when wearing impervious protective clothing.

TABLE 4 ALLOCATION OF WORK IN A CYCLE OF WORK AND RECOVERY

Sample number	Sample Instrument	Sample Point	WBGT (˚C)	Clothing adjustment (˚C)	Work/rest Regime
TH001	Lascar	Personal	29	40	0 to 25%
TH004	Lascar	Personal	29	40	0 to 25%
TH002	Lascar	Positional	22	33	0 to 25%
TH008	Quest Temp	Positional	22	33	0 to 25%
TH005	Lascar	Personal	22	33	0 to 25%
TH006	Lascar	Personal	22	33	0 to 25%
TH007	Lascar	Positional	21	32	0 to 25%
TH009	Quest Temp	Positional	21	32	0 to 25%
TH010	Lascar	Personal	20	31	0 to 25%
TH011	Lascar	Personal	18	29	0 to 25%
TH012	Lascar	Positional	19	30	0 to 25%
TH013	Quest Temp	Positional	19	30	0 to 25%
TH014	Lascar	Personal	19	30	0 to 25%
TH015	Lascar	Personal	19	30	0 to 25%
TH016	Lascar	Positional	17	28	0 to 25%
TH017	Quest Temp	Positional	17	28	0 to 25%
TH018	Lascar	Personal	18	29	0 to 25%
TH019	Lascar	Personal	16	27	0 to 25%
TH020	Lascar	Positional	16	27	0 to 25%
TH021	Quest Temp	Positional	17	28	0 to 25%

CONCLUSION

This study confirmed that thermal data loggers located inside fully encapsulated chemical suits to record temperature and humidity are a practical and user-friendly way to assess heat stress exposures of workers wearing C-suits. The use of small data loggers in place of the traditional heat stress monitors allows researchers

to gather personal exposure data over longer sample times and with a decreased impact on the wearer's activity. Data obtained from traditional equipment to determine WBGT correlated well with Lascar data logger results and these data loggers can be used to predict WBGT values. Using the small data loggers allows for easier management of predicted heat stress based on the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's) or other similar indices that require wet bulb temperature.

Furthermore, having established a Simple Linear Regression (SLR) model, predictions can be made as to the thermal condition inside the suit based on the ambient temperature. The model allows the user to predict temperature parameters only. To determine WBGT value inside the suit, a data logger is still required to enable the calculation of wet bulb temperature.

Results of this study can be used to establish a baseline for the evaluation of control measures such as further research on cooling and reducing humidity within C-suits.

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PREVENTION OF HEAT STRESS IN A SMELTER.

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ABSTRACT

Heat Stress is a life-threatening condition that poses a serious risk in many Australian workplaces. This case study revisited the management of this risk at an organisation with a metal manufacturing business located in the sub-tropics. Heat stress had been managed through the Risk Management Site Procedure rather than a stand-alone Heat Stress Management Procedure, which although relatively effective, with identified high risk heat stress tasks, it required close management by the Health & Safety department. In this study, high risk heat stress tasks were assessed using the Thermal Work Limit (TWL) measurement system and a three-tiered assessment approach prescribed by the AIOH "A Guide to Managing Heat Stress: Developed for use in the Australian Environment" (Di Corleto, et al., 2013). The process used a qualitative assessment tool followed by actual measurement of the environment, assessment of recorded measurements against the TWL and Predicted Heat Strain (PHS) Indices followed by physiological monitoring. A best practice stand-alone Heat Stress Management Procedure was developed and implemented to determine the organisations specific control measures per TWL zone, identified high risk heat stress tasks and critical role accountabilities. Control measures were recommended following analysis of the survey results and comparison to the heat stress management site procedure requirements. Physiological monitoring was also conducted to connect personal risk factors such as hydration status and body surface area to core temperatures. Group hydration levels were also reviewed to determine current hydration culture and to assist in the development of an intervention program to prevent heat related illnesses.

MANAGING MOULD OUTRAGE - FOR OCCUPATIONAL HYGIENISTS.

Samantha Clarke
BSc, GDipOHM, GDipOH, COH

INTRODUCTION

When confronted with hazards, workplace or otherwise, people usually respond in one of three ways - with:

- Apathy;
- Acceptance, or;
- Outrage.

This paper will focus on managing outrage, where the health risk is low. Whilst the hazard of mould will be used as an example, partly because of its own peculiarities, I hope this presentation will broaden your understanding and appreciation of the role of outrage in effective management of any risks.

Communicating Risk

Effective communication of risk involves consideration of emotions, as well as facts. As occupational hygienists we are good with facts. We use quantitative methods and exposure standards, and have the skills to demonstrate that an exposure is or is not acceptable. This is often made easier by us being seen as an expert in our area, as well as being an outsider to corporate chain of command.

But what if the data does not fall neatly on one side of the exposure standard line? What if there is no exposure standard to start with? Not only do we now need another tool to demonstrate risk to workers, but the impact of emotions and outrage is more likely to play an unruly role, so too has to be managed.

Why Mould?

The issue to addressing outrage, as well as the facts, came to light for me in the area of a mould assessment. I've spent years effectively appeasing concerned workers that asbestos remediation works (for example) were following best practice methods, outlined in government Codes of Practice and using quantitative data and independent Asbestos Assessors to ensure acceptable health standards were being met. Being independent, seen as the expert and using good science had been a winning combination to quell concerns.

However, on one fateful day this strategy failed me. Firstly, let me state clearly that whilst I feel quite comfortable around asbestos, dust and noise, I am still very much a student in the field of mould. During a presentation to staff prior to remediation works, I was confronted with 'what levels are safe?', 'how long has it been there?', 'have I been exposed?'. The answers to these questions were not as clear or reassuring because, for a number of reasons, mould is just different with:

- Limited legal or other guidance
- No exposure standards
- No wholly accepted methodologies
- No recognised accreditation for assessors, remediators or laboratories

Why don't we have the same attention to, and guidance for, mould as we do other hazardous materials? I suspect the answer is two-fold. Firstly, there is simply not enough concern for mould in the government or community to force a policy decision. Secondly, mould is different from other health contaminants. Whilst there is evidence of health effects associated with exposure, there is little dose-response data and, therefore, no exposure standards. Many moulds are in our everyday environment. Their extent is often unknown. Their mere presence doesn't automatically represent a problem. The health effects experienced by individuals vary greatly, including due to a

range of susceptibilities. We simply can't apply the same quantitative approach of mould as we're used to. So, if the public is likely to overestimate the risk, it's important that we don't underestimate the potential for outrange!

Is Risk Communication Enough?

I've mentioned the value of science and numbers to communicate risk, but is it really effective? If we we're to give a list of everyday hazards to a group of people, and ask them to rank them in order of risk, how do you think that would compare with actual, quantifiable risk data? Maybe this list would include well known hazards like smoking, crossing a road, driving a car, an aeroplane flight, drinking unpasteurised milk, mobile phone radiation etc. In fact, the correlation between the perceived and actual risk is very low, only 0.2. This is despite common knowledge that smoking is bad for you, planes are safer than cars etc. So, science isn't always enough, and in the case of mould we don't have much exposure-related science, only knowledge that we need to control exposures.

It was no real surprise that my attempt to communicate the risk associated with mould exposure, without my usual 'compare with an exposure standard' crutch was not my finest moment - a humbling experience. So, began my quest to find the missing piece of the puzzle – communicating risk with the, sometimes irrational, human factor.

Risk = Hazard + Outrage

A leader in the area of effective risk communication is Dr Peter Sandman. He flips our risk management formula on its head! Typically, in work health and safety we use the formula: risk = consequence x probability (where probability is a product of exposure and likelihood). We've all been exposed to various applications of this, using matrices, formulas and line diagrams. What is missing from these tools is the human factor, either apathy or outrage. Dr Sandman suggests that we rename 'risk' from the formula above to 'hazard', and plug this into a new risk formula: Risk = Hazard + Outrage.

A simple, but relevant, point to take from this formula is that if the hazard is low, but the outrage is high, we need to accept that we have a high risk to contend with. I had data demonstrating a low risk to remain in the building during mould remediation. Whilst staff accepted this statement of risk, they were still not comfortable staying there – the facts alone were not enough.

What are the contributors to outrage?

According to Dr Sandman, there are nearly twenty possible components of outrage, including organic vs natural, media attention and morality. But I'd like to focus on just three: Control (and power), knowledge and trust.

Control and Power

Control results in the implementation of action or inaction. That I am in control (e.g. driving a car) gives way to the feeling that I'm 'safer', than if I were a passenger. Of course, such control may also result in inaction – I've known for years that I can start eating better any time I like!

In a workplace, employees often feel they have limited control. The message often provided by companies/employers is two-fold: 'We're in charge, we have the expertise, we know what we're doing', followed by the second message 'so don't worry'. This follow up message is barely heard through the outrage of the first!

Sharing power and control is a very effective way to reduce community outrange, as you cannot simultaneously reassure others whilst keeping all of the control. As consultants (internal or external to a site) we need to not overestimate our power. The less power you have, the more sense it makes to collaborate. This is the crux of consultation – working together for the solution. In fact, we generally have too little power to get our own way coercively (our workers are too smart to just accept what they're told). Rather, with collaboration the gains in reduction of outrage far exceed any costs in real power.

Knowledge

Generally, the workforce or public will misperceive the risk, whilst the expert will misperceive the outrage!

To determine the solution, we need to understand that if the overestimation of the hazard is the cause or the effect:

- If people are outraged because they have overestimated the hazard, we can better explain the hazard, but
- If people are overestimating the hazard because they are outraged, then we have to understand what is causing the outrage and try to fix it.

Certainty, expert agreement and detectability all contribute to the public or worker's confidence regarding the knowledge of a hazard. The public will likely prefer a high risk with greater certainty (smaller error bars) than a lower risk with more uncertainty (larger error bars). Arguably the expert may prefer the lower risk, as probably outcome is better. A mould report is often confusing, discussing multiple species, inconsistent background (ambient) results and, of course, the lack of a safe exposure standard. The solution is to acknowledge that uncertainty is not the same as ignorance. That is, here is what we know, here is what we think and this is what we're unsure about.

Worse than certainty is expert disagreement. The public would likely be more assured if the consensus of experts was that the risk was a (theoretical) seven out of ten, than if the expert's opinions ranged from between three and seven out of ten. At my mould assessment debrief, the client invited a confident environmental professional to provide a 'reassuring interpretation' of the risk, which he based only on his visual (qualitative) assessment. Of course, his assessment was based on the fact that the visible mould he observed was "not nearly as bad as what he'd seen elsewhere"! Our polar conclusions do nothing to appease the concerned workers.

Detectability is another component of knowledge. -This is applicable for many carcinogens and chronic hazards like mould where the health effects don't come with a tag to advise when and how you got the disease! Data from the mould assessment provided detection of the hazard, but perhaps required communication to be limited to relevant data displayed more simply. Like a real-time CO monitor in an at-risk area, control sampling during remediation of adjacent areas may have been an effective way to provide workers with confidence of their work environment, empowering them to make their own informed risk assessment.

Trust

Unlike control and knowledge, trust relates of the people in control of the hazard, rather than the hazard itself. Most of us accept the risks of vaccination, for example, because we trust our doctors have our best interest in mind. Of course, betrayal of such trust leads to outrage, as seen by the actions of the anti-vaccination movement. Trust is a long-term goal that is easier to lose than it is to regain. To not lose sight of this objective, it is best to replace the expectation of trust with accountability!

In many circumstances I've found that my independence and clever-sounding role title is enough to win over the audience. However, I accept that am at risk of unwittingly distorting facts as I am driven with an intent to reassure or pursued. Sandman argues that 'most contenders in risk controversies are untrustworthy. Apart from the obvious distorting effects of self-interest, conviction probably is an even bigger source of bias'; i.e. I said that it wasn't a problem, so now I will continue to prove that it isn't a problem!

To replace an expectation of trust with accountability, we should ask our audience to not blindly trust us, but encourage them to share their concerns, allowing us to show them how to understand the problem. By implementing hazard monitoring tools, we empower them to make rational risk decisions. If the data is bad, then we agree that it's bad, and investigate together!

The Solution? Acknowledgment

Knowledge, control and trust all lead to the same place – by acknowledging the arguments of the other side, we are better armed to work them into our own communications. Further still, to acknowledge arguments not yet

even considered, we are always ahead of any bad news! Technical people, like ourselves, may be more likely to try and solve the problem before reporting it. However, we should be estimating risk on the high side when the story is developing, but acknowledging that it may not be this bad. A speaker who states only facts, and fails to acknowledge their audiences outrage, comes across as cold and untrustworthy.

In our occupational hygiene profession, I hope this doesn't happen too often We are paid or employed by the company, however have an ethical obligation to provide support to protect worker health. Our rapport with workers is a key tool to assist us to mellow any outrage – working with them, not against them. **Not by using power or statistics, but genuine care and an openness to share.**

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PREDICTING LEGIONNAIRES' DISEASE OUTBREAKS THROUGH QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA).

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Rio Tinto

ABSTRACT

Legionellosis is a severe form of pneumonia that can result in death if not treated in time. Legionella is widespread in nature, and many Western Australian (WA) mines have the environmental conditions that promote Legionella Pneumophila growth. In WA, there are 12 diagnosed cases of infection by Legionella Pneumophila each year.

Current practice to assess legionella risks includes water system inspections by a competent individual and routine water sampling. The latter, however, can be considered of limited value as the dose required to infect people, subject's variability, and legionella dynamics are not usually accounted in risk assessments, which are based solely on water sampling results.

This study predicts the risk of infection and mortality through the application of the Quantitative Microbial Risk Assessment (QMRA) model into Western Australian mines. The risk assessment brings together available site hazard information such as environmental conditions, aerosol composition, and water sampling results, with dose response analysis and exposure assessment for adequate characterisation of the risks.

The results found that QMRA risk estimates enhance the identification of appropriate control strategies, thus balancing the costs, effectiveness, and perceptions of each of them.

Keywords: legionella, QMRA

INTRODUCTION

Legionnaires' disease (also known as legionellosis) is a severe and sometimes fatal form of pneumonia. It is caused when Legionella bacteria are inhaled. Legionella are found naturally in the environment and thrive in warm water and warm damp places (Australian Government Department of Health, 2008).

The most common Legionella strain associated with causing human disease in Australia are Legionella pneumophila and Legionella longbeachae. In Western Australia, there are around 12 diagnosed cases of infection by Legionella pneumophila each year (Healthy WA, 2017). The mortality rate for Legionnaire's Disease is about five percent (WA COSH, 2010)

Legionella pneumophila is transmitted by breathing in water droplets or air-borne liquid droplets. Incubation period is between 2 to 10 days, and requires antibiotic treatment (WA Health, 2017).

The WA Prevention and control of Legionnaires' disease Code of Practice (WA COSH, 2010) discusses the use of water testing and their limitations in Legionella control. The Code explains that since Legionella is widespread in nature, bulk water sampling will often yield positive results, despite not being associated with infections. The Code also explains that it is difficult to determine the risk on water samples alone, as the dose of Legionella required to infect people, the subject's variability, and legionella dynamics are not fully understood.

One of the objectives of this study is to apply the Quantitative Microbial Risk Assessment (QMRA) process and modelling tools to predict legionella exposures and risks. This aligns with the American Industrial Hygiene Association' vision of hygienists in the future (M. A. Jayjock, 2000). AIHA's vision is that occupational hygienists

can borrow modelling tools from other disciplines, thus giving the hygienists a far better insight into the true risks, especially at low doses.

As discussed by Hamilton and Haas (2016), there have been several Legionella exposure models published; yet a standardised QMRA approach for Legionella has not yet been developed. This paper offers a simplified application of QMRA based on Hamilton and Haas (2016) proposed framework.

METHODS

QMRA is a five-step process that describe the magnitude of risk that may arise from exposure to microbial pathogens. The steps include hazard identification, exposure assessment, dose response assessment, risk characterisation and risk management (Rose et al., 2013, Storey et al., 2004).

A comprehensive review by Hamilton and Haas (2016) has explored many attempts by others to conduct QMRAs on Legionella. In their paper, a new framework was proposed; which has been adapted by the author for occupational hygiene use in Figure 1.

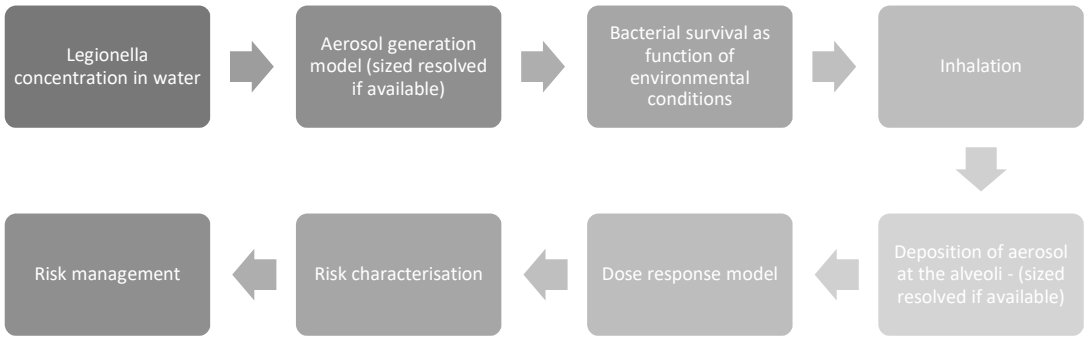

FIGURE 1: LEGIONELLA QMRA FRAMEWORK - ADAPTED FROM HAMILTON AND HAAS (2016)

1. Hazard Identification

The WA Code of Practice (2010) recognises cooling towers, evaporative condensers, air-handling systems, heated and cold-water systems as sources of legionella in Western Australian mines.

One of the methods to confirm the presence, the concentration and the species of legionella is through bulk water sampling. The current culturable method has a detection limit of 10 CFU/mL (Standards Australia, 2017), and is equivalent to 10 000 CFU/L.

The Code requires that a legionella test result of up to 1000 CFU/mL from a bulk water sample should initiate an immediate online disinfection with a biocide; while over 1000 CFU/mL should initiate an immediate online decontamination with a halogen based biocide.

Hines et al (2014) has reviewed other microbial concentrations in water, with 1000 CFU/mL value for classical risk factors, and 250 CFU/mL for high-risk patients.

2. Exposure Assessment

Armstrong and Haas (2007) and Hamilton and Haas (2016) have discussed two common approaches to estimate air concentrations of legionella. The first one is the use of a near field-far field model and the other is the use of

the bacterial air-water partitioning coefficient, also known as emission factor value (Hines et al., 2014). The partitioning coefficient is the most common approach for use in QMRA (Hamilton and Haas, 2016).

The air-water partitioning coefficient values depend on the physical configuration of the water system and the interaction between water and air on it. The known air-water partitioning coefficients are summarised in Table 1.

TABLE 1: SUMMARY OF AIR-WATER PARTITIONING COEFFICIENT VALUES FOR BACTERIAL CONCENTRATIONS IN WATER TO AIR

Exposure pathway	Partitioning Coefficients water / air	Reference
Cool mist humidifier (95% of particles in the inhalable range)	8.8×10^{-4} L/m3	Hines et al. (2014)
Hot water tap	5.6×10^{-4} L/m3	Hines et al. (2014)
Shower	10^{-6} to 10^{-5} L/m3	Schoen and Ashbolt (2011)
Toilet	1.3×10^{-6} L/m3	Hines et al. (2014)
Hot springs	1.6 to 3.1×10^{-5} L/m3	Armstrong and Haas (2007)
Splashes and sprays from fountains	2.0×10^{-10} to 1.1×10^{-7} L/m3	de Man et al. (2014)

The table above shows that the smaller the water particle is, or the more energetic agitation of water, the higher the emission factor value will be. Baron and Willeke (1986) explain that there is an enrichment of bacteria in the air, following the rupture of an air bubble rising through water. Energetic agitation; however, reduces the chances of bacterial enrichment, as the concentration of legionella will be more homogeneous in the air (Armstrong and Haas, 2007). These factors increase the difficulty to provide reliable estimations of air-water partitioning coefficients, which in turn, they are a major source of uncertainty in QMRA models, as per demonstrated by Schoen and Ashbolt (2011).

As indicated by the WA Code (WA COSH, 2010), the common sources in WA mining operations and associated processes that either produce a fine mist of water, or where water is energetically agitated are:

- Cooling towers and evaporative condensers.
- Air handling systems.
- Dust suppression systems
- Fire suppression systems
- Manual and automated equipment washing facilities.
- Use of jet or pressurised water for removal of sludge and debris from processing equipment.
- Eyewash stations and safety showers.
- Mine accommodation showers.
- Wet screening and material separation.

Armstrong and Haas (2007) estimated that 50% of aerosols to be in the respirable range and are deposited at the alveoli. A later study, (Schoen and Ashbolt, 2011) provided estimates of proportions of aerosolised bacteria per aerodynamic diameters. This study estimated that 75% of the aerosolised bacteria will be retained within aerosols sized between 1 to 5 μm; with an estimated deposition in the lung of nearly 100% efficiency.

Survivability of the aerosol depends on the temperature and humidity conditions of the environment. Baron and Willeke (1986) conducted experiments with two pools at different temperature and humidity conditions, from

36°C to 43°C, and surrounding dry cold air and temperate saturated air. The study demonstrated that stability of a droplet containing bacteria will be peak when water temperature is 43°C, and room temperature has a similar temperature, and relative humidity is close to 100%.

EPA (2011) has published a recommendation of short-term inhalation rates depending of the work intensity for use in the QMRA. The inhalation rates covered males and females, from 21 years to 61 years.

Four scenarios are considered for modelling and illustration purposes; based on author's current's experience; but do not represent actual examples:

a) Refrigeration technicians maintaining cooling towers and evaporative condensers across site
b) Fire services provider testing fire suppression systems across site
c) Mobile equipment maintainers washing heavy vehicles prior routine maintenance
d) Processing plant operator monitoring the operation of dust suppression systems, screening and material separation processes and using recycled water to remove slurry and debris from processing equipment

The assumed operational characteristics used in the model are summarised in Table 2.

TABLE 2: SUMMARY OF INPUT PARAMETERS USED IN THE QMRA FOR FOUR SCENARIOS

Parameter	Distribution selection	Scenario A	Scenario B	Scenario C	Scenario D
Legionella Concentration in bulk water range CFU/mL	Uniform (Azuma et al., 2013)	0 to 100 (treated water)	0 to 100 (treated water)	100 to 1000 (recycled water)	100 to 1000 (recycled water)
Selected air-water partitioning coefficient from Table 1 L/m3	Normal (Armstrong and Haas, 2007)	8.8×10^{-4}	1.1×10^{-7} L/m3	10^{-5}	10^{-5}
Inhalation rate range (m3 / minute) (EPA, 2011)	Uniform (Armstrong and Haas, de Man 2014)	1.2×10^{-2} to 1.7×10^{-2} Light intensity	1.2×10^{-2} to 1.7×10^{-2} Light intensity	1.2×10^{-2} to 1.7×10^{-2} Light intensity	2.6×10^{-2} to 2.9×10^{-2} Moderate intensity
Exposure time range (hours)	Uniform	1.0 -2.0	2.0 – 3.0	1.0 – 2.0	2.0 – 3.0
Fractional retention rate of the bacterial aerosol	Point value	0.75	0.75	0.75	0.75
Survivability in air	Uniform	0.5 – 0.75 (cool water, shaded environment)	0.75 – 1.0 (hot water, hot humid environment)	0.75 – 1.0 (hot water, hot humid environment)	0.90 – 1.0 (hot water, hot humid environment, shaded)

The input parameters above have different degrees of uncertainty. Inhalation rates have been studied

significantly (EnHealth, 2012, EPA, 2011); while the others such as the air-water partitioning coefficient require further development (Armstrong and Haas, 2007b, Schoen and Ashbolt, 2011).

The exposure dose can be calculated as follows (based on Hamilton and Haas 2016):

$$D = Cwater \times PC \times IR \times ET \times RR \times S$$

Where

- D = is the inhaled dose (colony forming units CFU)
- Cwater = is the concentration of legionella in water sample (colony forming units per litre, or CFU/L)
- PC = air-water partitioning coefficient
- IR = Inhalation rate (m3 x min -1)
- ET = exposure time (min)
- RR = Retention Rate of bacterial aerosol
- S = Bacterial survivability based on environmental conditions

3. Dose response assessment

The QMRA dose monograph (Rose et al., 2014) recommends an exponential model to evaluate dose response. This is based on experiment 241 on guinea pigs Muller et al. (1983). The exponential model is represented by:

$$P = 1 - e^{-r \cdot D}$$

Hamilton and Haas (2016) summarised dose response parameters for nine studies that a comprehensive QMRA analysis. The most common dose response parameters used on those studies are r(infection) = 0.06, r(mortality) = $1.7 * 10^{-4}$, which are based on Armstrong and Haas (2007a)

4. Risk Characterization

There are two types of risk characterisation. One is the point-estimate and the second is the probabilistic risk assessment, the latter used in this paper. To treat the uncertainties in the model, the model was simulated with by Monte Carlo techniques, using @RISK software (V7.5, Palisade Corporation, New York), with 10 000 iterations per scenario.

EnHealth (2012) discusses 'target' risk levels or 'acceptable risk levels': the level 1×10^{-5}, or one case in a 100,000 people, is generally suitable occupational settings.

5. Risk treatment

Rose et al. (2013) shows a procedure to identify the level of desirable risk treatment. First, the exposure dose that would cause the acceptable risk level is calculated, and then the microbial concentration that meets this acceptable risk. Finally, the desirable risk reduction can be calculated as follows:

$$D(P_{acceptable\ risk}) = \frac{\ln(1 - P_{acceptable\ risk})}{r}$$

$$\log_{10} reduction = \log_{10}(D_{calculated\ risk}) - \log_{10}(D_{acceptable\ risk})$$

(Storey et al., 2004) provided a reduction effectiveness of legionella for common disinfection methods, and the results have been reproduced in Table 3.

Table3: Storey et al. (2004) Log reduction of culturable planktonic L. penumophila exposed to thermal and chemical (free and combined chlorine) disinfection (contact time 10 min)

Thermal °C	Log reduction	Free chlorine mg/L	Log reduction	Combined chlorine mg/L	Log reduction
50	0.2	1	0.6	1	0.5
60	2.8	2	1.1	2	1.0
70	4.4	5	2.8	5	3.9
80	8.8	10	3.2	10	4.1

RESULTS and DISCUSSION

The following histograms (Figure 2 to 9) show the infection and mortality risk probabilities densities:

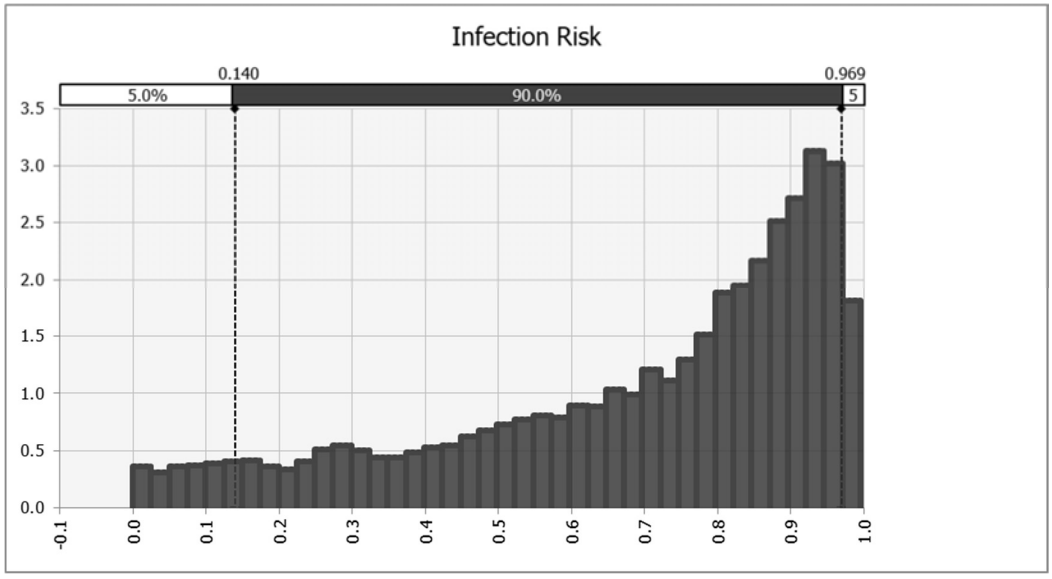

FIGURE 2: INFECTION RISK PROBABILITY DENSITY FOR SCENARIO A

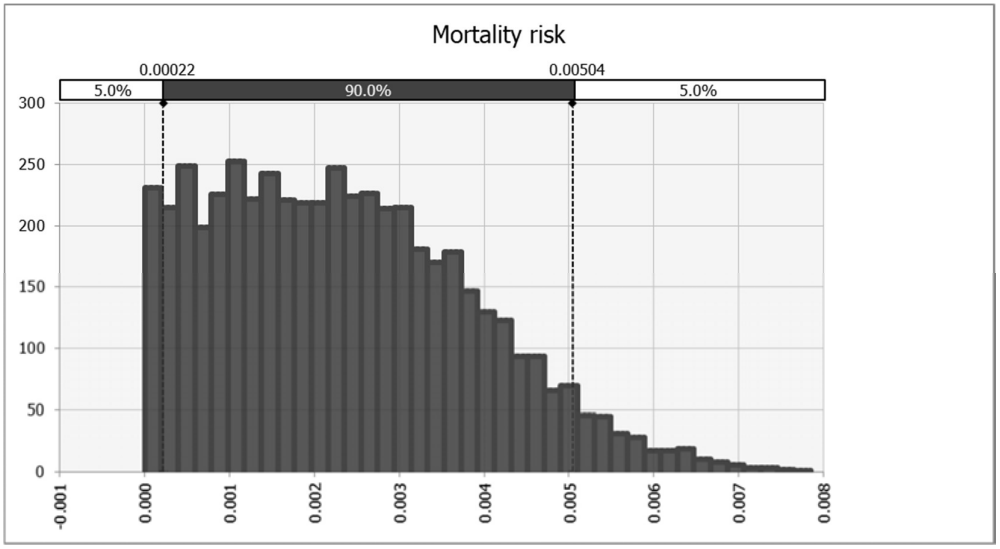

FIGURE 3: MORTALITY RISK PROBABILITY DENSITY FOR SCENARIO A

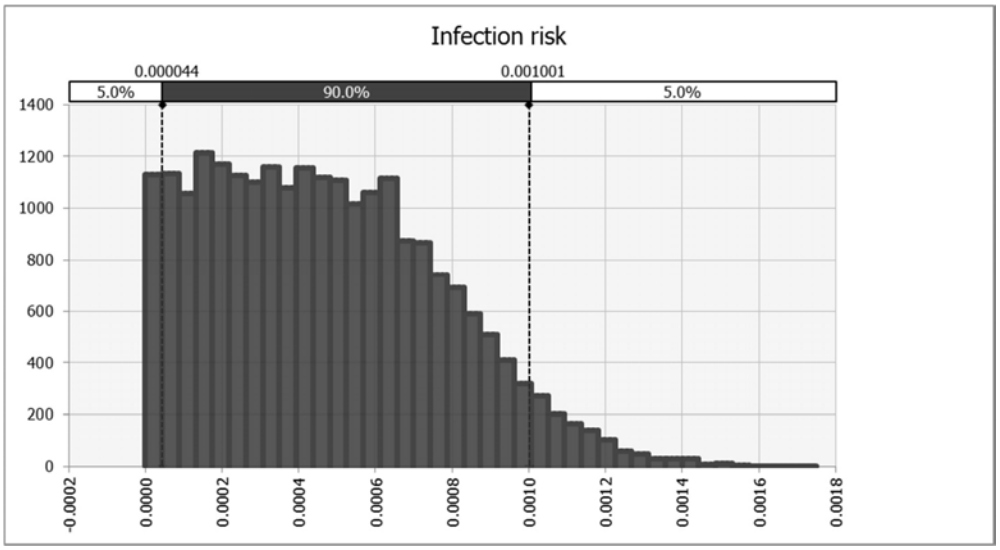

FIGURE 4: INFECTION RISK PROBABILITY DENSITY PLOT FOR SCENARIO B

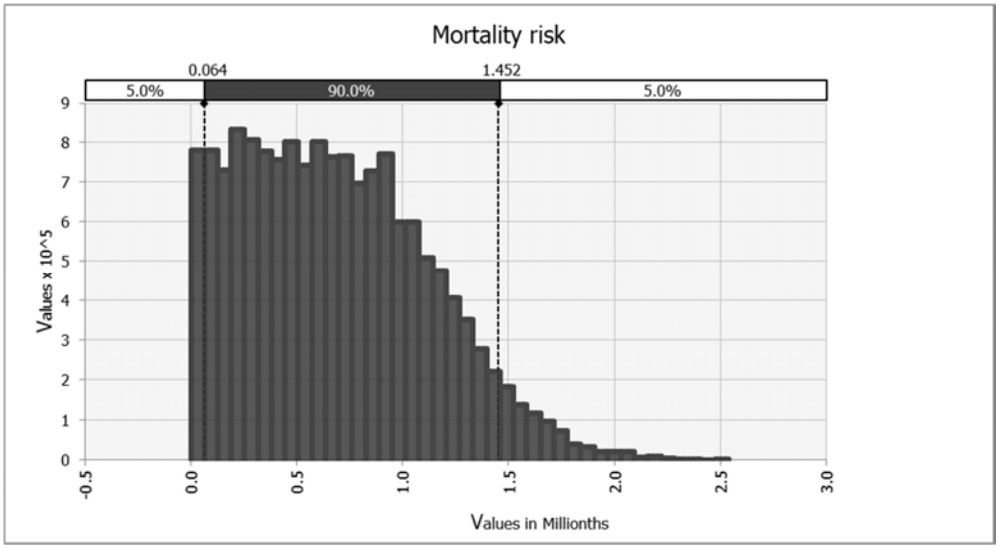

FIGURE 5: MORTALITY RISK PROBABILITY PLOT FOR SCENARIO B

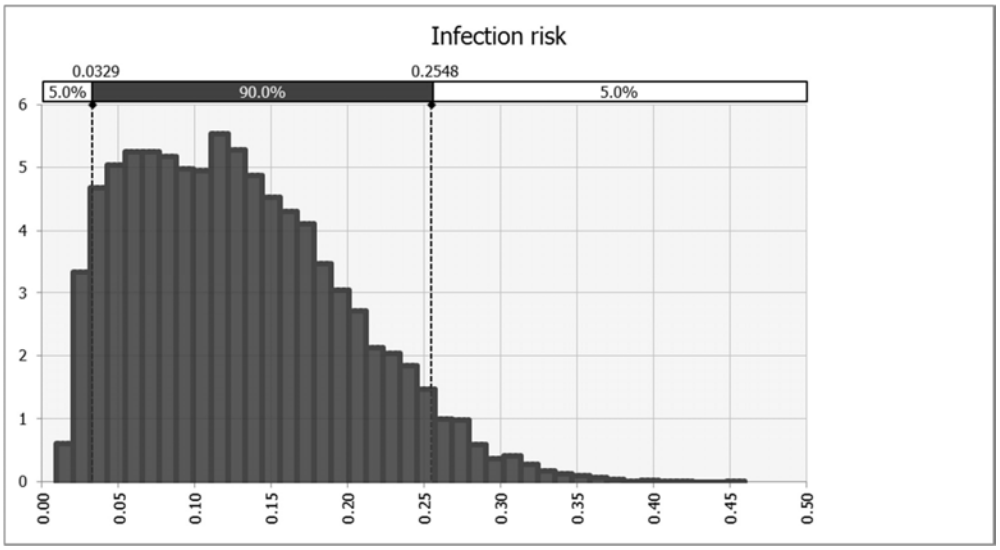

FIGURE 6: INFECTION RISK PROBABILITY DENSITY PLOT FOR SCENARIO C

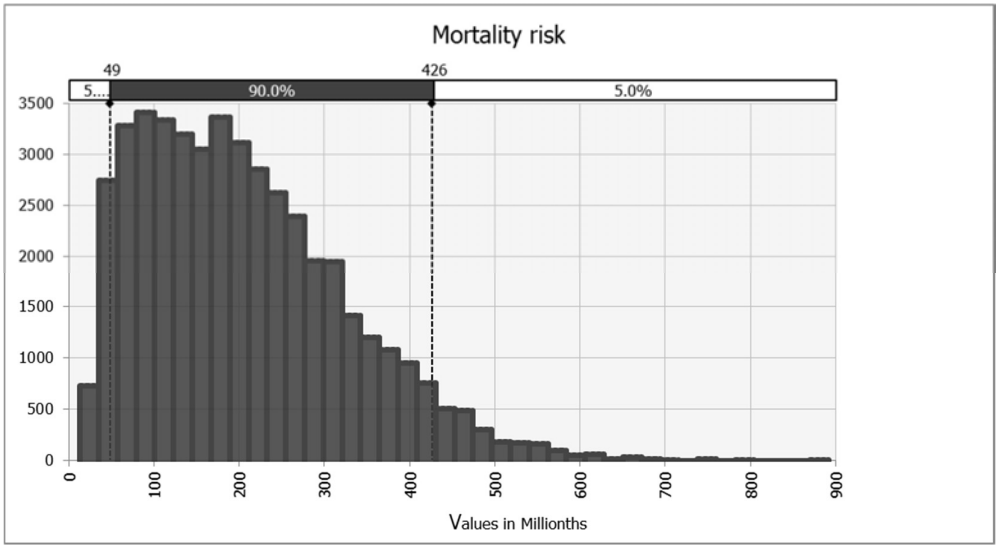

FIGURE 7 MORTALITY RISK PROBABILITY DENSITY PLOT FOR SCENARIO C

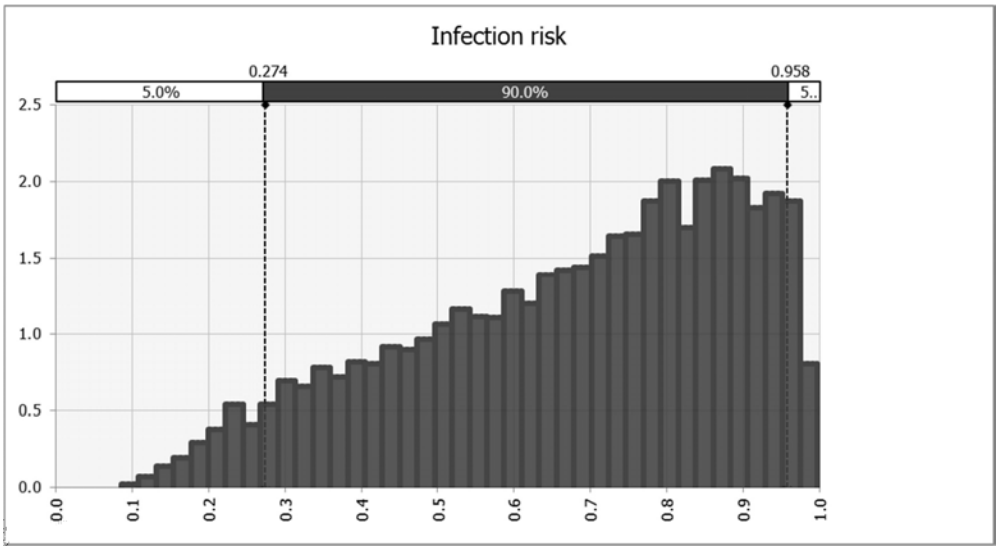

FIGURE 8: INFECTION RISK PROBABILITY DENSITY PLOT FOR SCENARIO D

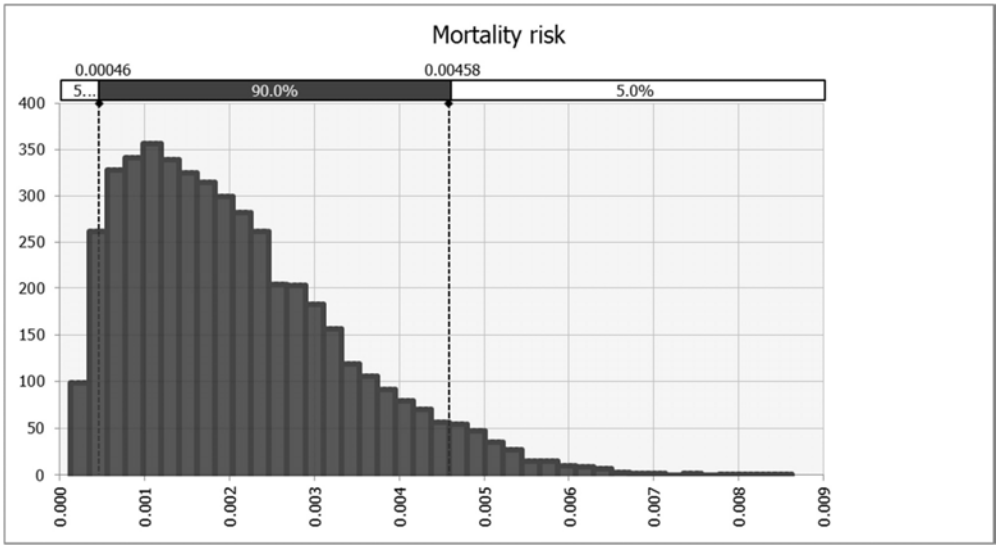

FIGURE 9: MORTALITY RISK PROBABILITY DENSITY PLOT FOR SCENARIO D

Sensitivity analysis

The following plots (Figure 10 and 11) represent sensitivity analysis for scenario A, ranked by effect on output mean. Scenario B to D showed similar sensitivity patterns.

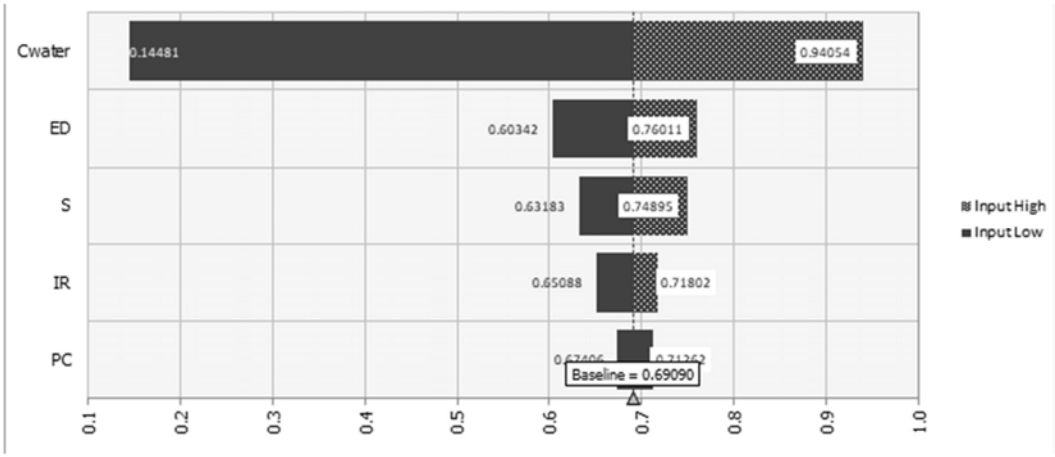

FIGURE 10: SENSITIVITY ANALYSIS FOR QMRA MODEL FOR SCENARIO A FOR INFECTION RISK

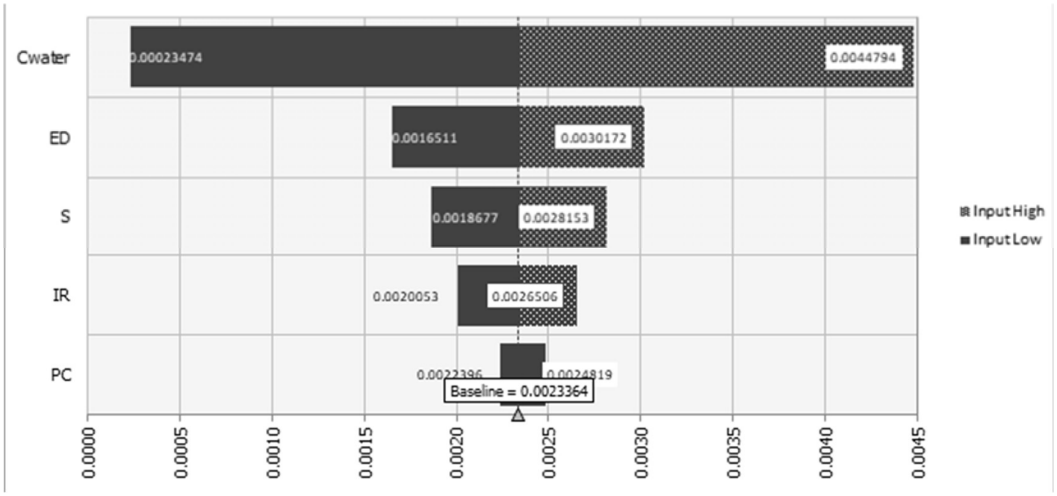

FIGURE 11: SENSITIVITY ANALYSIS FOR QMRA MODEL FOR SCENARIO A FOR MORTALITY RISK

The sensitivity analysis shows that the risk of infection is mostly affected by the concentration of legionella in water, followed by the partitioning coefficient. These results suggest that a qualitative risk assessment and a sound routine water sampling program should be performed prior QMRA.
The mean infection risks were used to calculate the desired log reduction. These results are summarised in Table 4.

Table 4: Summary of mean infection risks and the desired log reduction for Scenarios A to D

Scenario	Legionella concentration in water	Predicted retained dose of legionella at alveoli (CFU)	Mean Infection Risk Estimate	Desired log reduction	Risk reduction option
A	0 to 100 CFU/mL	19.6	0.69068	5.1	Elevate water temperature to 80C at source
B	0 to 100 CFU/mL	0.007	0.00047	4.1	Elevate water temperature to 70C at source
C	100 to 1000 CFU/mL	2.3	0.12874	1.7	Chlorination, reach 5mg/L of free chlorine
D	1000 to 1000 CFU/mL	18.7	0.67517	5.1	Elevate water temperature to 80C at source

The table above shows that similar water results can yield significantly different risk estimates when applying QMRA. It also allows to select the most appropriate risk reduction method.

Scenario A and Scenario B both had similar simulated bulk water concentration results (0 to 100 CFU/mL), yet the infection risk is different in four orders of magnitude (0.69068 to 0.00047); and the desired treatment includes raising temperature to 80°C (Scenario A) while the other to 70°C (Scenario B).

A second example, Scenario C and Scenario D also had similar simulated bulk water concentration results (100 to 1000 CFU/mL), yet the infection risk for Scenario C is five times smaller than Scenario D (0.12874 and 0.67517 respectively). The required log reduction for Scenario C is 1.7 while for Scenario D is 5.1.

These examples show that the application of QMRA to legionella provides more information than legionella concentration in bulk water samples. It provides information about relative risk and desired log reduction that can assist risk owners' decision making.

Limitations and assumptions

There are several assumptions made in the scenarios, and the selected parameters are subject to random variability. This QMRA has used a probabilistic risk assessment that propagates uncertainties through the model.

Some assumptions have not been modelled for simplicity or to the limited of knowledge or evidence of the variable to date. Legionella concentration in water is homogeneous and the loss viability of legionella in air is constant.

The most important limitation is the availability of air-water partitioning coefficients. For the QMRA model the type of aerosol generation that most closely resembled the air-water partitioning coefficient from previous QMRAs were used. There is an opportunity for further research in developing air-water partitioning coefficients by simultaneous sampling of airborne legionella and sampling of legionella in water.

CONCLUSION

This study has shown how quantitative microbial risk assessments can be used to model legionnaires' infection and mortality risks in Australian mines. The modelled scenarios have demonstrated that QMRA is a more robust risk assessment than the current practice of just comparing bulk water concentration results to a guideline. QMRA can be used to predict infection risks and mortality risks, based on a combination of factors such as exposure time, aerosol generation, level of activity and environmental conditions. Understanding these risks can help organisations to prevent outbreaks, by either treating the risk, or limiting exposure to infected areas with legionella.

Furthermore, these calculated legionella's risks can be compared against a 'target risk' levels, or other type of health risks, such cancer risks derived from exposure to chemical agents. Furthermore, it also provides a guidance for the selection of risk reduction method by calculating the desired log reduction. All these outputs from QMRA can benefit the risk owners to make more informed decisions; than simply relying on bulk water test results.

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Q FEVER – A RISK ASSESSMENT OF AN OPERATIONAL ABATTOIR.

Brian Murphy
EHS Assess Pty Ltd

BACKGROUND

The risk assessment was performed for a Victorian abattoir where four employees became infected with Q-Fever over a similar time frame. The facility, processed over 18 million livestock (bovine, ovine and calves) over a recent 10-year period. The risk assessment was commissioned as the regulator alleges that the facility should have done more to protect its workers from the risk of contracting Q fever in the workplace and that they failed to take steps which were reasonably practicable to eliminate or reduce the risk of its workers contracting Q fever.

OBJECTIVES

The objectives of the risk assessment were to provide professional opinion and justification on the following key points

- Do you agree that an abattoir in Victoria can be divided into high and low risk areas for Q fever?
- Are there any areas of the site which can be considered to be high risk areas where workers are more likely to be exposed to Q fever?
- Are there any areas of the site which can be considered to be low risk areas?
- In respect of visitors to the site, such as members of the public, job applicants, delivery people etc., what reasonably practicable measures could the abattoir take to eliminate or reduce the risk of visitors contracting Q fever at the site?

METHODOLOGY

To achieve these objectives, a qualitative occupational hygiene risk assessment was preformed to assess hazards related to Q fever during typical operations at the site. This method is based on the general principles of *AS/NZS ISO 31000:2009 Risk Management – Principles and Guidelines* combined with the fundamentals of occupational hygiene - anticipation, recognition, evaluation, and control of hazards. Specifically, the risk assessment process utilised a *Likelihood* and *Consequence* rating process to determine the level of risk associated with each hazard and to ensure adequate control of the hazard. While there is a number of varying approaches to qualitative risk assessments, the basic concept can be described in six steps as follows:

- **Step 1:** Selection of an individual or formation of a team to perform a risk assessment.
- **Step 2:** Collect and review all the relevant information to the area/system under evaluation.
- **Step 3:** Identification of the potential hazard(s).
- **Step 4:** Perform a systematic evaluation of the hazard, given in terms of frequency, severity and potential controls.
- **Step 5:** Mapping of frequency against severity.
- **Step 6:** Monitoring and reviewing.

Q FEVER - EPIDEMIOLOGY

Query fever, commonly known as 'Q fever' is a zoonotic disease (i.e. spreads from animals to humans). Acute primary Q fever may be highly incapacitating, but fortunately is rarely fatal. It is a severe, acute febrile illness of humans caused by *Coxiella burnetii*, an obligate facultative intracellular bacterium that is highly resistant to environmental stresses (such as high temperature, osmotic pressure and ultraviolet light). *C burnetii* is a highly infective and efficient pathogen. Studies on the most virulent strains have estimated that one *Coxiella burnetii*

cell is sufficient to initiate infection of an animal.[1] The organism has the ability to survive in the dried state in harsh environmental conditions, e.g.[1,8]

- On wool at 15-20°C for 7-9 months and almost twice as long at 4-6°C.
- On fresh meat in cold storage for >1 month.
- On salt meat for 5 months.
- In dried cheese made from infected milk for 30-40 days.
- In skim milk at room temperature for >40 months.
- In dry tick faeces for >18 months.

Q fever: Reservoirs of Infection

C burnetii has an exceptional host range and is found, for example, in ticks, native fauna, feral and domesticated mammals worldwide (with the possible exception of New Zealand).[3] In Australia, coxiella is present in several species of ticks, bush animals such as bandicoots, rats, kangaroos (and their ticks) and dogs.[1-3] Domestic ruminants – i.e. cattle, sheep and goats are the main reservoirs for human infection in Australia. Feral (i.e. introduced/escaped) mammals in the Australian bush such as goats, camels, horses, cats, dogs, foxes and rabbits are known from the world literature to be susceptible to Q fever infection[3] and hence are potential reservoirs of infection. Q fever transmission to humans from tick bite or tick excreta has been recorded but is very rare.[3] Infected parturient mammals may shed particularly high numbers of *C burnetii* in the placenta and in birth fluids,[4-6] and may contaminate meconium and the surface of the neonate. The coxiella may also be shed in milk of cattle, sheep or goats and unpasteurised milk and dairy products may be infective for humans.[1,7] Additionally, *C burnetii* may be shed in urine during acute infection[1,6] with the potential of contamination to bedding leading to aerosol infection of stock handlers etc. and cross infection of other animals.

At-risk Individuals

Q fever is principally an occupational infection in Australia in certain groups, particularly workers in the livestock rearing and meat processing industries and their dependent trades. However, Q fever is by no means restricted to those working directly with cattle, sheep and goats on the farm, in the shearing team or in the abattoir. Individuals in the community may be infected – e.g. by direct or indirect airborne infection from parturient animals, visits to stock sale yards, exposure to animal transporters or residences near feedlots or abattoirs. Worldwide, there have been innumerable outbreaks in the general population and sources have not always been identified. Outbreaks have also occurred in some unexpected or improbable settings e.g.[1-8] infection of poker player in a room where an infected cat was giving birth to kittens in the same room[9] and an outbreak in a school of arts – possibly associated with unwrapping a statue wrapped in straw.[10]

In their 2013 Guidance Note – Q fever Prevention, WorkSafe Victoria provide some examples of who may be at risk of contracting Q fever. These include:

- *Abattoir workers.*
- *Farm and dairy workers.*
- *Stockyard workers.*
- *Livestock transporters.*
- *Sheep shearers, wool classers, pelt and hide processors.*
- *Veterinary personnel.*
- *People or work with raw animal products, particularly reproductive organs including laboratory personnel.*
- *Worker involved in rendering.*
- *Council road workers who collect road kill.*
- *Administrative and maintenance workers at Q fever risk workplaces, visitors to these workplaces and members of the public who are near these workplaces.*

Human Infection - Routes of Exposure

Human beings are infected with *C burnetii* by direct or indirect contact with infected animals, or products from these animals.[1,7] Infected animals shed *C burnetii* in[1, 6, 11]

- Urine.
- Milk.
- Faeces.
- Birth products (in particularly high numbers).

Human infection can occur via a number of routes and in many circumstances. The commonest route of infection is via the respiratory tract after inhalation of contaminated aerosols[6,12] (fine droplets or dust) generated during parturition and/or during the slaughtering process, the manipulation of the uterus, placenta and foetus from infected animals. Air samples in the vicinity of parturient animals are positive for *C burnetii* for up to two weeks after parturition.[6,11] Soil and dust in animal holding areas may be contaminated with the organism from infected birthing animals, and the infected dust may be carried on work clothing, hair, straw, working dogs[1,11] and other fomites. *C burnetii* may then be liberated into the air and carried in other environments at distance – such as communal areas frequented by shepherds or meat processes or private homes.

After inhalation of the organism, the process of infection is thought to involve an intermediate step of multiplications in alveolar macrophages.[13] Consumption of unpasteurised infected milk or milk products may lead to infection[7] but at a lower rate than through airborne exposure.

Infection can also occur through subcutaneous inoculation,[6] but with a shorter incubation period than inhalation. Therefore, it is possible that infection might follow cuts with contaminated knives in an abattoir. Other less common routes of infection that are known to exist include transmission by blood transfusion[6], tick bite/tick excreta[1,3], person to person infection via the respiratory tract[6,14] vertical transmission of the coxiella via the female genital tract[15,16] and male genital tract may be involved with the infection of the testis and prostate and transmission of the infection during intercourse[17,18]. However, Q fever is not classified as a sexually transmitted disease.

SITE PROCESS

The site operates on a day and afternoon shift with load out crews operating up to 22 hours per day, 7 days per week and a cleaning crew at night time. In Australia, the killing of animals for food, fibre and other animal products (referred to as slaughter) is underpinned by the *AS 4696:2007 Hygienic production and transport of meat and meat products for human consumption*. Upon arrival at the Halal Accredited abattoir (either the day before or on the day of slaughter) by local and interstate transporters, the animals (cattle, sheep, bobby calves) are off loaded into either the beef holding yards (south of the site) or the sheep and calf holding yards. Both holding areas are within approximately 250m of the main office building with stock yard within 10m to the rear of the building.

Meat Process

The animals are provided with water, shade and shelter as appropriate. Animals are checked by a meat safety inspector to ensure they are healthy and suitable for human consumption. Sick or injured animals are segregated and given appropriate treatment or euthanised. Within 24 hours, animals are slaughtered.

On the way to slaughter, animals are walked up separate raceways into the abattoir where they are initially hosed/washed down with water to remove dirt and faeces prior to entering the stunning boxes. The stunning box separates the animal from the rest of the animals in the raceway. Within seconds of entering this box, an operator stuns the animal. With sheep, this is with an electrical stun. With cattle, this is with a captive bolt.

As soon as the animal is stunned and unconscious, within the kill floors it is shackled by a hind leg(s) and then, within seconds, the large neck blood vessels are severed to induce bleeding to allow bleeding out to cause death (a process known as 'sticking'). The rear quarters of the hide are treated with an anti-bacterial product.

Following stunning and bleeding, the carcasses are processed. The general processes for performing this are listed below with minor variances between the animals' types i.e. bovine or ovine:

- The hide and/or skin is removed.
- Head and feet are removed.
- Internal organs are removed (processed in the offal room) and foetuses/placentas (if present in pregnant animals) directed to either the calf slinking room in the tunnel where the bovine foetuses blood is drained and sent to the onsite laboratory for centrifuging and collection of foetal bovine serum. For sheep, the entire foetus is collected and packaged for Research & Development purposes.
- Carcass is further trimmed.

In the boning or cutting rooms the carcass is further processed through the following processes:

- The carcass is boned and cut.
- The meat is sorted by type of cut.
- Labelled.
- Packaged.
- Packed.

The meat product is then:

- Chilled or frozen.
- Cold stored.
- Scanned.
- Dispatched and distributed – locally and internationally.

All by-products are processed depending on the type with certain offal used for pet food and hides sent to the hide store for washing. Processing (slating treatment and storing) is performed across the road from the main abattoir facility and remaining waste, off-cuts are sent off-site for rendering and to be used in the manufacture of blood and bone fertiliser.

Within approximately two hours of the animal being stunned, the carcass is placed in a refrigerator for chilling or freezing. The process of slaughtering and further processing is designed to either destroy pathogens or prevent pathogenic growth and produce meat that is safe for human consumption

Hygiene Practices

Throughout the facility hygiene is paramount. Hand and boot wash stations are provided on the entry/exit points to the processing areas and hot water dip tanks for protected hands/forearms (disposal gauntlets) and equipment is utilised between each cut and at the end of each shift. Clothing/personal protective equipment (PPE) requirements on site depend on functional area of work and role. All personnel in processing areas wear company issued rubber boots, head covering, t-shirts and/or windcheaters or dustcoats, and trousers which are collected from the collect clothing store daily. Change room facilities are provided and lockers for the segregation of street and work clothing. Following the commencement of a shift, all equipment that contacts meat (such as smocks, aprons, gloves and knives) must not leave the controlled environment. Equipment is stored in the refrigerated anteroom/boning room on hooks provided for boning room personnel, or in the case of other processing rooms, the anteroom/or on the processing room apron and equipment hooks provided. All work clothing is returned to the laundry and placed in the bins provided and laundered on a daily basis using standard manufacturer recommended laundry processes.

Lunch rooms are provided on site with soiled work clothing not permitted within these areas. A separate breakout area is available for offal room workers where they can attend without fully removing all work clothing/showering.

First aid rooms and trained first aiders are available on site. The management of cuts/abrasions and protection of these is a key consideration in the employee induction training provided.

Current Controls for Management of Q Fever

Awareness regarding Q fever and the hazards of Q fever are documented in the Q Fever Policy. The policy identifies and lists the requirements for three different groups that will be entering, visiting and/or working on site. These are as follows:

- New Employees.
- Visitors.
- Contractors.

The following requirements have been stipulated in the abattoirs policy:

New Employees Entry Process

- Interview/Induction/Assess Q Fever status. Australian Q Fever Register Questionnaire provided and to be completed.
- If the worker states previously vaccinated or has had Q fever, then a declaration should be signed stating when this occurred or a Q Fever card presented.
- All new employees that will be involved in the plant at Warrnambool site and those involved in any Dairy activities who have not been vaccinated must have Q Fever vaccinations prior to commencing work. If an employee commences work within the 15-day period post vaccination they should be placed into a low risk area and a P2 mask worn.

Currently Low and High Risk Areas have been defined as following:

- **Low Risk Areas:** Boning rooms, loadout, chillers, office, transport, small stock kill floor (predominately in cattle), general outside duties away from cattle yards.
- **High Risk Areas:** Beef kill floors, offal rooms, tunnel area, yards, dairy activities, rendering plant.

Currently all workers on site (including administrative/office workers) are offered and provided vaccination.

Visitors

- Need to be asked if they have had Q-Fever or have been vaccinated. Asked to supply evidence of same.
- If no evidence supplied, then to only visit low risk areas or wear a face mask (at minimum P2).
- Document at front desk to be signed by visitors stating they have had Q fever and details explained to them; are either vaccinated or not.

Contractors

- Letter to be sent to all contractors regarding the abattoirs requirement for contractors to be vaccinated at their own cost. Include Q fever information sheet.
- All Managers to be made aware of this requirement for all new contractors.
- Risk assessment of work to be performed on task and location of works whilst on site.
- **Monday (Day 1):** Initial interview, paperwork (Australian Q Fever Register – Pre-Screening & Vaccination Form and Q Fever Employee Questionnaire provided). Q Fever and the Australian Q Fever Register Fact Sheet and Employee Manual issued to workers. Information provided in English, Korean and/or Chinese as required. Basic health check performed on site – audiometric and drug screening.

- **Tuesday/Thursday (Day 2/4):** Potential employees report to the required medical centre for the purpose of vaccination (if necessary). Before vaccination, a person must have three things:
  - A detailed history.
  - A blood test.
  - A skin test.

These tests are undertaken to help avoid unwanted vaccine side effects. If one of the tests (blood or skin) is positive, it means the subject may experience an adverse reactive to the vaccine. Then the person needs to return to the same doctor 7 days later to have the skin test read. If both tests are negative, the person is vaccinated. It then takes approximately 2 weeks for the vaccine to become effective. Note: The specifics/medical aspects of the pre-vaccination screening and actual vaccination immune response is beyond the scope of this assessment.

- **Friday (Day 5):** Potential employees report to site for formal induction (delivered through required languages to ensure it is understood by workers whose first languages may not be English) followed by a window tour of the facility (overlooking kill floor areas etc.).

Upon completion of the above, workers ordinarily commence work the following Monday (Day 7). It was reported work area/type of work that new hires start with is dependent on business needs at that time and the worker skillset. Assigning new workers duties in only low risk areas until 15 days following Q fever vaccination does not occur in practice nor does the use/implementation of respiratory protection for these workers.

DETAILED AREA RISK ASSESSMENTS

Detailed risk assessments were performed for each of the areas/key activities to assist with forming our opinions in Section 7.

DISCUSSION

To achieve the objectives of this assessment, as part of the discussion, professional opinion and justification on each of the questions raised by as part of this risk assessment are provided below:

- **Do you agree that an abattoir in Victoria can be divided into high and low risk areas for Q fever?**

  Yes, I concur contention that an abattoir in Victoria can be divided into high and low risk areas for Q fever. A literature review has identified that the most common route of infection is via the respiratory tract after inhalation of contaminated aerosols[6,12] (fine droplets or dust) generated during parturition or during the slaughtering process, the manipulation of the uterus, placenta and foetus from infected animals. Soil and dust in animal holding areas may be contaminated with the organism from infected birthing animals, and the infected dust may be carried on work clothing, hair, straw, on working dogs[1,11] and other fomites. Furthermore, a WorkSafe Victoria Guidance Note (April 2013) titled *Q fever Prevention* states to identify high risk work areas in an abattoir where employees are more likely to be exposed to Q fever. The areas listed are kill floors, livestock transport vehicles, yards and pens, offal rooms, skin sheds, rendering areas and handling foetal calves (e.g. slink rooms).[19]

  A synopsis of the findings of the risk assessment performed and provided in Appendix B - Risk Assessment Matrix & Risk Assessments indicated the followings:

  - The risk to occupants in **High Risk Areas** where workers can be routinely in direct or indirect contact with infected animals or products [urine, milk, faeces and birth products (in particularly high numbers)] [1, ,6 11] pre-implementation of controls is assessed as **HIGH** [Likelihood – **Likely** (not unusual, likely to occur regularly) and Consequence – **Moderate** (medical treatment needed and result in time off work)].
  - The risk to occupants in **Low Risk Areas** where workers are not routinely in direct or indirect contact with infected animals, or products [urine, milk, faeces and birth products (in particularly high numbers)] [1, ,6 11] pre-implementation of controls is assessed as **LOW** [Likelihood – **Rare** (the event may occur only in

exceptional circumstances) and Consequence – **Moderate** (medical treatment needed and result in time off work)] with the exception of the admin office.

Therefore, the site can be divided into high and low risk areas. Table 1 provides a summary of high, moderate and low risk areas on site.

Table 1: Summary of High, Moderate & Low Risk Areas	
Risk	**Area**
High	Livestock transport vehicles, yards and holding pens, kills floors, offal rooms, tunnel area (and associated rooms directly off the tunnel area), slinking room (handling foetal calves), laboratory (foetal bovine serum preparation) and skin sheds.
Moderate	Administration office.
Low	Boning rooms, chillers, freezers, warehousing palletizing, container prep, loadout areas) and workshops.

- **Are there any areas of the site which can be considered to be high risk areas where workers are more likely to be exposed to Q fever?**

Yes, there are areas of the site which could be considered to be high risk areas where workers are more likely to be exposed to Q fever. EHS Assess is basing this on the following:

As the literature review has identified that the most common route of infection is via the respiratory tract after inhalation of contaminated aerosols[6,12] (fine droplets or dust) generated during parturition or during the slaughtering process, the manipulation of the uterus, placenta and foetus from infected animals. Therefore, the work areas (and subsequently personnel working in these areas) that are routinely likely to be in direct or indirect contact with infected animals, or products [urine, milk, faeces and birth products (in particularly high numbers)] [1,6, 11] are kill floors, livestock transport vehicles, yards and pens, offal rooms, skin sheds, rendering areas and handling foetal calves (e.g. slink rooms).[19]

The findings of the risk assessment for the perceived aforementioned high-risk areas at the site, pre implementation of controls assesses the risk as HIGH [Likelihood – Likely (not unusual, likely to occur regularly) and Consequence – Moderate (medical treatment needed and result in time off work)]. Therefore, we can conclude that the site does have high risk areas where workers can be routinely in direct or indirect contact with infected animals, or products [urine, milk, faeces and birth products (in particularly high numbers)]. [1, ,6 11] As per Table 1, the high risk areas have been identified as: Livestock transport vehicles, yards and holding pens, kills floors, offal rooms, tunnel area (and associated rooms directly off the tunnel area), slinking room (handling foetal calves), laboratory (foetal bovine serum preparation) and skin sheds.

Under the *Occupational Health and Safety Act 2004* (OHS Act) the employer has a duty to provide and maintain a working environment that is safe and without risks to the health of employees and contractors. A duty also exists to ensure that other persons (such as visitors and members of the public) are not exposed to health and safety risks by the conduct of the business, so far as is reasonably practicable. Applying the principles of the hierarchy of control (elimination, substitution, engineering, administration and personal protective equipment) Q fever vaccination is a high order risk control measure to eliminate the risk of contracting Q fever.[19] Secondary (and supplementary) to a vaccination program, a range of other lower order controls (engineering, administration and personal protective equipment) exist.

While, we acknowledge that securing and retaining labour is a constant challenge for the industry (the site has had 6,572 individual workers from 1 January 2006 to 23 November 2015), the employer under *Occupational Health and Safety Act 2004,* has a duty to provide and maintain a working environment that is safe and without

risks to the health of employees and contractors. Therefore, implementation of a pre-screening and vaccination program which includes preventing workers from entering and/or working in high risk areas until immunity has been confirmed is, in our opinion, a reasonably practicable control to implement on site.

An analysis of seven trials estimated vaccine efficacy at 83-100%[20] with immunity to Q fever typically developing within 15 days after vaccination.[21] Therefore, placing potentially non-immune workers into high risk areas within 15 days of vaccination and without confirmation of immunity in order to meet the business staffing requirements is not aligned with the duty of care placed on an employer as per the *Occupational Health and Safety Act 2004*. Furthermore, within the 15 days after vaccination (particularly during the first 10 days), exposure to the organism may lead to an overt infection.[21] If it is not possible to delay new workers commencing until immunity has been confirmed (to secure their employment), best practice would be to assign duties in lower risk areas and development and implementation of a robust respiratory protection program and fit testing as per *AS/NZS 1715 Selection, use and maintenance of respiratory protective devices* until they are confirmed through testing to be immune. This is achievable and the business needs of the site met with proactive planning. One method to support this may be to cross-training of already immune workers from low risk areas to work in multiple areas and their positions backfilled temporarily by new starters awaiting confirmation of immunity. However, EHS Assess recognises that this is not always feasible as many of the tasks in the low risk areas require the highest skillset i.e. boning and not suitable for unskilled, inexperienced workers.

The benefits of such vaccination programs are tangible. During 2001-2002 the Australian Government established the National Q Fever Management Program (NQFMP) which ran in two phases to provide free vaccination to some high risk occupations including abattoir workers. Although the full success rate of the program is hard to precisely quantify, the greater than 50% reduction in notification rates seen from 2002-2010 has been largely attributed to it.[22, 23] Furthermore, there are financial benefits of such a program. Occupational-acquired, laboratory-proven Q fever is largely compensable[24] with Work Cover compensation claims estimated to cost $1.3 million per year.[25] Legal payouts can be substantial with a $1.1 million payout from an isolated case of occupation-acquired chronic Q fever recorded.[25]

- **Are there any areas of the site which can be considered to be low risk areas?**

Yes, there are areas at the site which could be considered to be low risk areas where workers are less likely to be exposed to Q fever. This is based on the following:

A literature review has identified that the most common route of infection is via the respiratory tract after inhalation of contaminated aerosols[6,12] (fine droplets or dust) generated during parturition or during the slaughtering process, the manipulation of the uterus, placenta and foetus from infected animals. Therefore, work areas (and subsequently personnel working in these areas) are less likely to be routinely in direct or indirect contact with infected animals, or products [urine, milk, faeces and birth products (in particularly high numbers)] [1,6, 11] are likely to include the boning rooms, loadout, chillers, offices/training rooms, workshop and general outside areas away from stock yards.

The findings of the risk assessment for the perceived aforementioned low risk areas at the Warrnambool site, pre implementation of controls assesses the risk as LOW [Likelihood – Rare (the event may occur only in exceptional circumstances) and Consequence – Moderate (medical treatment needed and result in time off work)] with the exception of the administration office. In the instance of the administration office on site presents unique circumstances due to its location and proximity to the stock yards and movement of stock vehicles and has been assessed as MODERATE [Likelihood – Unlikely (the event could occur at some time) and Consequence – Major (serious injury)]. A heating, ventilation and air-conditioning (HVAC) system exist on this building with make-up air collected from external to the building in the vicinity of the stock yards. With the aerosols of fine droplets or dust from stock in the MMP stock yards these could enter and be distributed throughout the admin office via the HVAC

system. While of lower risk compared with direct contact during the slaughtering process, the manipulation of the uterus, placenta and foetus from infected animals, it must be acknowledged and controls (e.g. high efficiency particulate arrestance filters installed) to capture fine droplets or dust entering the system. The ducted HVAC system should be maintained to the requirements of *AS3666 Air-handling and water systems of buildings - Microbial control.*

In the instance of low risk areas, greater adoption and implementation of lower order controls e.g. engineering, administration and personal protective equipment (PPE) as opposed to mandatory vaccination of all workers on site, regardless of role or area of work, may be considered reasonably practicable controls, However, where the abattoir determine that lower order controls for low risk areas cannot be effectively implemented and/or are non-conducive to their work practices (frequently moving individuals between different work areas based on the needs of the business or not being able to don respiratory protection) then Q fever vaccination and confirmation of immunity for all workers is a high order risk control measure that should be implemented throughout the business.

- **In respect of visitors to the site, such as members of the public, job applicants, delivery people etc., what reasonably practicable measures could the side take to eliminate or reduce the risk of visitors contracting Q fever at the site?**

At minimum all members of the public, job applicants, delivery people etc. should be provided with a visitor's induction for the site outlining Q fever risks that exist on site. Determining what are reasonably practicable control measures for members of the public, job applicants, ad-hoc maintenance contractors and delivery people should be assessed by a risk assessment on a case by case basis. Considering the findings of the literature review and what has been identified as the most common route of infection, the risk assessment needs to consider if members of the public, job applicants, ad-hoc maintenance contractors and delivery personnel will be entering high risk areas on site and if so what is the likelihood of direct or indirect contact with infected animals, or products from these animals? By considering these, reasonably practicable control measures can be determined and implemented.

While there have been innumerable outbreaks in the general population worldwide (147 cases in the general population in south Birmingham UK, arising from wind-borne infection from lambing sheep in pastures south of the city limits[26]) it is recognised that it is not reasonably practicable to vaccinate all members of the public. Assuming the public, job applicants and most delivery people (with the exception of stock deliverers) are likely to only occupy low risk areas during routine operations, then on the basis of risk assessment it is the opinion of us that lower order controls, e.g. engineering, administration and personal protective equipment (PPE), as opposed to mandatory vaccination of all personnel entering the site, may be considered reasonably practicable controls. Similarly, for ad-hoc visitors to high risk areas who are doing window tours or walk-throughs only and are not in direct contact with infected animals, or products from these animals, lower order controls, e.g. engineering, administration and personal protective equipment (PPE) of a P2 respirator (or greater), may be considered reasonably practicable controls. However, where respiratory protection is provided a respiratory protection program and fit testing as per *AS/NZS 1715 Selection, use and maintenance of respiratory protective devices* is necessary. Such control strategies in these instances are endorsed by WorkSafe Victoria Guidance Note (April 2013) titled Q fever Prevention. Therefore, in summary it is the opinion us that lower order controls should be considered reasonably practicable for members of the public, job applicants and delivery people. Moreover, higher order controls (vaccination) should be the required controls for trades/maintenance contractors performing planned work in high risk areas. However, it is recognised that situations arise where critical maintenance must be performed and a unique/specific skillset may not be available from a pool of vaccinated trades/maintenance personnel. In this instance (following completion of a detailed risk assessment on proposed activities), PPE options can be considered for non-immune personnel as an exception to the rule.

CONCLUSIONS

From the findings of the Q fever risk assessment performed, we concur with the regulator that the site can be divided into high and low risk areas for Q fever. The risk assessment indicates that the risk to occupants in high risk areas where workers can be routinely in direct or indirect contact with infected animals or products (pre-implementation of controls) is assessed as HIGH, whereas the risk to occupants in low risk areas where workers are not routinely in direct or indirect contact with infected animals, or products (pre-implementation of controls) is assessed as LOW.

Under the *Occupational Health and Safety Act 2004* (OHS Act) the employer has a duty to provide and maintain a working environment that is safe and without risks to the health of employees and contractors. A duty also exists to ensure that other persons (such as visitors and members of the public) are not exposed to health and safety risks by the conduct of the business, so far as is reasonably practicable. Applying the principles of the hierarchy of control (elimination, substitution, engineering, administration and personal protective equipment), Q fever vaccination is a high order risk control measure to eliminate the risk of contracting Q fever. The implementation of a pre-screening and vaccination program which includes preventing workers from entering and/or working in high risk areas until immunity has been confirmed is, in our opinion, a reasonably practicable control to implement on site. Therefore, placing potentially non-immune workers into high risk areas within 15 days of vaccination and without confirmation of immunity in order to meet business staffing requirements, is not aligned with the duty of care placed on an employer as per the *Occupational Health and Safety Act 2004*.

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FORENSIC MYCOLOGY, HOW DO HYGENISTS ADD VALUE?

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ABSTRACT

In recent years, there has been a substantial increase in awareness of mould and IAQ issues in general. Consequently, the number of “complaints" and "disputes" in relation to building defects have risen exponentially. Such disputes often result in litigation, and therefore in require legally valid and scientifically robust, expert advice on mould related issues. A case study into recent matter is presented where the building landlord was claimed to have "not maintained" the subject building properly, consequently causing a large amount of trading stock in a retail section of the building to become mouldy. Staff complained of upper respiratory symptoms such as sneezing and sore throats, after handling mouldy items. Data is presented on how the inspection of the building and the stock in question was conducted. Inspection and measurement revealed that the IAQ and mould levels where all within acceptable limits. Thus, IAQ and mould level measurements alone, did not explain why the stock was mouldy. Forensic mycology was used to determine the inoculum source of the mouldy stock. By detailed species analysis of the mould present, it became clear that the mould species found on the stock was not found anywhere else in the building. It was noted with interest, that not all items of stock were contaminated, for example, two identical stock items next to each other, sampling showed one to be contaminated, and the other not. By tracing the supply route of the stock, it was found that contaminated stock had recently arrived from a different retail outlet, that had ceased trading. It was not possible to obtain biological samples from the other defunct retail outlet, but it was possible to locate additional boxes containing stock from the same defunct source, stored in the warehouse of the building in question. Inspection and species analysis revealed that all stock from the defunct location was contaminated with both the same species *Aspergillus spp.* and *Penicillium spp.,* and in similar proportions to the contaminated stock in the retail shop. This analysis demonstrated that, on an overwhelming balance-of-probabilities basis, that the contamination source was not the subject building, but the stock relocated from the defunct outlet. On the strength of the inspection/measurement and forensic mycological analysis undertaken, the tenant retailer was able to identify contaminated stock and disposition safely, thus protecting staff and customers; the building landlord was absolved of liability, thus saving hundreds of thousands of dollars in Remediation and damages. In addition, using the analysis, the retailer was able to demonstrate that the stock damage was an insurable Event, and so was able to lodge a successful insurance claim. Finally, the legally valid articulation of the analysis enabled all parties to avoid very significant legal costs, and potentially protracted litigation.

INTRODUCTION

Mycotec was engaged to conduct an IAQ, mould and moisture assessment in a large commercial facility. The landlord of the building in which a warehouse and retail store were housed, was claimed by their retailer tenant to have not suitably maintained the premises resulting in an unacceptable IAQ standard. It was therefore claimed that as a direct consequence, trading stock within the warehouse and retail space had become mouldy. Staff employed by the retail tenant and working in the affected areas, reported various symptoms consistent with typical mould affectation. Subsequently, staff members so-affected, lodged formal health complaints with their employer. At that juncture and given the submission of formal complaints the retail tenant was compelled to act, and sought legal advice.

An initial assessment by a local environmental consultant did not identify any IAQ issues, however, microbial (mould) sampling was not conducted by this consultant.

It was recommended by the landlord's legal counsel that Mycotec be engaged to undertake an independent scientific study with the objective of identifying the underlying cause(s) of the observations and symptoms experienced by staff. Further, Mycotec was to propose remediative actions as indicated and supported by measured data and evidence gathered.

Mycotec undertook an inspection of the property, to conduct a comprehensive IAQ and mould survey. To this end Mycotec measured a number of salient air-quality indicator parameters, and a comprehensive acquisition of microbial samples.
Given the observed mould issues, Mycotec also undertook microbial sampling using fungal-focused techniques. These techniques utilised nutrient-media optimised for fungal growth and the facilitation of accurate identification of fungal species. The use of such nutrient-media is especially pertinent given that speciation is the corner-stone of forensic mycology.
In order to provide a comprehensive picture of the mycological environment within the building and identify any inconsistencies or anomalies in mould proliferation and/or growth patterns, Mycotec undertook a series of sampling regimes:

1) Viable air sampling to identify airborne mould species and relative proportions of different species.
2) Viable surface sampling to identify surface mould species and relative proportions of different species.
3) Total (viable & non-viable) surface sampling to identify total mould genera and relative proportions of different genera, along with the quantification of the proportion of 'live' (viable) and 'dead' (non-viable) mould.

The sampling regime undertaken facilitated Mycotec's forensic analysis, especially the determination of “what mould was the same as what”, and therefore “which mould came from where”. Without such a comprehensive sampling regime, such questions could not be answered with the robustness, rigour and evidentiary nature demanded by legal processes.

1. METHODS

Viable air and surface samples were taken using an SKC Quicktake30, 400-hole impaction sampler (Biostage 2) @ 28.3 litres/min for 2 minutes with 90mm Malt Extract Agar plates (2%MEA).

Viable Surface Mould samples were taken using 55mm RODAC surface press plate, filled with 2%MEA Minimum Incubation Conditions were 96 hrs at 20 ± 2 °C [(d)].

Non-Viable Surface samples were taken using Bio-Tapes (adhesive tape), stained with lactophenol cotton wool blue and observed under microscope at 400 times magnification.

Moisture Measurements were taken using a Protimeter MMS Plus and measurements reflected in %WME.

Air Temperature (^{0}C)/Relative Humidity (%)/Carbon Dioxide (ppm) readings were measured using a TSI IAQ-Calc 7545.

All instruments are calibrated and were in good working order. The samples were taken and analysed to “in house standard work procedures (SWP)” in accordance to international NIOSH methods.

2. RESULTS SUMMARY

Viable Airborne Fungal Concentrations Results

The airborne sampling results (Table) showed an average of 137 CFU/m^3 concentrations of indoor airborne fungi (mould) and had a rating of “Low”. This was lower than the outdoor airborne fungal concentrations. The air sampling of indoor locations tested had “Below Detectable Limits to Moderate” levels of fungal concentrations. The dominant genus present (Table 1) was *Cladosporium* sp. both in indoor and outdoor locations.

Viable Surface Fungal Concentrations Results

The surface sampling results in Table 3 show the locations tested had “Below Detectable Limits to Moderate” levels of fungal (mould) concentrations.
The dominant surface genus (Table) was *Cladosporium* sp.

Non-Viable Bio-Tape Surface Fungal Spore Concentrations Results
The surface sampling results in Table 5 showed all of the sampling locations tested had "Extreme Contamination" levels of fungal (mould) concentrations.
The identified fungal genera were *Aspergillus/ Penicillium* sp., *Cladosporium* sp. and A*lternaria* sp.

Indoor Air Quality Testing Results
Air Temperature (^{0}C)/Relative Humidity (%)/Carbon Dioxide (ppm) readings were within acceptable indoor air quality levels (Table 6).

3. RESULTS: VIABLE AIRBORNE FUNGAL CONCENTRATIONS

The purpose of collecting air samples is to detect and quantify bioaerosol presence, identify bioaerosol release from sources, assess human exposure to biological agents, and to monitor the effectiveness of control measures. Indoor/Outdoor relationships are assessed both by comparing concentrations and species compositions of comparably collected samples. In non-problem environments, the concentrations of fungi in indoor air typically are similar to or lower than the concentration seen outdoors. If fungal concentrations indoors are consistently higher than those outdoors, then indoor sources may be indicated [(g)].

The airborne sampling results (Table 1) showed an average of 137 CFU/m^3 concentrations of indoor airborne fungi (mould) and had a rating of "Low". This was lower than the outdoor airborne fungal concentrations. The air sampling of indoor locations tested had "Below Detectable Limits to Moderate" levels of fungal concentrations.

Table 1 Viable Airborne Fungal Concentrations (CFU/m^3).

Location	CFU/m^3	Rating	Above / Below OA
Outdoor Air Reference	618	High	NA
	530	High	NA
Shoes section middle	106	Very Low	Below
Shoes section front	230	Moderate	Below
Shoes section end wall	194	Moderate	Below
Shop front aisle	106	Very Low	Below
Shop end LH	141	Low	Below
Cashier	247	Moderate	Below
Shop middle aisle	BDL	BDL	Below
Shop end aisle RH	71	Very Low	Below
Indoor Average	**137**	**Low**	**Below**
Outdoor Average	**574**	**High**	**-**

CFU/m^3	BDL	18	<107	<142	<177	<354	<707	<2827	<5652	>7067
Rating	BDL	Single Colony	Very Low	Low	Low to Moderate	Moderate	High	Very High	Extremely High	TNTC

Notes:
1. This rating scale based on a 400 holes sampler head, 90 mm plastic petri dish, and 2 minutes sample time.
2. The rating scale does not give an absolute numeration of viable colonies or total spores in original air sample.
3. The detection limit of 1 CFU per plate = 18 colony forming units per cubic metre (CFU/m^3).
4. Ratings are based on proportionality to outdoor air levels - ref: AMG Table 1, page 9. The rating values provided above are based on typical levels acquired over many years, and are consistent with

internationally measured levels. It should be noted that values above are intended to represent a relative risk rating only from a practical stand point.

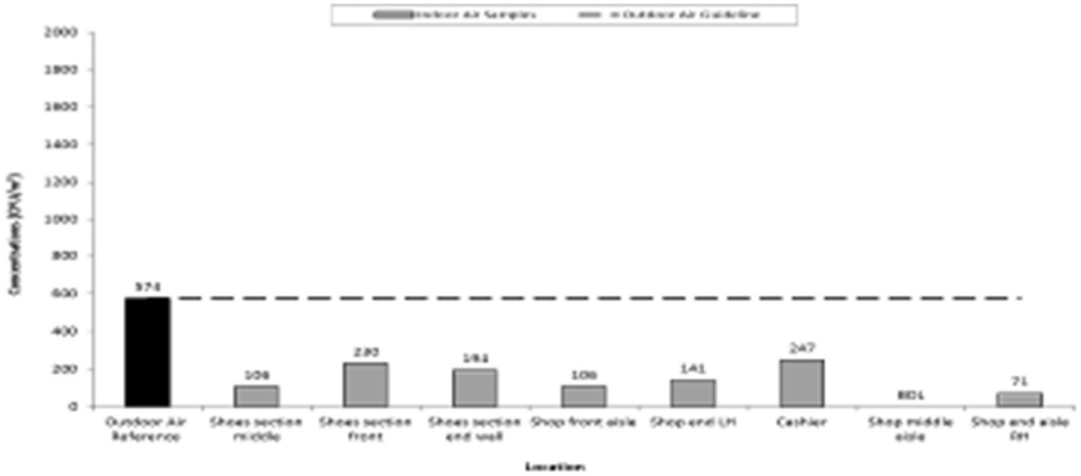

Figure 1 Viable Airborne Fungal Concentrations (CFU/m^3).

4. RESULTS: VIABLE AIRBORNE FUNGAL GENERA MIXTURE

The mixture of fungal genera provides information on the potential for fungal growth in a building, exposure to fungi and potential health effects, and the type of fungal damage (recent water damage versus older dried out water damage). This is done by comparing the genera normally occurring in the outdoor air with those occurring in the indoor air. Dominance in indoor air of fungal species not predominant in outdoor air indicates that these fungi are growing in a building and that the air quality is degraded (AIHA 1996a, b).

Results

The dominant genus present (Table) was *Cladosporium* sp. both in indoor and outdoor locations.

Table 2 Viable Airborne Fungal Genera Mixture.

Fungal Genera	**Locations**								
Cladosporium sp.	▣	☐	⊡	☐	☐	☐	⊡	×	☐
Alternaria sp.	☐	×	×	×	☐	×	×	×	×
Epicoccum sp.	☐	×	×	×	×	×	×	×	×
Penicillium sp.	☐	×	×	☐	☐	×	☐	×	☐
Sterile Mycelia	☐	×	×	×	×	☐	☐	×	☐
Yeast	☐	☐	☐	☐	×	☐	☐	×	×
	Outdoor Air Reference	Shoes section middle	Shoes section front	Shoes section end wall	Shop front aisle	Shop end LH	Cashier	Shop middle aisle	Shop end aisle RH

Legend

Symbol	×	☐	⊡	▣	◘	■
CFU/Plate	<1	<6	<18	<30	<60	>150
Rating	BDL	Several Colonies	Established Genera	Moderate Concentrations	High Concentrations	Dominant Genera

5. RESULTS: VIABLE SURFACE FUNGAL CONCENTRATIONS

Surface sampling may be used to confirm the nature of suspected microbial growth on environmental surfaces, measure the relative degree of biological contamination, and identify types of microorganisms and other biological agents present [g].

Results

The surface sampling results in Table 3 show the locations tested had Below Detectable Limits to Moderate" levels of fungal (mould) concentrations.

Table 3 Viable Surface Fungal Concentrations (CFU/Plate).

Location	CFU/Plate	Rating
Inside shoe contamination	25	Moderate
Inside shoe clean	BDL	BDL
HVAC vent	2	Very Low

Rating	BDL	Very Low	Low	Moderate	High	Very High	Extremely High	TNTC
CFU/Plate	<1	12	24	59	149	297	594	>594
CFU/cm^2	<0.042	0.50	1.00	2.50	6.30	12.5	25.0	>25.0

Notes:

1. This rating scale based on maximum of 25 countable colonies per square centimetre on a 55 mm RODAC plate.
2. The rating scale does not give an absolute indication of number of colonies/m^2 on the original surface.
3. The detection limit (BDL) of 1 CFU per plate = 0.042 CFU/cm^2 (421 CFU/m^2).

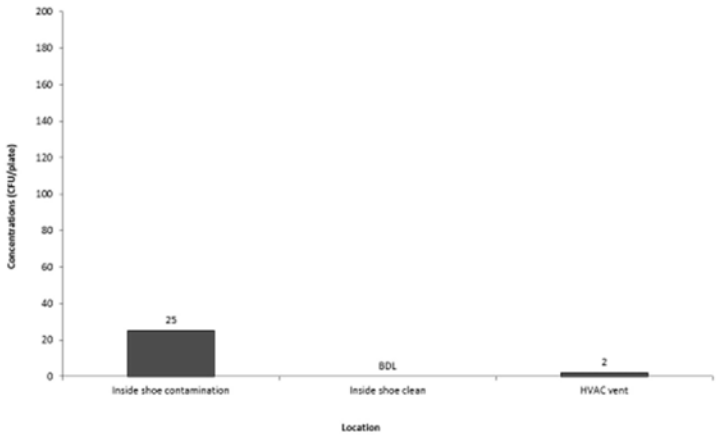

Figure 2 Viable Surface Fungal Concentrations (CFU/Plate).

6. RESULTS: VIABLE SURFACE FUNGAL GENERA MIXTURE

Many environmental factors influence fungal survival and growth. These include water, temperature, light and nutrient concentration and kind [f]. The mixture of fungal genera may indicate the types of environmental factors that are affecting the growth of fungi on surfaces tested and the damage occurring to the surfaces.

Results
The dominant surface genus (Table) was *Cladosporium* sp.

Table 4 Viable Surface Fungal Genera Mixture.

Locations	**Fungal Genera**					
Inside shoe contamination	⊡	☐	☐	☐	☐	☐
HVAC vent	☐	×	×	×	×	×
Inside shoe clean	×	×	×	×	×	×
	Cladosporium sp.	*Alternaria* sp.	*Aspergillus* sp.	*Aspergillus niger*	*Penicillium* sp.	Yeast

Legend

Symbol	?	?	?	?	?	?
CFU/Plate	<1	<6	<18	<30	<60	>150
Rating	BDL	Several Colonies	Established Genera	Moderate Concentrations	High Concentrations	Dominant Genera

7. RESULTS: NON-VIABLE BIOTAPE SURFACE FUNGAL SPORE CONCENTRATIONS

Surface sampling may be used to confirm the nature of suspected microbial growth on environmental surfaces, measure the relative degree of biological contamination, and identify types of microorganisms and other biological agents present [(g).]

Results
The surface sampling results in Table 5 showed all of the sampling locations tested had "Extreme Contamination" levels of fungal (mould) concentrations. The identified fungal genera were *Aspergillus/ Penicillium* sp., *Cladosporium* sp. and A*lternaria* sp.

Table 5 Non-Viable Bio-Tape Surface Fungal Spore Concentrations (spores/cm^2).

Location	**Concentrations (spores/cm^2)**	*Aspergillus/ Penicillium* sp.	*Cladosporium* sp.	*Alternaria* sp.	Gen Dirt & Debris (L, M, H, VH)	**RATINGS (BDL, L, N, E, C, EC)**
Inside shoe contamination	**6250**	6250	-	-	Low	**EC**
HVAC vent	**6020**	-	4606	1414	Very High	**EC**
Inside shoe contamination	**5530**	5528	1	1	Low	**EC**

****Total (Viable + Non-viable) Fungal Hygiene Guide for Indoor Surfaces**

Hygiene Rating	Total[a] Surface Fungal Spora Concentration
Below Detectable Limits (BDL)	<1 spore/m^3
Low[b] (L)	< 50 spores/cm^2
Normal (N)	50 to 500 spores/cm^2
Elevated[c] (E)	500 to 1000 spores/cm^2 + prevailing species
Contaminated[d] (C)	> 1000 spores/cm^2 + dominant species + Propagules
Extreme Contamination[e] (EC)	> 5000 spores/cm^2 + dominant species + Propagules + confluent spores

[a] The Total surface fungal spora guideline only pertains to a sampling and incubation method of "Tape-Life-Off" (eg. Zefon BioTape) with microscopic counting at 400x magnification (typically 40x objective + 10x eye piece). Either one horizontal or vertical transverse across the spore collection area needs to be counted. High and ext. high samples can use smaller areas to count and the results multiplied up. Results are reported in spores per square centimetre (total spores/cm^2).

[b] Typical low concentration can be detected directly after a surface has been cleaned. These surfaces left for a duration would attain <500 spores/cm^2 as per normal.

[c] Samples have more than might normally be expected and could indicate the presence of fungal contamination. Surfaces will require cleaning to remove surface mould. Porous surfaces may need inspection to determine if fungal growth has penetrated the surface.

[d] Samples have a concentration and species range of fungi that suggests surfaces are contaminated with either fungal growth or are laden with living fungal particles (e.g. From cross contamination).

[e] Confluent deposition of fungal particles with a dominant species present indicating severe fungal growth and possible decay of materials. Remediation or removal of all affected surfaces will be required.

** Australian Mould Guidelines AMG-2010-1

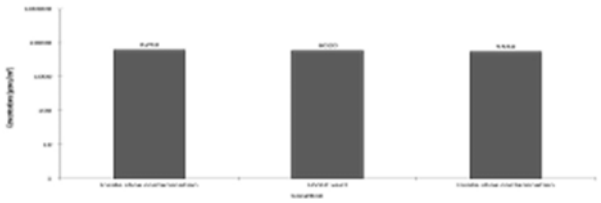

Figure 3 Non-Viable Surface Fungal Spores Concentrations (spores/cm^2).

8. RESULTS: INDOOR AIR QUALITY TESTING RESULTS

Indoor air quality data gives us an indication of the ventilation rates in the premises. Indoor air concentrations of carbon dioxide that exceed 1000 ppm are a marker suggesting inadequate ventilation (NIOSH Indoor Environmental Quality). Relative humidity in occupied spaces should be controlled to less than 65% to reduce the likelihood of conditions that can lead to microbial growth. (ASHRAE Standard 55-2004, ASHRAE Standard 62.1-2004). OSHA regulates formaldehyde, a specific VOC, as a carcinogen. OSHA has adopted a Permissible Exposure Level (PEL) of 0.75 ppm, and an action level of 0.5 ppm. HUD has established a level of 0.4 ppm for mobile homes. Based upon current information, it is advisable to mitigate formaldehyde that is present at levels higher than 0.1 ppm.

Results

Air Temperature (^{0}C)/Relative Humidity (%)/Carbon Dioxide (ppm) readings were within acceptable indoor air quality levels (Table 6).

Table 6 Indoor Air Quality Results.

Location	CO_2 (ppm)	Air Temp (°C)	RH (%)
Outdoor Air	368	24.1	48.2
Shoes end	442	23.7	51.5
Shoes middle	556	23.7	52.2
Cashier	548	23.9	53.4
Shop front	504	24.1	52.3
Shoes front	499	24	51.5
Ladies shoes	411	23.8	49.5

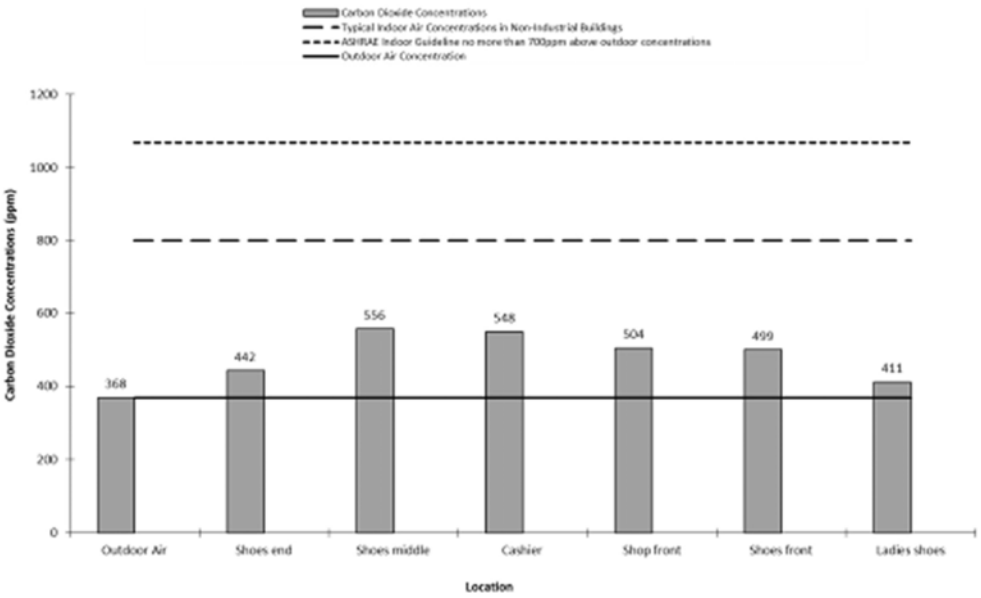

Figure 4 Carbon Dioxide Concentrations (ppm).

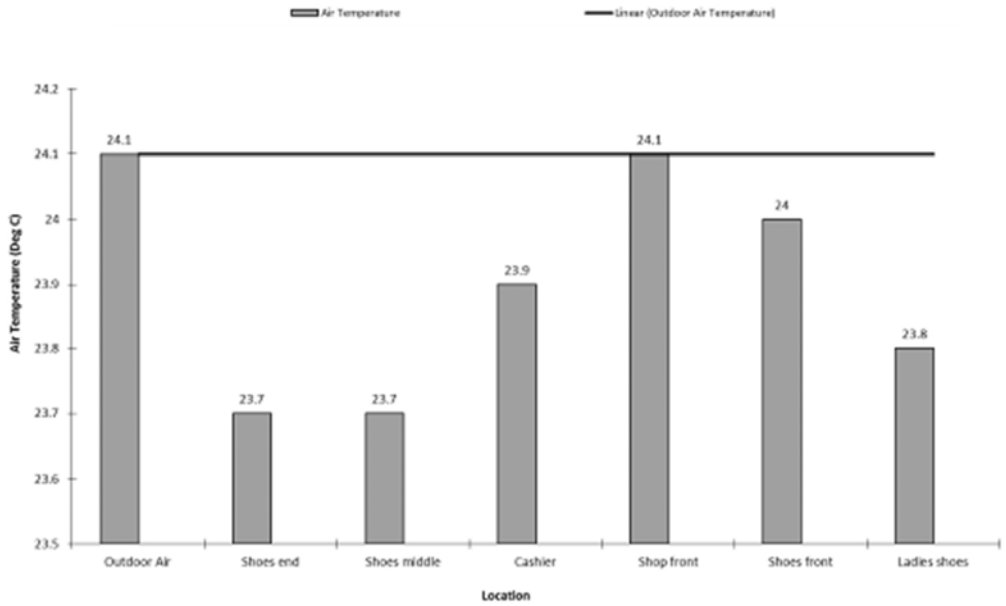

Figure 5 Air Temperature Readings (°C).

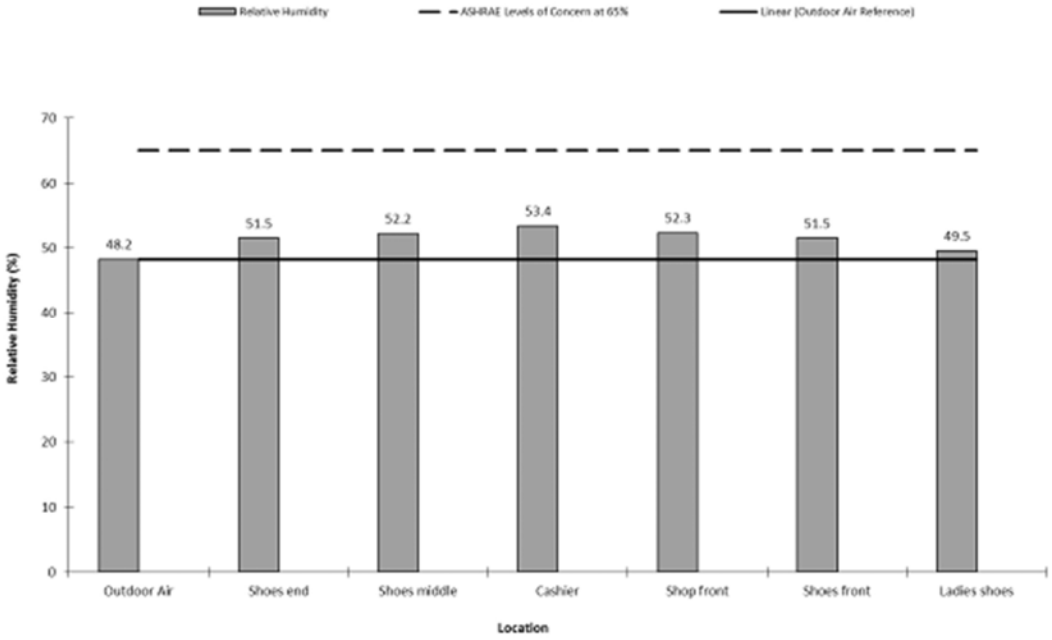

Figure 6 Relative Humidity Readings (%).

Building Inspection Notes and Comments

It was reported from staff, that in the last couple of weeks before the inspection, mouldy shoes were found, mainly in the man's section of the retail shop. The mouldy shoes were quarantined by staff, by packing them into plastic bags and taking them off site. Staff reported that the first-time mould was found on shoes was when they received stock from another shop of the same retail chain, that had recently closed.

On inspection of the premises there was no obvious moisture ingress into the premises or any condensation issues. No visible mould was found within the retail shop or the warehouse, except on 2 AC vents from the ducted HVAC system. The man's section was corded off from the public on inspection day. Inspection of all the shoes in this section, found 2 pairs of shoes heavily mould contaminated but only on the inside of the shoes. Shoes of the

exact same make directly next to the contaminated ones, showed no sign of mould. This pairs of shoes where surface mould tested on the inside to compare mouldy with non-mouldy shoes.
All measured IAQ parameters and mould contamination levels are within acceptable limits.
The analysis of samples reviled that the mould contamination of the shoes is not due to any environmental contamination. The shoes themselves are mainly contaminated with *Aspergillus/Penicillium* type of mould, while the HVAC vents where mainly contaminated with *Cladosporium spp* [(g,h)].

Recommendations

- It is recommended to HEPA vacuum and then down wipe the AC vents with Microfibre cloths and vinegar solution. There is currently no need for any further remediation actions of the premises [(a, b c, e & f)].
- The premises should be routine monitored annually for IAQ and mould in order to detect any possible building defaults and water ingress.
- A walk-through inspection of all shelves with an LED torch should be conducted, to identify any further mouldy shoes. This should than be carefully removed from the shelves and placed into sealed plastic bags. All cartons with stock from the defunct outlet should be quarantined. Plastic bags and cartons containing mouldy stock should be immediately removed from the premises to avoid further cross contaminations and possible further exposure to mould by staff.
- Mouldy stock should be inventoried for possible further insurance claims.
- Staff should be advised to seek medical assessments if any of the symptoms persist.
- A mitigation meeting between the involved parties should be held and liability, based on scientific data, should be established.

SUMMARY

Mycotec's analysis demonstrated that, on an overwhelming balance-of-probabilities basis, that the contamination source of mould was not the subject building, but the stock relocated from the defunct outlet. On the strength of the inspection/measurement and forensic mycological analysis undertaken, the tenant retailer was able to identify contaminated stock and disposition safely, thus protecting staff and customers; the building landlord was absolved of liability, thus saving hundreds of thousands of dollars in remediation and damages. In addition, using the analysis, the retailer was able to demonstrate that the stock damage was an insurable event, and so was able to lodge a successful insurance claim. Finally, the legally valid articulation of the analysis enabled all parties to avoid very significant legal costs, and potentially protracted litigation.

This case demonstrates that with proper sampling and analytical techniques, hygienist can make a large impact on the outcome of medical, legal and financial issues and their mitigation.

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WORKPLACE INHALATION EXPOSURE TO ETHANOL AFFECTING ROAD SIDE BREATH TESTING.

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Background

This study was undertaken at an industrial facility with a history of personal exposures to solvent mixtures containing ethyl alcohol (further as ethanol). After an employee failed a random road side alcohol breath test while on their way from work, concerns were raised whether this could be due to inhalation exposure at the workplace.

Methodology

A four-day workplace assessment was developed and conducted including personal exposure assessment to ethanol, real-time task specific volatile organic compounds (VOCs) monitoring, alcohol breath testing and a review of controls currently in place. The methodology included:

- Undertaking a combination of a desktop review and literature review. This included the following:
  - A comprehensive desktop review of all available documentation including but not limited to historical exposure assessment reports for the relevant areas.
  - A literature review of national and international studies on the topic, precedent legal cases (if any found), a basic toxicological review of ethanol exposure.
  - Engagement with the international provider of drug and alcohol testing technology/equipment (Dräger Australia) on the available studies/literature on the topic.
- Undertaking a walk-through survey of the areas to be monitored and review all activities/tasks including all processes and current controls in place.
- Engagement in discussions with relevant personnel in regards of current work practices, standard operating procedures and potential for personal exposure.
- Undertaking personal occupational hygiene monitoring for ethanol on relevant personnel.
- Undertaking static real-time monitoring for volatile organic compounds (VOCs).
- Undertake a "smoke test" to visually assess air movement and effectiveness of current ventilation systems.
- Performing alcohol breath testing on relevant personnel participating in the assessment at the start of the shift and after each rotation.
- Developing a final report with the findings of the personal exposure to ethanol, literature review and discussion whether correlation exists between worker's workplace exposure levels to ethanol and a police roadside and/or workplace Random Breath Test (RBT).

Ethanol Personal Monitoring

Due to potentially explosive atmospheres at this workplace and stringent rules for battery operated equipment, EHS Assess opted for passive sampling. Personal monitoring of ethanol was undertaken using SKC charcoal passive sampling badges. The passive sampler collects organic vapours by diffusion from the atmosphere into the sampler at a fixed rate. The sampler is validated for short-term and full shift (eight-hour) sampling. Over the course of the assessment, twenty (20) personal full-shift samples were collected to determine full-shift exposure level to ethanol. All samples were subsequently delivered under a chain of custody to an independent and accredited laboratory for analyses. Laboratory results were provided in micrograms (µg) and were recalculated to milligrams per cubic meter (mg/m^3) to allow comparison with workplace exposure standards.

VOCs Real-time Monitoring

A photoionization gas detector (PID MiniRAE^{2000} intrinsically safe) was used for real-time monitoring of volatile organic compounds. Information provided stated that the vapour is a combination of ethanol and other compound with a 1:9 ratio (10% of the vapour consists of ethanol, the remaining 90% consists of additional compounds). This information was used to recalculate combined real-time results into compound specific concentrations (such recalculated results are estimates only and should be interpreted as such).

Alcohol Breath Testing

A calibrated Dräger Alcotest® 5510 hand-held breath alcohol detection screener was used to assess worker's levels of alcohol as part of the workplace exposure assessment at the start of the shift and after each rotation. The instrument is designed to meet requirements of state regulations for preliminary breath testing. The unit permits the user to quickly take the breath alcohol sample, read the result, and proceed.

Alcohol breath testing was conducted in a controlled environment to prevent interferences. A photoionization gas detector (PID MiniRAE^{2000} intrinsically safe) was utilised to continuously monitor background levels to ensure the area is free of contaminants that could interfere with the breath test results.

Personnel were breath tested upon the start of each shift to confirm 0.000 Blood Alcohol Concentration (BAC) starting point and then breath tested after each rotation (up to three rotations over an 8-hour shift) to determine contribution of each task to potential BAC. Over three hundred (300) personal breath test results were collected over the period of the assessment.

Smoke Test

A smoke test to visually assess air movement and the effectiveness of installed extraction/ventilation systems was undertaken using Dräger air flow test tubes that generate "white smoke". A smoke tube and a rubber bulb is used to draw air through the tube. The reaction of the filling layer of the tube with the air humidity in the room releases sulphuric acid aerosol visible as white smoke.

Health Effects and Metabolism - Ethanol

Ethanol vapour is moderately irritating to mucous membranes and respiratory tract. Inhalation of the vapour may result in drunkenness or headache, nausea, incoordination, sleepiness and vomiting. Long term exposure by swallowing or repeated inhalation may cause degenerative changes in the liver, kidneys, gastrointestinal tract and heart muscle.

Vapours may irritate the eyes. Liquid and mists may severely irritate or damage the eyes. Contact with skin may result in slight irritation and redness. Prolonged or repeated contact and heavy skin contamination may cause skin drying and cracking and/or dermatitis with redness, itching and swelling. This may lead to secondary infection.

Persons with pre-existing liver impairment, skin and respiratory disorders may be at an increased risk. Absorption of some drugs may be affected potentially causing adverse health effects.

Ethanol is readily absorbed by the oral and inhalation routes and subsequently, metabolised and excreted in humans. Ethanol is not accumulated in the body[2]. The literature review did not identify any human studies that focused on comparing alcohol elimination times of the different intake methods. There were however, animal

[2]OECD (Organisation of Economic Co-operation and Development) 2004: SIDS Initial Assessment Report for SIAM 19 – Ethanol, Berlin, Germany.

studies done in the 1970s, showing ethanol elimination from inhalation was significantly faster compared to ingestion. The exact mechanism of this elimination, compared to ingestion, was not mentioned.

Alcohol has a high affinity for water and is therefore found in body tissues and fluids in as much as they contain water. Absorbed alcohol is rapidly carried throughout the body in the blood and once absorption of alcohol is complete an equilibrium occurs such that blood at all points in the system contains approximately the same concentration of alcohol.

The liver is responsible for the elimination - through metabolism of 95% of ingested alcohol from the body. The remainder of the alcohol is eliminated through excretion of alcohol in breath, urine, sweat, faeces, milk and saliva. The body uses several different metabolic pathways in its oxidation of alcohol to acetaldehyde to acetic acid to carbon dioxide and water[1]. During inhalation (as a route of exposure into the body), the liver's ability to convert alcohol to acetic acid is bypassed, therefore, the inhaled alcohol has a much higher strength and its effects becoming more potent.

Some drugs (e.g. paracetamol) were found to act as inhibitors of the metabolism of ethanol (meaning they slow down the metabolism of ethanol).[3]

Key Observations

- The process runs 24/7 with three 8-hour shifts. Occasionally, 12-hour shifts are required due to product demand.
- Production runs in five different buildings with different stages of the process being completed in each building. The amount of ethanol in the product remains the same throughout the entire process.
- Staff rotations are in place in some of the buildings due to larger amounts of product being handled there. Staff rotates usually every three hours.
- A combination of mechanical and natural ventilation/extraction systems are in place in all buildings and their effectiveness is checked on regular basis and adjusted as required. However, staff reported to turn off extraction systems particularly in winter during cold days.
- Multiple tasks were observed to cause elevated exposure e.g. decanting of VOCs mixture from large drums which caused gloves to get saturated and sprayed over long sleeves of uniforms and scraping of product from the walls of mixing equipment.

Personal Protective Equipment

- Drying of skin is regularly reported throughout the workforce. Skin protection (reusable gloves) are provided but not utilised in during some production stages and fine dexterity is required and staff prefers not to wear them and uses barrier cream instead.
- Respiratory Protective Equipment (RPE) is provided to all operators working within buildings handling larger amounts of products. These include disposable charcoal respirators (P2) and silicone half mask respirators with organic vapour filters. It was reported that RPE fit testing has not being undertaken. Furthermore, no formal training is provided on the use/storage and maintenance of RPE. It was observed that silicone respirators were not utilised at all. A small number of staff were observed to be intermittently using disposable charcoal respirators – mainly for cleaning drums/enclosed parts of equipment where close contact with high concentrations of ethanol was required. It was reported by some staff that the reason for using

[3] U.S. Department of Human Services – Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH) 1992 – NEG and NIOSH Basis for an Occupational Health Standard.

disposable respirators was to remove some of the organic vapour odour which otherwise makes them feel lightheaded at the completion of the cleaning task. However; none of the staff observed using a disposable respirator was clean shaven.

Results

Ethanol – Personal Full Shift Results

Employees out of all five buildings participated in the personal monitoring assessment. Twenty (20) personal full shift samples were collected and analysed by an independent accredited laboratory. All twenty personal ethanol concentration results ranged from 23 – 84mg/m^3. Workplace exposure standard (WES) for ethanol (inhalation) is 1880 mg/m^3.

Ethanol – Real-time Air Monitoring Results

All real-time results were measured within the staff's breathing zone. Each task was monitored at least twice to ensure consistent results.

Real-time Monitoring Results - PID		
Task	**Total VOC (ppm)**	**Ethanol (ppm)***
Loading mixing equipment - broken up solid product	239	24
Top of mixing equipment - checking process	324	32
Opening top of mixing equipment - preparation to add VOCs	150	15
Unloading mixed product	1280	128
Top of mixing equipment during unloading	520	52
Pouring VOCs into mixing equipment	914	91
Decanting of VOC	600	60
Scraping/cleaning inside mixing equipment - Operator's head inside to reach the back	1356	136
Scraping mixing equipment - operator's head outside, hands reaching inside	821	82
Second operator - collecting removed leftover product and breaking it into a waste bin - standing in the vicinity of the scraping Operator	1185	119
Loading mixed (broken up) product into a press	847	85
Feeding pressed product into cutting machine	212	21
Preparing pressed product for cutting - facing away from cutting machine	85	9
Press Operator (hydraulic press)	60	6
Press Operator (oil press)	350	35
Press Operator - checking pressed product	648	65
Cleaning the press	204	20
Workplace Exposure Standard (15-minute STEL)	-	-
*Calculated value - mixture was reported to contain 10% of ethanol.		

Alcohol Breath Testing Results

Findings of a selection of the alcohol breathe testing results of significance. Over 300 individual data points were obtained over the course of the assessment.

Alcohol Breath Testing Results					
Operator's name	**Alcohol breath testing results**				**Comments**
	Pre-shift	**Post 1st rotation**	**Post 2nd rotation**	**End of the shift**	
Confidential	**0.058**	-	0.000	0.000	Reached zero after 4 hours; continued with normal tasks. 2 rotations per shift.
Product cutting tasks	0.000	0.000	**0.011**	0.000	Cutting all shift; reached zero after 20 minutes and continued with normal tasks. 3 rotations per shift.
Confidential	**0.040**	0.000	-	0.000	Reached zero after 2 hours; continued with normal tasks. 2 rotations per shift.
Trainer	0.000	**0.033**	-	0.000	Training at a mixer; decanted VOCs just before breath testing. Reached zero after 58 minutes. 2 rotations per shift.
Operating mixer	0.000	**0.015**	-	0.000	Operating a mixer. Reached zero after 49 minutes. 2 rotations per shift.
Operating mixer	0.000	0.000	**0.273**	0.000	After cleaning a mixer. RPE (silicone mask) worn but not adjusted correctly (filter of unknown age). Reached zero after 75 minutes. 3 rotations per shift.
Operating mixer	0.000	0.000	**0.100**	0.000	After cleaning a mixer. RPE worn (disposable charcoal masks). Reached zero after 31 minutes. 3 rotations per shift.
Operating mixer	0.000	0.000	-	0.000	Cleaning a mixer. RPE (silicone mask) worn correctly (new charcoal filter), couldn't smell/taste anything. 2 rotations per shift.
Operating mixer	0.000	0.000	-	0.000	Cleaning a mixer. RPE (silicone mask) worn correctly (new charcoal filter), couldn't smell/taste anything. 2 rotations per shift.
Australian Road Rules Alcohol Limits*	**Zero Alcohol Limit**				**All visiting drivers or riders holding an overseas or interstate learner, provisional or equivalent licence (Learner ("L" plate), provisional ("P" plate).**
	Under 0.02 BAC				**Drivers of vehicles of "gross vehicle mass" greater than 13.9 tonnes. Drivers of vehicles carrying dangerous goods. Drivers of public vehicles such as taxi or bus drivers.**
	Under 0.05 BAC				**All other licenses (including overseas and interstate licence holders) not subject to a 0.02 or zero limit.**
BAC – blood alcohol concentration – the amount of alcohol in grams of alcohol per 100 millilitres of blood. A BAC of 0.05 means you have 0.05 grams of alcohol in every 100 millilitres of blood. Blood alcohol limits as per NSW Government – Centre for Road Safety.					

Discussion

Ethanol – Full Shift Personal Results and Real-time Results

- All personal results were found to be well below ethanol's WES. The highest personal result for ethanol was measured on a Press Operator (all shift operating press). The obtained result was 84 mg/m^3 (4.5% of ethanol's 8-hr WES of 1880 mg/m^3). This result was directly contributed by insufficient ventilation (air movement) in this position (located in the corner, all doors around the operator were closed). Smoke tests undertaken on the floor extraction vents (extraction located under the press) identified that capture potential of all vents was very low, practically non-existent. Smoke test was performed within 15 cm from the vents' openings.
- Real-time VOCs monitoring identified a number of tasks reaching/exceeding 1000ppm of total VOCs. These elevated levels were directly linked to insufficient capture velocity at relevant extraction systems (confirmed by a smoke test). Also, natural ventilation was identified to have significant impact on the extraction systems – opening/closing building doors depending on weather conditions appeared to affect indoor pressures causing vapours being drawn away from extraction systems.
- Scraping/cleaning of the mixing equipment provided the highest real-time results. During this task, one operator was cleaning the mixer (head inside the mixing equipment) and a second operator was standing nearby cleaning the floor, picking up and breaking product into small pieces and placing those into the waste bins. Both operators returned the highest real-time results. None of the operators was wearing RPE. This task lasts up to five minutes and is repeated up to twenty times during the shift.

Alcohol Breath Testing

- Two (2) operators returned positive breath alcohol levels **prior** to their shift start. They both reported having alcoholic drinks prior to going to bed. Neither of them had breakfast prior to being breath tested.
- In total, five (5) positive breath alcohol results were obtained during the assessment. These were all contributed to workplace exposure as each of the affected operators returned negative results prior to their shifts.
- The highest results (0.273 and 0.100 BAC) were obtained after cleaning of the mixing equipment at the end of the shift. This is a thorough task that can take up to 30minutes. Both operators were wearing RPE; however, one was only wearing a disposable charcoal mask (alcohol result of 0.100 BAC), the second operator was wearing a silicone mask (alcohol results of 0.273 BAC) but this mask was not adjusted correctly and filter used was of unknown age. The operator with the higher results (0.273 BAC) was also of a smaller build (female) and therefore required to spend more time having her head inside the mixing equipment to reach (and clean) the insides. She also reported always "feeling dizzy" after this task. The other operator was of taller build and did not need to insert his head inside the mixing equipment at any point during the cleaning process. These findings are particularly significant as cleaning of the mixing equipment is the last task of the day. Operators reported that after cleaning is complete, they immediately go home and in general operate their vehicles to do so. The operator with the higher results of 0.273 BAC took 75 minutes to return a zero result. This time frame suggests that the result was a combination of blood and mouth alcohol as such high reading would take much longer to bring down to zero if it was a true blood alcohol level.
- Another two (2) operators returned zero alcohol readings (both results were 0.000 BAC) post cleaning of mixing equipment when correctly wearing RPE (silicone respirators with brand new filters). Prior to cleaning, correct adjustments of respirators were checked (under the direction and supervision of the

hygienist); a negative pressure test was performed and respirators were donned for the whole duration of the cleaning process. Both operators were breath tested directly after the cleaning process was finished.

- A breath alcohol result of 0.033 BAC was returned by an operator who acted as a Trainer/Supervisor at the mixing equipment. He was standing adjacent the mixing equipment observing the trainee. The trainee returned a zero result which shows that current ventilation controls are effectively removing vapours from the operator's breathing zone. However, these are not being extracted but rather diluted, and carried through the hallway and possibly caused the elevated exposure of the trainer/supervisor standing nearby (all doors were also opened on the day with natural ventilation causing changes in the air movement inside the building). The trainer/supervisor also undertook decanting task directly before breath testing.
- A breath alcohol result of 0.015 BAC was returned by a larger mixer operator directly after scraping of the mixer. This scraping of this large mixer is performed twice per mixing cycle and the operator is required to stand directly above the mixer's opening scraping the mixer's walls.
- The final positive results of 0.011 BAC was returned by a Cutting Operator after she spent two consecutive rotations at the cutting machine. This could be contributed to ineffectiveness of the extraction systems within the buildings and limited natural ventilation. Outdoor temperatures were low during the period of the assessment and majority of doors were closed.

1. Recommendations

As part of recommendations, in line with the basic principles of risk management and considering the hazards identified/proposed works in the areas, the Hierarchy of Controls was adopted throughout the recommendations as far as reasonably practicable.

- **Elimination** - Is the most effective control. If you can't eliminate the process entirely, it is recommended to eliminate exposure to personnel. This may not be practicable due to the process set up/design.
- **Substitution** - This means to substitute the chemical compound with a less dangerous/toxic one. This step is not practicable for this situation.
- **Engineering controls** - These would include introduction of/alterations to the ventilation system to improve its performance or re-designing the process (involving enclosures, process automation etc.).
- **Administrative controls** - These controls would include placing signage around the affected area, workplace rotations to limit personnel exposure etc.
- **Personal Protective Equipment (PPE)** - PPE includes respiratory protective equipment (RPE) as well as other protective equipment. This is a last line of defence and these are not considered to be long term solutions.

While all reasonably practicable measures should be taken to eliminate the hazards, the work environment poses many challenges and administrative controls and PPE/RPE were required in combination with other higher-ranking control measures.

- Ensure extraction systems are serviced regularly and air flow adjusted to effectively remove vapours from Operators' breathing zones.
- Once extraction system is serviced, undertake smoke test for all extraction points and evaluate the effect of natural ventilation. Put rules in place about opening/closing doors based on the smoke test results.
- Respiratory Protective Equipment (RPE) – charcoal disposable respirators are designed to remove dust and nuisance odours. They are not intended to be used for removal of elevated concentrations of vapours and may not provide sufficient protection during tasks such as cleaning of the mixing equipment.

- Ensure all personnel provided with RPE are suitably trained in the use/storage and maintenance of RPE (including when to replace a filter) as per the requirements of the Australian Standard *AS/NZS 1715:2009 Selection, use and maintenance of respiratory protective equipment*. This standard also states that all personnel required to wear RPE shall be clean shaven and provided with a regular fit testing at least on annual basis and/or every time there is a significant change to facial features (scar, loss of teeth etc.).
- Set up a training schedule for all personnel provided with RPE and introduce a regular refresher training (at least every 2 years).
- Ensure operators undertaking cleaning of the mixing equipment as well as a near-by operators (assisting with clean-up) are provided with and utilise silicone respirators with organic vapour filters. Update the cleaning procedure to include the mandatory use of RPE for this task.
- Consider the introduction of "drink responsibly" training session. This should include:
  - Police breath testing limits for different licenses;
  - Healthy life style habits (consequences of drinking alcohol prior to early morning shift, the need for hydration and balanced diet etc.);
  - Alcohol metabolism rates.
- Consider installation of a wall-mounted breathalyser in the lunch room (or change room/gatehouse) where personnel could test themselves prior to leaving site.
- Consider mandatory alcohol breath testing prior to shift start and when leaving site.

Conclusion

All obtained personal results for ethanol were found to be below the workplace exposure standard (WES). The highest personal result for ethanol was measured on a Press Operator (all shift operating press). The obtained result was 84 mg/m^3 (4.5% of ethanol's 8-hr WES of 1880 mg/m^3).

Real-time results are showing elevated VOC concentrations (reaching and exceeding 1000ppm) confirming that vapours are not being successfully removed from the operator's breathing zone. These elevated concentrations were directly linked to insufficient capture velocity at relevant extraction systems (confirmed by a smoke test). Also, natural ventilation was identified to have significant impact on the extraction systems – opening/closing building doors depending on weather conditions appeared to affect indoor pressures causing vapours being drawn away from extraction systems.

Alcohol breath testing identified a number of tasks that have the potential to cause positive breath alcohol readings following completion of these tasks. These were directly contributed to workplace exposure as all operators returned negative results prior to the shift start. The highest breath alcohol readings were obtained after cleaning the mixing equipment and can be directly contributed to lack of awareness about workplace exposure leading to lack of RPE use.

POSTER ABSTRACTS

AIR TRANSPORT OF BATTERIES FOR THE TRAVELLING HYGIENIST

Philip Turner
WorkPlace Environment Consultants Pty Ltd

ABSTRACT

Occupational hygiene practice often requires the use of dangerous goods in equipment, spare parts, collection media, exhibits, and samples for testing. Dangerous goods include aerosol cans, asbestos, compressed gases, corrosive substances, infectious substances, lithium batteries, and flammable liquids. The transport of these goods is controlled by prescriptive regulations. Occupational hygienists should be thoroughly conversant with (and compliant with) these regulations, which apply to hand luggage, checked baggage, other motor vehicles, and courier deliveries (by air and by road).

PROFESSIONAL DEVELOPMENT THROUGH MENTORING, EXPERIENTIAL LEARNING, AND REFLECTIVE PRACTICE.

Laurie Southgate
VA Sciences

ABSTRACT

Situation
During the construction of a copper mine in Kazakhstan, a contractor had 17 health and safety team members with an average of 15.2 years construction experience but limited formal education in health and safety. This team needed to be trained to anticipate, recognize, and effectively control hazardous exposures.

Method
This study examined the application of weekly training workshops, mentoring strategies, and the use of reflective practice for continuous professional development. The mentoring program was assessed regularly through open forum review workshops. After 15 months of training and mentoring led by the client, the trainees were asked to reflect on their learning experiences. Trainees were asked to identify areas of professional competency weakness that required further ongoing learning through completing a questionnaire using a Likert scale of 1-5.

Results
The 10 highest priorities for competency development were identified as pre-commissioning safety, working at heights, emergency preparedness, safe use of chemicals, confined spaces, hot work activities, hazard identification and hierarchy of controls, crane lifting operations, occupational health exposures and leadership training. The trainees reported that they applied the training in their work areas, resulting in workers following their interventions for unsafe behaviours and conditions most time to always. (4.53). Trainees strongly agreed that they enjoyed their learning experience on the project and were growing as a professional (4.52).

Lessons Learned
Changing work environments are an opportunity for practical experiential learning experiences. Deep personal reflection on professional experiences is essential for continual growth in competency.

INNOVATIVE SOLUTIONS TO HYGIENE PROBLEMS AND THEIR INSPIRATION.

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ABSTRACT

In the early 20th century in the United States, Dr. Alice Hamilton led efforts to improve industrial hygiene. She observed industrial conditions first hand and startled mine owners, factory managers, and state officials with evidence there was a correlation between worker illness and their exposure to toxins. She also presented definitive proposals for eliminating unhealthful working conditions. At about the same time, U.S. federal and state agencies began investigating health conditions in industry. In 1908, the public's awareness of occupationally related diseases stimulated the passage of compensation acts for certain civil employees. States passed the first workers' compensation laws in 1911. And in 1913, the New York Department of Labor and the Ohio Department of Health established the first state industrial hygiene programs. All states enacted such legislation by 1948. In most states, there is some compensation coverage for workers contracting occupational diseases. The U.S. Congress has passed three landmark pieces of legislation relating to safeguarding workers' health: (1) the Metal and Nonmetallic Mines Safety Act of 1966, (2) the Federal Coal Mine Safety and Health Act of 1969, and (3) the Occupational Safety and Health Act of 1970 (Act). Today, nearly every employer is required to implement the elements of an industrial hygiene and safety, occupational health, or hazard communication program and to be responsive to the Occupational Safety and Health Administration (OSHA) and the Act and its regulations Hand hygiene is an important issue for improved surgical patient outcomes in that it helps prevent the risk of infection. Nonetheless, compliance with hand hygiene requirements is still a significant problem. The TST hand hygiene solutions address: Measuring the specific, high-impact causes of hand hygiene failures in a facility Targeting solutions to those specific causes Using resources effectively and efficiently to improve compliance Making washing hands a habit as automatic as looking both ways when crossing the street or fastening a seat belt before driving a car Serving as a role model by practicing proper hand hygiene Holding everyone accountable and responsible—physicians, nurses, food service staff, housekeepers, chaplains, technicians, and therapists Saving lives through the reduction of HAIs Industrial hygienists recognize several hazard control strategies to eliminate or reduce hazard are employee exposure. elimination - remove the hazard. this strategy totally eliminates the hazard from the work place substitution- reduce the hazard. this strategy should be use if it not feasible to eliminate the hazard engineering controls-remove/reduce the hazard through design or redesign of tools equipment, machinery and facilities so that hazardous chemicals are not needed or that exposure to those hazardous chemical s are not possible Administrative control -eliminate/ reduce exposure to hazards. this strategy to help to reduce exposure by developing and effective processes. Work practice control -eliminate/reduce exposure through safe practices. following safe procedures while operation production and control equipment and good housekeeping are good examples of work practice controls.

ASSESSMENT OF WORKER EXPOSURE AND SAFE USE OF HIGHLY HAZARDOUS FUMIGANTS AND PESTICIDES IN LARGE GRAIN STORAGE FACILITIES IN REGIONAL NEW SOUTH WALES.

Bhoopathy Sankaran
SafeWork NSW

ABSTRACT

Aim
To assess workplace health and safety compliance in relation to safe use and storage of highly hazardous fumigants such as phosphine, methyl bromide and organophosphate pesticides in large grain storage facilities.

Method
Forty-two grain storage sites across NSW were verified for compliance with Work Health and Safety Regulations. Biological monitoring tests were conducted for twenty-one workers who consented to provide biological samples from seven worksites for exposure to organophosphate pesticides and herbicides (including glyphosate).

Result and Discussion

Use of significant quantities of high dose hazardous fumigants and pesticides in grain silos make these workplaces high risk requiring specific controls and workers to have specific training and skills. Legally health monitoring for workers using these hazardous chemicals must be provided. Training and experience are required to handle fumigants and pesticides. Verifications identified issues in relation to safe use of fumigants, health monitoring, workplace hygiene and emergency facilities. In one of the workplaces visited highly dangerous method of fumigation was identified and appropriate measures taken and workplace safety ensured. Biological sample analysis indicated that some workers were exposed to pesticides/herbicides above the Biological Occupational Exposure Levels (BOEL) of TestSafe NSW when the results were corrected for individual's creatinine contents in urine. Reports on laboratory test results were provided to individual workers and to verified workplaces with general/specific workplace recommendations such as reading label and current SDSs for appropriate application methods, proper emergency shower and eye wash facilities, appropriately storing hazardous chemicals as per class, zoning risk area and on health monitoring to prevent exposure to pesticides and subsequent illness.

WHAT'S THAT SMELL? ATMOSPHERIC TOXIN RELEASE AND WORKER OVEREXPOSURE DURING INSULATION BURN-IN

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ABSTRACT

Newly installed insulation lagging on ship engine exhaust pipelines was found to release acrolein, formaldehyde, inhalable particulate and carbon monoxide at levels above the relevant occupational exposure limit (OEL).
The acrolein exposure of personnel entering the engine room during the 'burn-in' period was above the peak OEL.

The assessment followed complaints by workers of the smell associated with 'burn-in' of newly installed, painted insulation lagging on ship engine exhaust pipelines. Workers who routinely perform sea trials of newly installed ship engines were regularly exposed to the unknown contaminant causing the unpleasant smell, acrid taste, burning eyes and nausea experienced by workers entering engine rooms during the 'burn-in' period.

The insulation is designed for high temperature (500°C) use, however the Urea Modified Phenol Formaldehyde Resin binder inside the insulation, decomposes on initial heating above 150°C. Discussion with the insulation manufacturer indicated a range of possible chemical breakdown compounds.

Targeted analysis based on the heating decomposition chemistry of the resin and paint were determined and assessed during the engine trial, in addition to inhalable particulates and metals, diesel particulate matter and combustion gases.

Results in summary:
- Acrolein and formaldehyde were detected above the peak OEL.
- Inhalable particulate and carbon monoxide were detected above the OEL.
- Sulphur dioxide, ammonia, nitric oxide, nitrogen dioxide and some VOCs were detected
- Diesel particulate matter, inhalable metals and Amines were not detected.

METHYLAMPHETAMINE CONTAMINATION – THE ROLE OF THE OCCUPATIONAL HYGIENIST

Brian Murphy
EHS Assess

ABSTRACT

Australians are the world's second biggest users of methylamphetamine. Australia's ice epidemic has resulted in many clandestine drug laboratories where illegal drugs are manufactured or 'cooked', usually with improvised materials and methods. The chemicals used in these laboratories, together with the products, resulting waste and residues, can be toxic and harmful to the health of future occupants. While the focus of contamination has traditionally been to properties used as clandestine drug laboratories alone, methylamphetamine contamination at concentrations 60 times higher than the Summary of Investigation Levels (ILs) of 0.5µg/100cm² for residential buildings as per the Guidelines for Environment Investigations, Remediation and Validation of former Clandestine Drug Laboratory Sites (Guidelines) have been detected in properties of use alone. The study investigates assessment methodologies of suspected clandestine drug laboratories available to the investigating occupational hygienist, how to develop a sampling plan to a budget, challenges and pitfalls encountered and the different remediation strategies available to decontaminate properties. The study provides a comparison and insight of

methylamphetamine concentrations on different common building materials in clandestine drug laboratories compared with user only properties.

CLANDESTINE DRUG LABS - WHAT ARE WE ASSESSING AND WHAT ARE WE MISSING?

Morné de Beer
WSP

ABSTRACT

Australia has seen an increase in the number of clandestine drug labs producing synthetic drugs, resulting in the possible exposure of the perpetrators and the general public to a cocktail of chemical substances that adversely affect health. In the absence of legislation what are we assessing to declare areas used in the production of synthetic drugs as being safe for human habitation? What is being overlooked in this process? Do we fulfil our obligations in terms of the Act by not assessing the full spectrum of possible exposures in declaring dwellings fit for human habitation?

THE ROLE OF EXPOSURE TO FARM ANIMALS IN THE PERTURBATION OF THE HUMAN-ASSOCIATED NASAL MICROBIOTA OF FARMERS.

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ABSTRACT

The nostrils are one of the main interfaces between internal body and external environment and they are colonized by a large community of both opportunistic and commensal bacteria. Natural selection determines the characteristic of the microbial population and introduction of new bacterial strains can modify or even eliminate the previous established bacteria population. For instance, alteration of that “indigenous” community by invasion and colonization with zoonotic strains can have important consequences in terms of occupational and public health. To understand in-depth how nasal microbiota of pig farmers is affected due to their close contact with their animals and to know if airborne transmission of animal strains can occur, a precise and detailed characterization of the entire bacterial communities of these three environments (animals’ microbiota, air and human nostrils) is required. The goal of this project is to assess the role of exposure to farms’ animals in the perturbation of the human-associated nasal microbiota of farmers. With this “One Health” approach, 31 farms with 51 farmers were investigated four times over a year. Further, as controls, we collected nasal swabs from 26 cow-farmers and 40 workers without exposure to farm animals. The initial results of DNA sequencing show that the diversity and relative species abundance of the nasal microbiota of pig-farmers are different from that of cow-farmers and individuals with no exposure to farm animals. This strongly indicates that the pig associated bacterial communities alter qualitatively and quantitatively the human nasal microbiota. Physiological consequences of this alteration are currently not known.

COMPARISON OF BIOTAPE, SWAB, AND MYCOMETER SAMPLING TESTS FOR SURFACE FUNGAL LOADING FOLLOWING MOULD REMEDIATION

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ABSTRACT

Seven identical buildings (adjacent movie theatres) were tested in 5 random locations each for surface fungal load after mould remediation (including multiple wet wiping and HEPA vacuuming) using 3 different techniques in a side-by-side comparison study. Criteria for concluding that remediation had proceeded successfully within each theatre were pre-determined for each method Bio-tape samples were analysed via direct microscopy and scored in terms of fungal spores or structures per m^2 of surface area; measured values ranged from below the detection limit to >659 spores per cm^2. Mycometer samples (done in duplicate in adjacent areas) were scored using the proprietary MSV scoring system; measured values ranged from below the detection limit to a high value of 304. Swab samples were analysed by CFU/100 cm^2, with values ranging from below the detection limit to a maximum value of 115 CFU/100 cm^2.

There was poor agreement between the different tests, though there was good correlation of the two sets of Mycometer data. All 3 techniques had rather low median values, for the BioTapes, the median value was 6 fungal structures per cm^2, for the swab samples, the median value was 1 CFU/100 cm^2, and for the Mycometer the median value was 5 for one set, and 4 for the other. Using the above criteria 1. through 3., all the theatres passed, excepting Theatre 4, which passed 4 of 5 locations using the swab and 4 of 5 locations using the BioTape criteria, but failed the Mycometer criteria due to only 3 of the 5 tested locations identifying values <25 using Mycometer

From a practical decision-making perspective, use of BioTapes or swab sampling would therefore have resulted in the Contractor's remediation being called successful in all the theatres; one theatre would have required re-cleaning using the Mycometer 1 data but the same theatre would have passed using the Mycometer 2 data.

The lack of heterogeneity of surface loading is a significant limitation of the study.

AUDIOMETRIC PROFILES: NSW COAL MINING 1991 – 2015

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ABSTRACT

NIHL is an irreversible, preventable occupational disease which, once diagnosed, could have significant impacts on the economy and an individual's quality of life. Despite many strategies developed to facilitate management of excessive exposure to occupational noise with the aim of preventing NIHL, the number of compensation claims has not decreased over the last few decades. In addition, the workforce is aging, and NIHL is becoming evident at a younger age, compared to 30 years ago.

Many studies reporting on the prevalence of NIHL amongst specific populations do so based on the cumulative assessment of a number of other studies, which raises questions relating to the reliability and quality of data used and any subsequent conclusions. There are limited studies which investigate the hearing health of workers, based on audiometric profiles (audiometric data). An audiometric profile for the purpose of this research is a profile of the hearing health of a worker, as determined through audiometric testing.
The focus of this research is on investigating the hearing health of workers entering the NSW coal mining industry. The NSW coal industry records employee audiometric data at the time workers enter the coal mining industry (entry-level audiograms) and periodically during their employment at intervals of at least 2 years, in accordance with Work Health & Safety regulations. No studies on the prevalence of hearing loss amongst workers entering the NSW coal mining workforce have been identified. There is also no published literature available which reports any change over time in the audiometric profile of workers entering the coal mining workforce in NSW.

This research will report on any changes in the hearing health of entry level miners in the NSW Coal Mining Industry over the past 25 years. Subsequently, the results from this research could be used to inform future research, policy and practice relating to noise exposure management strategies.

NOISE LEVELS IN CONTACT CENTRES

Sue Reed, Martyn Cross, Jacques Oosthuizen & Maggie Davidson
Edith Cowan University

ABSTRACT

The use of open plan offices in face-to face contact centres and phone contacts centres has become a trend over the 20 years. This paper will present the outcomes of noise monitoring in two contact centres which deal with enquires from students in a university. The noise exposure of a minimum of 10 participants were measured in each location on a number of days, as specified in AS/NZS 1269.1:2005. This repeat monitoring was undertaken to ascertain if the exposures differed significantly between days and different office environments. In addition, the ambient noise levels were measured to determine if the environment met the design requirements for acoustics as specified in AS/NZS 2107:2016 Acoustics—Recommended design sound levels and reverberation times for building interiors. The results of the monitoring showed that none of the personnel exposures exceeded the Occupational Noise Exposure Standard Leq of 85 dBA for 8 hours, as expected. The highest personal exposure in Location 1 was 76.5 dBA and in Location 2 was 78.2 dBA, but this only occurred on one day each. The minimum ambient levels were within the specification of AS/NZS 2107:2016 of 40 to 45 dBA. The issue in these locations is not the potential impact on hearing but the impact on speech intelligibility which is greatly affected when background noise levels are too high as in these cases.

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