Investigating best practice to prevent illness and disease in tunnel construction workers

Kate Cole, 2016 Churchill Fellow
THE WINSTON CHURCHILL MEMORIAL TRUST OF AUSTRALIA

Report by  - KATE COLE  - 2016 Churchill Fellow

To investigate best practice to prevent illness and disease in tunnel construction workers

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Dated  July 14th, 2017
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key words

Health, Tunnel, Exposure, Silica

Kate Cole, MAIOH Certified Occupational Hygienist (COH)®
Occupational Health and Hygiene Manager
Ventia
111 Vanessa Street
Kingsgrove NSW
kate.cole@ventia.com.au
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Thank you to the many Australian tunnelling projects who have supported the work of professional occupational hygienists and who continuously strive to protect the health of their workforce. Particular thanks must go to Raymond Miranda for his drive, passion, and tenacity for making a change for the better, and for whom without, this research question may not have been posed.
Executive Summary

Each year, over 250 workers in Australia die from an injury sustained at work, while over 2,000 workers die from a work-related illness [1]. Although these statistics highlight the importance of focussing on health, all too often, health has played a secondary role to its better-understood, safety counterpart. Construction is a priority industry for work health and safety, with controlling exposures to disease-causing hazards identified as an area requiring improvement [2]. In comparison to the general construction industry, however, tunnel construction workers have an increased risk of developing silicosis, chronic obstructive pulmonary disease (COPD), adverse respiratory symptoms, double the rate of lung function decline than heavy smokers, asthma, general airflow limitation, and lung cancer, and thus represent a high-risk work group [3,4,5,6].

Australian tunnelling has reached a new chapter, planning to tunnel further in the next seven years than we have in more than the past two decades. Tunnel construction represents a vital 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 Fellowship highlights 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 in depth to understand international approaches, which included Leadership, Engagement and Collaboration, Training and Awareness, Standards, Health in Design, Program Health Risk Management, Targeted Health Risk Management, and Sustainability.

Visible and effective leadership starting with the client organisation was found to be essential, as it created more stakeholders that also began to drive health within their own organisations. It ensured that health risks were given adequate attention at the time of design, with the general finding that the more qualified and competent the stakeholder was, the stronger they lead health protection efforts.

All major tunnelling projects internationally have either mandated targeted contractual requirements or referred to health standards, that are more stringent than those in Australia. The method of leaving ill-health prevention to contractors alone does not appear conducive to a collaborative approach on this issue and essentially can create an imbalanced approach to tender selection.

Engagement and collaboration involving other stakeholders were observed to create a positive culture surrounding health protection. International best practice demonstrated that collaboration across multiple tunnelling projects resulted in extensive knowledge sharing, whereby good practices were adopted earlier than they may have otherwise. The development of various best practice standards for the control of silica dust, as they related to each project, provided a clear framework for contractors and subcontractors to follow when planning work activities. Some of the best guides were observed to be those that involved collaboration with the client, designers, and contractors.

The general level of awareness of health risks associated with tunnelling activities is mixed in Australia, ranging from an excellent understanding and robust control, through to a very low awareness, and range in between. International best practice in training and awareness practices involved the use of immersive, multi-media experiences involving behaviour-based learning and interactive approaches that elicited participation from the workforce, complimented by engaging awareness campaigns.

International health and safety regulatory authorities have worked to produce clear information to assist contractors to assess, document, communicate, control, maintain, and review health risks. The amount of focus and information published internationally on the assessment and control of health hazards such as silica, provide further guidance, clarity, and context on what is expected of employers and employees when controlling exposure.

International best practice in health surveillance includes the use of occupational physicians complimented by competent health clinical services, a standardised approach for what is deemed “fit for duty,” and the centralised collection of medical data to enable trends to be reviewed to inform future interventions and policy. All countries that were visited have a requirement to notify a central agency of a diagnosis of an occupational disease such as silicosis, further highlighting our current shortcoming in this area in Australia.

Different approaches were observed to define “competency” in health internationally. Pooled resourcing, in which the client procured specialist competent providers which were then used by multiple contractors, appeared to provide greater control of the quality provided by these specialists, in addition to greater knowledge sharing and priority of service.
Over one-third of Australia’s workplace exposure standards are out of date and some, such as respirable dust and diesel particulate matter (DPM), two key health hazards in tunnelling, are not included in Work Health and Safety legislation [7]. Our international counterparts are leading in this area, particularly with regards to enforcement of compliance with these standards.

Addressing the element of “health” as a design criteria internationally, has resulted in higher-order controls being able to be applied at time of design, where contractors are required to demonstrate how health risks will be mitigated, what controls will be applied, and how they will be applied for the project life-cycle from construction through to the operation and maintenance phase. While there are some good examples of the use of engineering controls such as ventilation and dust suppression in Australian tunnelling, a large inconsistency across industry exists. International best practice demonstrated improvements to such engineering controls as a result of a greater consideration of health at the time of design.

A heavy reliance on respiratory protection (e.g. “dust masks,” refer front cover) coupled with general low compliance, ultimately results in exposures above the workplace exposure standard. International best practice on controlling exposure removes the use of these “dust masks” and instead, focusses on the use of higher order controls (e.g. engineering) at the time of design. The use of disposable respiratory protection is not commonly used internationally to reduce exposure, due to improved work environments resultant of better planning and engineering controls coupled with strict enforcement by health and safety regulatory authorities.

Wellbeing programs designed to address demographic and personal risk factors, are part of international best practice programs. Standardised metrics for health and wellbeing were observed to lead to overall health improvements leading to a sustainable approach.

Ongoing independent verification of exposure controls by an authority able and willing to stop the contractors’ work, has shown to drive compliance and further control. Such review by an insurance agency (as is the case in Switzerland and parts of the USA), rather than a state or federal regulatory authority, may provide a sustainable approach without the need for additional public funding in this area.

There are many new tools that are available to enable occupational hygienists to assess exposures to dust and silica faster, and also provide greater clarity over the areas of peak exposures. Engineering controls such as the use of canopy air curtains, enclosed cabin filtration systems, dust suppression, and virtual training approaches, all demonstrate the strong linkage of tunnelling with the mining sector.

Overall, it is concluded that the existing health and safety framework that the tunnelling industry operates within, requires improvement to protect the health of tunnel workers. Our existing system has several limitations and would benefit from:

- greater widespread leadership on health from clients commissioning tunnelling projects, health and safety regulatory authorities, and contractors performing such work;
- greater considerations of health in design;
- a centralised and standardised health surveillance system complimented by disease notification requirements;
- a standardised health risk assessment framework leading to more robust exposure monitoring and higher take-up of health surveillance;
- increased regulatory enforcement of compliance requirements;
- engagement with research partners;
- an increase in training and awareness leading to greater knowledge and skills to effectively manage health risks; and
- an increased focus on prevention of exposure to health hazards leading to illness and disease.

In addition, the creation of a common framework for the collection of exposure monitoring and disease prevalence data would enable lessons that could be learned and then shared as collective knowledge across the tunnelling industry.

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

Silicosis has plagued sandstone workers in Australia since the early 1900s. After an initially recorded epidemic in the early 1900s, again in the 20s and 30s, and yet again in the 50s and 60s, these waves of disease due to exposure to high levels of silica dust during construction, are part of Australia's dark industrial history [8,9]. However for some, perhaps due to the many years gone past, because some in the industry are largely unaware of the issue, or because the true extent of silicotic workers is largely unknown, it is believed that this dark past has not, or will not, plague us again.

Tunnel construction represents a key part of building Australia’s necessary infrastructure and services and is complimented by world-class feats of engineering. However, it is reasonable to expect that the delivery of such world class infrastructure will not be the cause of yet another epidemic of industrial disease in the future.

As we prepare for our next infrastructure boom which will arguably involve the largest amount of tunnelling into sandstone (and other quartz-containing rock) that Australia has ever seen, we have an opportune time to not only learn from our past but to look outwards internationally to define a best-practice approach to prevent illness and disease.

There are areas of excellence within the tunnelling industry; there are pockets of greatness where project management, engineers, supervisors, safety professionals, and occupational hygienists have implemented risk management systems that represent some of the best in comparison to what I have seen on this Fellowship. While those pockets are moments for us to be proud of, illness and disease prevention can only be realised when a holistic approach is taken across the entire sector, and where we collectively focus on all exposures that tunnel workers experience.

To do this, I believe, that the current health and safety framework that the tunnelling industry operates in needs a drastic de-dusting. Unless we make a change, there is little evidence to suggest that another wave of silicosis will not be realised. This change will rely on a multitude of key stakeholders working together to address the issue in a collaborative manner as well as a change in our collective attitude towards the “health” in “health and safety”, because, in the words of Churchill himself, “attitude is a little thing that makes a big difference”.

This report is dedicated to the thousands of Australians who work in the great industry that is construction and tunnelling - an industry that has given me nothing but continued support.

Drawing on the guidance of Sir Winston Churchill, the master at communication himself, this report aims to highlight essential points and provide practical recommendations to positively impact the tunnelling sector.
SECRET.
W.P.(G)(40) 211.
1ST AUGUST, 1940.

WAR CABINET.

BREVITY.

Memorandum by the Prime Minister.

To do our work, we all have to read a mass of papers.
Nearly all of them are far too long. This wastes time,
while energy has to be spent in looking for the essential
points.

I ask my colleagues and their staffs to see to it
that their Reports are shorter.

(i) The aim should be Reports which set out
the main points in a series of short, crisp
paragraphs.

(ii) If a Report relies on detailed analysis
of some complicated factors, or on statistics,
these should be set out in an Appendix.

(iii) Often the occasion is best met by submitting
not a full-blown Report, but an aide-memoire
consisting of headings only, which can be
expanded orally if needed.

(iv) Let us have an end of such phrases as these:
"It is also of importance to bear in mind
the following considerations.....", or
"Consideration should be given to the
possibility of carrying into effect....."
Most of these wooly phrases are mere padding, which
can be left out altogether, or replaced by a
single word. Let us not shrink from using
the short expressive phrase, even if it is
conversational.

Reports drawn up on the lines I propose may at first seem
rough as compared with the flat surface of officious jargon.
But the saving in time will be great, while the discipline of
setting out the real points concisely will prove an aid to
clearer thinking.

W.B.C.

10, Downing Street.

9TH AUGUST, 1940.
ITINERARY
MAY 30TH TO JULY 3RD 2017

Institute of Occupational Medicine, Edinburgh, UK
Breathe Freely Campaign, British Occupational Hygiene Society, UK
Loughborough University, Loughborough, UK
Thames Tideway, London, UK

British Tunnelling Society
London, UK
High Speed Rail 2, London, UK
Crossrail, London, UK
World Tunnel Congress (WTC), Bergen, Norway

Arna-Bergen Double Track, Bergen, Norway
Norway Institute of Occupational Health, Oslo, Norway
ETH Combustion-Generated Nanoparticles Conference, Zurich, Switzerland
AlpTransit Gotthard, Switzerland

A2 Sanierungstunnel, Beichen, Switzerland
SUVA Occupational Medicine, Luzern, Switzerland
National Institute of Occupational Health Centre for Disease Control, Pittsburgh PA, USA
American Industrial Hygiene Association, VA, USA

Laborers Health and Safety Fund, Washington DC, USA
Anacostia River Tunnel, Washington DC, USA
SR-99 Alaskan Way Viaduct, Seattle WA, USA
The State of the Problem

On average, over 250 workers in Australia die from an injury sustained at work each year. By comparison, over 2,000 workers die from a work-related illness [1]. With construction forming a priority industry for work health and safety, controlling exposures to disease-causing hazards have been identified as an area requiring improvement [2].

Australia is on the cusp of an infrastructure boom, building more than 180 kilometres of tunnels between 2017 and 2022. In that 7-year period, we will construct more tunnels than we have in our entire tunnelling history since 1995, with the majority centred around the major metropolitan cities (refer Figure 1). Sydney will take the greatest share of more than 65% of all tunnelling undertaken in the nation's largest city with over 38 kilometres of twin tunnels being constructed in Sydney alone [10].

Around 4,000 workers [11] are required to support each major tunnelling project, and with seven major projects occurring in 2018, there appears no greater time to use best practice approaches to prevent illness and disease in those who work to support this sector.

“Occupational illness and disease” refers to those that are contracted from exposure to a work activity. Over three hundred years ago, Italian physician Bernadino Ramazzini, attributed causes of occupational lung disease in stone-cutters, sculptors, quarrymen, from dust "so fine that it penetrated the ox-bladders hanging in the workshop..." [12]. Since that time, many more physicians, toxicologists, epidemiologists, and hygienists have demonstrated the link between exposure to dust of varying types at work and the development of an occupational illness or disease.

The likelihood of disease development becomes greater with increasing exposure to health affecting agents, or "health hazards." Many of the health hazards that tunnel construction workers are exposed to are chronic hazards, which means that there can be long latency periods (of decades) between the time the worker was exposed and the time the disease is first diagnosed. This presents some challenges as often the link between exposure to a health hazard and the disease being diagnosed at the time is not made.

Figure 1 - Australian Tunnelling 1995 to 2021
1.1.1 Health Hazards in Tunnel Construction

Previous studies have shown that tunnel construction workers had the highest measured exposures to silica, a known human carcinogen within the construction industry [2,13,14]. With carcinogenic diesel exhaust exposure also presenting a risk to health, these workers are at a high risk of developing diseases associated with those occupational exposures [15,16,17].

The majority of tunnelling in Australia occurs in Sydney and Brisbane, where tunnels are constructed through high quartz-containing rock such as shale and sandstone. Tunnelling through any quartz-containing substance generates a type of dust known as respirable crystalline silica (“silica”). Silica is also present in shotcrete, which is used as structural support for mined tunnels, declines, and shafts, in addition to being contained in concrete and grout, which are staples of the tunnelling process. Therefore, silica exposure presents a significant risk on a national level within this industry, regardless of tunnel location.

Other health hazards that tunnel construction workers are exposed to include welding fume, noise, thermal heat stress, vibration, hazardous chemicals such as those contained in grout and shotcrete, and psychosocial hazards affecting mental health.

Of all the health hazards tunnel workers are exposed to in Australia, silica represents the highest risk of developing an occupational illness and disease [13][18], largely due to the high proportion of quartz that is present in our host rock in addition to the pervasive use of concrete and shotcrete. Silica is generated when any quartz-containing substance such as concrete, grout, shale, or sandstone is cut, crushed, hammered, sawed into, or otherwise disturbed. This means it poses a risk for the construction industry in general, but this risk is amplified in tunnelling in an underground scenario.

1.1.2 Common illnesses and diseases in tunnel construction workers

Over-exposure to silica is known to result in the development of an incurable and specific pneumoconiosis, known as silicosis, in addition to lung cancer and renal disease [19]. Being a chronic health hazard, there is a latency effect between exposure and the development of silicosis, which is typically 20 to 30 years. However, when quartz is freshly fractured, as is the case with tunnelling and construction, the toxicity of silica increases [19], which in turn can reduce the latency period down to 10 to 20 years [8]. There is also a form of silicosis known as “acute silicosis” in which silicosis progresses rapidly to acute respiratory failure, typically in less than two years [19].

Tunnel workers have an increased risk of developing chronic...
obstructive pulmonary disease (COPD) compared to other heavy construction workers [3], a higher occurrence of respiratory symptoms and nasal mucosal swelling [4], double the magnitude of lung function decline than heavy smokers [5], and those that use synthetic grouting resins have a higher prevalence of bronchial hyperresponsiveness, asthma, and airflow limitation [6]. Tunnellers are also subject to develop noise induced hearing loss, musculoskeletal disorders and poor mental health, as is common in the construction industry in general [2].

1.1.3 Exposure to health hazards in tunnelling

There can be a low level of awareness of how high concentrations of health hazards such as silica can be in tunnelling. Silica is invisible to the naked eye due to its small particle size, and therefore it can be overlooked as an issue that requires attention. The only way to determine the concentration of silica is to measure the hazard in accordance with a validated method and recognised standards, known as “exposure monitoring.” This involves measuring the amount of the hazard (e.g. silica) in the air that tunnel workers are exposed to using a personal pump and small cyclone attachment that clips onto workers’ collars which is performed by an occupational hygienist.

Tunnelling contractors typically engage occupational hygienists to perform exposure monitoring in which concentrations of dusts and silica, diesel particulate matter (DPM), gases, and noise are measured where there is a risk of exceeding the relevant legal Workplace Exposure Standard known as “Exposure Standards.” Exposure Standards are written into Work Health and Safety (WHS) Regulations in each state, and represent the concentration, or level, at which no worker should be exposed above. The results of exposure monitoring are compared to the Exposure Standards by occupational hygienists to determine legal compliance.

Notwithstanding those who may comply with these Exposure Standards, it is important to understand that over one-third of them are out of date [7] and some, such as respirable dust and DPM, have yet to be included in WHS legislation. Therefore, merely reducing exposure to just below the Exposure Standards that exist, will not sufficiently protect worker health, and will still present a significant risk of workers developing an occupational illness or disease.

While it is generally understood that exposure above Exposure Standards are prohibited, the only way of knowing if they are is through exposure monitoring. There is no current standardised framework within this industry that prescribes competency of the person performing such exposure monitoring or the frequency of which that monitoring must occur in Australia.

Exposure monitoring data collected from tunnel workers are retained by the Principal Contractor and is used to determine legal compliance and if the control measures in place are effective at reducing exposure
to below Exposure Standards. Such data is typically subject to confidentiality and is not routinely published, although it is mandatory for it to be kept for a period of 30-years [21].

The true extent of exposure to hazards such as silica or DPM in the tunnelling industry in Australia is largely unknown, due to the absence of a requirement for exposure monitoring to be submitted to a central organisation, such as the State WHS Regulator.

We can look internationally, where exposures have been reported to be above current Exposure Standards for silica and diesel exhaust in Norwegian tunnels [16] and for silica in London tunnels [17] however, the proportion of quartz in rock in Australia is much greater than in the tunnels that these studies were based on, and therefore that data is likely to be under-representative.

Notwithstanding the limited exposure data publicly available from Australian tunnels, the Queensland health and safety regulator reported that, average, silica concentrations in 2010 were above the Exposure Standard for most all tunnellers, rising to more than 50 times the Exposure Standard for those workers operating open-cabin road headers [22] which are still used in Australia. While it was noted that respiratory protection was supplied to tunnel workers, the extent or efficacy of its use was not reported.

In 2015, a case study on a major tunnelling project in Sydney using Tunnel Boring Machines (TBMs) reported silica exposures at around double the concentration of the Exposure Standard, which was lower by comparison, as is typically the case in TBM tunnelling, however respiratory protection was still required to reduce exposure [23].

Most recently, high silica concentrations in tunnelling have been getting attention as part of the inquiry into Coal Workers’ Pneumoconiosis. At a Public Hearing earlier this year [24], a representative from the CFMEU spoke of silica concentrations that were six to ten times the level of the Exposure Standard in a Brisbane tunnel. In addition, Dr. Robert Cohen, US black lung expert, highlighted the high toxicity of silica in relation to coal dust and recommended that Brisbane tunnel workers undergo testing for silicosis. It is important to note that the majority of tunnel construction workers are represented by the Australian Workers Union however, and not the CFMEU.

The recent parliamentary report published as part of the inquiry into the re-identification of Coal Workers’ Pneumoconiosis [25] made a number of recommendations that are anticipated to result in an overwhelmingly positive outcome for Queensland Coal Mine Workers. Many of those recommendations are directly applicable to the tunnelling industry also and would result in an equally improved outcome. However, tunnelling operates under a different regulatory framework and is understood not to be a current beneficiary of the recommendations made as part of that inquiry. The expansion of the terms of reference of that inquiry to include an investigation of the

There is no current standardised framework that prescribes the number of samples to be taken to measure exposure.

There is no current requirement for exposure data to be submitted to any central organisation.

Seven years ago in Brisbane tunnels, silica exposures were measured to be above the legal Exposure Standard, and in some cases 50 times that Standard.
extent of respirable dust and respirable crystalline silica exposure for all workers, including those who work in the tunnelling sector, would be a welcome initiative with the aim of improving the current system.

1.1.4 Influence of tunnelling methods on the magnitude of exposure to health hazards

The magnitude of health hazards differs relative to the method of tunnelling. The three main methods used in Australia are:

1. Mined tunnels, where road headers are used in conjunction with bolt, mesh, and shotcreting, such is the case on WestConnex in Sydney, and also commonly used to construct declines, station boxes, and cross passages which are common to most tunnel projects;

2. Cut and cover, where a shaft or decline is excavated to the required depth, and then an overhead roof support system is installed, which may be backfilled over, such us the case on most all tunnelling projects; and

3. TBM tunnelling, where one or more Tunnel Boring Machines (TBMs) are used along with pre-cast concrete segments to line the tunnel, such is the case on Sydney Metro and the West Gate Tunnel project in Melbourne.

Of all the tunnelling methods, TBM tunnelling results in the lowest overall exposures to silica and diesel exhaust, largely due to a large number of electrically powered and mechanised processes and the lower reliance on shotcrete for structural support. By contrast, mined tunnels (including cut & cover) constitute the highest exposures to health hazards such as silica and diesel exhaust. Although tunnelling Contracts typically include both design and construction, the Tender brief provided by the Client tends to dictate the overall method of tunnelling used through providing certain constraints as part of the overall concept design. In all cases, regardless of the tunnelling method used, exposures to silica and diesel exhaust can be anticipated to be above the Exposure Standard.

1.1.5 Incidence of illness and disease in tunnel construction workers

While the extent of exposure to health hazards such as silica and DPM is largely unknown to those not working on individual projects in Australia, one may assume that we can understand the extent of illness and disease from reviewing workers’ health surveillance records or workers’ compensation statistics that relate to lung diseases such as silicosis, COPD, or lung cancer. Unlike the mining industry, however, a centralised health surveillance program for tunnel workers does not exist. Rather, the Principal Contractor is

Road-header (mined) tunnelling presents the highest risk of exposure of health hazards to tunnel workers.

There is no centralised health surveillance program for tunnel workers.

There is no legal requirement for a diagnosis of lung disease such as silicosis to be reported to any central agency.
legally responsible for managing health surveillance for crystalline silica where there is a significant risk to the worker’s health [21].

Health surveillance programs operate independently on each tunnel project, which makes tracking the status of tunnel workers’ health challenging. Each Contractor may use a medical health provider of their choice, which may not include the services of an occupational physician. Due to the project-based nature of tunnelling, the current system does not require the health status of tunnel workers to be tracked over time.

While both silicosis and lung cancer are “deemed diseases” [26], a diagnosis of these diseases by a medical practitioner does not trigger a notification to a central or regulatory body. That is because while harmonised WHS legislation requires the Principal Contractor to notify the State WHS Regulator in the event of a serious illness, the definition of a “serious illness” is one that requires immediate treatment in a hospital or medical treatment within 48 hours of exposed to a substance neither scenario being likely in the case of a silicosis or lung cancer diagnosis.

Therefore, the determination of the extent of silicosis or lung cancer relies on workers filling for, and being successful, for worker’s compensation which may occur under the Workers Compensation (Dust Diseases) Act using NSW as an example [28]. As both of these deemed diseases have long latency periods, they often do not present with symptoms until many years. As such, the relationship between the development of lung disease and its association with work may not always be identified, therefore leading to under-reporting.

Another factor that impedes on the use of this data to determine the incidence of disease is that many workers who have lung diseases such as silicosis, continue to work in the tunnelling industry due to the higher-paid work in comparison to any financial benefit they may be provided through the workers’ compensation system.
What is Current Practice?

In order to understand what “Best Practice” might be, it is important to understand the current practices applied in Australian tunnelling in relation to the prevention of illness and disease.

2.1 Regulatory Framework

In Australia, health and safety in tunnelling is regulated under the Work Health and Safety Act and Regulations as adopted in each state [27]. Specific elements that relate to chronic health hazards such as silica include the requirement to ensure that Exposure Standards are not exceeded (Regulation 49), to monitor airborne contaminant levels (Regulation 50), and requirements for health monitoring for silica (Schedule 14).


The elimination of health risks associated with exposure to health hazards such as dusts, silica, and diesel exhaust is rarely practicable in a tunnelling environment, therefore leading to the requirement to minimise risks to health so far as is reasonably practicable (SFAIRP). That process involves the identification, assessment, control, and review of risks to health on an ongoing basis [18] which relies on a risk based approach to manage health risks.

Health and safety risk management is subjective in nature, in that social, psychological, and technical factors interact to shape risk perception [33]. That is, not every person, or project assesses the same identified risk, equally. Further, different stakeholders assess risks using their own perception which is influenced by many factors including: how much control one has over the risk; whether it is familiar; whether the consequences are delayed; who bears the consequence; and whether the hazard is encountered as part of work activities [34]. As instances of chronic diseases such as silicosis are not reported or broadcasted to the tunnelling community, it can result in a low risk perception and bias when assessing the risk to health from exposure to silica.

Performance-based health and safety legislation, rather than prescription-based legislation, can have the benefit of realising improved methods that can be implemented without needing an exemption to Regulations. However, a drawback can be that industry may expect the Regulator to offer advice and instructions on a particular matter if it is indeed so important. By contrast, the Regulator turns to industry and expects them to have a greater understanding of the hazards and controls [35].
2.1.1 Codes of Practice

There are many Codes of Practice that apply to the tunnelling industry which aim to provide practical guidance to achieve the standards required under WHS legislation. Following the Codes would achieve compliance with health and safety duties under legislation in most cases. They are admissible in court proceedings, however, compliance with WHS legislation may be achieved through following another method if it provides an equivalent or higher standard of work health and safety than the Code.

In NSW, A Tunnels Under Construction Code of Practice [36] existed prior to the introduction of harmonised Work Health and Safety legislation. Although that Code was developed based on the previous Occupational Health and Safety Act and Regulation, it is still current in NSW and can still be used as evidence of what is known about a hazard or risk, and what is reasonably practicable. Specific elements of that Code that relate to the prevention of illness in tunnel construction workers are:

- Explanations of common sources of harmful airborne contaminants such as silica dust and diesel exhaust.
- Recommends that the presence and likely generation of silica dust and diesel exhaust be addressed in a risk assessment in addition to outlining possible control measures.
- Recommends the use of respiratory protective equipment conforming to AS/NZS 1716 which is selected and utilised as per AS/NZS 1715, which requires workers to be clean shaven when using respirators that rely on facial fit to be effective for example.

There are no current mandatory Codes that specifically relate to the control of chronic acting hazards such as silica or diesel exhaust emissions that cause ill-health in tunnelling (or construction).

2.1.2 Guidance Documentation

Like Codes of Practice, Guidance documents aim to help duty holders comply with the law and may be tendered as evidence in court proceedings. However, in contrast to a Code, they allow duty holders wider discretion to choose the options that best suit their circumstances and purely contributes to the “state of knowledge” regarding hazards, risks, and controls [37].

The Guide for Tunnelling Work [18] was produced to provide practical guidance on the management of health and safety risks associated with tunnelling work. It includes references to published Codes of Practice, including for example:

- The requirement to manage risks through a systematic process involving hazard identification, risk assessment, risk control, and risk review [29]; and
The requirements for consultation, co-operation, and co-ordination [38];

With respect to occupational health and illness/disease prevention, the Guide includes the following information:

- Development of a WHS Management Plan prior to construction;
- Development of tunnel design including a pre-construction investigation of ground conditions and the workplace informing the method for excavation. Consideration of dust production; dust control measures; and airborne contaminants are to be considered when determining the most suitable excavation method; and
- Ventilation system design during construction, use, and maintenance, including the provision of extra localised extraction ventilation for dust, heat or fumes during excavation, post-blasting, operating large plant or other activities such as maintenance.

Overall the information in the guide is relatively limited with respect to health hazard management and is noted to have not been adopted in NSW.

2.1.3 Awareness Information

In the major tunnelling states, each WHS Regulator has produced guidance material relating to silica and/or tunnelling at varying levels of detail. This ranges from a publication on silica as it relates to Stonemasons in Victoria [39], through to a fact sheet in NSW which states, that silica exposure is, “…extremely unlikely nowadays, given modern work practices”, and does not identify tunnel construction workers as an “at risk” work group [40], through to a series of comprehensive fact sheets and the results of intervention studies from the QLD WHS Regulator. SafeWork NSW, when they were previously WorkCover NSW, previously published the Guide, How to Prevent Silicosis, however, this Guide is no longer available.

2.1.4 Workers Compensation Schemes

Each State in Australia holds their own Worker’s Compensation Act and system that is run independently of the state WHS Regulator. In NSW for example, the Dust Diseases Board (DDB) administers the requirements of the Safety, Return to Work and Support Act (2012) where they play a key and vital part of the system of occupational health. The DDB provides subsidised health monitoring examinations and workers compensation payments to ill workers and dependants. While the DDB is not involved in direct initiatives in the workplace that prevent exposure to health hazards of tunnel workers, its contribution is through welcome funding of research through a series of grants.
The DDB is not routinely used for medical screening for tunnel workers in NSW however, with Contractors typically choosing to use private medical providers for a range of reasons. These include the sheer size of the workforce on their projects and the desire to have all medical services (audiometry etc.) in the same location and to have all medical records standardised per worker in the company’s format and a range of other reasons mainly associated with project scale.

2.2 The Nature of Tunnel Contracting

Overall, the WHS Regulations, Codes, Guidance, and Awareness information pertaining to occupational health, could be improved through providing information on what compliance looks like, how it is achieved, or what the response or ramifications of non-compliance are. From a Contractor’s perspective, it can be reasonably challenging to understand what is required or expected to not only comply with legislation but also to prevent illness and disease in their workforce.

Tunnelling projects are traditionally delivered by one or more large Tier 1 Contractors, which may be coupled with an international tunnelling partner working together as a Joint Venture. Tier 1 Contractors, by their very nature, have mature, integrated and well-resourced WHS management systems that operate within a strong safety leadership culture. These systems are aligned to AS/NZS 4801 [41], which provide a WHS management system framework that includes a Health and Safety Policy; Planning; Implementation; Measurement and Evaluation; and Management Review. While AS/NZS 4801 has existed for over 15 years [41], little practical guidance is readily available on the methods to effectively apply to identify, assess, control and review the risk of chronic health affecting agents.

In most cases, Contractors are also accredited through the Australian Government Building and Construction WHS Accreditation Scheme, such that the Contractor can enter into contracts for work that is funded directly or indirectly by the Australian Government. Therefore, it is reasonable to expect that on any given major tunnelling project in Australia that the following level of WHS management could be expected [42]:

- demonstrated senior management commitment to WHS;
- integration of safe design principles into the risk management process;
- whole-of-project WHS consultation and communication;
- demonstrated effective subcontractor WHS management arrangements;
- whole-of-project performance measurement;
- WHS training and competency to deal with safety risks;
- demonstrated ability to deal with construction hazards and high risk activities;
- past performance in relation to workplace safety; and
- evidence of an effective WHS management system.

The Office of the Federal Safety Commissioner (OFSC) administers the Accreditation Scheme, part of which, involves an on-site audit. There are additional elements that relate to tunnelling and worker health in that Audit that include for example:

- H8.4 Air quality and ventilation system requirements;
- H8.5 Regular tunnel inspections to monitor the effectiveness of controls;
- WH14.1 Site-specific assessment of potential health hazards;
- WH14.2 Personal exposure to health hazards measured by a formally trained person;
- WH14.3 Documented process for health surveillance; and
- WH14.4 Inspection, measuring and test equipment to be calibrated.
2.3 Where are the gaps?

With all of these requirements, one may question why illness and disease in tunnelling would require a specific focus if health and safety management systems on major tunnelling projects were so comprehensive? There are a number of reasons summarised below.

1. Generally, the causes of work-related illnesses are not as well understood in comparison to work related injuries. It is not uncommon for some to not understand the true magnitude and effects of silica exposure, and therefore control measures that are designed and implemented may not be adequate to control such exposure.

2. The impacts or “cost” of ill-health associated with the design of a tunnel and ancillary structures to be constructed, is not always taken into account during the design process (e.g. “Health in Design”). Thus, when looking at the cost-benefit of one construction method over another (e.g.: selecting sprayed concrete linings over pre-cast concrete lining), the costs associated with ill-health of those workers who will perform those activities are typically not taken into consideration as part of that analysis.

3. Health risk assessments are not routine, and where they are conducted, it has been known for them to be completed by someone with limited competence and knowledge of the degree of risk. If the risk of exceeding the exposure standard is not appropriately assessed, then exposure monitoring may not occur (refer Regulation 50), it would not be known if exposure standards are exceeded (refer Regulation 49), and if a Significant Risk is not adequately determined, then health monitoring for silica would not routinely occur.

4. There is no centralised health surveillance scheme for tunnel construction workers. Thus, it is difficult to understand the true extent of occupational illness and disease in this sector. Further to this, it is not possible to analyse trends in disease that may, in turn, inform future policy or specific action.

5. There is currently no standardised training in occupational health hazards that is provided to managers, engineers, or the tunnelling workforce, to enable an understanding of the linkage between exposure to silica dust and their common sources, and the development of occupational illness and disease. All workers in the construction industry must attend general construction induction training to be eligible for a “White Card,” however, this training does not address chronic acting health hazards.

6. Due to the nature of tunnelling work, there can be financial pressures on Contractors preventing them from going above and beyond what they understand the minimum requirements to be. If there is no driver from their Client or the Regulator, it is not as likely to be adequately resourced as if their focus is in a competing area of interest, such as program risk or acute safety issues.

7. There can be limited enforcement of the exposure standards or health control measures, which can lead to the belief that it is not an issue that requires attention.

8. As there is no standardised frequency of exposure monitoring, it is possible for some to believe that collecting very few measurements on select “good” days is sufficient to meet the requirements of legislation or to understand the risk to health, which in turn results in lower exposure monitoring data, which may be artificially under reported.

9. There is limited independent research undertaken to understand the level of exposure of health hazards to which tunnel workers are exposed; nor epidemiological research into health conditions experienced by tunnel workers; nor the current extent of illness or disease. This presents challenges when making a case for change if quantitative data is not available to support such a decision.

10. There are no mandated minimum levels of competency for occupational hygienists in legislation. The term “occupational hygienist” is not protected by law, meaning that the term can be used by anyone. In the context of the complexities of the tunnelling environment, a Full or Fellow Member of the Australian Institute of Occupational Hygienists (AIOH) with experience in the hazards to be assessed, working under the governance of a Certified Occupational Hygienist (COH)” would be seen as the minimum necessary competency.
requirements in this high-risk sector. Notwithstanding, this is not always applied, and some Contractors engage “occupational hygienists” in good faith and are provided inaccurate information on the degree of health risk.

11. Some Contractors engage occupational hygienists to undertake exposure assessment and to provide recommendations for control. Those occupational hygienists, however, have no authority to stop the Contractors work, if those recommendations are not implemented. Consultants are typically bound by confidentiality agreements and therefore cannot discuss the details of the Project with external parties without express written authority from the Project. The existing system, therefore, relies on the good faith of the Contractor, a heavily engaged Client with sufficient resources to drive these issues, or on the Regulator to be heavily involved and with the knowledge and power to stop the work if needed.

12. The results of Exposure Monitoring are not required to be submitted to any Health and Safety Authority. Therefore, the ability to understand where areas of concern may be present is reliant on heavy regulatory intervention to request such data.

13. There are no Exposure Standards for respirable dust or DPM in this sector, and the Exposure Standard for Silica remains higher than what was recently recommended as part of the Coal Workers Pneumoconiosis Inquiry [25]. Therefore simply complying with Exposure Standards will not prevent occupational illness or disease from occurring.

14. There is limited sharing of best practice or lessons learned across the industry on illness or disease prevention strategies, which results in a widening gap of “what good looks like.” Limited sharing of information results in stifling of learnings that could be applied from one project to the next, irrespective of the Contractor, that would reduce the risk of ill health to the wider tunnelling workforce.

15. The short-term focus of a project-based environment prevents a long-term view. Due to the temporary nature of the work, there is a lack of data standardisation to enable the tracking of initiatives, exposures, and ill health over time. However, tunnellers will typically stay in the industry over the term of their working life (although they may work for a variety of different contract organisations and joint venture partners), and thus a long-term view is essential for ill health prevention.

16. Due to the lack of the need to report illnesses such as silicosis, these diagnoses largely go unnoticed. This continues to feed the level of knowledge, and hence the perception of the level of risk posed by exposure to silica, resulting in a continued low level of awareness and focus on the issue.

Notwithstanding the gaps and issues raised above, there are examples of good occupational health and hygiene programs that aim to prevent illness and disease in tunnel construction workers. These have been driven by experience, but largely, and most importantly, leadership on this issue. Demonstrated leadership from the highest levels of senior management provides a high degree of influence and focus, leading to greater control at the site level. Leadership by Site Supervisors has a great positive impact on a whole tunnelling shift crew. I have had the privilege of working alongside great leaders at both the Executive through to the Site level and witnessed some great positive outcomes as a result. However, there is a large inconsistency across this industry, with some projects operating at a proactive level and some relatively unaware of the magnitude of the issue at hand.
Best practice framework & methodology

3.1 Existing Frameworks

The term, “Best Practice” has been defined as the most efficient and effective way of accomplishing the desired outcome based on repeatable practices that have been proven to be effective for large numbers of people [35]. There are a few best practice frameworks that have been proposed in the health and safety sector, described herein, which were reviewed to understand possible areas of focus for this Fellowship.

3.1.1 Construction Innovation

A best practice framework for construction occupational health and safety was presented in a Guide published in 2007 by the Cooperative Research Centre for Construction Innovation [43]. The framework centred around six best practice principles for creating a strong safety culture, which was applied across four stages of a project’s lifecycle. Although the Guide refers to the term “safety” throughout, its intent was to include occupational health and the reduction of risk of work-related illness. As such, the six principles listed below have been modified slightly to be focussed towards occupational health and illness and disease prevention and include:

1. Demonstrating leadership in occupational health
2. Promoting health in design
3. Communicating health information
4. Managing health risks
5. Continuously improving health performance
6. Entrenching practices to protect worker health

The Guide identified each principle along each of the major stages of a project, being Planning, Design, Construction, and Post-Construction, with an understanding of the roles to be played by three primary stakeholder groups of the construction industry, being clients, designers, and constructors.

While much has changed since the time that report was published, including health and safety legislation [21], the underpinning elements of the best practice frameworks presented, are still relevant in today’s modern context.

3.1.2 Workplace Health

The Workplace Health Association Australia (WHAA) developed a set of guiding principles to support best practice workplace health interventions. “Workplace health” in that context referred to the improvement of health and well-being of workers through improving the work organisation, working environment, promoting the active participation of workers in health activities and encouraging personal development [44].

As aptly identified by WHAA, smoking cessation, chronic disease management, weight management, and stress management have a great impact on health and safety outcomes. Health and safety programs tend to be run separately independent of employee wellbeing programs, or indeed, have no wellbeing component to support a health and safety strategy [44]. A key principle to support best practice was to better integrate health and safety with worker health and wellbeing. The 15 guiding principles recommended for development and implementation of a results-oriented program included:
1. Active support and participation by senior leadership
2. Health as a shared responsibility
3. Engagement of key stakeholders
4. Supportive environment and culture
5. Participatory planning and design
6. Targeted health interventions
7. Evidence base, standards, and accreditation (competency)
8. High levels of program engagement
9. OH&S integration
10. Technology and online programs/content
11. ROI – assumptions and calculations
12. Innovative marketing and communication
13. Evaluation and monitoring
14. Commitment to ethical business practices
15. Sustainability

3.1.3 Risk Management

Further work in this area specific to the tunnelling sector has focused on best practice approaches in risk management [35]. In that context, rather than addressing principles separately in each discrete phase of a project, it was suggested that “best practice” involved stronger linkages between each project phase. The aim of enhancing stronger linkages was to enable seamless transitions between project phases; to harness knowledge contained within operations personnel as part of risk analysis; to centralise risk management across project phases with greater consideration of stakeholders leading to improved change management; evidence gathering, and continuous improvement processes.

3.2 Proposed Elements of Investigation

Drawing from these existing frameworks, the following elements were established to investigate successful “best practices” that may have direct relevance and benefit to the Australian tunnelling industry focusing on illness and disease prevention:

1. Leadership. Demonstrated leadership in occupational health was anticipated to have the greatest influence on worker health protection throughout the supply chain. This element sought to understand which stakeholder(s) had effectively demonstrated such leadership and if it resulted in a positive impact at the site level.

2. Engagement and Collaboration. Best practice in the prevention of occupational illness and disease was anticipated to rely on a multi-faceted approach involving collaboration and consultation with a multitude of stakeholders such as the Client, Designers, Contractors, Regulator, Industry, and Research partners. This element sought to understand if and how collaboration occurred, and if it had been beneficial to an improved approach for preventing ill health.

3. Training and Awareness. This element reviewed how health risks were communicated, including methods to raise awareness of health risks and their control. It included a review of methods used to up-skill the project team and the workforce, in addition to the methods used to elicit high quality education and training programs.

4. Standards. This element reviewed the extent that worker health protection was driven by legislation, industry, or a company or project standard. It also included an understanding of the extent and the effect of contractual specifications for Contractors and their supply chain.

5. Health in Design. This element reviewed the methods by which exposures were assessed at the time of design, how health was considered in the planning process, and how that information was shared across project phases during construction and operation.

6. Program Health Risk Management. This element reviewed the approach to integrate Workplace Health, Occupational Hygiene, and Wellbeing. It looked at the overall risk management framework and ongoing evaluation of those approaches on a holistic basis as to how risks to ill health were assessed, monitored and controlled systematically.

7. Targeted Health Risk Management. This element looked at specific measures and processes employed to eliminate or reduce exposures to specific health hazards such as silica and DPM.

8. Sustainability. Protecting the health of tunnel workers relies on a long-term sustainable approach, and as such, this element looked at whether programs were designed to be entrenched throughout the supply chain and positively affect the industry on a sustainable basis, far beyond looking at individual projects in isolation.
Figure 2 – Elements of Best Practice in the Prevention of Occupational Illness and Disease in Tunnel Workers
United Kingdom

Construction workers in the UK are 100 times more likely to die from an occupational illness than a workplace accident which is in stark contrast to Australia, where a ratio of 8:1 is reported [2,45]. Given the similar nature of the health and safety legislative framework and processes between the UK and Australia, it is highly doubtful that the UK has a disproportionately higher number of occupational illnesses, but rather more likely that these illnesses have historically been grossly under reported in Australia. As the majority of major infrastructure projects in Australia occur in high quartz-containing sandstone liberating toxic silica dust, in comparison to the low-quartz containing clays of the UK, it is also probable that the rate of illness in comparison to safety incidents is much actually higher than 100:1 in Australia.

The UK Construction Industry has had an increased focus on Occupational Health since the London Olympic Games. This increased focus and approach is attributed to the Head of Health and Safety for the Olympic Delivery Authority, Lawrence Waterman, who lead a program specifically designed to address the traditional poor health and safety record seen in the construction industry. The program resulted in excellent health performance on this major project and included a number of key occupational health initiatives that have now evolved and appear to be positively entrenched in the UK Tunnelling industry. Some key examples of these initiatives are [46]:

1. Taking a holistic approach to health that focused on the workplace, the worker, and wellbeing. This three-pronged approach includes preventing exposure (e.g. through occupational hygienists), managing the health status of the workforce (e.g. through clinical services) and the use of the workplace to promote health (e.g. wellbeing) and is known as the “health triangle” (Figure 3).

![Figure 3 – The Health Triangle](image-url)
Treating health like safety in risk assessment and using RAG systems (Red, Amber, Green) to simplify the communication and evaluation of health risks.

The development of an Occupational Health Maturity Matrix (OHHM) that demonstrated how health integrated into the project. Using interview and audit techniques along with site observations, Contractors were rated between 1–5 for each project and implementation plans were developed to drive improvements, leading to sustainability, in occupational health.

The use of an Occupational Health Impacts Frequency Rate (HIFR) which created a measure similar to a safety “near miss.” This approach treated health was reported like safety and also drove compliance for low-level control measures such as PPE.

Onsite health surveillance that linked in with health risk assessments that focussed on hand-arm vibration, noise, skin dermatitis and lung function.

Wellbeing programs that were targeted to key health issues facing the demographic of the workforce.

A key reason for visiting the UK was to meet with large tunnelling projects and their associated stakeholders, to understand how occupational health management had evolved since the London Olympics. Visits to the three largest tunnelling projects in the UK were scheduled, all of which are all at different stages of their project lifecycle (Figure 4), in addition to meetings with key stakeholders including professional societies, industry campaigns, and research institutions.

Figure 4 – Progress of Occupational Health across major projects in the UK
All three major tunnelling projects in the UK have signed up to the construction and civil engineering industries' pledge as part of their ongoing commitment to supporting health and wellbeing. The pledge covers areas such as a health and wellbeing strategy for staff and contractors and the use of accredited occupational health providers. It includes items such as:

1. Annual reporting on the health and wellbeing of employees;
2. Provision of clinical occupational health services;
3. Development of a programme to actively promote health and wellbeing, including:
   - Management of chronic health conditions
   - Healthy staff restaurants
   - Smoking cessation
   - Health checks for employees
   - Support for employees with mental health conditions
   - Physical activity in the workplace and active travel to work

Therefore, it was anticipated that these three major projects would, at the very minimum, have a focus on occupational health and ill health prevention.
4.1 Crossrail

4.1.1 Leadership

Crossrail as the Client was the key driver behind the Health and Wellbeing program. As an example of how the Client took the lead, Crossrail initiated collaboration with industry partners who together signed a *Health, Safety and Environment Agreement*, that set out key leadership behaviours that would be demonstrated by all signatories. The Agreement included a commitment to best practice in both innovation and sharing of best practice methods in a collaborative manner, in addition to a commitment to promote occupational health and wellbeing as key areas on the Project.

4.1.2 Engagement and Collaboration

Health and wellbeing have been a key area of focus of the Health and Safety program at Crossrail, with a concerted effort made to raise the bar across the industry. In 2013, Crossrail’s Health and Wellbeing Strategy contained a vision to improve the delivery of activities across the project through working with Contractors in a collaborative manner. As a result, the Project developed a baseline for good occupational health across the project, and the Crossrail *Occupational Health Standard* was produced with requirements replicated in the *Works Information* for all Contracts.

By 2014, Contractors had achieved the minimum requirements as standard practice across the project, so Crossrail instigated a review of the strategy to develop a model that went beyond minimum requirements and pushed further towards good practice. Undertaken in collaboration with Contractors, the review sought to simplify the strategy to move away from health being focused on health assessment and physical wellbeing (such as life style risk factors), but instead to include key elements such as fitness to practice and health risk management. It also changed the emphasis of wellbeing to mental health as well as physical health. This resulted in the production of the Four Corner Stone model and a new *Occupational Health and Wellbeing Strategy* which was rolled out in 2016 [47].

Another method of collaboration was the development of an *Occupational Health Forum* which consisted of senior representatives from the Client and Contractors and was chaired by an independent occupational health professional. This forum had oversight of the performance and delivery of all occupational health services which enabled a high-level view of performance across the entire project.

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**Key Contact:**

Martin Brown, Director of Health & Safety, Crossrail

**Project Snapshot:**

Crossrail is the new high frequency, high capacity railway for London and the South East. A 118-kilometre railway line, it involves the construction of over 21 kilometres of twin tunnels through central London.

At the time of the visit, the major tunnel construction portion was complete, and the project was in the process of fitting out tunnels, shafts and portals with cables, ventilation fans and communication and signalling systems required to operate the railway.

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*Figure 5 – Crossrail Occupational Health and Wellbeing Strategy*
4.1.2.1 Research

As part of the health risk assessment process, Crossrail identified a series of key occupational health risks across the project which led to a number of research projects commencing [47].

One of these was through the Institute of Occupational Medicine (IOM) who were engaged to investigate tunnel workers’ exposures to dusts, silica, and diesel exhaust. At the time, it was generally recognised that substantial exposures to tunnel workers from these hazards had been previously reported in scientific literature, and there was an understanding that there was a lot that could be gained from learning from the processes applied at Crossrail. This study was undertaken to document the extent of exposure and to ensure that knowledge could be shared across the industry as part of Crossrail’s legacy [17].

Over a period of 9-days in the field, IOM collected independent exposure monitoring data and were able to demonstrate that around one-third of respirable dust exposures exceeded the equivalent of the Australian guidance value for respirable dust (noting an Exposure Standard doesn’t exist in Australia), and around 10% of samples exceeded the Exposure Standard for silica, primarily during shotcreting. DPM exposures were all below the Australian guidance value. Although this was a relatively short snap-shot of exposures compared to the length of this project, the benefit of this approach was that the data was collected independently and subject to peer-review. Given the limited amount of published exposure data in tunnelling, this study was of great value as it led to an understanding of the common tunnelling tasks that required the use of specific controls, including the use of specialised PPE.

Research was also commissioned into fatigue and the comparison of rotating shifts within major tunnelling projects including Crossrail[48]. The aim was to understand the impacts of fatigue risks on staff working a number of common shift patterns, with typical rotating shift schedules. The research concluded that permanent night shifts had the highest fatigue risk; the shift pattern of 7 x 8-hour day shifts; 3 days off; 7 x 8-hour night shifts; 2 days off (averaging 45.5 hrs per week) had the greatest fatigue impact; and the shift pattern of 5 x 12-hour night shifts; 2 days off; 5 x 12-hour day shifts (averaging 60 hrs per week) had the lowest fatigue impact.

Some of the recommendations from this study were to restrict the number of consecutive nights to a maximum of 3 to 4 days and to use quantitative tools such as the use of a Readiband™ to measure fatigue, in addition to future exploring this topic on future projects.

4.1.3 Training and Awareness

Crossrail aimed to prevent work related ill-health through the delivery of the strategy and therefore ran a series of project-wide health campaigns targeted to work related ill-health. A powerful and realistic set of videos were anticipated to result in greater awareness than traditional methods.
One of those was entitled Dust/Respiratory Health: '999 Health Emergency: protect your lungs, they need you' which included the production of awareness material including professionally produced videos. One of these, known as “Jenny’s Story” https://youtu.be/r-QbfTVMDYU depicted a young female construction worker’s attitude to wearing respiratory protection and the resultant effects of her approach.

Powerful and realistic video's such as these provide a welcome alternative to the traditional poster and PowerPoint presentation campaigns and are anticipated to result in a more memorable impact on participants. The 999 Health Emergency campaign also included a “Dust for Managers” course, which involved practical demonstrations by suppliers on dust extraction systems.

![Figure 6 – Screen capture from “Jenny’s Story”](image)

4.1.4 Contractual Requirements

The Crossrail Occupational Health Standard was designed to provide a standardised framework for managing health risks. It included requirements for Contractors to perform health risk assessments and subsequently control health risks in accordance with the hierarchy of control, leading to monitoring strategies and the identification of health surveillance requirements, as well as documenting processes to control the risk of fatigue [49].

The Standard contained requirements around the provision of a proactive occupational health service and medical assessment in the form of both fitness for duty and medical surveillance for workers. It also contained requirements around employee wellbeing, campaigns, and education, and the requirement for Contractors to provide communication and training to line managers and supervisors on the health risks identified so that they could adequately identify these risks, leading to an appropriate level of control.

The Standard set the minimum requirements for all Contractors, which essentially set out clear expectations and a level playing field for prospective Tenderers.

4.1.5 Health in Design

Health in Design was addressed in the Crossrail Occupational Health Standard through requiring design teams to have access to

Crossrail standardised the framework for managing health risks.

Proactive occupational health services were required to be provided by Contractors.

Occupational health advice had to be sought as part of the design process.

**Red, Amber, Green** systems were used to simplify the way health risks were communicated.
occupational health advice such that health was included in design risk registers and procurement specifications. Designers were required to be trained in the occupational health standard and to share issues encountered at a designers forum [49].

4.1.6 Program Health Risk Management

From the outset, Crossrail had a significant focus on occupational health risk management at the Contractor level, particularly around the risk of respiratory disease. During tunnelling, there was a significant focus on this issue, which can be challenging to control in an ever-changing tunnelling environment. Now that the project is in the fit-out phase, the systems put in place to assess and control exposure appear to be continuing to improve working conditions for tunnel workers.

Similar to the London Olympic Games, health risks were treated like safety in risk assessment using RAG systems to simplify the communication of health risks.

The Occupational Health Maturity Matrix (OHHM) originally developed from the London Olympics was further refined and was used across numerous Contractors across the Project with implementation plans developed to drive improvements in occupational health. The Matrix provided a framework to work within and had the impact of being an educational tool on what “good looks like” at different levels of organisational maturity. The Occupational Health Impacts Frequency Rate (HIFR) was also utilised on this major project.

4.1.7 Targeted Health Risk Management

In collaboration with Contractors, Crossrail published an Air Quality Best Practice Guide that captured best practice approaches that were applied to reduce exposure to airborne contaminants [50]. Key areas that are seen as best practice over and above what may be considered “routine” in Australian tunnelling include:

- Reduced Exposure Standards for DPM and diesel exhaust gases
- Eliminating the use of brooms and replacement with vacuums
- Fitting all plant with Diesel Particulate Filters and Diesel Exhaust Fluid systems
- Deploying a small dust filter (Class L or M) during all underground welding
- Additional ventilation specific to shotcrete activities (sprayed concrete lining)
- The use of atomised spray rings for dust control (refer Figure 7)
- Training, fit testing and clean shaven policy for RPE
- Use of Full-face P3 Powered Air Purifying Respirator (PAPR) respiratory equipment for shotcretors and others within the
exclusion zone, rather than P2 “dust masks” (refer front cover photo)

- Monthly dust monitoring performed by an occupational hygienist accompanied by a report with listed recommendations for improvement
- Weekly dust monitoring inspections by engineers using direct reading (real time) instrumentation which is reported to the occupational hygienist
- Lung function testing every 2-months for those workers likely to be exposed to the highest dust levels
- Minimum requirements for health surveillance based on role, rather than perceived level of risk, which included all TBM workers, mined workers, and shotcretors

### 4.1.8 Sustainability

The Learning Legacy website for the London Olympics was set up a year following the Games, however, on Crossrail, it was developed during construction in consultation with the Contractors, which made it relatively easier to capture the information prior to the major project works being completed. The learning legacy webpage collates good practice, lessons learned and innovation from the Crossrail construction programme aimed at raising the bar in the industry and showcasing the good work performed by the Project [47]. Essentially “good practice” became “standard practice” through sharing these approaches across the industry.
4.2 Thames Tideway

At the time of the visit, Tideway had secured all of their major delivery partners (Contractors) across each of the main three site sections, being West, Central, and East and had been performing onsite works for almost a year as part of preliminary construction activities.

Tideway has set legacy objectives under five broad themes that capture the range of opportunities created by the project. One of those key themes is, Health, Safety, and Wellbeing, which has the key objective to raise standards and performance in health, safety and wellbeing including raising the standard of inductions and onsite training, promoting new standards and working practices, and introducing a new health and safety communication standard to name a few.

What was made very clear from talking to numerous people across the project was the drive for this project to improve from the norm, and to stretch the boundaries of a best practice approach. Often using the phrase, “Transformational Health, Safety and Wellbeing,” the project was reported to strive beyond mere compliance with minimum legislative and contractual requirements, but rather, strive for international best-practice in worker health protection.

4.2.1 Leadership

The occupational health and hygiene program at Tideway has evolved from successes and learnings from previous mega projects such as the London Olympics and Crossrail. With an enthusiastic health and safety team led by Steve Hails, it was clear that the prevention of illness and disease is heavily driven by the Client on this project, who appears to work in a collaborative process with other key stakeholders such as the Regulator, Contractors, Research Partners, and Industry Campaigns, such as the BOHS Breathe Freely initiative and MATES in Mind.

While leadership in health was evident from the Health & Safety Director, numerous people across the project repeatedly referred to health leadership and influence, coming from the Project CEO (Andy Mitchell) also, which had a significant impact on the way health was viewed down through the supply chain.
4.2.2 Engagement and Collaboration

There are two key industry groups through which Tideway collaborates and shares information which includes the Health in Construction Leadership Group (HCLG) and the Transforming Tunnel Safety Group (TTSG). Both founded by members of the Tideway project and others, these groups tend to focus on the two greatest health risks facing the construction industry, being respiratory risks and mental health.

A key theme that was apparent when mentioning the UK health and safety Regulator (the Health and Safety Executive) was one of collaboration, which is not unlike the process adopted in Australia as mega projects such as these present opportunities for collaboration from both parties. Similar to the process of “collaboration agreements” between Client and Regulator in Australia, the project shares their approach and structure of the system applied and provides access to the Regulator to the project’s training courses and access to sites for new inspectors to train in and be able to understand the processes applied by these projects to manage health and safety. Notwithstanding this, it was also common for many people to note that the Regulator had a keen eye for dust control measures including local extraction ventilation, dust suppression, respirator use, fit testing, and the requirement to be clean shaven when using close-fitting respiratory protection.

4.2.2.1 Research

Another way that the project seeks to be transformational is through partnering with Loughborough University by undertaking longitudinal research from the outset of the project. In contrast to the London Olympics and Crossrail, where researchers were brought in towards the end of the project, Tideway sought to change the model and engage the value of research early on.

Tideway provides funding for four researchers which are embedded with the Contractor teams. In this role, they perform observations on a day to day basis, and due to their location on the Project, they will also acutely be exposed to and be able to understand and highlight, the pressures of construction work. The value of this is around the use of focus groups for feedback and improvements. For example, if researchers go out and take a survey of workers and 90% say that an intervention was particularly poor, then that information would be used to improve that intervention, rather than just carrying on the same path and getting poor results.

4.2.3 Training and Awareness

In what was an incredibly immersive and powerful program, facilitated by method actors and trainers, I attended the Employers Project Induction Course, known as “EPIC.” This one-day project induction forms part of the mandatory training to work on the Thames Tideway Project.
The day was centred on the theme of, “A Day in the Death of Michael Clark” and consisted of many inter-connected parts. The first part was an immersive, multi-media experience played out in a number of different rooms and zones. As a participant, I witnessed a fatal incident on a construction site, followed shortly by entering a living room flat where the orphaned child, now in her early twenties, spoke of her life since the fatality. In the next room, I observed the process employed by the Regulator to interview key stakeholders immediately following the incident, and then lastly, we were taken straight to a room where we witnessed the moments before the event played out by both Contractor management and the Client.

The second half of the day focused on Safety Leadership Skills where we were introduced to various communication techniques. We then had to deploy these techniques in real time with method actors acting the part so realistic, it took me instantly back to what could be any construction site in Sydney. This process essentially taught us as participants how to affect a positive outcome and how to prevent the incident from occurring.

Far from the traditional methods of induction via power point presentation, this induction essentially taught participants desired behaviour, safety leadership, and most importantly, how it is applied.

4.2.4 Standards

Tideway specifies occupational health and hygiene requirements to their Contractors in a document known as a “Works Information,” which contains specific items including the need to engage an on-site health clinical team (e.g. nurses) and occupational hygienists, which together are termed an “Occupational Health Service Team.” Rather than specifying methodologies, the Works Information specifies outputs or performance requirements that the Contractors have to meet, and it is up to the Contractors, in collaboration with the occupational health service team, to develop the methodology to achieve those outputs.

Examples of the level of detail in the Works Information includes competency requirements and the need for an “outreach occupational health service” whereby the health service is proactive in its approach, and travels out to smaller construction sites to promote health, in addition to providing onsite clinical treatment services. It also includes requirements around training of line managers and service providers such that they can adequately identify health risks to employee health from their work activities.

4.2.5 Health in Design

Occupational hygienists are involved in design and planning activities to ensure that health control measures are selected as high up the control hierarchy as practicable. Occupational hygienists collaborate
with the design team to produce a “RAG” list which is a matrix of commonly chosen methods of work which produce varying degree of health risks, with a list of helpful lower-risk alternatives.

Items listed in the “Red” category are only permitted with specific written authority to proceed, “Amber” tasks are for proceeding with caution, and “Green” tasks are the preferred design methodologies. An example of a “Red” task would be spray painting with isocyanate-based paints; the applicable “Orange” task would be to substitute the paint that doesn't contain isocyanate, and “Green” would be to change the paint and the method for example so that it is brushed and not sprayed on.

4.2.6 Program Health Risk Management

I visited the Chambers Wharf site in Bermondsey which will be used to drive the main tunnel to Abbey Mills Pumping Station, Stratford and receive the main tunnel from Kirtling Street to the west. It will also receive the connection tunnel driven from Greenwich Pumping Station, in the east. The Principal Contractor is a JV Contracting team comprised of Costain Ltd, VINCI Construction Grands Projects and Bachy Soletanche.

Spending the morning with the occupational hygienist for the Contractor, James Barnes demonstrated the extent that occupational health and hygiene is embedded into risk assessment at the Project level. Occupational hygienists conduct a range of services which for example, include providing training to line managers on items such as occupational health in risk assessment, which provide context and an understanding of typical levels of exposure that certain tasks produce.

At the commencement of the project, a health risk assessment is performed of the overarching processes which are broken down by main worker groups. The level of risk assessed drives the decision for health surveillance and exposure monitoring in a similar way that these processes are applied in Australia. The occupational health nurse receives a copy of the health risk assessment from the occupational hygienist such that planning can be undertaken for health surveillance for those workers to be onboarded.

Occupational hygienists are involved in the day to day aspects of the project to support onsite health and safety teams and are utilised full-time on average across each major operating site. To collaborate, plan, and share lessons learned, there is an occupational health working group that meets once per month and consists of the clinical team and occupational hygiene team from each of the projects.

Not unlike Australia, there is an increasing focus on mental health in the Construction industry in the UK. A key challenge in Australia is how to integrate psychosocial hazards into the health risk assessment process, and this challenge exists in the UK also. At Tideway, psychosocial hazards are kept separate from the health risk assessment process, and there is a focus on key factors leading to occupational health working groups meet monthly to disseminate good practice.

Involving occupational hygienists in the design process has led to higher-order controls being applied to reduce risks to health which reduces the reliance on PPE.

Occupational hygienists are embedded in project teams and work with Contractors to produce useful information to enable risks to be managed in a straightforward approach.
poor mental health, being primarily fatigue, in addition to reducing the stigma and raising awareness.

The Health in Construction Leadership Group is in the process of developing an awareness and training campaign on mental health in construction. Known as “MATES in Mind,” it adopts a similar staged training model to the MATES in Construction framework in Australia. At the time of the visit, the MATES in Mind program was in the final stages of development and was planned to be rolled out across its major project sites later in the year.

To manage fatigue, the project routinely follows the published guidance from the Health and Safety Executive, in addition to researching best-practice methods in fatigue management. Following on from previous research conducted on the Crossrail project, Tideway is investing in a series of Readibands™ which are wearable fit-bit type devices that capture sleep data which sync through a phone App [51]. The plan is to procure a select amount for use by high-risk (safety-critical) work groups over a period of time, and through researchers at Loughborough University, understand the benefit of their use in monitoring and reducing fatigue.

The use of technology to manage health and safety risks is strong and includes a Tideway in-house “App” which is used to document inspections and observations and can also be used for workers to make an appointment with the health nurse for an onsite health check for example.

Tideway utilise the Health Impact Frequency Rate (HIFR) which is essentially a uniform approach to record health impacts in the same way as near misses where the potential consequence could be an accident. The HIFR enables health issues to be given equal prominence to safety. Originally devised as a voluntary scheme during the London Olympics [52], and then on Crossrail, Tideway are the first project to use the HIFR as a measure across all of its operating sites across all of its Contractors.

Each week, the occupational hygienists dedicate a two-hour period to the HIFR, where they walk through each operating site and observe if control measures are in place. For example, if they observe 5 workers without hearing protection in a noisy area, then that is recorded as 5 impacts. If they observe 2 workers without respiratory protection in a signposted area, then that is recorded as 2 impacts. A rolling tally is recorded which is reported each month across each operating site to the Client.

The HIFR has helped to shine a light on the prevalence of non-compliance, which in turn has focussed attention to compliance initiatives and resulted in improved compliance across the project. While the HIFR is a Client-driven initiative, it has the support of the Contractors along the project. For transparency and reporting purposes, the top items reported from the HIFR are communicated up to the leadership team on a monthly basis.
4.2.6.1 Resourcing the Program

The occupational health and hygiene program at Tideway is well resourced and has evolved since Crossrail. An example of this evolution includes the use of "Pooled Resources" across the major Contractors and works areas.

Tideway has changed the model for the provision of occupational health and hygiene services for Contractors. Historically on other major projects such as the London Olympics, such a service was procured by the Client, and then on Crossrail, the service was procured directly by each of the major Contractors. As a result, on Crossrail, there were 5 to 6 different occupational health and hygiene organisations that were contracted directly to each Contractor, which presented challenges when the Client looked for standardised outcomes due to the differing levels of quality provision. This disjointed approach resulted in a challenge to understand similarities and differences across each project at a program level, and also for obtaining consistent and timely information.

Tideway requires the Contractor’s occupational health provider to be accredited to a certain standard, known as SEQOHS accreditation. This is a set of standards and a voluntary accreditation scheme for occupational health services, both clinical and from a management perspective. SEQOHS accreditation is awarded to occupational health service providers that have demonstrated competence in the delivery against the measures in the SEQOHS standards. The scheme is managed by the Royal College of Physicians of London on behalf of the Faculty of Occupational Medicine [53].

Tideway specified that Contractors had to engage on-site occupational health and occupational hygiene resources in their Tender, but rather than the Contractor choosing who that would be, Tideway directly procured those services as a “Pooled Service” as a single provider for both clinical and hygiene services from which the Contractors were required to use.

There were many reasons behind this approach – firstly, it made it easier for Contractors to access experienced occupational hygienists and nurses who were familiar with the project, who were inducted, who already knew the system to be applied, and would give their Contractors priority. Secondly, Tideway could better ensure that reports that flowed back up to them as a Client were of a consistent quality, which had been an issue on Crossrail, where the quality of the provision of services was not uniform. Thirdly, issues around sharing information and the transparency of information between the Contractor and the Client and between project to projects is also overcome by Contractual requirements in the Works Information on Tideway. Another evident advantage is using the economy of scale of the entire project for a better commercial outcome for these services.

Another improvement from previous projects is that senior occupational hygienists from the Pooled Service, coordinate all other
hygienists across the program. This resource works directly for Tideway as the Client also. This centralised approach enables a consistent approach and a single point of contact for Tideway.

While the drawback of mandating a pooled service may be that Contractors would be less likely to engage an in-house occupational hygienist and develop that relationship as part of a project-team approach, the reality appears to be that given the nature of Joint Venture contracting, where many members of the project team are new, the occupational hygienist, although a consultant, is embedded into the project team, and is treated like any other project resource. This was evident on a visit to an operating site, where the occupational hygienist’s activities were embedded into the Contractors works packages, schedule, and team.

This approach appears to foster increased linkages between project phases as knowledge between design and execution, for example, is transferred using the same Pooled Resource across each of the processes.

4.2.7 Targeted Health Risk Management

At the time of the visit, shaft sinking and tunnel construction had not yet commenced and therefore targeted measures for silica control in these environments could not be observed. However, as part of the risk assessment and health in design approach, occupational hygienists collaborated with Contractors to develop a series of “Best Practice” standards, one of which was for silica. That standard contains typical exposure concentrations of silica dust for common tasks; standard control measures; visual standards (explaining “what good looks like”); and an audit tool.

There is a requirement that risk assessments take into account the likely exposure level in relation to the Exposure Standard with control measures dependant if exposure is below the Exposure Standard, below 10% of the Standard, or above the Exposure Standard.

4.2.8 Sustainability

Recognising that each major Contractor may look at health a different way and use different overarching corporate systems, Tideway uses the Occupational Health Maturity Matrix (OHMM) to understand how each Contractors’ system complies with the Works Information and how it drives Industry best practice. In what is essentially a scale by which Contractors are measured and how they mature over time, the OHMM is used as a benchmarking tool from which Contractors are scored. Examples include how they complete Health Risk Assessments (HRA), what do they do with the outputs of those HRA’s, Embedding occupational health with occupational hygiene and wellbeing, provides a holistic approach to health management across this major project.

The project strives to be “transformational” and uses tools to benchmark Contractors performance well over the minimum Contractual Requirements.

These tools push for sustainability through the supply chain and across to external stakeholders.
how they feed into campaigns, and how they share lessons learned.

The OHHM provides measures around occupational hygiene, clinical services, and wellbeing and is structured around the concept of “what good looks like” across each of the items on the scale. Coupled with a 6-monthly audit process performed by the Client occupational hygienists on each Contractor, it provides both a standardised approach and also a guide for improved health performance.

The OHHM has evolved since Crossrail with an additional measure known as “Transformational.” Measures in this element are centred around the project’s ability to influence external stakeholders on a sustainable level over time.
4.3 High Speed Two (HS2)

At the time of the visit, HS2 was in the early works phase, with major construction works yet to commence. Notwithstanding this, a significant amount of work had been put into pre-planning and the strategy behind the creation of an industry-leading occupational health and hygiene program on this major project.

4.3.1 Leadership

HS2 has set a strategic goal to deliver the railway to the highest health and safety standards, as well as proactively managing risk and setting new standards in occupational health. HS2 has worked to define what that means for both the Client and Contractors, through the identification of clear and measurable commitments and standards throughout its supply chain.

4.3.2 Engagement and Collaboration

One of the Client’s main drivers for the project was a focus on occupational health and the prevention of illness and disease for all workers around the “Top 5” key areas which were nominated as:

1. Occupational Cancer;
2. Respiratory Disease;
3. Hand Arm Vibration Syndrome;
4. Noise Induced Hearing Loss; and
5. Skin Sensitisation (e.g. Contact Dermatitis).

HS2 works in a collaborative manner with the Regulators (the Health and Safety Executive and the Rail Safety Regulator) to demonstrate examples of positive practices that can be used to improve the way health is managed across the UK. The occupational health program is developed to create a long-lasting legacy for the industry as a whole, rather than being developed for the project in isolation.

The Works Instruction requires Contractors to be transparent and share knowledge across the program. This is achieved by Contractors identifying and reporting best practice approaches which are then shared by the Client to other contractors, which are required to implement these approaches where relevant. Contractors must be transparent and provide information such as health data and exposure records to the Client also. There is a section on collaboration in the Works Information whereby Contractors are only paid if they are seen to be collaborating with other parties on the project.

Key Contacts

Deborah Edmonds, Head of Occupational Health Strategy, Corporate Health and Safety

Maria Winter, Health and Safety Manager for Railway Systems.

Project Snapshot:

HS2 is a new high-speed railway that will link London, Birmingham, the East Midlands, Leeds and Manchester. It will be the second high-speed rail line in Britain, following High Speed 1 (HS1) which connects London to the Channel Tunnel.
4.3.3 Training and Awareness

HS2 has committed to a program wide induction programme and a Safety Leadership Induction for all frontline leaders within the supply chain.

4.3.4 Contractual Requirements

HS2 as the Client has specified occupational health and hygiene requirements to Contractors in a Works Information that includes requirements to embed health in design processes; installs competency requirements for both leaders and staff; and outcomes to be achieved with regards to the level of control of exposures to the top 5 causes to name a few.

One of those requirements is centred around a "Passport Scheme" whereby each worker has a “Passport” that captures digital information on items such as their level of competency, training, skill set, functional medical capacity, and working hours. This information is used to enable the worker access or prohibition to certain areas onsite. For example, certain competencies and medical requirements would be required to enter a tunnel area. If the worker had not gained those items, then no access would be granted until such time that they had been completed. The Passport also aims to record the workers’ level of exposure to the top 5 causes.

4.3.5 Health in Design

The Works Information includes a focus on Health in Design whereby Contractors are required to provide evidence on how they have engaged with specialists such as occupational hygienists, ergonomists, and medical practitioners, during the design process. The aim is to bring these specialists in at the design stage to afford all parties an understanding of the risks that exist when using certain materials and methodologies as part of the construction project. If health risks cannot be eliminated at the design stage, then Contractors are required to demonstrate how health risks will be mitigated, what controls will be applied, and how they will be applied for the project life-cycle from construction through to the operation and maintenance phase. This essentially highlights the cost of ill-health prevention measures and enables the inclusion of health in the cost-benefit analysis process when selecting appropriate control measures.

Contractors are required to perform Health Risk Assessments from which outputs are used to inform a Health Hazard Evaluation Mitigation Plan (HHEMP) that describes control measures necessary to reduce exposure.
4.3.6 Health Risk Management

In contrast to Tideway, HS2 takes the approach that the Contractors should engage their own occupational health service, including hygienists. The rationale behind this is that HS2 seeks to create “business tangibles” meaning that when the project is finished, and the JV is disbanded, the aim is for Contractors to take health back into their respective business as an integrated function.

With an understanding that occupational health aspects were generally not well understood within the construction sector, HS2 seeks to engage with stakeholders early on to raise the profile of occupational health with an overall aim that everyone would be as healthy if not healthier than when they started on the project. Key elements of the program include:

- Knowledge sharing – of both information and exposure data
- Developing a case study to inform the setting of Project Exposure Standards, which reduce over time. For example, over the 10-year project, the first few years are spent driving compliance with the legal limit, the next few years have a focus on reducing by a figure of 10% to 20%, etc., where appropriate in terms of health
- Developing occupational health standards and acceptability criteria for the health of the workforce performing different tasks
- Key Performance Indicators
- Health Risk Assessment Process
- Deleterious (prohibited) hazardous substances processes

To best inform their Works Information, HS2 funded research pieces around these key elements of their occupational health program. This included an engagement with IOM to inform the setting of Project Exposure Standards, which reduce incrementally over time. Contractors are required to demonstrate how they plan to incrementally reduce exposure through the various project stages (e.g. construction and O&M) in line with these Standards that have now been set by HS2.

Future research is on the agenda at HS2 with the project currently in the process of identifying research topics that will add value to the project. One of those will include the use of instrumentation and monitoring where gaming technology and the use of “virtual rooms” are used to predict health and safety risks in the future state. For example, the design is inputted into a VR system based on Level 2 BIM data, which includes predicted air flows and staging programme, along with weather predictions, which enables teams to aligned to the health and safety risks that present themselves at different points in time. This may include for example, a prediction of what the air quality or noise levels may be at that time, which can then in turn inform HS2 aims to reduce exposures over time and as such mandates lower standards as the project progresses.

Contractor's wellbeing initiatives must be targeted towards personal risk factors identified in the working population.

IOM have performed research on Crossrail, Europe's largest infrastructure project and have been supporting High Speed Rail 2.

Health Performance Indicators are used to rate Contractors.
decisions on the need for additional control measures in a specific area at a certain period.

One item of the program that seeks to push the boundaries on HS2 is that they seek to move away from the concept of a “safety critical medical” with strict performance criteria, but rather move towards a health needs assessment and functional capacity assessment. The difference is that they aim to create an environment where everyone can contribute to work, rather than an environment that prohibits or restricts workers from performing work activities based on a set criteria. Further to this, the idea behind performing a health needs assessment, seeks to get the Contractors to understand their work demographic and therefore what strategies that can be applied to address identified risks such as wellbeing programs designed to target personal risk factors including the obesity epidemic for example.

4.3.7 Sustainability

Following on from Occupational Health Maturity Matrix used on Crossrail, Health and Safety Performance Indicators are used to outline requirements for health risk management, health risk control, exposure assessment, wellbeing, and leadership to name a few. These Performance indicators rate Contractors across 6 component parts ranging from Developing at the basic level, through to Sustainable at the highest level. Contractors are not given the go-ahead to commence work until they have demonstrated a basic level of compliance at the Developing level and are required to provide evidence against each of the measures listed which are then vetted by the Client to determine the final score and rank.
4.4  Collaborating Stakeholders

4.4.1 Health and Safety Executive (HSE)

Australian health and safety legislation is based on the British model and is therefore similar in nature. The UK Control of Substances Hazardous to Health Regulations requires employers to assess and document health risks, communicate significant health risks, control exposure in accordance with the hierarchy of control to below the Workplace Exposure Limit (which is the same level as Australia’s Exposure Standards), maintain control measures, provide training and instruction, monitor silica concentrations in air, and provide health surveillance [54].

Key areas of UK health and safety legislation that differs from Australia, however, include the requirement to notify the Regulator of a diagnosis of any pneumoconiosis including silicosis in addition to lung cancer [55]. Another difference is the amount of focus and information published by the Health and Safety Executive (HSE) on the assessment and control of health hazards, such as silica. Such publications provide further guidance, clarity, and context on what is expected of employers and employees when controlling exposure.

Such guidance documentation ranges from general silica awareness and an outline of minimum legal requirements including the need to be clean shaven and facial fit tested for respiratory protection [56], through to typical engineering practices to control exposure during construction, including minimum standards, training, inspections, and the need to wear a full-face respirator unless exposure data can demonstrate that a lower class can be used [57]. There is guidance on designing heavy vehicle plant cabins to minimise silica exposure including the use of forced ventilation, filtration systems, maintenance, examination and testing [58], dust control systems for hand held tools [59], exposure measurement [60], health surveillance [61] and general guidance on construction dusts [62].

In addition, the HSE publish guidance for possible areas of enforcement by the Regulator which include whether the employer has recorded the extent by which prevention and substitution has been considered, that exposure has been controlled to levels that are as low as reasonably practicable for carcinogens (i.e. adequate control must be achieved, using good control practice, instead of just complying with a ‘legal minimum’ exposure limit), if respiratory fit testing has been conducted, and if PPE is “lying around in a state of obvious disuse or a duty work environment where local exhaust ventilation is provided” for example [63].

The HSE manage the Occupational Disease Web community site to encourage and promote the exchange of ideas and initiatives for tackling occupational disease. With a primary focus on reducing the incidence of cancer and respiratory disease, it provides free information on activities and initiatives to address these issues [64].
4.4.2 British Tunnelling Society (BTS)

The BTS publish a number of best practice guides including controlling exposure to diesel exhaust gases, specifically nitrogen monoxide, working in compressed air, and hand arm vibration syndrome. The BTS is also a key contributor to British Standard 6164 being the *Code of practice for health and safety in tunnelling in the construction industry* which includes requirements for ventilation, dust suppression, and the use of respiratory protection.

Key areas of influence of the BTS include the Tunnel Design and Construction Course; a week-long course held every year at the University of Warwick in addition to a two-day Health and Safety course, both developed and delivered by industry professionals.

The BTS plan to survey the industry to gain an understanding of the impact of these guides and also to understand where additional guidance may be needed. In parallel to this, the BTS has started to produce documentation of a more general nature targeted to a wider audience, beyond engineers, to promote awareness of tunnelling and underground space. One example of this is a resource pack which has been developed for teaching tunnelling as a science based subject in schools to encourage students to take up the profession and enter the industry.

At the time of the visit, the Institute of Civil Engineers (ICE) in London were holding a Tunnel Engineering Exhibition. Open to the public, the exhibition aimed to inspire and celebrate how engineers create, solve, design, and innovate to shape a better world [65].
4.4.3 Institute of Occupational Medicine (IOM)

IOM has a strong international reputation for high quality published research, and one of those areas includes a recent study into occupational exposures during Crossrail as previously discussed.

IOM perform a range of research and consultancy services to other industries in addition to tunnelling and have a department dedicated to ergonomics, which includes items such as the ergonomics of PPE, musculoskeletal disorders, thermal heat stress, and psychosocial hazards, all of which are relevant to the tunnelling industry.

Dr. John Cherrie of IOM also volunteers his time for the Institution of Occupational Safety and Health (IOSH)’s No Time to Lose campaign. The campaign aims to get carcinogenic exposure issues more widely understood and help businesses take action. It works to raise awareness of a significant health issue facing workers in the UK and internationally; suggests some solutions on a UK scale to tackle the problem – a national model that can be transposed internationally; and offers free practical, original materials to businesses to help them deliver effective prevention programmes.

Apart from the single study published by Work Health and Safety Queensland [22], research of an independent nature in the tunnelling industry is sparse in Australia. With many major tunnels under construction, there is a unique opportunity to commission a study that seeks to understand how well exposures are managed in Australian tunnelling. This would not only provide a valuable body of knowledge but a point for comparison within tunnelling contractors and the industry in general.

Key Contacts

Dr John Cherrie, Principal Scientist IOM and Professor of Human Health, Heriot-Watt University
Sheila Groat, Head of Health and Safety Services IOM
Dr Karen Galea, Section Head – Exposure Science IOM
Dr Joanne Crawford, Head of Ergonomics and Human Factors

Snapshot:

IOM was originally established over 40-years ago as a not for profit organisation working within the national coal company on research into the prevention of Coal Workers Pneumocloniosis (commonly known as “black lung”). Around 20 years ago, IOM moved out of the public sector and became an independent institution which has since diversified to focus on many more aspects of occupational, environmental, and public health. IOM performs a balanced mix of research and consulting and maintains a laboratory onsite. Activities of focus are widely varied and include dusts, chemicals, nanoparticles, air pollution, noise, physiological stressors, ergonomics and human factors.
4.4.4 BOHS Breathe Freely Campaign

Within the UK, the majority of deaths from occupational illness or disease are due to lung disease or cancer. The Breathe Freely campaign was launched by the British Occupational Hygiene Society (BOHS) on Workers Memorial Day in 2015 with a sole focus on the construction sector, where this focus has remained for the past 2 years.

As part of the campaign, the BOHS collaborated with partners who included the Regulator (The Health and Safety Executive UK), a large construction client (Land Security), a large contractor (Mace), and a health service provider (Constructing Better Health). These partners helped drive the campaign and its reach across the industry.

The campaign is led by a steering group consisting of members of the BOHS and the Regulator. As a first step, members of the steering group went out and visited construction sites with the purpose of engagement to gain a better understanding of the way construction projects operated across the industry. Engaging with industry early on was crucial as it enabled the campaign to better understand what the main needs were such that the campaign could work to help deliver guidance material that was solution focussed.

The campaign itself has attracted unprecedented levels of support from employers, trade unions and other influential people and organisations and has signed up more than 160 supporters from across the construction industry. More than 60 Breathe Freely talks have been delivered at roadshows, events and meetings across the UK, all designed to offer practical advice on managing health and equipping attendees to make improvements on their sites [66].

The campaign is based on the premise that workers’ health can be protected and that deaths caused by lung cancer and other respiratory diseases are preventable through good occupational hygiene practice.

In the past two years, the campaign has been successful at providing the following:

1. A web based information hub known as the Breathe Freely website [www.breathefreely.org.uk](http://www.breathefreely.org.uk) which contains a range of useful, practical and free resources, to protect workers’ health including best practice case studies, fact sheets, and an occupational hygiene Good Business Case [66].

2. The Health in Industry Management Standard, known as the “HI Standard” which outlines best practice criteria for worker health protection.

3. A HI Standard self-assessment tool which helps companies better manage workplace health risks through identifying strengths and weaknesses, set priorities and develop action plans.

Key Contacts

Mike Slater, Director, Diamond Environmental 
Jennie Armstrong, Head of Occupational Health and Wellbeing, Tideway

Snapshot:

Breathe Freely is an initiative by the British Occupational Hygiene Society (BOHS) which aims to reduce occupational lung disease in the UK, which causes significant debilitating ill-health and an estimated 13,000 deaths per year. Breathe Freely is about raising awareness both of the problem and providing information on solutions to protect workers’ health and to prevent diseases and deaths.
4. The Construction Managers Toolkit which is a series of toolbox talks, checklists and a guide to help Managers in the Construction industry manage on-site risks and health hazards.

Essentially, using the tools provided, the aim is to enable construction managers to be guided to focus on the prevention of work-related ill health, for example putting controls in place and ensuring compliance with exposure limits rather than simply relying on respiratory protective equipment (RPE). To date, over 130 contractors have signed up to adopt the HI Standard tool for self-assessment in managing workplace health risks [66]. The information, tools, and resources published as part of this campaign were targeted towards the top tier of management, with the knowledge that they had the greatest amount of control over worker health protection. Although resources were developed for use at the worker level such as tool box talks, the campaign primarily focuses on top levels of management with the understanding that there was little point in raising awareness amongst the project workforce unless management was prepared to do something about it.

The campaign is largely run by volunteers and has only one part-time resource. From the amount of work produced by this campaign, it is evident that the BOHS has an enthusiastic membership base willing to volunteer for a cause such as this.

The campaign has also helped highlight the missing link that occupational hygiene sometimes has within the worker health system. For example, according to Mike Slater, the idea of “Wellbeing” was relatively well understood, as was the idea of “Occupational Health” (being clinical medical services), however, the “Occupational Hygiene” element, which works to control exposures occurring in the first place, was less understood. Without that missing link, workers would be coming to work healthy and leaving in ill health.

On June 7th, I attended a Breathe Freely in Construction Workshop which was hosted by Thames Tideway. This event was well attended by representatives from the Contracting industry (e.g. Mace and Bechtel), Research (Loughborough University and the Health and Safety Laboratory), occupational hygienists (e.g. Park Health and Safety), and many others.

The Breathe Freely campaign is based on the premise that workers' health can be protected and that deaths caused by respiratory diseases are preventable through good occupational hygiene practice.

This is a campaign lead by specialists, but through engagement, understanding and support of the industry, as part of a collaborative approach to tackle this issue.

The development of an industry health standard enables contractors to benchmark themselves as to where they are, or need to be, in relation to best-practice.
Workshops or “roadshows” such as this are used to both disseminate the latest information about the campaign, but also engage with attendees to understand what is happening in their work area and what their needs are, such that the campaign can work to support the industry as a whole in future endeavours.

At this event, the BOHS outlined that they were in the process of working towards a Hi Standard Audit Scheme, whereby external occupational hygienists are engaged to audit contractors against the criteria in the Hi Standard. The general feedback from industry had been that this is something that was desired and brought with it benefits including:

- A competitive edge, whereby contractors could demonstrate commitment to preventing ill health
- A means to benchmark performance over time
- Helping to deliver the Regulator’s strategy on Tackling Ill Health.
- An overall reduction in occupational illness

To date, the audit tool has been piloted across three organisations and is hoped to be released in early 2018.

Another new initiative of the campaign is the development of a Certificate in Controlling Health Risks in Construction (CCHR|C). It was recognised that training on health risks was needed at the Supervisor and Manager level. A qualification accredited by the BOHS, the CCHR|C is a one-day course that focuses on typical construction hazards such as dusts, noise, and vibration and includes case studies and practical examples centred around the principles of risk control. To date, two pilot courses have been offered, and the BOHS aims to start to run the course later this year.
4.4.5 Loughbrough University

Researchers from the University are part way through a project to track and inform health and safety leadership, policies, and practices on the Thames Tideway Project. The research was commissioned through both the Institution of Occupational Safety and Health (IOSH) and the Tideway project, with the study slated to be the first of its kind, in the study method used for the project. Known as “Longitudinal Tracer Methodology,” the project studies the impact and process of health and safety initiatives in real time.

Researchers are embedded into the project through the three major tunnelling contractor teams on Tideway where they monitor the status of select items as they are implemented so they are able to explore what does and doesn’t work and the common factors that influence this. Certain items are “tagged” for research, such as the training program (EPIC), the management of dusts under “Occupational Hygiene Management,” and design for health initiatives.

The main difference between Longitudinal Tracer Methodology and a traditional research approach, is that the Longitudinal methodology is not a snapshot approach, but rather tracks things over time. This means that there is a unique opportunity to monitor things within a “living lab” and, in some cases, to enable real-time feedback to be provided that will enable the project to evaluate the effectiveness of items and make changes or improvements during the course of the project. Tracer methodology enables the collection of data on what is actually happening on the project at that time and has the advantage of reduced collection bias in comparison to studies where workers may be asked to recall a time in the past or what may have occurred at various stages of the project. It is a flexible approach that enables the researcher to hone down on things that become important and apparent over time. The overall outcomes are intended to be used to inform best practice and to be shared across the wider construction industry to positively influence future health and safety practices.

Further to the approach of doing things a bit differently, Tideway are in the process of collaborating with Loughborough University to use their LUSKInS as part of a simulation-based training program. Recently designed and developed at the University, LUSKInS stands for Loughborough University Sensory and Kinaesthetic Interactive Simulations. They are wearable and hand-on simulations that are used as part of a training program for young people entering the workforce [67].

LUSKInS include wearable gloves that resemble the resultant effects of chemical skin contact through dermatitis and the result of hand arm vibration syndrome (HAVS), commonly known as “vibration white finger.”

Key Contacts

Professor Alistair Gibb Professor of Construction Engineering Management
Professor Andrew Dainty, Director, Loughborough University Graduate School
Dr Wendy Jones, Research Associate
Karin Boers, PhD Candidate

Snapshot:
Loughborough University is a public research university located in Loughborough, Leicestershire, UK.
Figure 10 – Simulation of Hand Arm Vibration Syndrome

Figure 11 - Simulation of dermatitis
4.4.6 Health in Construction Leadership Group

In January 2016, a Health in Construction CEO Breakfast Summit was held at Battersea Power Station in London. Attended by over 150 key business leaders and industry influencers in the construction sector, the CEOs came together and made a commitment to reduce ill health and disease caused by exposure to health hazards during construction work, as well as to address the growing incidence of mental ill health in the workforce.

Known as the Health in Construction Leadership Group (HCLG), this is a collaborative group, comprising contractors, clients, the Regulator, professional bodies, trade associations and trade unions.

Steve Hails (Tideway, then Crossrail) was one of the initial members who founded the HCLG along with others including Lawrence Waterman (Park Health and Safety), where a relatively small group of people came together with the aim of removing the disjointed approach to health across the industry. The aim of the HCLG is to unite the construction industry in order to eradicate the ill health and disease caused by exposures to health hazards on building sites and to achieve a cultural shift within the sector so that health is managed like safety [68]. Since its inception, the group has run another health summit in 2017 and has started to focus on the top two key health risks facing the construction industry, being respiratory health and mental health.

4.4.7 Transforming Tunnelling Safety Steering Group

With key objectives to "transform the health and safety performance of the UK Tunnelling Industry," this group includes Client and Contractor representatives from large tunnel construction projects being undertaken in the UK including Tideway, High Speed 2, and the Shieldhall Strategic Tunnel. The British Tunnelling Society (BTS) plays a key role in this group where lessons learned are discussed, and a holistic strategy applied around changing behaviours in a positive way towards key health and safety risks facing tunnellers in the UK [69].
5.1 World Tunnel Congress, Bergen

Tunnelling and underground space have been an important part of the development of Norway, with the construction sector forming one of the Country's largest industries. On average, Norway tunnels around 4 million cubic metres of solid rock each year, rising up to a peak during 2016 of 7 million cubic metres [70], which is a significant amount of tunnelling.

The WTC was an invaluable stop along the Fellowship, as it resulted in many opportunities to understand the technical and commercial constraints that are present when clients and designers first commission a project, in addition to understanding the latest developments internationally regarding health and safety and technological advances. It was also a great opportunity to understand the process behind the development of the various good practice guidelines, including those focused on health and safety in tunnel construction [72]. Some brief highlights are provided herein.

The Sir Muir Wood lecture was delivered by Hakan Stille entitled, “Geological uncertainties in tunnelling – Risk Assessment and Quality Assurance.” In his presentation Hakan made a number of key points that although were made in a geotechnical context, are also directly applicable to health, which included:

“Tunnelling is riskier than other civil engineering works,” with the concept of risk around the effect of uncertainties on the overall objectives. The level of uncertainty surrounding health risk is also high when looking across the range of tunnels and associated control measures implemented to reduce exposure in tunnels being delivered in Australia.

“Rules are necessary but are not sufficient. An understanding of the effect of uncertainties is necessary”. Using any control measure to reduce exposure contains uncertainty. It is only by understanding that uncertainty and the associated limitations of that approach, that a true understanding of the risk can be achieved.

“Risk management is a part of project management. The Project Manager must understand that risks are prevailing, and everyone must understand that these risks need to be communicated, monitored, and reviewed”. Health is no exception. The Project Manager must be aware of the health risks facing their work crew and must be able to clearly communicate the risk, monitor, and review it also.

“Two parties own the risk.” There can be much debate as to who is at fault over design decisions that impact health. One key example...
is a client providing a concept design that can only be delivered within the stated time constraints through a mined tunnel (road header) design in comparison to TBM tunnelling which would pose lower risks to health. Clients should be aware of this impact, and include the costs of ill health into their design analysis, understanding the uncertainty that certain control measures have with regards to disease prevention.

“There is no substitute for experience, without it, any risk management process will fail.” Professionals with experience in complex work environments such as tunnelling working across disciplines in a collaborative environment are key to the success of any occupational health and hygiene program.

5.1.1 Exhibition

Part of the WTC involved a large trade exhibition which was well attended by suppliers, manufacturers, Clients, and Contractors. To better understand how health risks are understood through the supply chain, the opportunity was taken to speak with major manufacturers and suppliers of sprayed concrete, additives, and associated chemicals.

Sprayed concrete, or “shotcrete” is used for ground support where pre-cast concrete support is not suitable. By its very nature, sprayed concrete contains a proportion of silica from the cement itself. However, shotcrete can also contain additives to assist with strength and durability in addition to the accelerant used to set the shotcrete upon application quickly. These additives and accelerants also contain hazardous substances in varying degrees. One of the common additives used is known as “silica fume” or “microsilica.” Silica fume is made from quartz and used because it positively contributes to the properties of concrete by increasing pumpability, providing improved adhesion on the surface, and provides a higher final strength and lower permeability [73].

Although silica and dust exposures to shotcrete workers during application are typically in excess of Exposure Standards leading to chronic disease, this knowledge was not readily understood by many of the manufacturers of these products nor from the manufacturers of the machines used to apply them, dependant on the country of origin.

From speaking with multiple suppliers of these products and sprayed concrete machine manufacturers, a common theme emerged. Product manufacturers supply Safety Data Sheets and categorise their products under the Globally Harmonised System (GHS) system and understand the contents of their product, but they lamented that they could not be held responsible for the method used for how it was applied. The machine manufacturers stated that they obtain the chemical information from the suppliers and follow their instructions. The missing link appears to be that suppliers are not required to provide information on typical levels of dust or hazardous substance exposure during the application of the product with respect to the machinery used.

There were few examples of manufacturers providing information from exposure monitoring data. One manufacturer provided information showing “fine dust” to be below the “maximum allowed value” for wet-mix shotcrete. However,
these data do not appear to correlate with typical exposures found in industry. There were also many photographs of workers applying these products in visually dusty environments without using respiratory protection or using it incorrectly.

Overall, awareness of the magnitude of the health risks posed from sprayed concrete lining was varied and in some cases quite low. However, it is doubtful that Australia is unique in this aspect. The collection and communication of exposure data during real-life application of these products would greatly assist in communicating the magnitude of exposures potentially leading to greater awareness and understanding of the problem faced by this industry leading to the production of greater control measures.
5.2 National Institute of Occupational Health

Owned by the Ministry of Labour and Social Affairs, the National Institute of Occupational Health, known as STAMI, is an independent institute that operates separately, although under the same structure, as the Government Labour inspectorate (Regulator). With the majority of its funding provided by the Government (>85%), which is supplemented by research grants, STAMI provides research and advice on occupational health matters when requested.

Divided into four main departments including the i) Department of Work Psychology and Physiology, ii) Department of Occupational Medicine and Epidemiology, iii) Department of Chemical and Biological Work Environment; and iv) National Surveillance System for Work Environment and Occupational Health, it provides a range of research and expert advice to many stakeholders.

5.2.1 Engagement and Collaboration

In Norway, every Contractor is required to have a connection with an occupational health service, which consists of a clinical team and occupational hygiene expertise at the Contractors expense. The occupational health service is tasked with performing routine health monitoring and exposure assessment in accordance with the Regulations.

Over-and above this legal requirement, STAMI regularly collaborate with Contractors and trade unions to provide advice and research on their projects. Norway, by comparison to Australia, is a smaller country, and as such, STAMI noted that the extent of expertise in occupational health and hygiene across the Country is not that large. As such, assistance from STAMI has been requested many times by Contractors, and as a result, they have performed an extensive amount of research on major tunnelling projects, which have been performed at no charge to the Contractor.

It is evident that there is a high degree of trust between STAMI and the Norwegian workforce and tunnelling Contractors based on the sheer number of willing study participants and number of research studies performed in this sector. The Doctors at STAMI noted this was part of Norwegian culture and that workers readily had a large amount of trust for medical professionals in the knowledge that they were there to look after them. Companies were also willing participants as they have a keen interest in the research and how they are performing in this area. STAMI noted that they had not had any instances where there were any restrictions around publishing the data collected.

Key Contacts:
Dr Dag Ellingsen
Dr Bente Ulvestad
Dr Nils Petter Skaugset

Snapshot:
Based in Oslo, Norway, the National Institute of Occupational Health (known as “STAMI”), is a government-funded research institute with the aim of facilitating good working environments, preventing illness, and promoting good health [116].

The institute aims to promote knowledge in the relationship between work, illness and health; to evaluate risk factors; and to offer preventive measures where needed. STAMI is involved in over 60 research projects including both long-term pure research-projects and sub-projects, and shorter projects with a more practical base.
5.2.2 Research

STAMI have published an extensive amount of research papers on health exposures to tunnel workers. The studies published represent the most comprehensive research into tunnel worker exposure and health at a global level. Examples of such research include:

- A study of 123 tunnel workers demonstrating that exposure to synthetic grouting resins resulted in a higher prevalence of bronchial hyperresponsiveness, asthma, and airflow limitation [6];
- A study involving over 400 construction workers demonstrating that tunnel workers (representing half the study group) had an increased risk of obstructive pulmonary disease [3];
- A study of 55 concrete workers demonstrating that those who worked underground had a higher occurrence of respiratory symptoms and nasal mucosal swelling [4];
- A study of 189 tunnel workers demonstrating that shaft drillers and TBM workers were exposed to silica at around 3 to 4 times the legal Standard [16];
- A study of 96 tunnel workers to determine the increased risk of lung function decline and respiratory symptoms relative to cumulative exposure to respirable dust, silica, oil mist, and nitrogen dioxide exposure [5];
- A study of 90 tunnel workers demonstrating that shaft drillers, injection workers, and shotcretors had the highest exposures to thoracic dust and silica [74];
- Despite efforts in reducing dust and gas exposure, this study reviewed spirometry questionnaires from 90 tunnel workers both at the start of their 12-day consecutive work shift and at the end and demonstrated a negative impact on lung function [75]; and
- A study of a comparison of inflammatory biomarkers in tunnel construction workers exposed to dust, silica and diesel emissions which demonstrated that tunnel workers had lower serum CC-16 concentrations than non-tunnel workers [76].

STAMI are currently performing research on Norway’s largest TBM tunnelling project which involves the collection of medical surveillance data (lung function, nasal epithelial cells, blood, serum) of over 500 workers and also exposure data for various parameters including respirable and thoracic dusts, silica, and diesel exhaust. The project, which involves tunnelling through granite at approximately 20-30% quartz, represents the most recent research into exposure and health effects and is due for publication within the next 2-years.

These ongoing studies form part of the culture of Norwegian
tunnelling, with the results of these studies shared not only across the scientific community but also in publications produced by the Norwegian Tunnelling society, such that learnings and findings are communicated to the relevant target audience [77].

5.2.3 Training and Awareness

STAMI formed part of a working team that developed a system known as Picture Mixed Exposure, or “PIXMEX,” which is an integrated piece of software and equipment that brings together video recording and real-time levels of exposure of various parameters. This is used as an educational tool and also to determine where the main sources of exposure occur over the period of a working shift.

PIXMEX can be integrated with real-time dust, noise, vibration, and gas monitoring systems for example, and graphically display the concentration of these items at the same time that the worker's activities are being recorded. This has been used in many sectors including the tunnelling sector during drilling/bolting and also during the application of shotcrete to pinpoint the key exposure periods and sources.

Training tools such as these enable a greater understanding of the many sources of exposure at work and also enable targeted control measures to be implemented to best control exposure.

5.2.4 Standards

In Norway, tunnelling work is governed by Regulations relating to the performance of work. The principles of occupational health are based on a risk-management approach; however useful guidance documentation is provided on how to apply this framework to hazardous substances that may also be chronic acting health hazards.

Norwegian law requires the employer (Contractor) to map health risks from exposure to toxic and hazardous substances. If the Contractor cannot document that exposure is at a “safe level,” then regular measurements are required to be collected[78]. While measurements of the workplace air are seen as an important part of the identification and assessment process, they are understood to form only part of the factors related to the quality of the working environment [77]. The law refers to the use of occupational hygienists for the collection of samples and makes it clear that illnesses may occur even if standards are met. Norway has the same exposure standard for silica as Australia.

The LIA promotes a four-step risk assessment framework of:

1) Initial assessment;
2) Preliminary investigation;

Guidance documentation explains how to apply a risk based framework to chronic acting health hazards.

A step by step process outlines the risk assessment framework.

Useful guidance is published that explains what needs to be done if an exposure measurement exceeds the limits.
3) Detailed survey; and
4) Periodic measurements.

After each step, a decision is made whether sufficient information exists to determine if exposure is acceptable or if control measures are required to reduce exposure to an acceptable level. If it is, then a report is prepared and documented and reviewed within 2-years. If it is not, then the framework proceeds through to the next step until finally exposure remains below acceptable levels and a report is produced.

The principles of occupational hygiene assessment in Norway are not dissimilar to those in Australia, whereby workers are grouped into Similar Exposed Groups (SEGs), and monitoring occurs from a representative number of workers in that group. The LIA provides a guide for the number of measurements to be performed within groups of various sizes, which is slightly different to the practices typically adopted in Australia. For example, in Norway, the aim is to sample the same worker at least twice in the group, and all workers are assessed where group sizes are 5 workers or less (which is not a strict requirement in Australia).

One slight change from the norm in Australia is the concept of exposure assessment per task in situations where daily tasks are highly variable. For example, workers may perform different tasks during the working day, and only in certain combinations do they prove hazardous. The idea is that exposure is measured during each task, along with the time spent, which is then calculated on all different combinations of work tasks that may occur.

One area that is different in Norway to Australian Regulations is in the use of stationary measurements. In Norway, these can be used instead of personal measurements if workers are not exposed to local sources, but are mainly exposed to a contaminated general working atmosphere. Static samples can be taken locations that are representative of worker exposure (e.g., head height), and chosen as a worse-case scenario, or where exposure is anticipated to be the highest. Static measurements can be only be used once it has been demonstrated that they correlate with personal measurements.

The ILA provides useful guidance on what to do if an exposure measurement exceeds the limits – for example:

1️⃣ Exposure above the limit = introduce immediate control measures and re-test;
2️⃣ Exposure above one-quarter of the limit, but below the limit = control and collect periodic measurements; and
3️⃣ Exposure below one-quarter of the limit = maintain control measures.

The concept of outlining the consequences of exceeding the exposure limit is a welcome one as it provides an expectation to Contractors on what needs to be done

5.2.4.1 Reporting ill-health

If an occupational disease is diagnosed by a medical practitioner, then there is a requirement to inform the Labour inspectorate. Norway is understood to have a well-paid worker’s compensation system, whereby compensation payments are not too dissimilar from their regular take home wage. However, it was communicated that even if workers may be diagnosed with an occupational disease that would grant them access to the worker’s compensation scheme, it was still common for that worker to continue in the tunnelling industry for some time (years) due to their love of the work and the family environment it creates. Notwithstanding this, it is not uncommon for many tunnel workers to
retire onto the worker's compensation scheme at an approximate age of 57 years old.

5.2.4.2 Sampling and Analysis

STAMI own an analytical laboratory which is routinely used by Contractors occupational health services in addition to its own research. As part of this, STAMI rent out occupational hygiene monitoring equipment (known as a "pump bank") which is used by the service, and then STAMI performs the analysis. Therefore, when STAMI report the results of exposure assessment, it is not just the analytical weight or concentration of a substance on a filter that is reported, but it is the exposure measurement itself, which is calculated based on the run time of the pump in addition to additional contextual information required to be provided such as the use (and type of) respiratory equipment utilised.

The results of exposure monitoring are passed through to the labour inspectorate (Government inspectors). As exposure monitoring data is reported in units directly comparable to the Exposure Standards (e.g. in mg/m$^2$ rather than mg/filter as in Australia), it enables the inspectorate a broad overview of what Exposure Standards are being exceeded and the location of these exceedances.
5.3 Arna-Bergen

5.3.1 Leadership

The general understanding in Norway was that there was strong Regulation in place for health and safety, with an active Regulator who seeks to be involved in tunnel construction. Leadership in health, therefore, appeared to be shared across many parties, with the Client working in collaboration with the Contractor, Regulator, Trade Unions, and Researchers (from STAMI).

5.3.2 Engagement and Collaboration

Health risk is assessed by the Client, prior to awarding the Tender, and then again once the Tender is awarded in a collaborative process at regular intervals. The Contractor’s occupational physician is involved in this risk management process after Tender award.

As an example, understanding that the risk to ill health was greater when the TBM would tunnel through high-quartz containing rock such as quartzite, these areas were mapped, and the occupational physician provided recommendations that were implemented by the Contractor. This included the requirement for workers to utilise respiratory protection when tunnelling through quartzite as an additional control measure. Other recommendations included the requirement to be clean shaven and have fit testing prior to use also. The occupational physician works in collaboration with occupational hygienists who undertake exposure measurements to understand the level of exposure to dusts and silica in these high-risk areas.

Recommendations made by the Contractors occupational health service form a crucial part of managing health risks over the life of the project. The health service will make recommendations for control by the Contractor for anticipated high-risk tasks which would include using respiratory protection while changing out the cutter heads at the front of the TBM, and those workers performing shotcreting for example.

5.3.3 Training

Tunnel workers are required to undertake a series of inductions including online and face to face training onsite in health and safety. Language barriers and the risk of not understanding health and safety instructions is a key risk on this project. As a result, there is a requirement that at least one worker on each work team speaks English.

5.3.4 Standards

The Client specifies compliance to the Norwegian health and safety legislation which includes requirements for occupational health for its Contractors.
5.3.5 Health Risk Management

Health risks are managed in conjunction with safety risks through typical measures such as a Health and Safety Plans, health and safety risk assessment, and control plans, etc. The tunnel is being constructed through quartz containing gneiss and quartzite (which is predominantly quartz), and as such the risk of exposure to dusts (and noise) were featured in the projects 8 priority health and safety risks. Similar to the approach in Australia, exposure measurements collected by occupational hygienists are targeted to workers performing tasks or that are located in areas, which represent the highest-risk. Routine occupational exposure measurements are not collected where exposure is typically below 25% of the exposure standard. Exposure measurements collected by the Contractors occupational hygienists are provided to the Client for information.

It is standard practice for workers to receive a medical at least once every 3-years through the Company occupational physician. If a diagnosis of an occupational illness or disease is made, then the physician is required to notify the health department of that diagnosis.

5.3.6 Targeted Health Risk Management

Building a tunnel using a TBM inevitably results in a curved base, due to the circular shape of the TBM. In Australia, following the installation of precast concrete segments that form the ring of concrete lining, the flat surface on the base of the tunnel is subsequently created through the use of concrete paving machines. This is performed after tunnel construction and involves casting concrete in place. This task presents many health and safety risks, including high silica and diesel exhaust exposure.

On this project, a precast concrete invert was designed and installed during the construction of the rings which resulted in a flat surface throughout the tunnel.
6.1 ETH Conference on Combustion Generated Nanoparticles

Held at the Swiss Federal Institute of Technology in Zurich, this conference brought together representatives from research, industry, and regulatory authorities and served for many robust discussions on all aspects of nanoparticles, including those emitted from diesel exhaust and the impact of these particles on health.

The key focus of the Conference was on nanoparticles, being between 1 and 100 nanometres in size (which in relation to common measures such as PM\textsubscript{10} or PM\textsubscript{2.5} would be expressed as below PM\textsubscript{10}). The health effects of exposure to nanoparticles are varied dependant on the toxicity of the core molecule, but the general consensus is that ill-health effects have been measured to within some statistical degree of significance. However, a threshold value (Exposure Standard) has not yet able to be established. The focus, therefore, was on control of these particles, preferably at the source.

6.1.1 Diesel Exhaust Emissions

Tunnel construction relies on the use of diesel-powered equipment in varying degrees. From Moxy’s to transport and remove spoil from the excavation of shafts, cross passages, and road-header operations, through to Front End Loaders needed to load road haul trucks to remove spoil offsite, the use of diesel equipment is a common occurrence underground. The amount of diesel powered equipment used will vary dependant on the type of tunnel construction method, however. Tunnelling via the TBM method typically utilises less diesel equipment as spoil is removed via overhead conveyor system and many items of plant are powered via electricity. In contrast, Road Header tunnelling typically utilises the highest amount of diesel powered equipment due to the use of Moxy’s to remove spoil from the numerous road headers in operation. In any case, all tunnelling projects need to manage the risk of exposure to diesel emissions, particularly as the particulate fraction is a human carcinogen [15].

Exposure to diesel exhaust during the construction of the Gotthard tunnel in Switzerland was identified as a key risk to health. An exposure assessment campaign undertaken in the early 1990s demonstrated that exposure to carcinogenic DPM was well above accepted limits. It was recognised that the solution to reduce these particulate emissions would rely on collaborating with teams of stakeholders including engine manufacturers and industry experts. Ultimately specific requirements surrounding DPM control were included in legislation and Contract documents as part of future
Andreas Mayer, founder of first ETH-Conference in 1997, was a vital part of the development of the original diesel particulate filter (DPF). Andreas was appointed the engineer in charge to address this issue on the Gotthard tunnel. Working in collaboration with SUVA and other stakeholders, “VERT” was born (which stands for “Verminderung der Emissionen von dieselbetriebenen Maschinen im Tunnel-bau” / Reduction of emissions from diesel-powered tunnel construction machines). After testing several particle filtration systems over long-term trails in extreme conditions, it was found that retrofitting DPFs resulted in a reduction of particle emissions by more than 95%. In the year 2000, SUVA subsequently introduced a requirement for all diesel engines in tunnel construction to use DPFs in Switzerland [79].

Since its inception in 1993, VERT has aimed to promote best available technologies to reduce emissions with a focus on emissions based on particulate numbers. VERT tests and certifies diesel particulate filters through a “VERT-certification” process. VERT developed the particle filter system testing protocol in Swiss Standard SN 277206 with approval criteria centred around minimum filtration rates for solid particles, minimum steady-state filtration efficiencies, and maximum particle emission limits. VERT collaborates with authorities worldwide to develop clean air policies and programs for new and in-use combustion engines, and engine emission regulations.

When DPF’s become certified, they end up on a readily accessible VERT Filter List. While not a legislative requirement in Australia, the VERT standard has become a part of several legally binding codes in many countries. The Switzerland regulations require the use of a “Best Available Technology” for the control of emissions from internal combustion engines which includes the use of DPFs.

What is clear, however, is that not all diesel-powered equipment operates the same way, and some emit more diesel particulate and pollutant gases such as nitrogen dioxide (NO₂) than others do. The ETH Conference further highlighted that fact with key presentations on the continued, albeit lower, health risk of diesel emissions despite highly effective emission control. Therefore, not only is a thorough understanding of the limitations of any diesel exhaust control measure needed, ongoing maintenance, monitoring, and assessment are essential.
6.2 SUVA Occupational Medicine

6.2.1 Overview

In Switzerland, there are two main laws governing occupational safety and health (OSH). The Labour Law covers work hours, health protection, workplace building standards and the protection of personal integrity. The Accident Insurance Law covers the prevention of occupational accidents and diseases which are caused almost entirely by work. The cantonal labour inspectorates, SUVA (the main accident insurance authority), and the State Secretariat for Economic Affairs (SECO) enforce the laws. A coordination commission (EKAS) oversees and finances the inspection system for accident prevention.

The Ordinance on the prevention of accidents and occupational diseases, known as “VUV” provides information on the prevention of occupational diseases. There is an EKAS Directive Underground work which describes how the protection objectives of the VUV is achieved in underground work. There is also am EKAS Directive Work equipment which describes how work equipment is safely used when working in tunnels and tunnels [80].

It is mandatory for every Tunnel Contractor to obtain workers compensation insurance from SUVA which insures employees at, or on their way to, work [81]. SUVA currently insures over 2 million people from over 127 companies which include those in the Construction, Forestry, and High-Risk Work industries.

SUVA has three main areas of governance:
1. Workers Compensation Insurance;
2. Prevention of Safety Incidents in industries where SUVA insures companies, and the prevention of Occupational Diseases across all industries and trades; and
3. Rehabilitation services for safety incidents and occupational diseases.

6.2.2 The Nature of Health Risk Management

Switzerland's Federal Law for public procurement requires that a Contract cannot be let until the Contractor guarantees that work health and safety rules are respected. What this essentially means, is that the Client must include specific details on relevant health and safety items in Tender bid documents, and the Tender process must include an evaluation of the Contractors plans to ensure conformance with health and safety regulations [82].

This is slightly different to Australia, where Tender documents may require a commitment from the prospective Tenderer that they will comply with certain requirements, but the specific details of how these requirements will be met (e.g. through providing a Comprehensive Ventilation Plan) does not occur until after Contract Award (which may
be within 30-days of award for example).

The Swiss system requires the Tenderer to evaluate the risk of health hazards and provide evidence of control measures that have been designed and will be implemented to reduce health risks. Once a Contract is awarded, Contractors are required to meet with SUVA to review their Health and Safety Plan and risk assessments. A detailed review of the ventilation plan including measures to ensure air quality and associated measurements, expected temperatures and the use of PPE are discussed and itemised [80].

To standardise the process of health and safety risk assessment, SUVA published the "Suva method for assessing risks in workplaces and workflows" [83] which describes the methodology for conducting a risk assessment. Some key differences between SUVA’s process compared to the equivalent Australian Code of Practice [29] are:

1. SUVA requires that Contractors “determine the system boundaries” before identifying the hazards, meaning that working areas or groups to which these hazards present themselves, need to be defined. The Contractor needs to subdivide its operations or areas of work into processes and determine “critical processes” which include those operations or areas of work that statistically result in days lost due to safety incidents or occupational diseases.

2. SUVA requires that risk assessments are performed by an “interdisciplinary team” which must include a leader and 3 to 5 other members that include the Operations Manager, Engineer, Operator/Manager of the Workplace, a specialist in health and safety, and the planning engineer.

3. SUVA supply statistics on the incidence and consequence of occupational diseases identified from their medical surveillance program to inform the determination of likelihood and consequence selection by Contractors.

SUVA visit the Contractors Project site regularly (at least every 6-8 weeks) as a standard practice to confirm the status of the control measures documented in the Health and Safety Plan and Risk Assessment in addition to undertaking unannounced periodic audits. If SUVA discovers that a measure listed in the Health and Safety Plan is not in place or not effective, then the Project can be shut down until such time as the Control measure is reinstated. However, this does not happen in every case and is dependent on the severity of the breach.

During SUVA’s routine visits, if an observation is made that is minor in nature, then it is recorded as a minor default and a letter is issued to the Project. The Contractor then has two weeks to write back to SUVA explaining the measures taken to rectify the defect. SUVA then follows up in two weeks’ time to confirm the implementation of these measures. If there is a serious breach, then a report is issued as a
written warning, and the same process is followed. If a Contractor receives a fourth written warning, then a meeting is called, and the Contractor is sanctioned, meaning that the Contractor has to pay an additional 20% on top of their normal insurance premium for 12-months. Given that the insurance premium ranges from between 10% to 12% of the salary/wages of the entire Contractors workforce, being sanctioned has a large financial impact. In all cases, life-threatening issues result in the project being shut down immediately including sanctions.

While these insurance premiums may be higher than Australian worker’s compensation premiums, it is important to understand that they essentially include all medical surveillance costs (which is an additional cost to Contractors in Australia) and the work of the health and safety regulator combined.

6.2.2.1 Medical Surveillance

All tunnel workers are required to have preventive medical exams by an occupational physician prior to starting work which is performed by either SUVA directly, or through one of their accredited providers. The contents of the medical exam and the associated pass/fail or “fit for duty” requirements are dictated by SUVA.

Tunnel Contractors must advise SUVA when they plan to commence work and list the names of the workers who will be involved so that SUVA can cross-check their existing medical information. Mandatory pre-start medical requirements for tunnel workers include audiometry (hearing), thermal heat stress tolerance, and various respiratory function tests, all of which are conducted every 2-years. Various tests are performed for these medicals including ergo spirometry and the collection of blood and urine samples. In addition, a chest X-ray is performed every 3-years.

SUVA covers the cost of medical exams which are performed by an occupational physician along with the cost of the lost time from being away from the workplace.

There are instances where the occupational physician may determine that existing medical conditions render the worker to be unsuitable, or conditionally suitable to perform certain work activities. SUVA noted that although their fit-for-duty requirements may appear to be quite strict, that the aim of the medical surveillance program is actually to not prohibit people from working. The medical requirements are set to a standard that prevents the aggravation of an occupational disease [84] and to ensure that the risk of medical restrictions is discovered, clearly communicated, and appropriately managed. If a worker has been declared to be conditionally suitable to perform a role, a number of measures, or restrictions, may be applied to the worker’s role and job activities. In such cases, SUVA attends the Project site to confirm if these conditions are being implemented on a regular basis.

All tunnel workers undertake a mandatory medical examination for lung function, hearing, and heat tolerance.

Strict fit-for-duty requirements are set by SUVA.

Any medical restrictions are checked by SUVA on-site.

Workers diagnosed with pneumoconiosis are prohibited from working underground.
Some of the most common diseases that require a declaration of *unsuitability* include skin and respiratory diseases (e.g. pneumoconiosis). In such cases, workers are provided compensation for a period of up to 4-years in cooperation with unemployment insurance, at a rate similar to the worker’s usual wage. SUVA also pay for costs associated with retraining and rehabilitation with the aim of assisting the worker back into a suitable industry for employment [84].

Under no circumstances are workers permitted to work in a tunnel if they have been diagnosed with a pneumoconiosis. SUVA consider this risk to be too-high to the worker to continue to be located in a high-risk environment such as tunnelling. This is in stark contrast to the Australian system whereby tunnel workers who have pneumoconiosis are still working across many of the tunnels under construction, many possibly without medical restrictions.

Similar to Australia, in Switzerland, certain diseases are automatically linked to occupational exposure which includes the pneumoconiosis’ for example. If a worker is diagnosed with a pneumoconiosis such as silicosis, then SUVA declare that to be related to a past work activity and provide compensation, where there is a reduced capacity to work. If a worker is diagnosed with a pneumoconiosis such as silicosis, it becomes a “case” for SUVA. The worker is then seen by an occupational physician at SUVA directly, and SUVA manages the medical treatment plans for the worker under their rehabilitation section and covers the cost of medical treatment for the worker.

This system is a stark contrast to Australia where each Contractor must organise medical surveillance for their workers and also fit the bill each year for such surveillance. The pass/fail requirements for tunnel construction workers are not standardised in Australia, and there are no notification requirements for the occupational illness or diseases that tunnel workers commonly experience. The approach at SUVA enables greater control over the uniformity of medical surveillance and a standardised approach to defining fitness for duty. It also enables the centralised management of medical surveillance data such that SUVA is able to strategise and plan awareness campaigns and to focus on controls as part of compliance efforts. It also enables a greater understanding as to whether the existing Exposure Standards (known “MAK” values) are sufficiently low enough to prevent illness and disease occurring.

Based on SUVA’s medical data, the top three occupational diseases in Switzerland are (in order):

1. Noise Induced Hearing Loss (NIHL) (accounting for more than one-third of cases of illness of disease);
2. Skin diseases such as dermatitis and UV exposure; and
3. Lung diseases which mainly include asthma and pneumoconiosis.

SUVA run various awareness campaigns that target the highest risk areas as identified by medical data. SUVA is currently running a campaign on protection from UV radiation for outdoor workers.

*Figure 13 – Inside SUVA’s medical assessment facility showing ergo spirometry*
6.2.2.2 Workplace Exposure Standards

Switzerland has an Exposure Standard of 6 mg/m³ for respirable dust, which is considered to be a relatively high concentration for occupational hygienists (who typically use 1 mg/m³ as a trigger value [85]), however Switzerland is still a better position than Australia as an Exposure Standard for respirable dust in tunnelling does not yet exist.

The Exposure Standard for silica in Switzerland is 0.15 mg/m³ which is higher than the Australian Exposure Standard of 0.1 mg/m³ and is a source of much discussion within SUVA. While it is recognised that it could be lowered in keeping with international counterparts, SUVA stated that they felt it was more effective to drive compliance across the whole industry and to ensure that controls reduced exposure to their strict requirement for 0.15 mg/m³ not be exceeded at any time (as an 8-hour time weighted average), rather than to reduce this number.

One key difference with the use of Exposure Standards in Switzerland is the consideration of the use of respiratory protection to reduce workers' exposure to below the Exposure Standard. To explain this, in Australia, if exposure is measured to be above the Exposure Standard then a Contractor can use respiratory protection (e.g. a “dust mask,” refer to picture on the front cover) to reduce worker's exposure by a factor equivalent to the protection afforded by the respirator. As an example, if exposure is measured to be 0.3 mg/m³ (three times over the Exposure Standard), then the effective use of a dust mask would reduce exposure to 0.03 mg/m³ (as it provides a minimum protection of 10 times) which is below the Exposure Standard of 0.1 mg/m³. In many cases, the use of dust masks is prescribed for many groups of workers for use at all times with the aim of complying with the Exposure Standard in Australia.

By contrast, in Switzerland, the use of dust masks (e.g. P2 respiratory protection) cannot be used to reduce exposure to below Exposure Standard as a routine event. This is because SUVA considers it unreasonable for a worker to use a dust mask for their entire shift or on a long-term basis, given the heavy workload often performed, the thermal heat stress impacts, and overall the general lack of compliance resulting in it largely being ineffective. In circumstances where exposure is short-term (i.e. less than a couple of hours per day), then dust masks can be used providing that the worker has been medically cleared to wear it, and all other engineering and administrative control options have been implemented. There are few select tasks where respiratory protection is an accepted practice, which include shotcreting or road header offside workers, but these workers must use Powered Air Purifying Respirators (PAPRs) equipped with the equivalent of P3 filters. In comparison to Australia, shotcretors have been known to wear no respiratory protection or a P2 dust mask, but rarely a PAPR P3 system.

SUVA noted that in the 5-years up to 2014, there were less than 20 cases per year of pneumoconiosis reported. Perhaps it is due to the low amount of reliance on dust masks, and stringent requirements
6.2.2.3 Exposure Monitoring

In Switzerland, Tunnel Contractors typically engage their own occupational hygiene specialists to perform exposure monitoring for the various hazards that are commonplace in tunnelling (e.g.: noise, dust, silica, heat). These results are used to help the Contractor understand key areas or tasks that may require additional controls to reduce exposure. In addition, SUVA has a team of specialists that travel to Contractor’s work sites to perform exposure monitoring every 6 to 8 weeks. Such monitoring is targeted to high risk work groups and areas that workers may frequently be located. As SUVA have regular involvement on each tunnel, they are familiar with the work operations and typical areas/tasks that cause high exposures. Therefore, these exposure monitoring campaigns are well planned and targeted, and are not performed as part of random monitoring events. Sampling is performed using both real-time dust measurements equipped with a cyclone to measure respirable dust, in addition to integrated sampling using the traditional personal sampling method. The proportion of quartz (silica) is estimated based on the proportion in the host rock for real-time measurements as a conservative approach.

In the case where an exposure monitoring result exceeds the Exposure Standard, then SUVA issue a formal letter to the Contractor that requires them to respond with their planned control measures to reduce exposure. The Contractor then provides a Plan detailing the controls which must be developed in the following order: System, Technical, Operational, PPE, which is known as “STOP”:

1. System control measures: for example, what is the process by which these controls will be implemented (when, where, how) and how does it integrate into the Contractors health and safety system.
2. Technical control measures: for example, what engineering controls will be implemented (additional ventilation, increased rate, dust suppression.
3. Organisational control measures: for example administrative controls.
4. PPE control measures: for example the use of Powered Air Purifying Respirators. Dust masks are not considered to be a suitable long-term control but can be considered for short-duration tasks as an additional control measure only.

The addition of the “System” control measures would be a welcome addition to an Australian-based control hierarchy. There is little point of documenting a control measure unless it is integrated into the Contractors health and safety system and therefore will be carried through on future projects.

SUVA consider it unreasonable for a worker to use a dust mask for their entire-shift or on a long-term basis.

Switzerland have a low incidence of pneumoconiosis.

SUVA conduct exposure monitoring that is targeted to high risk areas.

SUVA's Control Hierarchy has the added first step of a “System” control, which requires Contractors to explain how the control measure will be integrated into the Company's H&S System.
If exposure is measured above the Exposure Standard due to the planned control measures not being in place, then SUVA can issue a warning, or in severe cases, issue a notice to the Contractor to stop work. SUVA noted that in some cases of obvious non-compliance, they issue a notice to stop work prior to receiving the results of exposure motoring laboratory certificates. Work can only then recommence after a) the control measures have been implemented; b) SUVA undertakes additional exposure monitoring, and c) the results of that exposure monitoring are below the Exposure Standard. It is not uncommon for SUVA to stop work for periods of 3-weeks or greater due to uncontrolled health exposures, and therefore this is given great attention by the tunnel Contractors to make sure that they are compliant.

Contractors provide the results of their monitoring records to SUVA. As an example, during the construction of the Gotthard tunnel, the Contractors safety engineer provided a weekly report to SUVA that contained the results of all temperature, humidity, and air velocity measurements in the form of a WBGT index for each day of operation.

As noted in Section 2, under the Australian system, occupational hygienists working for Contractors have no authority to stop the Contractors work, if recommendations for control are not implemented. The Swiss have overcome this limitation through having the insurance authority tightly involved with the health and safety aspects of the project and providing appropriate powers to ensure compliance. In this way, SUVA insures its own insurance system through ill health prevention activities that have resulted in a more effective system of managing occupational exposures.

6.2.3 Site Visit

On the 23rd of June, I accompanied SUVA to the Belchen Renovation Tunnel (A2 Sanierungstunnel Belchen) for a site visit. This tunnel traverses the Jura Mountains and stretches between Basel and Egerkingen. Although it is a relatively small tunnel in distance (3.2 km), it makes up for it in diameter at just under 14m.

The tunnel is constructed using a TBM with pre-cast concrete lining in a similar process as used in Australia. However, a key difference observed was an alternate configuration for ventilation whereby supply and return air is designed in a way that provides fresh air to work environments that typically suffer from poor air flow (such as close to the cutting face and the ring build area).

Other noticeable differences included the use of diesel particulate filters (DPF) on all items of heavy plant, both above and below ground with all items of machinery equipped with back-pressure monitoring systems that alert the operator when retrofitted DPFs require changing. A dedicated mechanical shed was used for regeneration of retrofitted DPFs which tended to need to be changed out every 2-days, but new machinery that was procured already included inbuilt
DPFs with inbuilt regeneration.

6.2.4 Sustainability

SUVA share and publish their collective knowledge and the results of their work, and contribute to international guidance documents used in tunnelling on the topics of health and safety [72,82,86,87,88].

Overall, the Swiss approach of integrating medical surveillance, exposure control, and rehabilitation, appears to be a more effective system to reduce the incidence of occupational illness and disease and is a model that deserves further exploration.
6.3 Gotthard Base Tunnel

6.3.1 Leadership

In speaking with the Client for this mega-project, the stakeholder that had the greatest impact and influence on worker health protection was understood to be SUVA. Although the project had a strong focus on health and safety, the view was that the general standards across the industry would have been lower if SUVA were not constantly, yet welcomed, driving health and safety. As SUVA had powers to stop the Project if control measures were not adequate, it resulted in a continued focus on making sure that controls were in place and working as per design. There was a reputational risk associated with this also, as Site closures by SUVA were typically advertised via media channels.

Similar to Australia, this Project had a policy that responsibilities for health and safety were embedded within every person’s role starting from the CEO and flowing down to each person on the project. Health and safety for each project site was mainly driven by the respective Project Manager.

6.3.2 Engagement and Collaboration

AlpTransit collaborated with its numerous Contractors and SUVA on health and safety measures throughout the project. Periodically the project leadership team would convene to review lessons learned, health and safety statistics, and review the key health and safety risks and control measures.

6.3.3 Training and Awareness

Health and safety training requirements were documented in a specific Management Plan. They included requirements around specific key risks to the project, the associated control measures, how they were monitored and who was responsible.

With workers originating from over 17 different countries, managing risks associated with language barriers were high. This was managed through multi-lingual signage and instructions with the predominant language of German in the north, and Italian in the south.

To ensure that all workers had been provided with health and safety training that was relevant, Gotthard used a "licence system" that granted or prevented access to certain work areas at certain times. This meant that work phases were sectioned into discrete areas where a licence was issued to access the project at certain phases. For example, one phase was when tunnel workers were working adjacent to vehicles (or vehicles were allowed in the tunnel). Another phase was initiated when low-speed trains entered the tunnel, and another when high-speed trains entered. New licences were issued to
workers who had completed specific health and safety training that was relevant to the phase. Without that training, their electronic access cards would not work to allow them into the tunnel site.

### 6.3.4 Standards

Understanding the competitive nature of Contracting, both SUVA and AlpTransit wanted to ensure that health and safety requirements were clearly outlined at the time of Tender. Thus clear performance requirements were placed in Tender documents with health and safety forming part of an award criterion of between 10-20%.

Some examples of items that were specified included Competency requirements for health and safety professionals; the need for Contractors to have a new campaign each month that focused on a key risk that was identified on the project (ranging from PPE compliance through to the purpose of certain engineering controls); and using additional overhead protection measures that were over and above the current standards in Switzerland.

### 6.3.5 Health Risk Management

The health risk management process was largely dictated by SUVA as previously discussed. However certain initiatives originated from AlpTransit also. One example was the methods used to effectively communicate health risks and control measures required, where the Project erected a board (~1m$^2$) that had the conditions of the environment clearly written alongside the controls that were necessary. For example, if radon was high in a certain area, it was noted along with the need to use respiratory protection if workers were to access that area.

### 6.3.6 Controlling Exposure in Design and Construction

As previously mentioned, SUVA engaged with AlpTransit early on in the Project since prior to Contract award and worked with AlpTransit to clarify specific health and safety control measures that would be applied to address the project’s key risks. These included thermal heat stress, silica dust, diesel emissions, radon, and noise.

#### 6.3.6.1 Thermal Heat Stress Management

The Lütschberg and the Gotthard tunnels were constructed under massive overburdens of up to 2,500m with distances between access points of up to 20km in length. Temperatures above 40°C along with humid conditions were anticipated from the rock itself, with heat from machinery and humidity from water ingress and shotcreting expected to contribute further to generally poor working conditions. One of SUVA’s requirements for a safe working environment is one where the thermal heat stress was a major risk during construction of the Gotthard tunnel.

SUVA set work limits at 30°C WBGT.

High rates of ventilation coupled with localised cooling of air was required to meet the temperature limit.
temperature does not exceed 28°C to 30°C (measured as *Wet Bulb Globe Temperature*, WBGT), which meant that ventilation and cooling mechanisms needed to be designed to effectively reduce the expected heat load [82].

Prior to the Tender period, SUVA worked with AlpTransit and reviewed the geological profile to understand what rock types (and percent quartz) would be expected and what temperature modelling had been performed to predict expected underground work environments. This information was used to inform the design requirements for the ventilation system so it would be of suitable size to both remove airborne contaminants and to reduce the temperature to meet legislative requirements.

There were many technical issues associated with different rock types, and SUVA's Safety Engineer was therefore heavily involved to understand these complexities and planned control measures before on-boarding of the Contractors. It is through this process that “health” was driven during the design phase with the key driver of designing out health risks, or to use “technical measures” (engineering controls) to reduce exposure to below the legal criteria.

It is important to highlight that rather than recommending an average air velocity in the tunnel along with a risk assessment such as in the Australian *Guide for Tunnelling Work* [18], the issue of heat management is managed similarly to the NSW Code of Practice [36] which requires removal of persons at a certain temperature (as WBGT).

Essentially this means that the Contractor has to ensure that more air is delivered to the tunnel and that air cooling mechanisms are designed to supplement areas of expected high-heat load. On the Gotthard, this meant that in addition to high air velocities, localised cooling units were utilised underground to cool certain sections where workers were located. This was used during concrete paving works for example, as those works were located well back from the ventilation at the face. As a result, although the risk of thermal heat stress due to ambient working conditions was high, SUVA stated that the project had very few cases of heat related illnesses.

The effectiveness of health and safety control measures are required to be regularly evaluated, and in some cases, this evaluation must be performed by a professional with select competencies. Using heat stress as an example, the Contractor was required to engage a specialist to monitor and regulate thermal climatic conditions. This person had to be a “person of trust” that was officially recognised by the Client, the Contractor, the employees, and SUVA [82].

### 6.3.6.2 Diesel Particulate Management

As previously mentioned, SUVA was involved in the development of the original VERT certification system and require diesel particulate filters on all diesel-powered plant and machinery. On the Gotthard, the Contractor submitted records of monitoring data to SUVA each week.

All diesel-powered plant was required to use Diesel Particulate Filters. The same requirement does not exist in Australian tunnelling.

The focus of silica dust control was at the source, where extraction needed to be regularly re-located to be as close to the cutting face as possible.
this resulted in a significant amount of plant being retrofitted with filters until the newer models came equipped with inbuilt regenerating filtration systems. There is still a small amount of diesel powered plant in operation in tunnels that use the retrofitted system, although this is slowly almost phased out as most now have integrated systems.

The main issue with retrofitted systems is that the filters must be changed out regularly (e.g. every 2 days or so) and regenerated (where soot is transformed into carbon dioxide and water). Each item of plant is fitted with a monitoring device that records back pressure to enable the operator to know when the DPF must be changed.

Although Switzerland has had the requirement to use DPFs since the year 2000, there is no such requirement in Australia. Unlike similar Guidance documentation for mining operations [89], the Guide for Tunnelling Work [18] does not mandate the use of DPFs. The Code of Practice for Tunnels Under Construction [38] also does not refer to the use of DPFs.

6.3.6.3 Silica Dust Management

In terms of airborne particulate management, silica dust control was also a key focus of SUVA’s with quartz percentages in the host rock typically ranging up to 40% in the Gotthard tunnel. Dust management focussed on extraction ventilation at the source of dust emissions through de-dusters (scrubbers) complimented with fresh air supply. The extraction ventilation system was regularly relocated to be as close to the source of works as possible, while not allowing road header operations to extend very far without adjusting the location of ventilation.

Other dust control measures that proved effective included: optimisation of conveyor transport including housing it in the tunnel; limiting dust emissions from the top of rail cars; exclusive use of wet shotcrete, and systematic disposal of dust residues in the tunnel.

Real-time dust measurements were required to be collected (and reported to SUVA) on a routine basis to verify that extraction ventilation was sufficient to prevent dusts from travelling past the extraction system. In addition, fixed water spray nozzles were required to be affixed to heavy plant, and de-dusters were required on conveyor belt systems.

While this is largely similar to what typically occurs in Australian tunnelling, the added requirement surrounding routine real-time measurement and strict adherence to moving extraction ventilation would result in an improvement to Australian working conditions.

Real-time measurements of dust are required to monitor the effectiveness of ventilation.

Lessons learned are captured in a book authored by more than 100 people who were involved with the project.
6.3.7 Sustainability

To capture the wealth of information from the project and to ensure that lessons learned were recorded for future projects, the project published a 720-page book entitled, *Tunnelling the Gotthard* in which more than 100 people who were involved in the project authored specialist articles on various themes.
7.1 The Silica Rule

The final rule on *Occupational Exposure to Crystalline Silica in Construction*, commonly known as the “Silica Rule” established a new Exposure Standard and contained other provisions that apply to the US Construction Industry. The rule became effective on June 23, 2016, with obligations (i.e. Regulatory enforcement by OSHA) planned to commence on June 23, 2017. However, in April this year, that date was pushed back to September 23, 2017 due to the Silica Standard requiring the development of additional guidance materials [90]. In summary, the new Silica Rule contains the following provisions:

- Reduces the Exposure Standard to 0.05 mg/m³, which is equivalent to half the level of the Exposure Standard in Australia.
- Requires employers to: use engineering controls (such as water or ventilation) to limit worker exposure; provide respirators when engineering controls cannot adequately limit exposure; limit worker access to high exposure areas; develop a written exposure control plan, offer medical exams to highly exposed workers, and train workers on silica risks and how to limit exposures.
- Requires employers to provide medical exams to monitor highly exposed workers and give them information about their lung health.
- Provides flexibility to help employers including small businesses protect workers from silica exposure.

The rule contains a prescribed list of specific Exposure Control Methods when working with materials that contain Silica. Commonly referred to as “Table 1”, it lists common construction tasks with the associated dust control methods. If these methods are used correctly, then exposure monitoring for silica is not required. However, companies have a choice and can use other methods not listed in Table 1, but if they do, then exposure monitoring must occur to confirm that exposure is reduced below 0.025 mg/m³, and workers must be protected from exposure above the Exposure Standard.

One way of looking at the Silica Rule is that it reduces the probability that dust masks will be used to reduce exposure to below the exposure standard as a first resort. There are a set series of engineering controls

![Table 1: Specified Exposure Control Methods When Working with Materials Containing Crystalline Silica](image)

*Figure 14 – Excerpt from OSHA’s Fact Sheet [118]*
that are mandatory, and if they are not followed, then the Contractor
would need to engage an occupational hygienist to conduct exposure
monitoring to verify their new method was effective. Arguably,
complying with the engineering controls in Table 1 would be a more-
cost effective approach for smaller businesses.

In contrast to Australia, this appears to be a welcome approach, as the
Regulator in the US is clearly articulating “what good looks like” and
what needs to be done to demonstrate compliance. It is doubtful that
many small businesses are engaging occupational hygienists to
assist them with exposure control methodologies to silica dust in
Australia, based on the author’s experience, so providing a step by
step control-focused guide is seen as a positive approach.

Another interpretation of this, for large business especially, is that the
value of engaging an occupational hygienist on an ongoing basis may
be to design an exposure control program that is specific and flexible
to the Company or Project’s needs, rather than needing to follow each
prescriptive step in Table 1 if it may not be practicable. The final rule
will be implemented over a period of five years, with enforcement
coming most quickly to the construction industry.
7.2 American Industrial Hygiene Association

The American Industrial Hygiene Association (AIHA) has played a key role in advocating for the advancement and implementation of the Silica Rule since its inception and have played an active role in raising awareness of its benefits to both its wider membership and to Congress.

7.2.1 Advocating for the Silica Rule in US Congress

The implementation of the Silica Rule is expected to save over 600 lives and prevent more than 900 new cases of silicosis each year [91], however there is a large movement of around 100 members of US Congress (approximately one-fifth) who are currently opposed to the rule as they view it as harmful to the construction industry [92] through being expensive and impractical [93].

In response, in February of this year, the AIHA held a congressional briefing [92] for members of Congress and their staff, but also for other stakeholders including AIHA members and the general public to raise awareness of the benefits of the rule and what it aims to achieve.

The AIHA is not alone in its support of the rule and as such it partnered with other groups who are also strongly supportive including the American Association of Occupational Health Nurses (AAOHN), the American College of Occupational and Environmental Medicine (ACOEM), the American Board of Industrial Hygiene (ABIH), the American Society of Safety Engineers (ASSE), and the Board of Certified Safety Professionals (BCSP). It was through this collaborative approach that the congressional briefing essentially represented more than 60,000 occupational health and safety professionals across the US [92].

Although the Silica Rule is in effect, it is still under threat from these members of Congress who do not currently support it. The main threat comes from the potential lack of funding through an appropriation bill which essentially authorises the government to spend the money needed for enforcement. Therefore, the funding of the “enforcement” piece of rule implementation and the need for adequate funding in an appropriation bill, is where AIHA’s government relations strategy is currently focussed.

The AIHA also produce “Action Alerts,” which essentially call for action and support so that AIHA members can campaign directly to their local members of Congress. The Action Alert contains a template letter that clearly outlines the issue, the importance of it, and provides a simple process for AIHA members to send it to their local member of Congress. Action Alerts have been generated for the Silica Rile, and the AIHA released another recently to support the continued level of funds assigned for NIOSH.

Key Contacts:

Lawrence Sloan, Chief Executive Officer
Mark Ames, Director Government Relations

Snapshot:

The AIHA is a non-profit organisation with the mission of creating knowledge to protect worker health. With approximately 8,500 members, more than half being Certified Industrial Hygienists (CIHs), it is the largest professional organisation for occupational hygienists globally.

The AIHA has an active membership base with more than 45 scientific and technical committees, task forces, and working groups worldwide.
7.2.2 Raising Awareness and Providing Resources

AIHA members hold technical talks and chapter meetings across each state to both discuss the impacts of the Silica Rule. They work to help other Stakeholders understand how to comply with it in addition to holding specific sessions at their annual Conference on the method and benefits of implementation.

To support the Silica Rule, the AIHA has produced a White Paper that outlines the basic body of knowledge needed to provide meaningful worker protection from overexposure to silica. The Silica Rule uses the term “Competent Person,” and this position paper provides a list of recommended subject-specific skills and competency objectives that silica-competent persons should have to enable them to perform the job successfully [94].

The AIHA has also hosted webinars to help their members understand the detail of the rule through outlining the comparison between previous legislation in this area, monitoring techniques, and results interpretation [95].

The AIHA's strategy to support the Silica rule is through three main areas:

1. Providing knowledge to lawmakers to aid in making informed decisions.

2. Leveraging the collective knowledge of its members to influence broader public policy.

3. Raising awareness through holding events and providing helpful resources to support members and the wider community.
7.2.3 Government Relations Beta Group

The AIHA recently stepped up its advocacy work through the recent launch of its Government Relations Beta Group. This group essentially leverages the collective knowledge of their members to influence public policy. There are over 90 voluntary members who conduct their work via task force where they essentially meet with members of congress and discuss matters relating to the development or funding of, bills that protect the health and safety of workers. Some of their current task forces are focused on safe patient handling and teen workplace safety.

Most recently, the AIHA worked with the Texas State House Representatives and the State Senate to introduce a bill known as “Safety Matters” which is focussed on teen workplace safety. The bill encourages school districts and educators to include workplace safety training information in the curriculum of appropriate courses for students in Grades 7–12 [96].

The AIHA has been working on improving teen workplace safety for some time and has partnered with NIOSH to help develop the Safety Matters program to provide basic safety skills and raise awareness among teens. The program is free with no special training needed to deliver it [97]. The bill was successfully signed into law on June 9, 2017, and the Beta Group are now working to have the law passed in the remaining US States.

The importance of this level of advocacy from a professional society cannot be understated. The Silica Rule is arguably one of the largest pieces of federal legislation to positively impact the health of more than 2 million construction workers in the US. The AIHA's multi-faceted approach of targeting federal members of congress in addition to raising awareness from their 8,500+ membership base further advances their mission of “creating knowledge to protect worker health.”
7.3 Laborers Health and Safety Fund of North America

A total of 4,836 fatal work injuries were recorded in the United States in 2015. It is estimated that another 50,000 workers will lose their life due to a work-related illness or disease. The largest causes of fatalities from safety incidents are from falls from height, but according to Walter Jones, the biggest impact are fatalities due to motorist intrusions into the work zone. The largest health issue may well be the diseases of the lung. Similar to Australia, the Construction Industry in the USA does not have a centralised health surveillance program. Therefore the true extent of disease is difficult to determine.

Of the 9 million Americans who work in the Construction sector, approximately 1 million are members of a Union. Separate Union organisations exist for each trade (e.g. electrical workers, ironworkers, etc.), with labourers typically members of the Labourers International Union of North America (LiUNA).

The Labourers Health and Safety Fund of North America (LHSFNA) operates as a separate entity and a support organisation for LiUNA members. It operates across three main areas of health and safety, health promotion, and epidemiology.

Associate Director Walter Jones is a Certified Industrial Hygienist (CIH) in the health and safety section and provides occupational hygiene support for LiUNA members. This support ranges from writing Health and Safety programs and providing chemical safety advice leading to site specific method statements, through to performing site inspections and performing exposure assessments where deemed necessary.

Key Contacts:
Walter Jones CIH, Associate Director
Occupational Safety & Health

Snapshot:
The Laborers’ Health and Safety Fund of North America (LHSFNA) is committed both to healthier Laborers and healthier employer bottom lines. The Fund embraces the collaborative strategy of the Labourers International Union of North America and its signatory employers to build market share for union Laborers. It embodies the common interest of union members and union employers in the areas of health and safety.

The LHSFNA is dedicated to:
- Enhancing jobsite health and safety
- Bolstering the health of Laborers and their families
- Strengthening the health benefit services of LIUNA health & welfare funds
- Boosting the competitiveness of LIUNA signatory employers
- Supporting the Laborers’ International Union of North America
It was recognised that LiUNA members might not have ready access to occupational hygienists, so the LHSFNA fills this gap by providing this expertise as part of the service to its Union membership base (i.e. at no additional charge).

In this role, LHSFNA has visibility of the varied work practices across the Construction sector, including tunnelling. Part of their service is to identify areas of good practice that are applied on one site or specific area for example and to share those good practices to members on other sites, such that the industry ultimately benefits and in turn improves, through these collective learnings.

The LHSFNA has recently focused on providing training and awareness to LiUNA members in response to the Silica Rule through the following initiatives:

- Development of awareness material for members which are shared at associated briefings. The general message is to inform members that the Silica Rule is out there, what is in it, what it can do for them, and that compliance is not difficult.
- The LHSFNA have contributed information on silica in addition to general occupational health hazard identification and control training in the OSHA 10-hour training that all Union apprentices undertake through the LIUNA Training & Education Fund.
- The LHSFNA have provided technical expertise into the development of a course that meets the requirements of a “Competent Person” as specified in the Silica Rule e.g. “A Competent Person...who is capable of identifying existing and foreseeable respirable crystalline silica hazards in the workplace and who has authorization to take prompt corrective measures to eliminate or minimize them. The competent person must have the knowledge and ability necessary to fulfill the responsibilities…”

Members of the LHSFNA advocate for health and safety through contributing to the Construction Sector Council, the North American Building Trades Union, the American National Standards Institute (ANSI), the American Society of Safety Engineers (ASSE), the American Industrial Hygiene Association (AIHA) and the Center for Construction Research and Training (CPWR) to name a few. This ensures that health and safety of labourers, no matter if they work for large Contractors or small organisations, are represented.

One of the challenges that smaller Contractors face in Australia is access to specialist advice and expertise from an occupational hygienist, due to them being less able to fund such resources. There is also less opportunity for advocacy in the area of health and safety as it relates to small businesses. LHSFNA aim to essentially fill that gap for their members through providing access to specialised services that advocating across the broad base of their membership.
7.4 National Institute for Occupational Safety and Health (NIOSH)

NIOSH is a research institute focussed on the health and safety of workers. Part of the Centre for Disease Control and Prevention (CDC), the Office of Mine Health and Safety Research within NIOSH is considered to be one of the world's leading institutes for related research in this area.

NIOSH has been working on a number of research projects on the control of silica exposure to help the mining industry. Although the silica rule does not apply to the Mining Sector, many of the areas of research currently being conducted have direct relevance to the Australian tunnelling industry, with key examples highlighted herein.

7.4.1 Helmet-CAM

Helmet-CAM assessment technology enables users to identify high periods of exposure through linking real-time measurement devices with video footage. While Video Exposure Monitoring (VEM) itself is not necessarily a novel concept, using it for this application with the efficiency in which it can be done, is an innovative approach to assessing exposure leading to more targeted control.

To explain the value of this approach requires some understanding of how the Exposure Standard for silica is applied. The Exposure Standard of 0.1 mg/m$^3$ applies to a measurement collected as a Time Weighted Average (TWA) that represents an 8-hour period. Within that period, a tunnel worker will inevitably be exposed to varying concentrations of silica, some high, and some low. The sample analysis will return a measurement value that represents the TWA, and therefore it will not be known from that measurement alone, when or where the periods of high exposure occurred during the workers’ shift. To address this issue, occupational hygienists typically stay onsite during the sampling period and observe the workers while noting down tasks that are anticipated to result in higher exposures which form the basis for recommendations for control in the exposure assessment report. However there are some limitations with this approach including the fact that many workers are sampled during a shift and cannot be observed during each working moment; some areas are not accessible at certain times due to spatial restrictions near the excavated face; and respirable dust and silica, by their nature, are not visible to the naked eye.

To address this, NIOSH developed a software known as Enhanced Video Analysis of Dust Exposures (EVADE), which is now freely available [98]. The software facilitates the post-processing of the data from a wearable camera (on a Helmet or on the lapel of a backpack for example) and a real-time respirable dust monitor (e.g. ThermoFisher PDR or other brand models of a similar nature), located in a backpack. Many different brands of wearable cameras and monitoring devices
are compatible for this purpose, and many can be used at the same time. Up to 5 different real-time monitoring instruments can be loaded into the EVADE software simultaneously, which means that other parameters such as diesel particulate, diesel exhaust gases, noise, or vibration, for example, could also be assessed simultaneously.

The idea originated from a large silica sand manufacturer who wanted to know how they could better reduce the amount of silica exposure in their facility through pin-pointing field issues with high exposures at specific times. The Company was performing a large amount of national and international audits in this area involving a significant amount of travel and wanted to develop a more sustainable yet effective approach. Essentially rather than the Corporate HSE team traveling to many different locations and performing audits, the Company combined the idea of the backpack with a camera and monitoring device and had them sent out to the Company sites so that locally based occupational hygienists could work with the facilities to collect the data. The Corporate team could then review the data back in their head office and make recommendations based on the data obtained at a holistic level.

The Helmet-CAM technology can be housed in many different formats, but the most popular appear to be through the use of a backpack setup. Workers are asked to wear the backpack for a period of a few hours of representative work, and then the data is instantly downloaded to a laptop onsite. The video and dust data appear on the same time-bar graph to enable the hygienist to quickly select the highest periods of exposure and then see the work activities that were occurring at that time. The worker is involved in reviewing the data which aids in understanding as to why certain processes or tasks are performed a certain way, but more importantly, it highlights those sometimes-unknown periods of exposure, and then an approach for control can be determined in a collaborative manner with the workers involved.

NIOSH has performed many field studies using the Helmet-CAM technology on over 250 mine workers) and have found many previously unidentified sources of exposure that have led to improvements. Some examples include:

- Replacement of fabric gloves with non-fabric alternatives due to the liberation of dusts.
- Replacing carpets with a smooth surface as exposure from dust-laden carpets in conference rooms were shown to be a key source of exposure.
- Replacing the method of dust suppression due to a forceful spray (e.g. high-pressure hose) resulting in the liberation of respirable dust which was replaced with a lower pressure system.
- Replacing fabric seats with leather seats in heavy plant cabins as they then liberated dust each time the worker sat down.

Figure 15 – Screenshot from EVADE Software (courtesy, NIOSH)
Reducing the drop distance between conveyors and hoppers which resulted in a reduced zone of dust influence around the hopper area. This removed the need for respiratory protection due to an 80% reduction in respirable dust exposure.

Modifying the design of screening systems as the use of elastic that secured the screens in place was found to be a key contributor to exposure. The elastic/cloth system was redesigned through a segmented screen deck in conjunction with the manufacturer.

Dust laden hose reals were identified to be a significant source of exposure.

A significant behavioural change has been observed through the use of this technology also. Through collaborating with the workforce and taking the time to review the data with the participant, it has resulted in a change in attitude and behaviour around administrative controls for dust exposure.

Overall the Helmet-CAM system enables the quantification of an exposure issue through providing objective data that can be essential when identifying the need to make a change in a process. This has led to engineering controls and behavioral interventions ultimately being implemented to reduce exposures [99].

Helmet-CAM enables the identification of high periods of exposure through linking real-time measurement devices with video footage.

Often, periods of high exposure to respirable dust are not obvious and therefore this system enables resources to be focussed on the areas where they will have the greatest impact.

This has led to engineering and behavioural control measures being quickly implemented to reduce exposure.
7.4.2 Field-Based Monitoring for Silica

One of the existing challenges of assessing exposure to silica in Australia is that there are currently no real-time sampling methods that can be used that provide a representative measure of exposure. Presently the time between sampling and obtaining results of silica exposure takes approximately two weeks. Respirable dust samples are collected onsite and then sent offsite to a NATA accredited analytical laboratory to be reported (refer Figure 16). This means that there is considerable time that goes by before results are available. A lot can happen in two-weeks in a tunnelling (or construction) environment, which means that any opportunity that a Project may have had to make an improvement may have since passed.

While some real-time monitoring instruments exist for the measurement of respirable dust, the amount of quartz (and therefore silica) in relation to the amount of measured dust is highly variable (ranging from less than 10% to greater than 75% from workers during the same shift on the same site). Therefore, merely measuring respirable dust does not provide an accurate indication of silica exposure.

Researchers at NIOSH have developed a way to measure silica exposure quickly, and onsite, which enables quicker action to be taken to reduce high silica exposure [100]. Essentially the process developed by NIOSH works onsite as follows (refer Figure 17):

1. Occupational hygienists collect silica samples using existing methods.
2. At the end of sampling, the sample cassette containing the filter is removed and placed into small portable instrument (refer Figure 18).
3. Using an infrared technique, the instrument measures the concentration of silica in less than one-minute.
4. NIOSH’s software provides specific quantification models (calibration models etc.) which correct for common interferences, and an accurate result is obtained.

The entire process takes less than 2-minutes, and the sample filter used for this field testing can still be sent to the analytical laboratory for confirmatory sampling and validation if need be.

As silica concentrations in tunnelling constantly change, due to the nature of the multiple processes occurring at any one time and the locations of those activities in relation to ventilation, the ability to have a faster turnaround of results is a welcome one. It essentially means that controls relating to modifying the location of ventilation, or the use of PPE, can be put in place for the next shift, rather than waiting approximately 2 to 3 weeks to understand the level of the risk posed to the workforce.
Of the challenges that NIOSH had to overcome was the presence of minerals other than quartz that may be present in the dust, some of which were anticipated to impact the accuracy of the measurement of the field based instrument. NIOSH have been working over the past couple of years to identify the specific minerals that have an impact on the analysis, identifying what type of environments they are found in (e.g. different compositions between granite operations or mineral mining), and then determining what correction factors may need to be applied to compensate for the presence of these interfering minerals to enable reliable quantification.

NIOSH has used several methods including looking at a “region specific”, “mine specific”, or “commodity specific” correction factors to address this bias, which essentially takes aggregated data from a region, mine, or mining type, and use complex mathematical formula to calculate a specific correction factor that is unique to the sample being analysed. The NIOSH software interfaces with the software that comes standard with the portable instrument purchased so that the end user does not have to understand, or calculate complex mathematical models, but rather the entire process is simplified through entering one item of data to obtain a result.

The method has a low limit of quantification (0.015 mg/m³), meaning that it can accurately measure low concentrations that are well below the existing Exposure Standard. Accuracy ranges in the order of 1% to 30% dependant on the nature of the respirable dust measured, however, this accuracy can be reduced through beta-testing in collaboration with NIOSH in a relatively short amount of time. Beta testing involves providing NIOSH with samples of previously collected filters or bulk samples of the dust such that the mineralogy can be assessed.

Currently, there are four commercially available portable infrared units that can be used together with NIOSH’s software. The portable units run at an average cost of approximately USD$17K. However, NIOSH provides the associated software free of charge, which means that after the initial outlay, there are no further charges apart from the existing costs to collect the samples. As silica samples analysed by XRD typically run in the order of more than $100 each (and around 10 to 12 samples are collected on each day of monitoring), the cost-benefit of this system could be realised in less than 6-months (in approximately half to one-third the duration of a single Australian tunnelling project).

One hurdle that would have to be overcome in Australia would be the fact that the field based testing device does not meet the definition of a “NATA-accredited laboratory.” While the use of a NATA-accredited laboratory is not specifically listed in the WHS Regulations for silica [21], guidance documentation published by Safe Work Australia states that the analysis of samples taken in the workplace should be carried out by such a laboratory [101], which is standard practice. As the test-method using the portable instrument is non-destructive however, it means that a sub-set of filters could, in fact, be sent for analysis to a NATA-accredited laboratory to ensure the analysis is valid.

NIOSH have developed a way to measure silica exposure quickly, and onsite. This system enables quicker action to be taken to reduce high silica exposure. NIOSH researchers are eager to work in a collaborative approach with Australian projects to further promote the use of the system leading to an improved ability to control exposures for Australian workers.
analysis by the NATA-accredited laboratory. As there are no requirements for minimum sample numbers to be undertaken by law, one potential pathway to address this hurdle may be that a sub-set of filters are sent off-site for testing to a NATA-accredited laboratory to both demonstrate compliance with the Exposure Standards and to validate the accuracy of the samples collected on an ongoing basis.

NIOSH researchers are currently eager to work in a collaborative approach with Australian projects to further promote the use of the system leading to an improved ability to control exposures for Australian workers.

7.4.3 Other relevant areas of Research and Technology

7.4.3.1 Real-time DPM monitor

NIOSH developed a wearable instrument to measure real-time DPM (as elemental carbon) which has now been commercially developed. Manufactured by FLIR Instruments, the Airtec™ monitor showed no statistical difference from the current validated method (NIOSH 5040) and is unaffected by dust and humidity [102]. The monitor runs at approximate USD$5K and can be used in conjunction with the Helmet-CAM technology also.

Given the number of diesel driven plan in mined tunnels, the use of a real-time monitor on a regular basis is anticipated to result in an improved understanding of the level of exposure, which should lead to a stronger focus on controls.
7.4.3.2 Personal Dust Monitor (PDM)

NIOSH collaborated with an instrument manufacturer, government partners, labour representatives, and coal industry leaders to develop the continuous personal dust monitor (PDM) which is a technology that offers miners, safety personnel, and operators real-time exposure information to help protect miners’ health [103].

The PDM uses mass-based measurement to quantify the concentration of respirable dust through a TEOM, which is a more-accurate method than the light-scattering technology used by other respirable dust monitors on the market. At an accuracy equivalent to the gravimetric samplers used under the current Australian Standard, these PDMs are used instead of traditional gravimetric pumps in US mining.

The PDM is worn on miner’s belts and measures and displays the real-time, accumulated and full-shift exposure to respirable dust. Reporting dust concentrations in real time enables immediate action to avoid excessive airborne dust levels. Unlike the samples from existing dust sampling devices that require several days to collect, ship and process, this enables immediate, full-shift exposure data. The PDM was approved by the Mine Safety and Health Authority (MSHA) and the National Institute for Occupational Safety and Health [104]. Effective since February 1st, 2016, they must be used quarterly for sampling certain mine workers ranging from 5 to 15 consecutive days. The measurements are displayed on the screen and stored for later downloading and review. Certain actions are taken in the case of exceedances of the Exposure Standard, and all results are transmitted to MSHA within 24-hours at the end of each sampling shift.

It is noted that these units are Certified for use in the US coal mining sector, however, they are not yet recognised for compliance purposes in relation to the Exposure Standards in Australia. An additional challenge in a tunnelling environment is that there is no Exposure Standard for respirable dust. Although these units are relatively expensive (at approximately $20K per unit), they enable quick rectification of an over-exposure scenario ultimately resulting in a reduced risk of ill health.

Figure 20 - Personal Dust Monitors (PDMs)
7.4.3.3 Canopy Air Curtains

In tunnelling, roof bolting is performed to support the cut face, not unlike the process in mining. Generally, this is performed when roadheader operations have ceased. However, there are some instances in mined tunnels, where roof bolting occurs near the cut face, and benching (road header mining) occurs behind this activity. Dependant on the design and layout of the ventilation system, the roof bolters can end up being located in between benching activities and the ventilation extraction system. This means that they are subjected to exposure from high concentrations of dusts and silica generated from cutting activities.

The most common control measure applied to these workers is the use of respiratory protection. To address this issue, NIOSH researched and developed an engineering solution to control roof bolters' exposure to respirable dust through the installation of a canopy air curtain built in to the bolting rig. The air curtain is a filtered air system that supplies a clean curtain of air over the roof bolter operator through a plenum mounted beneath the canopy. While it is recognised that the design of roof-bolting equipment differs dependant on the size and manufacturer, this engineering control was demonstrated to be effective in both laboratory and field testing trials [105].

7.4.3.4 Enclosed cabin filtration systems

Cabin filtration systems are used on road headers as an engineering control to reduce the road header operator's reliance on respiratory protection. The effectiveness of these systems are mixed, however, and the operator typically is required to wear respiratory protection as part of routine operations.

NIOSH recently completed a 15-month study evaluating the effectiveness of a filtration and pressurisation system in an enclosed cabin which involved comparing the effectiveness of filters (both n99 and n95) [106]. The study demonstrated that the use of a higher-grade filter (n99) actually resulted in less protection due to the restrictiveness of the filter and the associated pressure drop and leakages than the lower grade filter (n95). This is in contrast to what may have been expected and warrants consideration during the design phase for future cabin designs.

7.4.3.5 Dust suppression

One of the challenges when using water to suppress respirable dust and silica is understanding the type of suppression spray system needed which depends on the application and purpose it is designed to achieve. In tunnelling, much of the equipment used needs to be retrofitted with individual dust suppression systems of varying types. No matter how complex retrofitting dust-suppression to heavy plant seems to be, it is more effective at reducing exposure than by using manual dust suppression. The old-fashioned method of using a worker (spotter) holding a hose, results in major silica over-exposures to the worker and has little effect on dust control. NIOSH has produced a number of technical publications [107,108] on the issue, which are broadly summarised into a tunnelling context overleaf:
Conveyor Belts: Most effective are high flow low pressure systems located close to the source with full-cone spray nozzles best suited for conveyor-belt transfer points;

Road-header: Hollow-cone spray nozzles would be best-suited for attachment to the boom directly behind the road-header cutter head (as close as possible), as they are effective for dust knockdown, as well as re-directing dust away from the worker. Flat-fan nozzles are suited for dust-containment, and may be suitable for use on the side of the road-header to contain dust to underneath the boom, allowing for the dust to be captured by the scrubber system;

Air-atomising sprays are suited for airborne dust capture (e.g. inside a spoil shed, or along the walls of a shaft). There are two main types: hydraulic and air-assisted, with air-assisted producing the smallest water droplets and being more effective at dust capture. However, they can be complex to install and have high maintenance requirements. There is a balance that needs to be achieved with the distance of the spray system and the spoil, whereby the system needs to be far enough away to provide adequate coverage, but close enough so that the water spray isn’t carried away by air currents;

Solid-stream nozzles are suited to deluge an area before cutting or loading;

Where dust suppression systems are automated, they should be placed on a delayed timer to enable the spray system to operate for a short-time period afterwards to increase its effectiveness;

For airborne dust capture, smaller high-velocity droplets are needed to impact the dust and remove it from the air (refer Figure 22). To optimise dust suppression, the particle size and the water droplet size should be approximately the same size. Respirable dust is less than 10 µm in diameter, with 50% cut-off point at 4 µm. Water droplet sizes in the range of 10 to 50 µm have been found to be effective (similar to fog); and

The use of surfactants can result in less water being needed for dust suppression. However, there are some limitations.

7.4.3.6 Virtual Immersion and Simulation Laboratory

The Virtual Immersion and Simulation Laboratory (VISLab) uses a 360-degree 3D display to simulate virtual environments for training mineworkers. Stereoscopic projection systems simulate mine emergencies and hazardous situations. With over 32 different scenarios containing a mock-up of multiple mine hazards, NIOSH researchers place eye-tracking glasses on willing training participants to track their effectiveness at spotting them. Participants are given a buzzer and press it when they see a hazard on the screen, and at the end of the simulation, they are shown where they looked and how many hazards they correctly spotted as part of an education exercise. Other scenario’s that are used include training in the operation of a continuous miner, and a recreation of an underground fire, in which participants have to navigate the safest way out of the mine without coming to an untimely end. This type of realistic real-world virtual training, coupled with follow-up review and learning, is a similar style experienced in London on the Thames Tideway EPIC Induction, although sector-specific. An active tunnel construction environment is equally as hazardous as mining, and the use of technologies such as these, given the similar facilities available in Australia, is worth further investigation.
Hazard Spotting in the VI$lab$

Learning how to operate a continuous miner
7.5 Anacostia River Tunnel

7.5.1 Leadership

In speaking with the Contractor, the biggest driver in tunnelling was noted to be dependent on the State the Project was located and the Client’s interests in the topic. While Contractors always have health and safety as a priority, it is understood that some States in the US have a better-funded Regulator (OSHA) and therefore may be subject to more frequent visits and inspections. Some Clients may have a keen interest in certain health and safety aspects and therefore insert additional Contractual requirements that are imposed on the Contractor in addition to heavily resourcing their health and safety team. This project came to the latter strategy, with the Client being the key driver visible on the Project.

7.5.2 Standards

Tunnel Contractors in the USA are bound by OSHA’s *Safety and Health Regulations for Construction* [109]. These Regulations include more detailed requirements than Australian WHS Regulations, with one example being the use of respiratory protection. While Australia may place such requirements in an Australian Standard, the US places these requirements into legislation. While this results in many “rules,” it also provides clarity on the minimum compliance requirements given that many Australian Standards are not referred to in the WHS Regulations.

On the Anacostia River Tunnel Project, the Client (DC Water) also placed a number of health and safety requirements on the Contractor through both the Contract and the Insurance Program. A Contracts Management team manage the Contractor (and Health and Safety aspects of the Contract) on behalf of DC Water. In addition, the Insurance Program, known as the *Rolling Owner Controlled Insurance Program* (ROCIP) engage a management consultant to manage the health and safety requirements set by the Insurer.

The ROCIP provides workers’ compensation, general liability and excess liability insurance coverage for all Contractors working on the Project. Essentially each Contractor buys into the Insurance program, and the Program undertakes governance and verification of the Contractors work during the insurance period. Benefits of such a program are stated to include lower insurance premiums due to bulk purchasing, consistency of insurance provided on each project, enhanced safety and loss control, and cost savings.

As part of the ROCIP, DC water produced a *Construction Safety & Health Manual for Contractors* [110] which included additional health and safety requirements which were a mandatory part of obtaining such insurance. While the *Mine Safety and Health Administration* (MSHA) has no authority over tunnelling projects, many of the...
requirements that MSHA would typically regulate are captured in this Manual. In addition, some of the aspects of the Silica Rule, although not yet legally enforceable by OSHA, are in the Manual also, such that they have become Contract requirements and are enforceable by the Client. Some examples include the need to perform concrete cutting and grinding “wet” to reduce dust exposure.

The ROCIP management consultant team is well staffed and regularly undertake inspections of the work site to ensure that the Contractor is undertaking its duties in accordance with the ROCIP Manual. This is a similar approach to what is undertaken in Switzerland through SUVA. However, the scale of ROCIP is localised to one major project, rather than the entire US Construction Industry.

7.5.3 Targeted Silica Management

The TBM was an Earth Pressure Balanced (EPB) type due to the tunnel alignment going through soft clays and under the river. Excavated spoil on an EPB TBM is removed via a screw conveyor and a series of overhead conveyor belt systems.

Although clays have a relatively low quartz content and an EPB TBM typically results in less exposure to dust from the cutter head, dusts and silica still present an exposure problem if not appropriately managed. Given the focus from the Silica Rule, controlling silica dust was still a key focus on the project.

7.5.3.1 TBM Ventilation

A number of engineering solutions were implemented to reduce exposure to silica dusts. Starting with ventilation, the fresh air supply was designed to be delivered to the front-most portion of the TBM via hard ducting so that fresh air was targeted and delivered to the ring-build area. In addition, to ensure that fresh air was supplied to other areas on the TBM, it was designed to have a number of registers (vents – similar to a building air conditioning system) at each TBM gantry that were fitted with dampeners. These registers could be opened or closed to enable fresh air to be released where workers were located, without significantly dropping the air velocity that was delivered to the ring build area.

Each TBM is designed differently, with the possibility of being supplied by many different manufacturers. However, it is up to the designer to specify where air flow is required on the TBM. Specifying the location for exhausting fresh air is critical to reducing exposure to silica dusts. The system implemented on this Project is anticipated to have resulted in lower exposure to dusts, and in turn, silica for these workers.

7.5.3.2 Conveyor Belt Wash Box

One key source of silica dust in TBM tunnelling is from the conveyor belt. Although the use of water sprays at conveyor transfer points may be used, the spoil on the conveyor dries out over longer distances and sticks to the conveyor. When it has dumped the spoil and begins to return back to the TBM, it goes over a series of rollers which then cause that dried spoil to become airborne, and dust is liberated into the air.

To address this issue, the project installed a conveyor wash box that the conveyor belt passed through after discharging the spoil. The wash box included a series of return sections on the belt, scrapers, and high pressure water sprays to clean the conveyor belt so that it was returned to the TBM clean, without liberating dusts.
7.5.3.3 PPE

In all cases, if a worker is required to use respiratory protection to reduce exposure to silica, then the worker is offered a medical and is provided a half-face reusable respirator fitted with the equivalent of P2 filter cartridges (example Figure 23). The worker also receives a respirator fit test, and the process is managed through a Respiratory Protection Program.

Disposable dust masks (example Figure 24) are only used voluntarily and cannot be used where they are needed to reduce exposure to below the Exposure Standard. On this project, the main work crew that uses respirators, are shotcretors.

7.5.3.4 Exposure Assessment

Independent monitoring for dust and silica were undertaken over the source of the project over four major campaigns over the 12-month period of tunnelling which helped drive continuous improvement.
7.6  Alaskan Way Viaduct SR99

7.6.1  Leadership

The stakeholder with the greatest positive influence for worker health protection was the Contractor, Seattle Tunnel Partners (STP). The project team largely attributed this to the previous work of Dan Weathers CSP, Health and Safety Manager (retired), as the main driver who was instrumental in the implementation of a strong system from the onset of the Project. That commitment to health and safety leadership from the highest level of the Project ultimately led to a strong health and safety culture and was a testament to many of the positive practices observed during the site visit.

STP is known within the general industry as having a good health and safety record. So good by industry comparison, that State of Washington gave STP a 32% discount on their workers’ compensation insurance [111]. Highlighting areas of “best practice” was therefore challenging, only from the position of there being many areas that could be discussed, and having to hone in on only some examples of the many that related to health when visiting the project.

7.6.2  Engagement and Collaboration

STP as the contractor regularly engages with the Client on a monthly, weekly, and daily basis dependant on the nature of the work. In what was observed to be a collaborative approach, STP share health, and safety information, including occupational exposure data with both the Client and the Union upon request.

7.6.3  Training and Awareness

While there are no specific competency standards set by law for health and safety professionals, the Project chose to set such a Standard with nationally adopted certification schemes used to link in with competency requirements. This has resulted in an observed improved level of understanding and competence with regards to managing health risks.

As an example, the recently retired health and safety manager was a Certified Safety Professional (CSP). The existing health and safety manager is an Associated Safety Professional (ASP) and is working towards her CSP. The project also has the following competencies within the health and safety team:

- Two members are Construction Health and Safety Technicians (CHST) which leads to the ASP designation.
- Two members are OSHA Certified trainers that can deliver onsite safety and health training. Further, these professionals can deliver first aid training to members of the workforce.

Key Contacts:

Chris Dixon, Project Manager, Seattle Tunnel Partners
Sandy Winter, Health and Safety Manager, Seattle Tunnel Partners
Chris Miele, Certified Industrial Hygienist, Amec Foster Wheeler

Snapshot:

The SR 99 Alaskan Way Viaduct is being replaced with an approximately two-mile tunnel underneath downtown Seattle. Built via a 17.4m diameter TBM known as “Bertha”, it is the world’s largest earth pressure balanced (EPB) TBM.

At the time of the visit, Bertha had broken through, however the project was still a hive of activity with many civil works occurring in addition to the mammoth task of TBM disassembly.
The site also has at least one Emergency Trained Staff (EMT) on site at any point in time.

In addition, occupational hygienists support the project through a separate consultancy firm. Those hygienists are Certified Industrial Hygienists (CIH), which is similar to the Certified Occupational Hygienist (COH) designation in Australia.

In addition, the Project installed the requirement that all workers on the project must have completed the OSHA 10 hour Construction Training Course, with Supervisors needing to complete the OSHA 30 hour Construction Training Course and First Aid/CPD training.

### 7.6.4 Standards

Within the US health and safety regulatory framework there are what’s known as “state plan states.” These states are able to run their own health and safety programs as they have been deemed to be at least as effective as OSHA. Therefore, in these States, OSHA does not have jurisdiction over health and safety (with some exceptions) [112]. Washington is one of those states, and their health and safety regulation is performed by the Division of Occupational Safety and Health (DOSH). DOSH, therefore, Regulate against the Standards, which are at least as protective as those from OSHA, including the impending Silica Rule.

There were no specific Standards pertaining to health imposed on the Contractor from the Client, over and above the legal requirements from the State of Washington. However, it was clear that the Contractor had placed a large degree of focus on this key area, and in many areas were operating above and beyond these requirements.

The Contractor is a large Joint Venture that consists of many large organisations, and as such, they needed to develop a consolidated health and safety system. To do this, they built on the existing programs of each of the JV partners to create a strengthened program. Due to its success on this project, it is now being used as a template for future tunnelling projects carried out by the JV partners on their own separate projects.

### 7.6.5 Health in Design

The health and safety team were heavily involved in the original design process which meant that the TBM had a lot of engineering controls designed to minimise risks to health and safety, including a focus on dust control.

As an example, the ventilation ducting on the TBM was hard-smooth ducting with no flexible ducting on the TBM (which traditionally results in losses to air velocity). Fresh air was delivered to the back of the TBM via a vent bag and then split into two hard ducts which routed the air both on the left and the right-hand side of the TBM to where it was
delivered to the ring build area with dampeners installed to direct the flow. The air then travelled out of the tunnel through the TBM and civil works areas. All ventilation was designed to be operated in reverse air flow in case of fire.

The TBM broke down during the course of the project which created its own challenges. However, the health and safety team also saw that this downtime created an opportunity to undertake testing to determine if additional modifications were needed, one of which related to the ventilation system.

Extensive testing was performed to document the air velocity at different locations throughout the TBM, in the tunnel, and in the civil works area. The impact of the civil works crews, which were located approximately 300m behind the face, raised questions regarding their impact on the overall ventilation efficiency throughout the tunnel. The results of air velocity testing were reviewed by a ventilation specialist who developed a 3D air flow model to validate the original design. As a result, minor modifications were engineered through the use of dampeners to improve airflow throughout both the TBM and the tunnel area (refer Figure 25).

The excavated spoil was relatively dry from the TBM, so water and polymers were added to keep it wet while it was conveyed out of the tunnel. To further control dusts, the conveyor system was enclosed inside the tunnel in certain areas which had been found to be sources of dust exposure (e.g. near areas of high ventilation). After the conveyor belt had left the tunnel and had dumped the spoil on the surface, it went through a series of belt washers and belt scrapers so that the belt returned clean therefore minimising dust exposure from the conveyor.

Clean-up on the TBM was performed through wet methods (water) and HEPA vacuum control which assisted in dust control also. Dry brush sweeping was prohibited.

Dust controls included:
- Dampeners to improve air flow
- Covered conveyors in the tunnel
- Conveyor belt wash station with belt scrapers
- HEPA vacuums
- Prohibition on dry brush sweeping

Occupational hygienists were involved in developing protocols for new processes to ensure a focus on health protection.

Figure 25 – Right-hand side ventilation ducting showing dampener
7.6.6 Health Risk Management

Integrating occupational health with other key areas of safety and occupational hygiene was challenging on this project as there are no legal medical “fit for duty” requirements in the US. Despite trying, the Contractor could not impose minimum health standards that workers needed to meet to ensure a certain level of health, as this was opposed by the local Union. Due to this, health risk management focused on controlling exposures to the workforce.

One of the main functions of occupational hygienists was to work with the Project at the start of any new process. The hygienist was involved in the planning and set up, and performs monitoring at the start of the process or activity to verify if control measures are effective or if improvements are required. The hygienist then provides a list of recommendations that carried through into Activity Hazard Analysis (equivalent to a SWMS) for that activity.

Given the scale of this project, many of the specialised designed tasks and processes involved were unique. This meant that occupational hygienists were heavily involved in the start of the project to assist the Project team in developing protocols that ensured that health and safety risks were adequately controlled.

Occupational hygienists continue to support the project through providing specialist advice and monitoring at varying stages of the project on a regular basis. They are also used as a technical resource if the project team have questions or concerns relating to a question of exposure or control.

This project is unique in that the civil construction process occurs at the same time as tunnelling, with civil teams working approximately 300 metres behind the face of the TBM. This meant that the project needed to manage health risks associated with tunnelling and civil construction in parallel, in addition to managing the risks associated with the interface of both teams, and the work of one crew impacting on others. It was due to this complexity that a significant amount of focus was placed on collaborating with specialists to design protocols at the start of each activity with period monitoring and inspection as the task progressed. On this project, the presence of control measures are checked as part of daily site walks in conjunction with daily monitoring.

Overall the top health and safety risks reported were associated with pH-modified water (from water runoff from concrete pours) in addition to concrete burns, working at heights and manual handling risks.

A project-specific Silica Control Program clearly outlined what was required for each set task.

These requirements were carried through into SWMS.

Respiratory protection used was always reusable which resulted in better compliance than using disposable dust masks.
7.6.7 Targeted Control Measures

7.6.7.1 Silica

The Silica Rule has not made a noticeable impact on this project recently, primarily due to the fact that many of the requirements in the rule were already being implemented as a best practice approach prior to its release, including the lower Exposure Standard.

The project has a documented Control of Exposure to Respirable Crystalline Silica (RCS) Program which outlines the methods by which the project controls exposure to silica. As part of that program, the project activities that generate silica are clearly listed, along with the minimum mandatory control measures that are to be implemented and carried through into the SWMS (refer to the example in Table 1).

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>MANNER OF ACTIVITY</th>
<th>ENGINEERING CONTROLS</th>
<th>ADMINISTRATIVE CONTROLS</th>
<th>PERSONAL PROTECTIVE EQUIPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean-up of materials that are known to or could foreseeably result in the generation of airborne respirable crystalline silica.</td>
<td>Clean-up within an enclosed area.</td>
<td>(2) The HEPA filtered ventilation machine shall continue to operate until clean-up is complete.</td>
<td>(1) Supervisors will assure the use of compressed air, dry sweeping, and reuse of vacuum filters are prohibited.</td>
<td>(1) None, if engineering control is effective.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) Horizontal surfaces shall be wetted and cleaned using a HEPA filtered wet/dry vacuum, or be wet wiped.</td>
<td>(2) Slurry and wetted debris shall be containerized for disposal.</td>
<td>(2) Use of a negative pressure, air-purifying respirator with protection value of 10 or greater if engineering control is ineffective.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3) For large areas, a berm will be built and the floors shall be water washed; squeezed, and the slurry picked up using a HEPA filtered wet/dry vacuum.</td>
<td>(3) Filters, including wet/dry vacuum filters will be containerized.</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 – Excerpt from the SR 99 STP Control of Exposure to Respirable Crystalline Silica (RCS) Program

During a site walkthrough on the project, many silica exposure control measures were observed which included:

1. Concrete drill operators used drills suppressed by water and used half-face re-usable respiratory protection with particulate filters;
2. Hollow drilling in place using inbuilt ventilation extraction through a HEPA filter;
3. Wet saw systems with catch pans used to capture and recirculate the water to prevent muck build up; and
4. Many portable HEPA filtration systems onsite for ease of access and use.

The project uses respiratory protection as a last-resort, or where higher-order control measures are in the process of being implemented only. Any worker who is required to wear a respirator is provided a silica medical, must be clean shaven, and is provided a fit test for the make and model of respirator used, along with training as part of a respiratory protection programme. In instances where a worker who is enrolled in the programme is identified as having an occupational lung disease, such as silicosis, the Contractor is required to notify the State (DOSH), the Union, and the worker.

For the majority of tasks, tunnel workers did not require the use of respiratory protection. However, there were a number of tasks in which it was required for civil workers due to the need to drill or cut into precast concrete.

Regardless of the number of engineering controls in use, there always remains some control measures that rely on human behaviour to be effective such as administrative and PPE controls. During the site walkthrough, the compliance with the use of respiratory protection was observed to be excellent, which across this major project with hundreds of workers still heavily involved, is a testament to itself.

There were a few factors that are anticipated to have resulted in better compliance than have been observed in Australian tunnelling operations. These included the use of reusable, rather than disposable, respiratory protection,
and also the way in which non-compliance was addressed. For example, if a worker is observed not wearing respiratory protection in an area where they should be, they receive an immediate warning. If a worker receives three warnings, then disciplinary action is taken on the worker's Supervisor, if the Supervisor does not take effective action, then the Superintendent is disciplined. If effective action is not taken at that level, then the company owner is disciplined.

7.6.7.2 Diesel emissions

Tier 3 and 4 diesel engines were used with each item of heavy plant fitted with diesel particulate filters (DPFs). Each item of plant was tested for diesel emissions prior to being able to work underground, and air quality testing was performed on a daily basis by a trained member of the STP health and safety team.

Daily testing includes measurements for air velocity, temperature, humidity, carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen dioxide, and aldehydes (at 5-feet and 10-feet away from the source, and downstream). In addition to this testing, the CIH attends site and performs routine testing for DPM. The project uses strict action levels, which if exceeded, result in modifications and additional controls.
Relevance to Australia

8.1 Leadership

Demonstrated leadership in occupational health and hygiene is an essential part of an effective and sustainable program that reduces ill health. It is more than the traditional focus on fitness for duty, rehabilitation, or drug and alcohol testing, but more so on the prevention of occupational illness or disease.

International leadership in this area was demonstrated to come in many forms including successful Client-driven programs in the UK, from the Regulator in Norway and Switzerland, and from a mixture of the Regulator, Client, and Contractor, in the USA. These visits demonstrated that Leadership, from at least one, but preferably multiple stakeholders, were an essential element in driving occupational health protection. Leadership resulted in the prioritisation of health by upper management, which led to a focus on standards, performance management, review, and then continual improvement.

The importance of occupational health and wellbeing is key theme in the health and safety strategy of major projects in the UK. Leadership on this issue at the highest levels of the Client organisation was observed to be successful in driving a focus on ill health prevention during design, as part of the project culture, and through the supply chain which subsequently created more stakeholders that also took ownership and in turn, their own leadership on this issue.

Notwithstanding, Regulatory involvement, and enforcement, by its nature, creates a positive impact in the amount of attention, awareness, and therefore leadership, and cannot be understated.

A common theme among each key leading stakeholder was the depth of awareness and experience that the particular stakeholder had in this area. That being, the more qualified and competent the leading person or group within that stakeholder was, the more of a driver they had to protect the health of their workforce.

Another common element was the level of resourcing to ensure that occupational health received adequate focus. Whether that be from the Client, the Regulator, or the Contractor, managing occupational health and preventing illness and disease, requires a well-resourced team that collaborates with specialists such as occupational hygienists and medical practitioners. In each example of health leadership, the stakeholder was well equipped with the necessary resources to enable them to manage the risk to their workforce effectively. Each of the leading stakeholders had qualified resources that were specifically managing occupational health and occupational hygiene on their major projects, in addition to, and in collaboration with, their safety team, which resulted in a well-balanced approach.

The UK model, in which Leadership is publicly displayed through charters and strategic plans, which is then followed through via contractual arrangements to the Contractor along with the provision of adequate resources, is anticipated to be most readily applicable to an Australian context. As that model involves both governance and collaboration across a multitude of stakeholders, it is anticipated to ultimately drive a culture of health leadership through the supply chain, leading to greater sustainability in the industry. Added leadership from the Regulator on this issue is anticipated to result in a renewed amount of interest, and therefore attention, to compliment a Client-driven approach.
8.2 Engagement and Collaboration

Engagement between Clients, Contractors, the Regulator, researchers, and industry organisations, has resulted in a large amount of knowledge which has been successfully shared across tunnelling projects in the UK. This open process of discussing lessons learned, and then investigating and sharing solutions and best practice approaches, has enabled these mega-projects to adopt good practices earlier than they may have otherwise. It has also resulted in the production of improved best-practice guides and benchmarking tools that drive improved health performance overall.

Initiatives on these major projects such as Occupational Health Forums provide great opportunities for each key stakeholder to participate and share lessons and good practice. Some projects have placed contractual incentives for close collaboration, appreciating its importance in driving health protection.

The formation of industry groups through which major projects collaborate and share information, provide a consultative forum for driving best practice approaches, as they take into account the needs of all stakeholders through consultation and a participatory approach, ultimately resulting in useful tools and guides that positively impact the industry.

Recognising the number of stakeholders involved, there is no one size fits all approach to collaboration in the form of one single industry group. While many different groups were observed, they complimented and respected each other through their multifaceted approaches.

One of the challenges in reducing ill health is getting the information to the people that need it most. It is recognised that while larger organisations may have the luxury of having an occupational hygienist on staff or consulting to them, many smaller organisations just cannot afford a hygienist to work for them within their organisation. Industry campaigns such as Breathe Freely were observed to be a key conduit in raising awareness of the issue of occupational lung disease. In addition, industry groups have been successful in advocating for stronger legislation through raising awareness at the highest levels of Government in addition to grass-roots campaigning.

Working in collaboration with key industry groups and stakeholders in Australia would greatly assist in raising awareness amongst the wider industry. Coupled with the provision of useful tools including benchmarking guidance, it would help make a real difference on Australian work sites.

In Australia, each tunnelling project operates in relative isolation to each other with little collaboration between major projects on health issues. While knowledge sharing may occur between tunnelling sites on the same project, it rarely occurs between major projects. Having an industry group where large tunnelling projects and key stakeholders are invited to collaborate and share lessons learned is seen as a key part of a best-practice framework.

8.2.1 Research

Collaboration with research institutions is also a common theme internationally. Engaging research partners to undertake independent assessments has resulted in a greater understanding of the extent of exposures across the industry in the UK and Norway, which has lead to greater awareness and subsequent controls being designed and implemented.

International tunnelling projects understand and utilise the value of independent research to track the effectiveness of current practices on the magnitude of exposure, the extent of illness and disease, and the impact of certain strategies such as shift rostering on fatigue for example.

With so many mega-projects planned for, or in progress, in Australia, we are being presented with a rare, yet vital opportunity, to learn and adapt from the processes being implemented along the way. The concept of longitudinal research, coupled with traditional research, is a welcome one, particularly where researchers are embedded into Contractor teams to gain an understanding of the effectiveness of interventions as they occur.
8.3 Training and Awareness

8.3.1 Training

Training that involves practical examples, behavioural modelling, and dialogue has been demonstrated to be more effective than other methods of safety and health training such as passive computer-based and distance training methods[113]. It is becoming increasingly popular for tunnelling projects in Australia to include mandatory health and safety training in an on-line system that participants must access and complete prior to arriving onsite. Such training in health aspects is not always prepared by an occupational hygienist and is not always accurate. Further, conveying the importance of health over a computer-voiced distance learning module has not appeared to result in any increased awareness of health risks based on the author's observations.

Moving away from the traditional classroom-style PowerPoint filled with dot points of information, and towards an immersive, multi-media experience of behavioural based learning was the theme well demonstrated in the UK and the USA. Specifically, induction courses such as the one on Tideway, target human behaviour as the root cause of health and safety incidents. Rather than training participants in a select number of rules to follow, which can be readily forgotten, that course leaves participants with a lasting memory of how it felt to be in each situation, and how the various communication techniques were applied.

The use of simulations, such the LUSKInS developed by Loughborough University, or the use of Video Exposure Monitoring through a Helmet-CAM system, are all interactive approaches to training that represent an improvement over traditional methods.

8.3.2 Awareness Campaigns

Project-wide awareness campaigns that target silica and dust control across common areas and tasks have been effective at both raising awareness, but also demonstrating its importance. The use of powerful and realistic videos, such as the ones on Crossrail provide depth to a campaign, highlighting that they need to be more than a simple “poster” approach.

8.3.3 Regulator-produced Material

The Regulator in the UK, Norway, Switzerland, and the US have all worked to produce clear guidance information ranging from general awareness, typical expected controls, and clear processes that will be followed in the event of a non-compliance. All of these items are identified as gaps in the current Australian WHS framework.
8.4 Standards

8.4.1 Legal requirements

International health and safety Regulators have worked to produce clear information to assist employers to assess, control, maintain, review, and communicate health risks. Helpful information was sighted on the provision of training and instruction, explanations of how to monitor for hazards (e.g., silica concentrations in air), and requirements surrounding health surveillance. At a basic level, there is a requirement to notify a central agency of a diagnosis of an occupational disease such as silicosis in each country.

The amount of focus and information published internationally on the assessment and control of health hazards such as silica, provide further guidance, clarity, and context on what is expected of employers and employees. It was also common for countries to publish guidance for possible areas of enforcement by the Regulator, and what needed to happen in the case of a non-compliance.

The level of international legal requirements highlighted the lack of an equivalent level in Australia. In an Australian context, the use of a Code of Practice, rather than Guidance material, is suitable where:

a) Guidance is necessary to enable compliance with duties contained in the WHS Act and/or Regulations, as the legislative provisions for health are outcome focussed and do not provide much detail;

b) There is clear evidence of a significant risk or widespread WHS problem where evidentiary status of a code will elevate the importance of the issue;

c) There are certain preferred or recommended methods to be used (or standards to be met) to achieve compliance; and

d) Information on the hazard, risks and control measures is well established, reflected the state of knowledge and therefore will not require frequent updating [37].

Based on international standards reviewed on this Fellowship, along with an understanding of the current state of the tunnelling industry in Australia, the production of a Code of Practice would bring Australia closer in line with international legal requirements.

8.4.2 Contractual Requirements

All major tunnelling projects in the UK have mandated additional targeted Contractual requirements for occupational health, occupational hygiene, and wellbeing. Those in the US, Norway, or Switzerland, either have additional requirements or refer to legislation that is more stringent than in Australia.

Clearly outlining such requirements not only sets a level playing field during the Tender process, but it also enables the Client to reduce the amount of uncertainty with regards to the provision of resources and measures that will ultimately result in reduced illness and disease on tunnelling projects. Simply requiring a Contractor to comply with WHS Regulations is an insufficient approach to prevent occupational illness and disease.

Key elements that were identified to be necessary for such Contractual requirements include specifications for:

- Levels of competency and resourcing for clinical staff, occupational hygienists, and health and safety professionals;
- The need for a formalised Health in Design process involving specialists;
- Transparency and information sharing on exposure assessment information;
- Standardised health risk assessment, control, review, and reporting approaches;
- Level of detail required in training programs;
Reporting against prescribed benchmarks to track health performance;
- Key Performance Indicators;
- Collaboration on research;
- Health surveillance; and
- Wellbeing.

8.4.3 Competency

The vagueness of the term “competent person” in Australian legislation, can result in the lack of qualified and experienced resources engaged to manage health risks. There were a few different approaches observed to overcome this challenge internationally, which included linking certain roles with professional industry certification schemes (e.g. Certified industrial Hygienist and Certified Safety Professional in the USA) or for the Client to clearly outline minimum competency standards, which are then procured for use by Contractor teams (as in the UK).

The importance of a competence framework in this area was highlighted by many projects, where clear competency requirements were set for the occupational health team, occupational hygienists, clinical teams, and safety professionals.

The model of “pooled resourcing” in which the Client procures specialist providers which are then used by multiple Contractors, provides greater control of the quality provided by these specialists in addition to greater knowledge sharing and priority of service. Such pooled resources then provide training to key members of the project team (e.g. project management and supervisors). This model still enables the Contractors and occupational hygienists to take responsibility (and risk) for the work performed but makes it easier for Contractors to access experienced occupational hygienists, which is can be a key issue in Australia due to limited resource availability.

8.4.4 Exposure Standards

There were two differing models observed internationally with regards to the use of Exposure Standards. The Swiss approach to a strict Exposure Standard, whereby no sample can exceed the prescribed limit at any point, provided a clear approach to compliance. In comparison to the Australian and UK model, where compliance with the Exposure Standard can be achieved where data is below the Exposure Standard, to within an “acceptable degree of certainty” [101], the Swiss approach is straightforward and has led to overall lower exposures, as the Regulator (insurer) can stop the Contractors work in the instance of any breach. The use of P2 respiratory protection, aka “dust masks” are also prohibited to be used in Switzerland to reduce exposure as a long-term control, thereby resulting in an improved focus on engineering controls.

The concept of reducing the Exposure Standards over time as is being done on HS2, is a novel one, particularly as the majority of Exposure Standards in Australia, including silica, are not protective of occupational illness and disease. A key challenge for Australian tunnelling in the first instance for some projects, however, may be to comply with the current Exposure Standards, rather than prescribing a lower level. Notwithstanding this, if there was a requirement to reduce exposure even lower over set periods of time, this may drive the focus to higher level controls as the cost-benefit of investing in more efficient engineering controls may be realised over extended periods of time.
8.5 Health in Design

The involvement of specialists such as occupational hygienists and health practitioners in the design stage has become commonplace in the UK. Addressing the element of “health” as a design criterion has resulted in higher-order controls being able to be applied at the time of design.

The concept of requiring Contractors to provide evidence on how they have engaged with specialists such as occupational hygienists, ergonomists, and medical practitioners during the design process is a welcome approach. If health risks are not eliminated at the design stage, then Contractors are required to demonstrate how health risks will be mitigated, what controls will be applied, and how they will be applied for the project life-cycle from construction through to the operation and maintenance phase. This essentially highlights the cost of ill-health prevention measures and enables the inclusion of health in the cost-benefit analysis process when selecting appropriate control measures.

8.6 Program Health Risk Management

8.6.1 Health Risk Assessment

The use of an initial health risk assessment to drive decisions regarding controls, monitoring, and health surveillance, is a standard practice in the UK. Some countries and projects have further simplified their approach through mandating health surveillance for all tunnel workers, regardless of the assessed risk. The use of technology to assist with this process, such as in the UK, was identified as an innovative approach also.

8.6.2 Leading Indicators

Taking a specific focus on health risk management has been a consistent message across all three major UK tunnelling projects. Where occupational exposure data is reported in Australia above legal standards, it is typically followed by a statement that respiratory protection was available to the workforce but without comment on the level of compliance. There have not been any consistent measures adopted in Australia that record the efficiency of the use of PPE to control occupational exposure.

The use of the Health Impact Frequency Rate (HFIR) as a measure of PPE compliance is a great initiative with direct relevance to Australian tunnelling. Not only would it provide an understanding of the degree of compliance, leading to incremental improvements over time, it is also anticipated to raise awareness of the ineffectiveness of relying on the adequacy of this control measure in the long-term.

8.6.3 Wellbeing

Wellbeing programs designed to target the personal risk factors identified in health needs assessments, result in more meaningful outcomes for the working population. While often wellbeing programs include items such as yoga or free fruit etc., they are not always customised to address the real issues that will make a difference in workers lives. International best practice in this area links the demographic and personal risk factors identified from health surveillance with a wellbeing program.

The inclusion of a performance metric such as the Occupational Health Maturity Matrix whereby the measurable improvement is tracked each year provides a feedback loop for determining the value of the program.

8.6.4 Health Surveillance

Health monitoring can be performed by any medical practitioner in Australia, including those that may not have a good
understanding of the health hazards associated with tunnelling work. A standardised approach would invariably reduce the amount of interpretation on what may be an acceptable degree of ill-health for a tunnel construction worker.

International best practice in this area includes the use of occupational physicians to manage the program complimented by competent health clinical services. It includes a standardised approach for what is deemed “fit for duty” for certain roles and the centralised collection of medical data to enable trends to be reviewed to inform future interventions and policy.

The development of occupational health standards, or the determination of what criteria are acceptable for workers to meet prior to being deemed “fit for duty,” would provide a standardised approach to health management, much like the system that is applied in Australia for Rail Safety Workers. Further, the international approach observed would be a welcome improvement to the current approach taken in Australia.

8.6.5 Review

A program involving a regular and independent review of control measures by persons familiar with tunnelling and occupational hygiene are needed to drive exposure control. Whether that be similar to the Swiss approach where the insurance company audits the Contractor, or the UK approach, where the Client’s occupational hygienist performs an audit, complemented through Regulator involvement, the implementation of controls must be checked by a stakeholder independent of the Contractor. It is important that the Stakeholder has the ability to stop the work if control measures are insufficient.

Heavy involvement and governance from workers compensation insurance agencies such as the approach adopted in Switzerland and the US (for ROCIP), provides a sustainable model without the need for public funding of additional Regulatory resources. It enables greater flexibility of the Standards imposed by those insurance agencies who ultimately are ensuring their own liability, and in doing so, are preventing occupational illness and disease.
8.7 Targeted Health Risk Management

There are many new tools that would enable occupational hygienists to assess exposures to dusts and silica faster, and also provide greater clarity over the areas of peak exposures. The use of the Helmet-CAM system is anticipated to be a useful approach to verify areas or sources of high exposures that may not otherwise be apparent in the regularly changing environment of tunnel construction. The use of a field-based monitoring approach to silica would enable quicker action to be taken to reduce high exposures, and the use of real-time DPM monitors would provide greater clarity on the effectiveness of ventilation and other controls in many areas of a tunnel system. Other initiatives such as the use of canopy air curtains, enclosed cabin filtration systems, dust suppression, and virtual training approaches, all demonstrate the strong linkage of tunnelling with the mining sector. Greater collaboration with the mining sector is seen as an essential step in developing best practice approaches in Australia.

The development of best practice standards for the control of silica dust, as they relate to each project, provides a clear framework for Contractors and Subcontractors to follow when planning work activities. Some of the best guides were those that involved collaboration with the Client, Designers, and Contractors.

A summary of international best-practice engineering controls include:

- Designing airflow on TBMs to result in efficient delivery and extraction where workers are located across the TBM gantries.
- The use of hard ducting on TBMs with air being supplied to the front most portion of the TBM, being the ring build area.
- The use of registers and dampeners to assist in providing air flow to low-velocity areas of the TBM.
- Installation of conveyor belt wash boxes to ensure the conveyor belt is washed, scraped and returned clean to the TBM after delivering spoil to the dumping area.
- Installing covers over conveyors inside the tunnel where high airflow can dry out spoil along the conveyor.
- Using a small dust filter (Class L or M) during all welding activities underground.
- Supplying additional ventilation for tasks located back from ventilation extraction systems such as shotcrete activities.
- The use of atomised spray rings for dust control.
- The use of localised cooling underground to reduce thermal heat stress.
- The use of precast concrete invert panels instead of concrete paving after TBM ring construction.
- The use of specific types of nozzles for dust control, dependant on the application, to maximise its effectiveness.
- The use of in-built or retrofitted Diesel Particulate Filters (DPFs), along with in-built alarming systems alerting the operator when changeover was required through the installation of real-time backpressure alarm systems.
- The use of enclosed cabin filtration systems with air flow directed down towards the floor, which is monitored and assessed on an ongoing basis to inform filter changeout.
- The use of canopy air curtains to protect operators from high levels of dust exposure to reduce reliance on PPE.

A summary of international best-practice administrative controls include:

- Using real-time monitoring coupled with real-time video (e.g. Helmet CAM) to identify peak sources of exposure.
- Using field-based monitoring for silica to enable quicker action to be taken to reduce silica exposure.
- Using previous data to inform typical levels of exposure to hazards such as silica, to inform risk assessments in the field.
- The use of reduced Exposure Standards to drive increased engineering controls.
- Use of HEPA vacuums and water for clean-up and the elimination of use of brooms.
The provision of training, fit testing and implementing a clean shaven policy for respiratory protection.

A minimum of monthly dust monitoring performed by an occupational hygienist accompanied by a report with listed recommendations for improvement.

Regular (daily) dust monitoring inspections by trained engineers using direct reading (real time) instrumentation which is reported to the occupational hygienist.

Centralised health surveillance programs with defined fit for duty requirements, complimented through frequent lung function testing and medical surveillance for those workers likely to be exposed to the highest dust and silica concentrations.

Minimum requirements for health surveillance based on role, rather than perceived level of risk, which includes all TBM workers, mined workers, and shotcretors.

A summary of international best-practice PPE controls include:

- Use of Full-face P3 PAPR RPE for shotcretors and others located within the shotcreting exclusion zone (typically 20m around that activity).
- The use of half-face reusable RPE with P2 filters for any other workers who are required to use RPE.
- P2 disposable dust masks to be used only for short-duration activities, not to reduce exposure to below the Exposure Standard, and never for the period of an entire shift.
8.8 Sustainability

Systems such as the use of the Occupational Health Maturity Matrix (OHMM) drive best practice through the supply chain. The ability to benchmark performance lead to a greater understanding and a focus on the processes needed to reduce ill health. The use of a standardised OHMM system in the Australian tunnelling industry would enable improved health performance, centred around the projects ability to influence external stakeholders on a sustainable level, over time.

Each major tunnelling project in the UK has or is in the process of developing a Legacy Learning website. Establishing a platform where knowledge is shared early on, has enabled good practice guidance to be developed and ensures that “good” information is not lost when team members leave the project. It also creates a library of good practice methods which ultimately raises the bar across the industry as a whole. The creation of case studies or knowledge documents on health is rare in Australia, with only one tunnelling project taking the initiative and publishing such information, compared to the many currently under construction [114].
The new tunnel will be the biggest infrastructure project ever undertaken by the UK water industry.

The 7.2 km long storm tunnel is part of Thames Water's £2.2 billion Thames Tideway project to clean up the River Thames. The tunnel ships 1.2 My every storm event to allow a natural flow.

The tunnel runs 25 m below ground from Old Street to Acton Storm Tanks in West London to south Bermondsey in the east. The tunnel will be 24 m below ground in central London.

In 2018 we see the start of 10 years of tunnelling under London.

A solution for London.

SEE THE THAMES TIDEWAY TUNNEL'S ROUTE THROUGH LONDON

Find out more about the Thames Tideway Tunnel, one of the world's largest, by visiting our new display.

The Thames Tideway Tunnel is the largest project in the UK water sector, and one of the world's largest infrastructure projects.

The tunnel runs under London's history, from the ancient Roman era to today's modern city. In 10 years, it will be completed, bringing a cleaner River Thames for future generations.

ACTON STORM TANKS

Starting in the west, the tunnel will help prevent pollution to the river and further reduce occur.
Conclusions

For every Australian worker who loses their life from an injury sustained at work, more than 8 will die from a work-related illness or disease each year [1]. Controlling exposures to disease-causing hazards have been identified as an area requiring improvement within the Construction sector [2]. In comparison to the general construction industry, tunnel construction workers have an increased risk of developing silicosis, COPD, adverse respiratory symptoms, double the rate of lung function decline than heavy smokers, asthma, general airflow limitation, and lung cancer [3,4,5,6].

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.

The existing health and safety framework that the tunnelling industry operates within needs improvement to protect the health of these workers. It has limitations, largely due to a low level of awareness and focus in this area, and would benefit from greater widespread leadership on health; greater considerations of health in design; a standardised health risk assessment framework leading to more robust exposure monitoring and higher take-up of health surveillance; a centralised health surveillance system complimented through disease notification requirements; increased regulatory enforcement; engagement with research partners; and overall, an increase in training leading to greater knowledge and skills to effectively manage these issues. In addition, the creation of a common framework for the collection of exposure monitoring and disease prevalence data would enable lessons that could be learned and then shared as collective knowledge across the tunnelling industry.

This Fellowship sought to understand the limitations of our current approach and investigate international best practices to fill these gaps through visits with international organisations and tunnelling projects in Norway, Switzerland, the UK, and the USA. Eight overarching elements were established based on a review of existing health and safety best practice frameworks. Each element was reviewed in depth to understand the relevant best-practice approach taken internationally, which included:

1. Leadership
2. Engagement and Collaboration
3. Training and Awareness
4. Standards
5. Health in Design
6. Program Health Risk Management
7. Targeted Health Risk Management
8. Sustainability

This fellowship demonstrated that visible and effective leadership starting with the Client organisation, formed an essential part of preventing illness and disease. Leadership elicits involvement and awareness of health issues across multiple stakeholders, and ensures that health risks are given adequate attention, focus, and therefore management, through the supply chain. The focus on occupational health must start at the design phase before Tenders are awarded, and must continue to be promoted and outlined through Contractual requirements.

All major tunnelling projects internationally have either mandated targeted Contractual requirements or referred to Standards that are more stringent than in Australia. In an Australian context, simply requiring Contractors to comply with WHS Regulations is insufficient to prevent illness and disease, and therefore Contractual requirements that
pertain to health must be outlined and included in Tender documentation. The method of leaving ill-health prevention to Contractors alone is not conducive to a collaborative approach on this issue, and essentially creates an imbalanced approach to Tender selection, if one Contractor has solely taken the initiative to plan a work environment that controls exposure to carcinogenic agents in comparison to one that has not. While one may argue that going above and beyond the minimum legal requirements to protect the health of the workforce may be seen as a possible competitive advantage in a highly competitive market, all things come at a cost, and the competitive advantage is only realised if the Government Client who commissioned the work, includes such requirements as part of the Tender submission and evaluation process. Of all the major tunnelling contracts in Australia, only one has demonstrated their leadership on this issue and included this requirement for the Principal Contractor to date [115].

International best-practice in leadership came in many forms, including leadership from the Client, the Regulator, and from Contractors themselves. Leadership from the highest level (Client or Regulator), was observed to create more Stakeholders that also began to drive health within the supply chain, with the general finding that the more qualified and competent the Stakeholder was, the stronger they lead health protection efforts.

Engagement and collaboration involving other stakeholders were observed to create a positive culture surrounding health protection. International best practice demonstrated that collaboration across multiple tunnelling projects in the UK has resulted in sharing of knowledge whereby good practices were adopted earlier than they may have otherwise. Initiatives to collaborate within individual projects were also observed to be beneficial, including the use of occupational health forums, and incentivising Contractors for collaborating through Contractual arrangements. Industry groups in this sector have both raised awareness and driven a best practice approach, and engagement with research partners has enabled a greater understanding of the magnitude of the issues leading to better control measures being implemented.

The general level of awareness of health risks associated with tunnelling activities is varied in Australia. It is becoming increasingly popular for Australian projects to include mandatory health and safety training in an on-line system that is completed prior to arriving onsite. Such training in health aspects is not always prepared by specialists, however, and is not always accurate. Further, conveying the importance of health over a computer-voiced distant learning module has not appeared to result in noticeably increased awareness of health risks based on the author's observations. International best practice in this area involved the use of immersive, multi-media experiences involving behaviour-based learning and interactive approaches that elicit participation from the workforce, complimented by engaging awareness campaigns.

International health and safety Regulators have worked to produce clear information to assist employers to assess, document, communicate, control, and review health risks. They have provided guidance on training and instruction, how hazards can be monitored, and all have a requirement for surveillance. At a basic level, there is a requirement to notify a central agency of a diagnosis of an occupational disease such as silicosis in each country. The amount of focus and information published internationally on the assessment and control of health hazards such as silica, provide further guidance, clarity, and context on what is expected of employers and employees when controlling exposure.

Different approaches were observed to define “competency” internationally. Pooled resourcing, in which the Client procured specialist providers which were then used by multiple Contractors, provided greater control of the quality provided by these specialists in addition to greater knowledge sharing and priority of service.

A heavy reliance on disposable respiratory protection with general low compliance ultimately results in exposures above the Exposure Standard in Australia. International best practice removes the use of “dust masks” and forces a focus on higher order controls, with higher level PPE used for set tasks. Further, there are no exposure standards for respirable dust or DPM in Australia. Internationally it was found that other countries have adopted these Exposure Standards, and the Swiss model of imposing a strict “do not exceed at any time” approach, provides a clear and straightforward approach to compliance. Disposable respiratory protection is not used to reduce exposure to the Exposure Standard in the US, UK or Switzerland, and there is a strict prohibition of exceedances, with applications
required by exception from the Regulator in Switzerland to use respiratory protection.

Addressing the element of "health" as a design criteria has resulted in higher-order controls being able to be applied at time of design in the UK, where Contractors are required to demonstrate how health risks will be mitigated, what controls will be applied, and how they will be applied for the project life-cycle from construction through to the operation and maintenance phase.

Wellbeing has an impact on health and safety performance but is often not included in health and safety programs in Australia. Wellbeing programs designed to address demographic and personal risk factors are part of the international best practice approach. Standardised metrics for health and wellbeing were observed to lead to overall health improvements.

Current approaches to health surveillance in Australia are mixed. International best practice includes the use of occupational physicians complimented by competent health clinical services, a standardised approach for what is deemed "fit for duty," and the centralised collection of medical data to enable trends to be reviewed to inform future interventions and policy.

Ongoing independent verification of exposure controls by an authority able to stop the Contractors' work, has shown to drive compliance and further control. Such review by an insurance agency, rather than a Regulator, appears to provide a sustainable approach without the need for additional public funding in this area and is a model recommended for review.

There are many new tools that would enable occupational hygienists to assess exposures to dusts, silica, and DPM faster, and also provide greater clarity over the areas of peak exposures. Engineering controls such as the use of canopy air curtains, enclosed cabin filtration systems, dust suppression, and virtual training approaches, all demonstrate the strong linkage of tunnelling with the mining sector. Greater collaboration with the mining sector is seen as an essential step in developing future best practice approaches in Australia.

The development of various best practice standards for the control of silica dust, as they relate to each project, provides a clear framework for Contractors and Subcontractors to follow when planning work activities. Some of the best guides were observed to be those that involved collaboration with the Client, Designers, and Contractors.

Specific control measures are needed to target health hazards, and a number those identified internationally are over and above what are typically implemented in Australia. Some of these include the better use of ventilation, the use of specific dust control measures, the use of Diesel Particulate Filters, and the use of higher-grade respiratory protection. The control measures identified are all directly relevant to an Australian context and should be reviewed with the aim of implementing them in a practical manner on Australian tunnelling projects.

Establishing a platform where knowledge is shared early on, enables good practice guidance to be developed and ensures that "good" information is not lost when team members leave the project. It creates a library of good practice methods which ultimately raises the bar across the industry as a whole. Each major tunnelling project in the UK has or is in the process of developing, a Legacy Learning website where best practice information is shared. The creation of a legacy website early on in the project is seen as a best practice approach for information dissemination.

The prevention of chronic health risks relies on a sustainable approach over time. Performance measures that drive sustainable approaches are commonplace in the UK. Frameworks such as the Occupational Health Maturity Matrix provide a benchmarking tool that drives such sustainable change.

While there are areas of excellence for us in Australia to be proud of, illness and disease prevention can only be achieved when a holistic approach is taken across the entire sector on a sustainable level. There is a large inconsistency across the industry, and as a whole, we can only be judged by our poorest performing project and not our greatest. A number of recommendations are made in the following chapter with the aim of ultimately preserving the health of all Australians who work in the tunnelling industry.
Recommendations

The following recommendations are made with respect to implementing a best-practice approach to the prevention of illness and disease in Australian tunnel workers:

1. A Centralised National Health Surveillance Scheme for workers exposed to a dust disease is needed that includes:
   i. Governance by an occupational physician and specialist in respiratory disease;
   ii. A standardised framework for health surveillance including standards that outline acceptability and appropriate training materials to assist medical practitioners to identify silicosis and other common diseases in tunnel construction workers;
   iii. A system of mandatory reporting of deemed diseases, including silicosis, to be reported to a centralised occupational lung disease register. This should involve addressing the current gap in Australian Work Health and Safety Legislation to include an updated definition of a "serious illness" to include "deemed diseases" such as silicosis, therefore triggering the notification of such diseases, to the State WHS Regulator; and
   iv. The ability to evaluate health surveillance data to enable trends to be reviewed to inform future interventions and policy.

2. Each State WHS Regulator plays an important role in this industry. It is recommended that WHS Regulators engage with major tunnel projects and:
   i. Demonstrate their leadership on health, in addition to safety, through engagement with project leaders and perform regular site visits underground by their competent occupational hygienists;
   ii. Regularly request copies of exposure monitoring data collected from tunnelling projects for review;
   iii. Produce clear guidance to support the existing WHS framework through articulating how compliance can be achieved, what to do if exposure is measured above the Exposure Standard, and the process and consequences of non-compliance; and
   iv. Take a strong approach to regulatory enforcement where inadequate control of health risks are observed and/or where breaches of the Exposure Standard occur.

3. Where the WHS Regulator is incapable of performing the items above due to resource restrictions or lack of qualified occupational hygienists on staff, the model of using an insurance agency, rather than a Regulator, as is the case in Switzerland and the US, may provide a sustainable approach without the need for additional public funding, and is a model that is recommended for further review. Further, the use of an expert advisory body comprising representatives from clients, unions, industry specialists, and government departments, similar to the Standing Committee on Dust Research and Control in NSW mining, may also provide a suitable model.

4. The existing Guide for Tunnelling Work [18] should be replaced with a Code of Practice. that addresses the current gaps of:
   i. Installing requirements to engage and consult with health specialists including occupational hygienists, as part of Health in Design;
   ii. A standardised framework for health risk assessment, control, and review;
   iii. Mandating Workplace Exposure Standards for diesel particulate matter (as elemental carbon) and respirable dust;
   iv. Mandating the use of Diesel Particulate Filters along with a comprehensive diesel emissions control strategy;
   v. Information on typical levels of exposure to silica, diesel exhaust, and other health hazards, along with associated good practice exposure assessment and control methods;
   vi. A standardised framework for exposure assessment, including minimum roles, tasks, and frequency of
assessment;

vii. A standardised framework for health surveillance such that the requirement to undertake such surveillance becomes mandatory for all underground workers;

viii. The current gaps around a “competent person” such that the Code prevents untrained or inexperienced persons from being responsible for assessing the risk to the health of the workforce. Such competency requirements should at minimum be a Full Member of the Australian Institute of Occupational Hygienists (AIOH), working under the governance of a Certified Occupational Hygienist (COH) with experience in the hazards to be assessed; and

ix. Outline of the minimum training requirements for varying roles (e.g. Supervisors and HSE professionals).

It is recommended that the Code is produced through collaboration with professional technical societies such as the Australasian Tunnelling Society (ATS) and the Australian Institute of Occupational Hygienists (AIOH).

5. The prevention of occupational illness and disease relies on effective, knowledgeable, and well-resourced leadership in this area. All Government Clients that fund tunnel projects in Australia should embed an occupational health and hygiene program specifically targeted to the prevention of illness and disease on their major project. To do this, the Government Client should:

i. Include the prevention of occupational illness and disease in their health and safety strategic plan;

ii. Ensure the program focusses on illness and disease prevention (occupational hygiene), medical surveillance (through an occupational physician), and wellbeing;

iii. Work with their Principle Contractors to elicit demonstrated and visible leadership through Occupational Health Charters, or Agreements, which set out clear goals for each party, including a demonstrated commitment and pathways to achieve best practice in occupational health;

iv. Embed specific contractual requirements pertaining to occupational health and hygiene in addition to including such as part of Tender evaluation. Such requirements should afford governance and assurance over health risks through an open and transparent process of documenting risk assessment, risk control, risk review, and continual improvement. At a minimum, Contractors should be required to undertake regular (minimum monthly) exposure assessments for respirable dust, silica, and DPM with results freely provided to Clients along with explanations of control and continuous improvement mechanisms. It should also include performance metrics such as the Occupational Health Maturity Matrix (OHMM) and the Health Impact Frequency Rate (HFIR) to drive compliance initiatives leading to best-practice;

v. Harness the value of independent research through partnering with research institutions to gain an independent view into the efficiency of the process adopted and to inform future policy making; and

vi. Develop a legacy learning website to publish good practice information throughout the project for the benefit of industry.

6. Each tunnel Contractor should document a Health Hazard Exposure Control Management Plan that includes clear roles and responsibilities, how the management plan fits in with the Contractors WHS system, control measures duly listed as per the control hierarchy, methods for ongoing measurement and evaluation, and the requirement that relevant controls should flow down into safe work method statement (SWMS). It should contain the requirement for an awareness campaign to raise the general level of awareness of the health risks associated with silica dust, diesel exhaust and other significant risks to health that are identified.

7. Independent research is needed to define the magnitude and extent of silica dust exposure and ill health incidence in Australia. It is recommended that an independent review is conducted to quantify the extent of disease prevalence in this industry along with current levels of exposure and control effectiveness.

8. Training programs need to be improved to include:

I. Moving to interactive learning involving behaviour-based approaches that elicit participation from the workforce;

ii. Awareness information of the health risks associated with tunnelling work, to be developed in
consultation with occupational hygienists to ensure that information communicated to the workforce is accurate;

iii. Training targeted to management and supervisors to equip such persons with the necessary skills to manage these risks effectively; and

iv. Provision of basic training in the principles of occupational hygiene for all health and safety professionals.

9. Contractors accredited under the Office of the Federal Safety Commissioner (OFSC) are required to submit information on their WHS performance which enables the OFSC to determine WHS trends and benchmarks on a regular basis. However, the information currently required to be reported relates to safety items alone. It is recommended to improve this system through adding a requirement for accredited Contractors to submit health data which should include at a minimum exposure monitoring records, along with a record of actions taken in response to breaches of the Exposure Standard. This would enable a centralised repository of exposure assessment data at a Federal level.

10. The formation of an Industry group with representatives across the major tunnelling projects, is seen as an essential step to collaborate, share lessons learned, raise awareness, and drive a best practice approach. This would also be an appropriate forum to:

i. Collaborate with Clients, Contractors, Regulatory Authorities, and industry associations such as the Australasian Tunnelling Society (ATS), the Australian Institute of Occupational Hygienists (AIOH), and the Thoracic Society of Australia & New Zealand for example;

ii. Launch an industry-wide campaign targeted to the prevention of occupational lung disease;

iii. Develop “best-practice” standards for specific tasks and work groups with known high exposures to silica or other health hazards;

iv. Develop an industry health standard to enable contractors to benchmark themselves as to where they are or need to be in relation to worker health protection; and

v. Collaborate with the mining sector to review synergies with regards to exposure assessment and control measures.

It is noted that some of the recommendations listed above are mirrored in those listed in the Queensland parliamentary inquiry into Coal Workers Pneumoconiosis [25]. The expansion of the terms of reference of that inquiry to include an investigation of the extent of respirable dust and respirable crystalline silica exposure for all workers, including those who work in the tunnelling sector, would be a welcome initiative with the aim of improving the current system.
Limitations

This Fellowship was performed over a period of 5 weeks between May and July 2017. It is not a comprehensive literature review of best practice principles from every country in which tunnelling is performed, and does not propt to include all international best practice approaches. This Fellowship targeted anticipated or known areas of excellence internationally and presented a summarised condensed version of those practices as they are relevant to an Australian context. Further detail can be obtained by contacting the author if required.

While it is recognised that there are limitations with every system, this report does not aim to outline the limitations of other countries’ systems, nor is it intended to defame any person, organisation, company, or country. Notwithstanding this, the recommendations listed in this report do take into account such limitations and have been made with the best intentions with the ultimate aim of preventing illness and disease in Australian tunnel construction workers.

References in the report regarding the magnitude of occupational exposure and the extent of illness and disease in Australian tunnel workers are made with respect to the author’s experience in addition to the experience of others working in the tunnelling sector. They do not relate to one specific project, organisation, company, or client, and should not be construed as such.
References


