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Title: The Application of Risk Management Methods to the Control of Respirable Dust in Underground Mines

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ABSTRACT

Respirable dust is a considerable hazard for underground coal mines, with long term exposure potentially causing disabling lung diseases for workers. Australian mines typically have leading-edge and robust policies and plans for safety hazards such as fire or vehicle interactions. However, applying a risk management framework to the control of dust requires extra thought and consideration. In terms of risk management analytical techniques such as bow-tie analysis, factors such as cumulative exposure effects (time and space), long-developing disease periods and individual worker differences must be taken into account when identifying the unwanted event, the causes that precede it, its subsequent consequences and the controls that prevent or mitigate it. Aggregated effects challenge the normally linear approach of bow-tie methodology.

The aim of this paper is to evaluate the overall approach the Australian coal mining industry has taken in recent times in managing respirable dust. To guide the discussion, a bow-tie for managing risks associated with hazardous levels of dust in the underground coal environment has been developed. The bow-tie included controls that are indicative of those being used by the industry. Another aim is to evaluate the application of bow-tie analysis to health-related mining hazards.

Results show that although controls are available to both prevent the amount of atmospheric dust generated and reduce the amount of time that workers are exposed to a harmful atmosphere, the recent resurgence of black lung disease in Queensland suggest that controls have not been performing as effectively as was believed. We highlight, using the bow-tie, that prevention or dust suppression techniques must be the focus of any dust management system and determining appropriate methods to assess and validate their operational performance is vital.

INTRODUCTION

This paper addresses the management of coal dust in underground mining operations in Queensland. For a number of years, exceedances have existed which indicates that the magnitude of this problem has not been clearly understood (Bofinger, Cliff & Tiernan 1995; Cliff & Kizil 2002; Djukic & Gill 2016) and subsequently has not been managed adequately across the industry. The key to implementation of modern Workplace Health and Safety (WHS) legislation is the requirement to reduce health and safety risks to workers to as low as reasonably practicable. There is an emphasis on Duty of Care, where the onus is on the mine operator to establish risk levels and provide a work environment in which employees are not exposed to unacceptable levels of risk and where information, instruction, training and supervision are provided. The Duty of Care is shared between employer and employee, however the primary responsibility rests with the employer, who has the largest control over working conditions. The legislation provides guidance on acceptable levels, through exposure standards, not to be exceeded. The Queensland Coal Mining Health and Safety Regulations 2001 limit respirable dust exposure to levels not exceeding 3.00 milligrams per cubic metre (mg/m3) of air during any eight hour shift.

The safety maturity model concept has been likened to a journey with a strong focus on the continual improvement and effectiveness of the standards relating to safety culture development rather than simply compliance. This concept has been applied within a number of “high hazard” industries such as aviation, rail and petro-chemical industries, with the level of maturity referring to the maturity of the organisation’s behaviour and not the maturity of the safety managements systems. Maturity levels move through a set of ascending step changes from “vulnerable” to “reactive” to “compliant”, with the largest step change being movement from “compliant” to “proactive”. The final step is described as “resilient” which indicates successfully integrated safety and risk management strategies within organisational operations.

However, safety management is more advanced than health management, often due to the perception of risk (or lack thereof) surrounding health issues. Safety risks are generally more visible, and therefore more salient, whereas health risks are often not immediately visible. Safety consequences usually have an immediate impact whereas health consequences are generally less visible immediately and often have a latency period of many years. Adding to the complexity of the situation are confounding risk factors such as the multi-factorial nature of most occupational diseases, individual inherent health differences (e.g. predisposing medical conditions) and transiency within the workforce making it difficult to identify exposure and understand causal relationships.

The health effects of long term exposure to coal dust are significant. The inhalable dust fraction has been defined by ISO 7708 (AS3640-2004) and is the dust fraction of the airborne particles which are taken through the nose or mouth during breathing into the body. Inhalable dust is made up of all the dust sizes that can deposit throughout the respiratory tract, and includes dust which will deposit in the upper and lower airways of the respiratory tract and through mucocilary clearance mechanisms in the gastrointestinal tract. The larger particles deposit in the upper airways (nose and throat). The smaller particles can penetrate the upper airways and deposit in the lungs (thoracic fraction) and respirable finer particles can penetrate alveolar region or gas exchange region (respirable fraction). The potential of coal dust to cause pneumoconiosis has long been recognised, and is essentially linked to exposure to respirable dust.

In 1995 Bofinger, Cliff and Tiernan reported on personal and static respirable dust monitoring over three years at four longwall mines in Queensland. Conditions between mines varied and the results of the personal monitoring also showed considerable variation within the mines (Figure 1). During the years 1992 to 1994, twenty per cent of measurements exceeded the Queensland Regulation respirable dust limit of 3mg/m3. Static measurements indicated a trend for increasing dust concentrations as the distance from the maingate increased. In 2002, Cliff and Kizil analysed personal respirable coal dust measurements recorded by each mine and the Department of Natural Resource and Mines up to mid-2001 for the 11 longwall mines in Queensland. Measurements exceeded the statutory eight-hour equivalent exposure standard in 15.6% of cases (Figure 2). Most recently, in a presentation at the 2016 Queensland Mining Health and Safety Conference, Djukic and Gill indicated respirable dust exposure levels regularly exceeded acceptable levels across a number of mine sites measured between 2000 and 2016 (Figure 3).

WHY IS OCCUPATIONAL HEALTH DIFFICULT TO MANAGE?

It is generally well-recognised that occupational health is more difficult to manage than safety and is sometimes described as the “poor cousin of safety” in terms of the time and resources spent on health management and the cost associated with illness and disease resulting from occupational exposures (Hopkinson & Lunt 2014).

Although the most recently reported total costs of injury and illness in the mining industry in Australia are $1280 million and $1160 million respectively (Safe Work Australia 2015), indicating that injury is a more significant cost, it is also recognised that cases of work-related disease are under-reported in both workers compensation data and through ABS surveys of the workforce. (NOHSC 2000; Safework Australia 2015). Because some diseases have long latency periods (e.g. cancers and pneumoconioses) and others are difficult to link to occupational exposures (e.g. cardiovascular and respiratory diseases), Workers’ Compensation data significantly under-represents the actual incidence of occupational diseases (Safework Australia 2014).

Occupational disease is under-reported because the data systems are ineffective in capturing data on prevailing work environments and establishing relationships with health outcomes. There is no comprehensive system of surveillance for occupational disease or illnesses in the mining industry in Australia.

One of the challenges with health is the lack of an immediate impact, and the connection between cause and effect is less obvious than safety. The longer term health issues are underestimated in consequence when compared to the immediate effects of safety.

A further complexity for the management of occupational disease is the interaction of occupational exposures and lifestyle factors and the complication of individual issues that might make a person more vulnerable to dosage and exposure (e.g. effect of smoking or asthma) on the results of exposure to dust. Unlike injury, where there is usually a clear relationship between an incident and the workplace, most occupational diseases are multi-factorial in nature, with workplace exposures constituting one important part of the risk matrix.

Symptoms of occupational disease often do not manifest until after an employee has left the workplace or retired from work. Tracking a person once they have left the work place is difficult and costly – however, it can be done. A good example is Health Watch from the Australian Institute of Petroleum (Monash Centre for Occupational and Environmental Health 2013). Follow-up of individuals is further complicated by changes to occupation over a work life and the lack of records of work history including no occupation recorded on the Australian National Death Index.

The image of the mining and minerals industry as hazardous to health persists in the community and this has been spotlighted by the recent reports of pneumoconiosis in a number of Queensland coal workers.

In safety, there is a strong recognition of the advantages of leading indicators such as high potential incidents, in addition to lagging indicators, to demonstrate management of an issue. In occupational health, there remains a nearly total reliance on lagging indicators, such as the incidence of disease, to determine the effectiveness of the management of occupational health issues. The faulty logic of this is demonstrated by the Queensland situation. The lag indicators used included x-rays which have been shown to be faulty in terms of the implementation, quality and diagnosis (Monash Centre for Occupational and Environmental Health 2016)

The data systems that could provide information on leading indicators are ineffective. They do not capture data on prevailing work environments which could be used as a lead indicator and this would assist in establishing relationships with health outcomes. In terms of lagging indicators, there is no comprehensive system of surveillance for occupational disease or illnesses in the mining industry in Australia.

The time lag from exposure to manifestation of the dust related disease, the limited avenues to address the disease once it has been diagnosed, the difficulties with diagnosis and trouble tracking individuals show that we need to be pro-active in the management of occupational health issues.

USING THE BOW-TIE APPROACH TO MANAGE RESPIRABLE DUST

The bow-tie method is commonly used by Australian mining companies to assist them in the implementation of safer operations – generally within a risk management framework. It provides a visual representation of the barriers used to prevent an unwanted event and mitigate its consequences (Figure 4). The unwanted event is the knot in the bow-tie – and is the point at which control is lost. To the left of the knot are the causes and preventative controls (i.e. a fault tree) and to the right are the mitigating controls and consequences (i.e. an event tree). The inclusion of both types of controls, plus the visual nature of the outputs allows gaps in the application of controls to be more easily identified. A problematic situation whereby there is a reliance on mitigating controls to reduce the severity of injury is quickly detected.

A more proactive approach would be characterised by robust levels of preventative controls (on the left side of the bow-tie) that minimise the exposure of workers to a hazardous event. The inclusion of mitigating controls is important to reduce the severity of harm, but the ideal scenario is preventing the event from occurring in the first place. Seatbelts are a mitigating control that reduces harm, but they do not prevent the vehicle losing control; controls that address driver behaviour, road surfaces, fit-for-purpose vehicles, etc. help to achieve this. Successive layers of barriers are required to safeguard workers from adverse events – as described by Reason (2000) in his 'Swiss Cheese' metaphor.

The aim of this paper is to evaluate the overall approach the coal mining industry has taken to manage respirable dust. To guide the discussion, a bow-tie for managing risks associated with hazardous levels of dust in the underground coal environment has been developed (Figures 5 and 6). The bow-tie includes controls that are indicative of those being used by the industry and have been drawn from those currently recommended in literature, provided by government mining and non-mining agencies (including mining regulations, codes of practice[1], guidelines[2] and safety bulletins[3]) and those known by the authors to be used by the industry[4].

The authors also accessed information from RISKGATE, an Australian Coal Association Research Program (ACARP) funded website, which has bow-ties for 18 mining-related hazards (see www.RISKGATE.org, Kirsch et al. 2013). RISKGATE was developed between 2010 and 2014 from information provided by industry experts. The 'dust in atmosphere' bow-tie is within the RISKGATE Occupational Hygiene Topic.

The bow-tie's unwanted event is hazardous levels of dust in the underground coal environment. Harm occurs from a combination of the type of dust (coal, silica and other respirable minerals; size), concentration and duration of exposure. There is a focus on longwall mining, which is the most

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[1] e.g. Safe Work Australia Ventilation of Underground Mines, Draft, July, 2011

[2] e.g. MDG3006 Guideline for coal dust explosion prevention and suppression, December 2001; QGN03 Healthy atmosphere in underground mines, October 2008

[3] e.g. QLD Mines safety bulletin no. 151: Preventing dust-related lung disease, 30 October 2015

[4] For a more definitive list of controls used to manage respirable dust see, for example, Aziz, Cram and Hewitt (2009).

common form of underground coal mining in Queensland. It is thought to give rise to four times as much dust as continuous mining, particularly when production rates (machine speeds) are high and bi-directional cutting is used (Monash Centre for Occupational and Environmental Health 2016).

The bow-tie has six threats:

1. Coal drying due to gas drainage
2. Dust generated during development face operations
3. Dust generated during longwall operations
4. Dust generated during second working operations
5. Dust generated on conveyors
6. Dust generated as a result of movement along roadways

Controls designed to eliminate or minimise the amount of dust generated are designated as preventative controls; while those that reduce or manage excessive exposure to a harmful atmosphere are mitigating controls. When identifying controls, the authors were guided by the International Council on Mining and Mineral's new framework for OHS control management which defines a control as an act, object (engineered) or system (combination of act and object) intended to *directly* (or *of itself*) prevent or mitigate an unwanted event (ICMM, 2015, 2016; see also Hassall, Joy, Doran & Punch, 2015). In this view, a control should be specifiable, measurable and auditable. Accordingly, dust monitoring is not deemed a control, as it does not in itself prevent the generation of dust or mitigate the exposure to dust. Rather, timely and efficient monitoring is a means of verifying the performance of controls. Similarly, mining plans and procedures, such as ventilation plans and traffic management plans are activities that support controls.

The preventative controls used in the bow-tie can be generally grouped into five categories: proper use of water sprays; ventilation (including use of extraction fans); fit for purpose cutters; cutting practice (e.g. speed, direction); and dust suppressant in the water system. An exception is those controls related to movement along roadways, which involve quality, type and watering of roadways.

Two consequences are identified: (1) excessive levels of coal dust in the lungs and (2) development of respiratory disease. They represent different stages in the trajectory of respirable illness. Excessive levels of coal dust in the lungs may not necessarily lead to respiratory disease, but where it does, prognosis often occurs many years after exposure. Methods to reduce the amount of time that workers are exposed to harmful levels of dust include remote control mining; rostering, task rotation and work practices (including the positioning of workers near/on equipment); the segregation of returns and respiratory protective equipment. A caution given by Aziz, Cram and Hewitt (2009) regarding the use of personal dust protection, could more broadly be applied to other mitigating controls – "[they] should only be used as a last line of defence and must not take the place of prevention or dust suppression techniques" (p. 568).

Medical surveillance (e.g. X-rays, spirometry) is initially used for the detection of early stages of respiratory abnormalities consistent with coal mine dust lung disease, that in-turn is used to prompt follow-up, referral and intervention. After diagnosis of CWP medical surveillance is used to track and manage disease progression.

The current bow-tie does not address the impact of important individual factors (e.g. smoking, pre-existing lung capacity) that may confound the trajectory of illness and or cause one worker compared to another to be more vulnerable to adverse outcomes. However, highlighting the role of individual factors can hinder the implementation of effective controls. For example, it can lead to screening and recruiting of employees rather than a focus on preventing safety risks in the first place (see a more thorough discussion of a similar scenario in the Education and Health Standing Committee, Parliament of Western Australia's report into the impact of FIFO work practices on mental health, 2015). Also, a recent finding of the Monash Review of Respiratory Component of the Coal Mine Workers' Health Scheme for the Queensland Department of Natural Resources and Mines found that there was a tendency for companies to attribute abnormal respiratory results on smoking rather than exposure to harmful levels of dust (2016, p. 8).

The dust management bow-tie developed for this paper shows that controls are available to prevent and mitigate harmful levels of respirable dust in the underground coal mine environment. What is the reason then for the recent confirmed cases of CWP in Queensland? The following section discusses these issues.

DISCUSSION

If workers are exposed to excessive respirable dust levels then either there are insufficient controls in place or they are ineffective. Given the plethora of research and advice that abounds on the subject there can be no reason for having insufficient controls. Controls fail to be effective because they are inherently inadequate or their effectiveness is eroded.

Examples of control erosion include turning off or reducing the frequency of dust suppression water sprays because they impede the ability of the shearer driver to see where he is cutting. Lack of water pressure, poor maintenance of sprays and failure to change cutter picks often enough are all examples of factors that will erode the effectiveness of controls. A key factor in establishing control effectiveness is monitoring the implementation to not only ensure that the controls are installed and operating as designed, but that they actually achieve the desired level of control. Monitoring must go beyond installation and extend to operations and maintenance.

In these days of cost control and production pressures, it is easy to see where the continued operation of some dust suppression controls might be seen as negatively impacting on production. For example: production downtime whilst sprays are maintained. The current standard practice of monitoring exposure over a whole shift is not designed to detect sources of dust nor locations where a worker has been exposed to excessive dust levels. Real time dust monitoring is required if control effectiveness is to be monitored. Unfortunately, there are currently very few real time monitoring devices approved for unrestricted use in Australian underground coal mines, though they have approval in the USA.

Because disease associated with excessive dust levels is a long term, cumulative impact, the immediate effect of ineffective controls is not obvious and can lead to a false sense of security, and a questioning of whether or not the control was really required in the first place. The apparent CWP free period of over twenty years may have led to a complacency and a questioning of the need for dust controls other than personal protective equipment (PPE) and resulted in inadequate the exposure monitoring of the workforce. This complacency would be compounded by pressure from other areas of health and safety that have received attention in modern times, such as fatigue management, mental well-being, drug abuse and alcohol consumption – putting pressure on limited WHS budgets.

There may also be an over reliance on the effectiveness of respiratory protective equipment as the major dust exposure control. It is easy to ignore the lack of robustness RPE offers as a control. The Sim report into the inadequacy of the current Coal Workers' Health Scheme (Monash Centre for Occupational and Environmental Health 2016) has highlighted the problems that occur when reliance is placed upon a monitoring process that is inherently unable to prevent harm to the worker. The failings of the current scheme have meant that a number of workers have been exposed to excessive dust levels without the early stages of the disease being identified at the appropriate time. Because of the cumulative nature of the exposure to cause the disease it is arguable as to whether even if the scheme had been functioning as designed that many of the cases would have been able to be prevented through greater awareness of the issue after a few cases would have been detected. Detection of the onset of CWP will prevent the worker from proceeding to higher levels of CWP if the worker is removed from the dusty environment but not prevent him getting the disease in the first place. Other tests such as spirometry may be a more sensitive indicator of respiratory abnormality, if carried out properly.

In essence this all suggests the absence of an effective respiratory dust management process and a reliance on ad hoc or individual controls. The NSW Work Health and Safety (Mines and Petroleum Sites) Regulation 2014 defines dust as a Principal Hazard and thus mandates the creation of a principal hazard management plan to control exposure to it. This is not a requirement in Queensland, though following the recent detection of CWP in Queensland coal miners, most Queensland underground coal mines have formed dust management committees and developed dust management plans.

Under the Duty of Care based legislation in force in Australia, the primary responsibility for ensuring a safe and healthy workplace rests with the company undertaking the mining operation. It is the company's responsibility to ensure that the workers are not exposed to excessive respirable dust levels. The regulatory oversight of respirable dust exposures differs significantly between the two major underground coal mines states of NSW and Queensland.

In NSW, Coal Services, an industry body jointly owned by the NSW Minerals Council and the CFMEU, is the principal provider of both health monitoring and respirable dust monitoring. Minimum dust monitoring requirements to be carried out by Coal Services Inspectors are specified under Order 42 issued under the Coal Industry Act 2001. In addition, Order 40, issued under the same Act requires Coal Services to review and approve mine plans to limit dust creation and exposure for each operating longwall panel. Copies of all dust results are sent to the mine operator, the relevant Inspector of Mines and the industry safety and health representative. Coal Services maintain a Standing Committee on Airborne Contaminants with tripartite representation that also reviews all dust monitoring data. In addition to the regulatory monitoring campaign, companies can undertake their own monitoring.

In Queensland, the mine is responsible for establishing a respirable dust monitoring program and informing the Mines Inspectorate of the results of the program. This monitoring may be carried out by mine personnel or by a contractor. Currently, in Queensland, there is no formal guidance on the minimum requirements for monitoring of respirable dust. Since 2012, the mines have provided the Inspectorate with the survey results.

Neither State publicly reports the outcomes of the monitoring. In response to the detection of CWP in Queensland, work is underway to provide guidance material for monitoring respirable dust in Queensland mines.

CONCLUSION

This paper has considered the management of exposure of workers to respirable dust in Queensland underground coal mines which has generally not been managed in the same way as safety hazards. Applying bow-tie analysis to this issue has shown that considerable preventative controls are available to prevent workers from being exposed to hazardous levels of dust. These include the proper use of water sprays, ventilation, fit for purpose cutters, cutting and dust suppressant in the water system.

Despite this, there has been intermittent evidence of exceedances in statutory exposure levels of respirable dust in Queensland mines in the past twenty years. But most importantly, since May 2015 there have been 18 confirmed cases[5] of CWP reported by nominated medical advisers to the Department of Natural Resources and Mines (Queensland Government, 2016). Prior to this, there had been no cases of CWP reported to the department for many years, leading to a view that CWP had been eradicated in Queensland.

The over reliance on mitigating controls, the lack of monitoring of the effectiveness of the controls and the mistaken reliance on medical examinations to indicate any adverse outcome has meant that CWP is still an issue in Queensland coal mines.

By adopting a systematic risk management approach, incorporating techniques such as the bow-tie methodology outlined above and paying proper attention to monitoring the effectiveness of controls, the authors consider that this risk can be managed.

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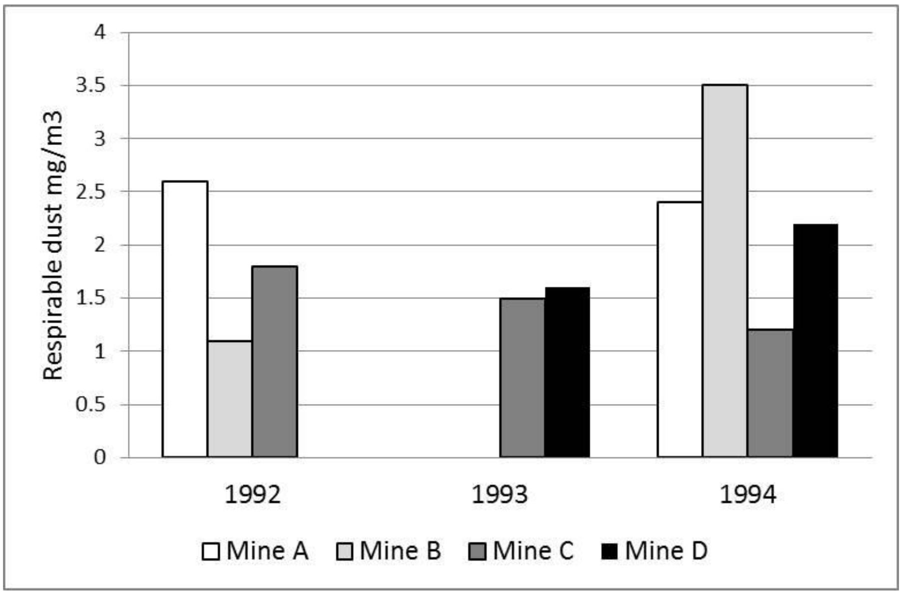
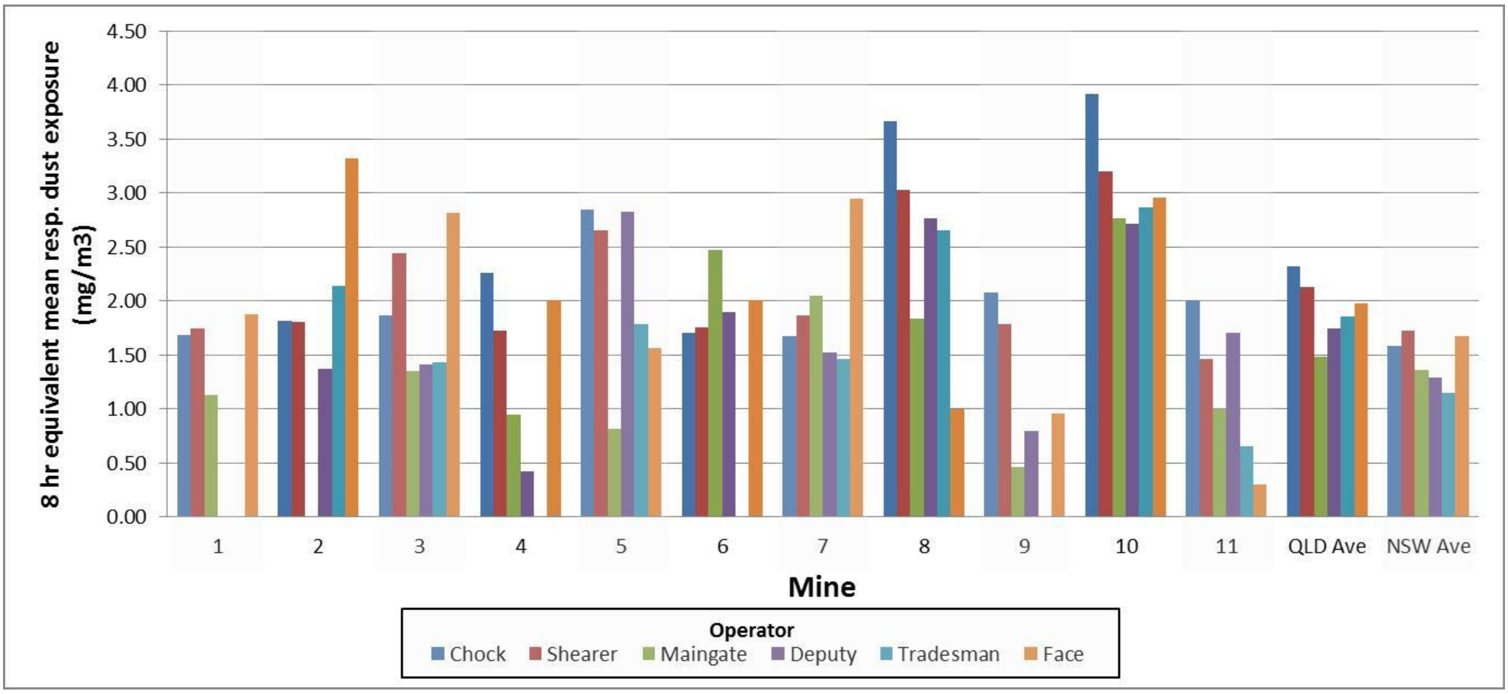


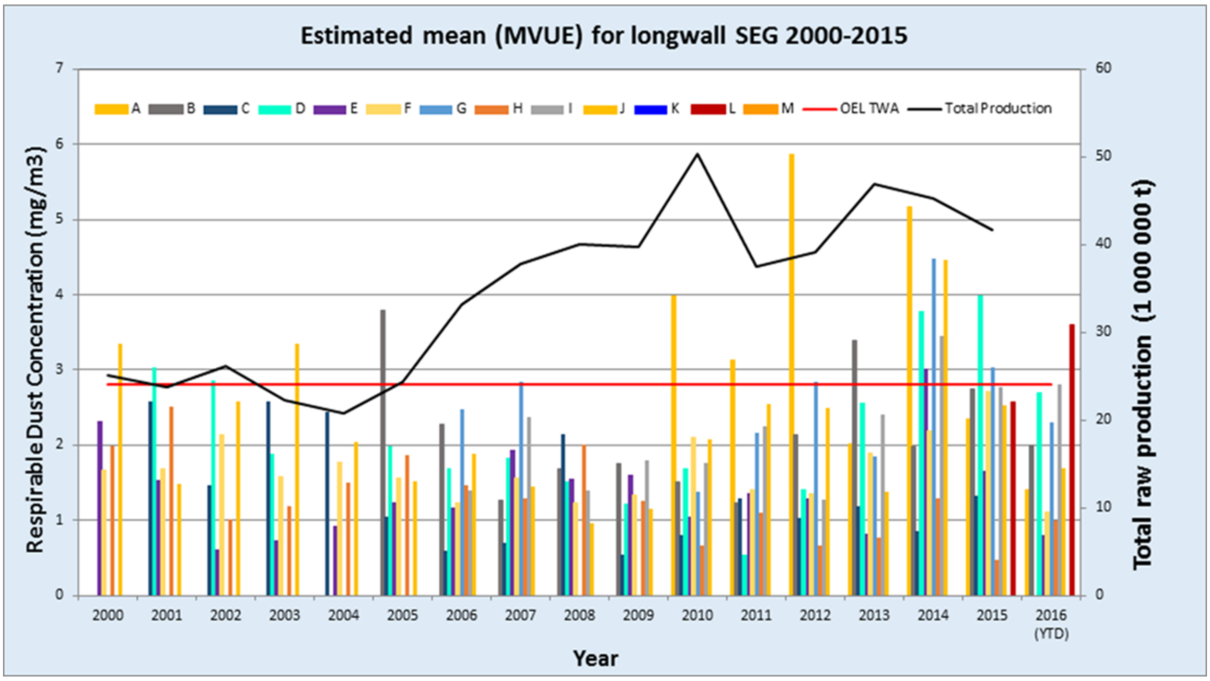
Note. Source: Bofinger, Cliff & Tiernan (1995). Data represents personal respirable dust exposures of 166 longwall face workers. Dust sampling was not conducted at Mines A and B during 1993, and Mine D did not commence full production until 1993. Mine B shows a threefold increase in personal dust measurement from 1992 to 1994.

FIG 1 - Average personal respirable dust measurements during longwall operations for four Queensland mines (Bofinger, Cliff & Tiernan 1995)



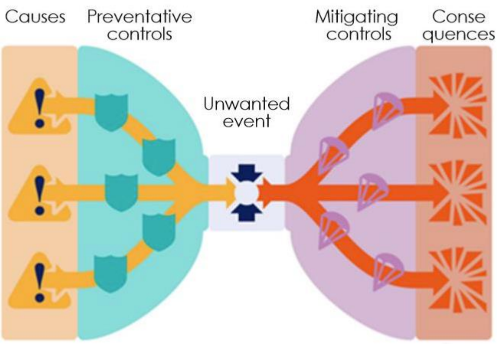
Note. Source: Table created from data taken from Cliff & Kizil (2002)

FIG 2 - Operator category eight-hour equivalent mean respirable dust exposure (Cliff & Kizil 2002)



Note. Source: Djukic & Gill, 2016; The black tracer line represents the total production across all sites with operating longwalls. The data show that for the period 2000-2013, 10% of mines longwall SEGs were equal to or greater than the adjusted regulatory exposure limit. For the year 2014, 60% of mines longwall SEGs were equal to or greater than the adjusted regulatory exposure limit. This number fell to 18% of mines longwall SEGs equal to or greater than the adjusted regulatory limit, in the year 2015.

FIG 3 - Estimate mean (MVUE) for longwall SEG 2000-2015 (Djukic & Gill, 2016)



Note. Source: www.RISKGATE.org

FIG 4 - A schematic of the bow-tie approach

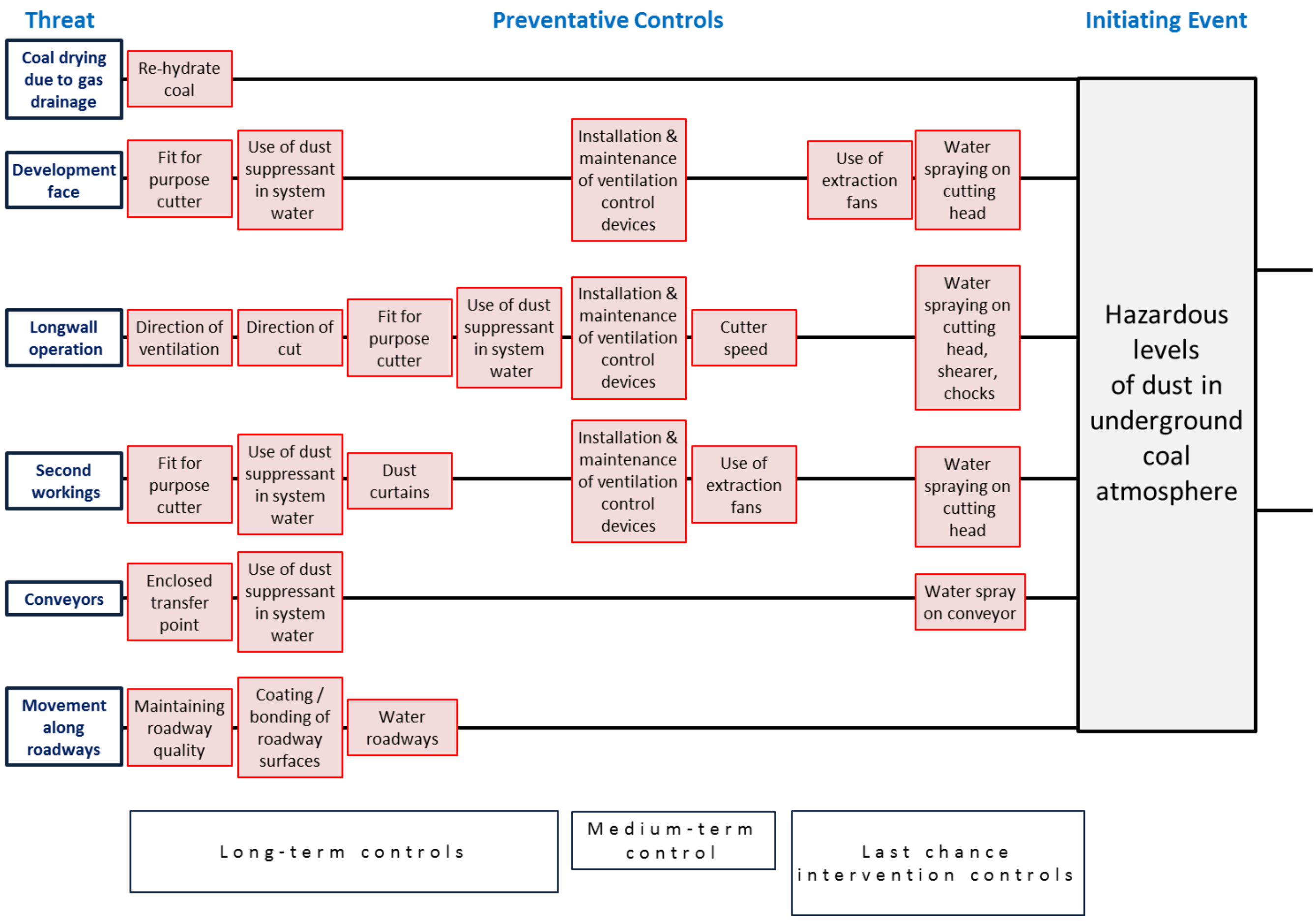


FIG 5 - Threats and preventative controls (left-side) of the hazardous levels of dust in underground coal atmosphere bow-tie

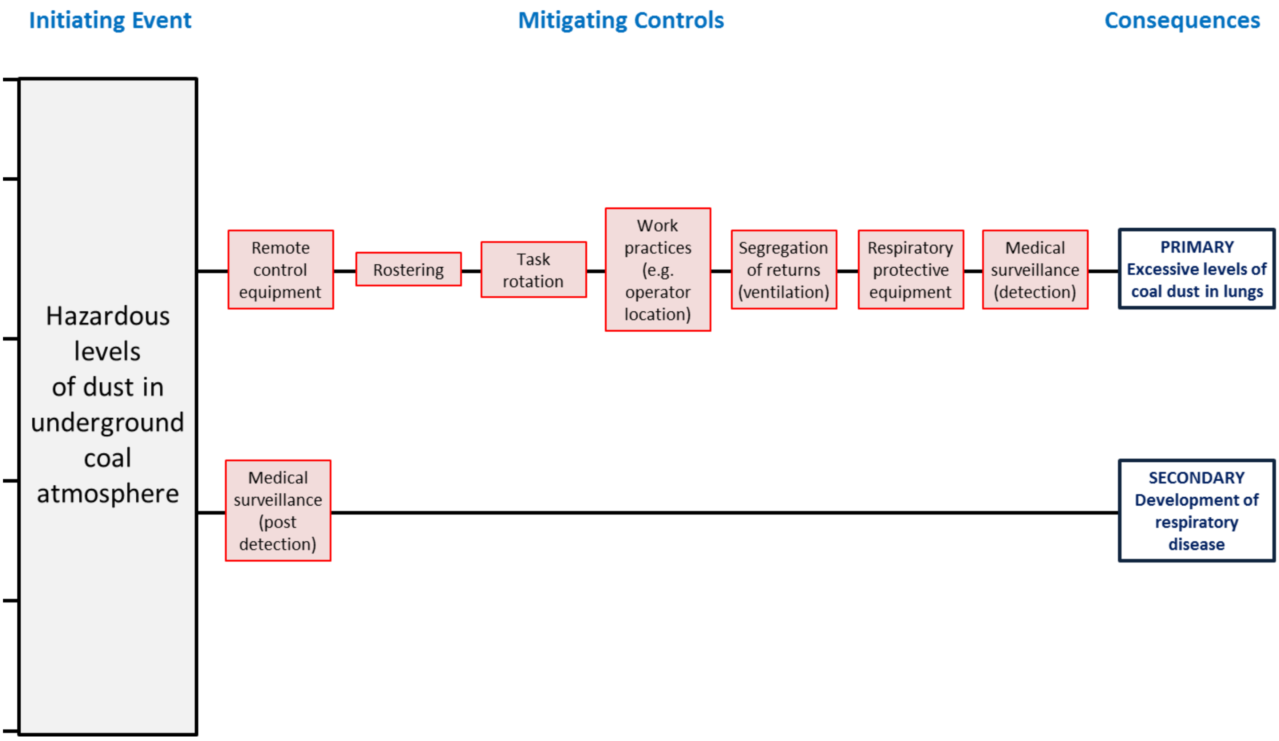


FIG 6 - Mitigating controls and consequences (right-side) of the hazardous levels of dust in underground coal atmosphere bow-tie