Workplace Health and Safety Queensland

Tunnelling road header and related operations: dust conditions and their control

A report supporting the Occupational Disease Strategy 2007 – 2010

Department of Justice and Attorney-General

Queensland Government

Introduction

In 2002, on the back of national concern over the increasing monetary and social costs of occupational disease to the Australian community, the federal government released its *National Occupational Health and Safety Strategy 2002 – 2012* (the strategy). The strategy's principal priorities included a reduction in both the high incidence and severity of occupational disease in the workplace, and to develop the capacity of workplaces to manage occupational health and safety (OHS) more effectively.

The *Occupational Health and Safety Strategy 2002-2012* specifically targeted eight work-related diseases, one of these being respiratory disease.

The priorities of the Strategy have been adopted by Workplace Health and Safety Queensland (WHSQ) in its Occupational Disease Strategy 2007-2010.

Workplace Health and Safety Queensland recognises there is a wide range of work-related respiratory diseases across many different industries in Queensland. Therefore it is necessary to consider respiratory disease (and its causative agents) a high priority and to develop programs that specifically target the disease or its causative agents (in this case quartz, free silica or respirable crystalline silica).

Background

Silica exposure occurs in industries such as quarrying, mining, tunnelling, foundry works, stonemasonry, cement manufacturing, construction, brick and tile manufacturing, ceramics and metal polishing.

Respirable crystalline silica (RCS) remains an important risk factor for respiratory disease amongst tunnelling workers. While silicosis is a historically important disease in tunnelling, RCS is now known to cause chronic obstructive lung disease including chronic bronchitis and emphysema. Chronic exposure to elevated levels of RCS is found to cause cumulative loss of respiratory volume, and still poses a risk of silicosis. Levels which are a concern for silicosis are also now a concern for lung cancer.

The effects of specific silica exposures will not be observed until two or more decades have elapsed (long latency). Outcomes cannot be fully predicted from conditions measured during this survey, although long term research may help in such predictions. However, the constant efforts to minimise exposures, by dust control and through use of personal protective equipment, will certainly be accompanied by a decreasing risk for all diseases.

In 2004, the National Occupational Health and Safety Commission (NOHSC) reduced the exposure standard (ES) for RCS from 0.2 mg/m^3 as measured by the British Medical Research Council (BMRC) penetration curve down to 0.1 mg/m^3 measured by the penetration curve defined by the International Organisation for Standardisation (ISO). This corresponded to a real reduction in the ES of around 30 per cent. This standard has been adopted into the *Workplace Health and Safety Regulation 2008* (WHS Regulation).

Most operations in tunnelling involving dust and RCS are however not directly regulated by the WHS Hazardous Substances Regulation. This is because the RCS which is encountered in tunnelling arises mostly from rock cutting or drilling and the RCS does not enter the workplace as a product with a material safety data sheet (MSDS). It does not qualify as a hazardous substance under the provisions of WHS Regulation. Rather, the person on whom the workplace health and safety obligation is placed meets their obligations through Sections 26, 27 and 27A of the *Workplace Health and Safety Act 1995* and by adopting and following the way stated in the *Tunnelling Code of Practice 2007*.

Tunnelling for roadway traffic on a large scale is a relatively new operation for Queensland workplaces and, over a period of a decade or more, will employ some thousands of different workers on the several major programs which are currently being undertaken or are being planned. Considering this, tens of thousands of Queensland's industrial workforce remain at risk from exposure to silica.

The purpose of this intervention

This specific intervention report is the second on sectors involving silica exposure. The intervention targets respirable dust and respirable crystalline silica (RCS) and their control in **road tunnelling**.

The purpose of the intervention is to:

- determine the respirable dust and RCS concentrations associated with road header tunnelling operations
- evaluate the dust controls being used to determine the extent of compliance
- provide timely feedback and enhance the operator's capacity to control this risk.

Information available from this intervention program is also available for informing national needs on future development of the RCS exposure standard. To accompany the program a WHSQ website page on silica was organised and two documents were developed to assist health and safety personnel in silica affected businesses.

Note: Australia's RCS exposure standard (ES) is in line with that of the United Kingdom and the current European Occupational Exposure Limit (EU-OEL) but only one fourth as stringent as the current recommendation of 0.025 mg/m^3 from the American Conference of Governmental Industrial Hygienists.

The intervention

The program of intervention involved regular visits to different sites to conduct occupational hygiene monitoring for respirable dust and RCS conditions. Observations were made on dust control measures which included tunnel ventilation, mobile equipment dust filtering, dust suppression by use of water and use of respiratory protective equipment.

Respirable dust was sampled in accordance with *Australian Standard 2985:2004 Workplace Atmospheres – Method of sampling and gravimetric determination of respirable dust.* Dust was sampled in the breathing zones of all target operators using a vertical cyclone elutriator connected to the lapel of the worker. Dust laden air was drawn through the elutriator using a small portable battery powered pump located on the belt of the worker. Some in-cabin samples were obtained where ergonomics prevented personal sampling. The elutriator/pump combination was calibrated to an air flow of 2.2 L/min to meet the International Organisation for Standardisation (ISO) sampling efficiency curve for respirability and the pumps were operated for periods from 6–7.5 hours.

Some peak measurements of dust were made using a DustTrak™ direct reading dust monitor fitted with a vertical cyclone elutriator operating according to the ISO sampling efficiency curve. This proved useful for identifying some phases of an operation with the greatest potential for generation of dust, and some likely peak dust excursions. Lighting conditions underground in tunnelling are not immediately conducive to recognising the presence of respirable dust, and the DustTrak™ can provide this information in real time.

Results of 17 monitoring interventions, together with recommendations to improve dust control were provided to the business operator. Dust sampling was conducted during day production shifts. Ventilation rates were measured in most operations and observations were made on the style of ventilation to the working face and of respiratory protection worn by each sampled operator.

The targets of the intervention

This intervention commenced in 2007 and was completed in 2009 and specifically targeted respirable dust and RCS in road header and ancillary operations at three sites in a large tunnelling operation. Information from all sites has been combined. The monitoring programs did not include ground works in earth and rock moving operations, drilling or excavating exterior to the tunnel or to the tunnel boring machine (TBM) operations.

Similarly exposed groups

From a simple task analysis, the program identified and targeted seven (7) separate similarly exposed groups (SEGs)[1]. These included:

- road header operators in open cabs
- road header operators in closed cabs
- shotcreters (sprayed concrete coating operators)
- drilling rig jumbo operators, roof bolters and tunnel labourers
- fitters, boilermakers and electricians
- truck and equipment drivers and crane operators
- supervisory staff.

Rock material

The rock material being tunnelled produced dust with considerable amounts of RCS, ranging between 12.6 to 22.9 per cent.

Exposure

Shotcreting operators were exposed to dusts with smaller amounts of RCS (6 percent) as the predominant dust source was not from the ground rock but from the concrete. Fitters, boilermakers and electricians were exposed to dusts with the lowest RCS content (4.4 percent), reflecting other possible sources such as diesel particulate, welding fumes or cement dust.

Controls

As it was identified, in this potentially very dusty work environment, controls were strategically employed, since it is only by the application of permanent high quality controls that the risk can be adequately managed.

- A system of extraction ventilation (particularly for work at the road header faces) was provided as close to the road header as was practicable to exhaust as much of the dust directly from the working face as was possible. All first bench advancing workings appeared to be provided with this arrangement, but some lower bench or multiple heading operations in the one drive were differently arranged. Some examples are shown in Appendix A2.

[1] The term "exposed" refers to the dust conditions, not to ultimate exposure which can be moderated by use of personal protective equipment.

- A second simultaneously applied control was the use of pressurised, filtered air-conditioning systems on road headers with closed cabins.
- The third level of control universally applied in the operation was use of respiratory protective equipment (RPE). The majority was in the form of disposable P2 filter respirators with a minimum protection factor of 10. For many operations away from a working face, where exhaust ventilation did not need to be the significant controlling influence, RPE provided the best control. Open cab road header operators were provided with half-face piece RPE with continuous flow air line supplied compressed air.
- A fourth control, water suppression of dust, was also used in face working but not consistently.

The results of the intervention

Over the three sites a total of 90 paired samples for respirable dust and RCS were taken over a period of 25 months. Most emphasis was placed on the road header operations as observation and an early survey indicated that this SEG was the major risk group and likely to be in need of regular assessment. Average respirable dust concentrations for each SEG are displayed in Figure 1 and averaged RCS concentrations are displayed in Figure 2.

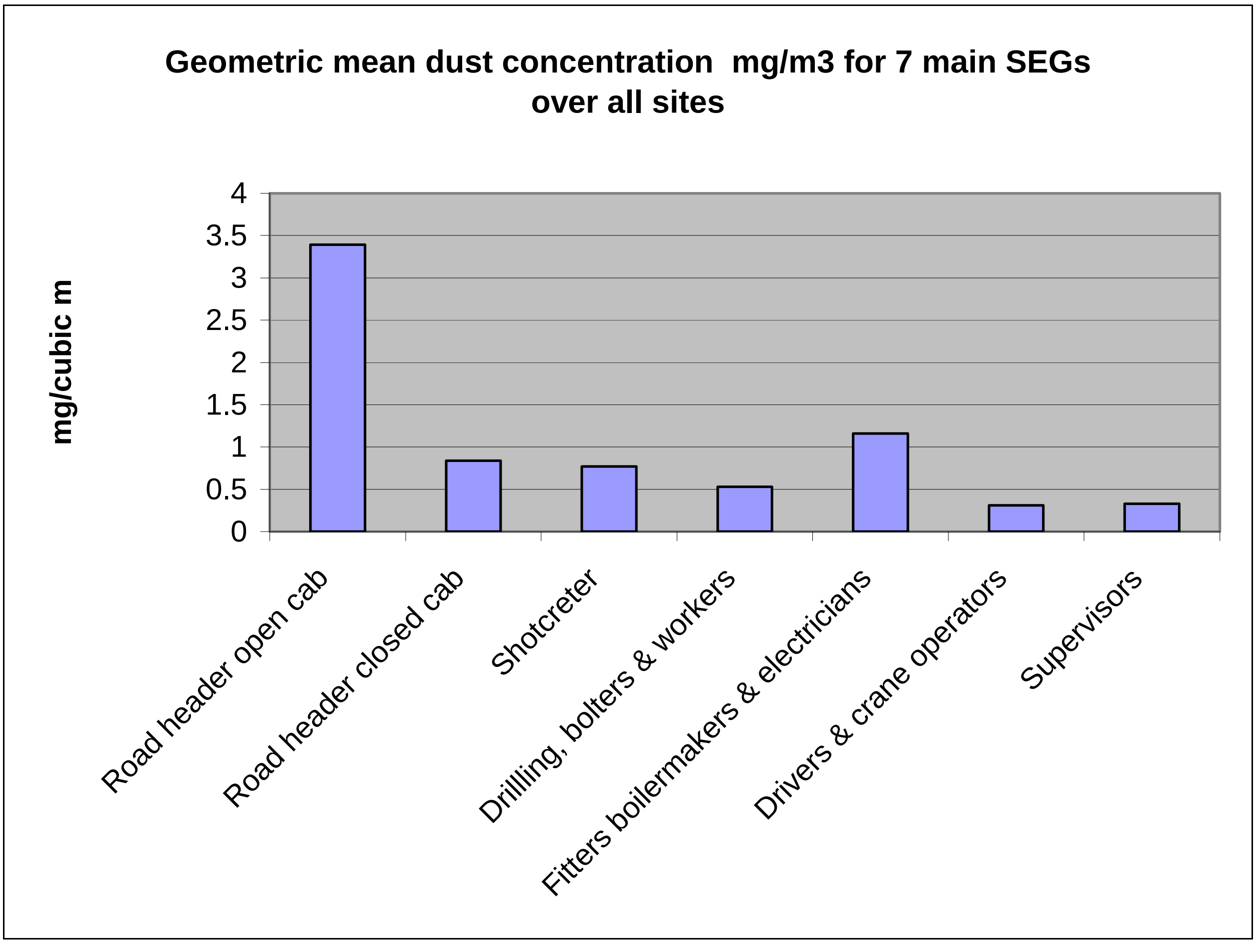


Figure 1: Average respirable dust concentrations for each of 7 SEGs for period from 2007–2009.

There has been no previous monitoring work in tunnelling in Queensland to serve as a base to examine any trends in either respirable dust or RCS concentrations. However, this survey might serve as an indicator for the kinds of dust concentrations found in these SEGs in a tunnelling project, and equally importantly, identify the magnitude and locations of greatest risk for improved control strategies. The working population in this industry is partly itinerant, moving from one tunnelling job to another. Some will have worked on tunnels in Sydney or Melbourne prior to commencing work in the Brisbane tunnels. Professional engineering staff also move from project to project, but are usually not placed in the conditions of potential extreme dust exposure that are regularly experienced by face workers.

Shift working length in this operation was typically longer (at 10 hours) than the standard eight-hour working day for which the exposure standard is normally expressed. This requires a downward adjustment in the relevant exposure standard to accommodate for the altered work shift length. Using the Brief and Scala method as recommended by SafeWork Australia, the $ES_{adjusted}$ for RCS for a 10-hour work shift has been reduced from 0.1 mg/m^3 to 0.07 mg/m^3.

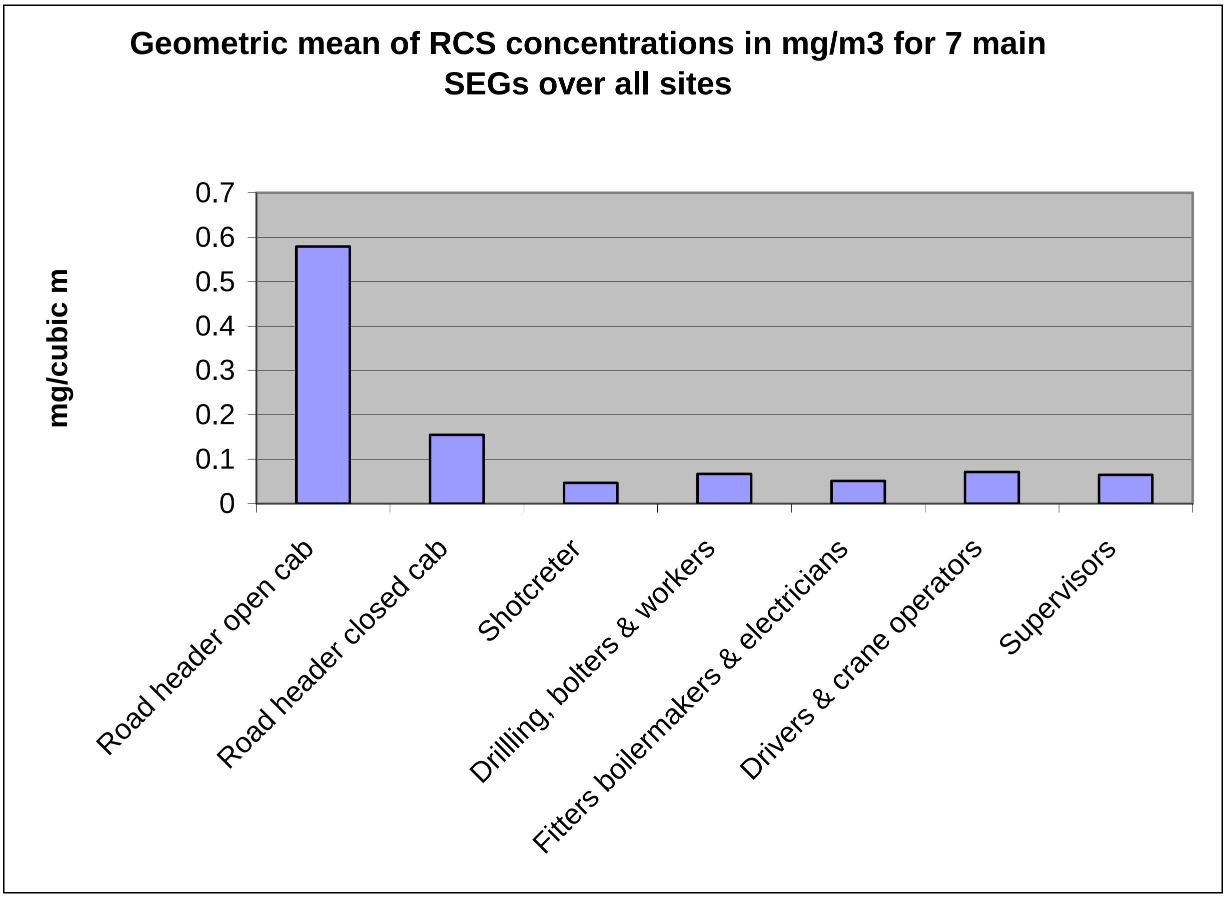


Figure 2 Averaged RCS concentrations for each of 7 SEGs for the period 2007–2009

Discussion (i.e. trends in dust concentrations, compliance and controls)

Dust concentrations

The seven SEGs are reasonably representative of the major groups associated with the underground road heading operations in this tunnelling operation. Road header drivers were divided into the two groups according to whether the road heading machines were fitted with a cabin or not as these represented two quite separate SEGs. More detailed information on the measured dust concentrations can be found in the Appendix Table A1. Results in Table A1 have been expressed to suit best occupational hygiene practice.

Open cab road headers

Open cab road header operators recorded the highest average personal dust concentrations for both respirable dust and RCS. One daily averaged respirable dust concentration was measured at 20 mg/m^3 and RCS estimated about 4 mg/m^3. Excessive peak dust concentrations were temporarily observed. On one occasion, the respirable dust concentration measured by DustTrak™ during face working was 100 mg/m^3, measured in the dust cloud behind a road header as it worked the face on the side opposite the extraction exhaust inlet. The potential risk posed to open cab operators from RCS is considerable with an average concentration of 0.58 mg/m^3 (range 0.04 ~ 4 mg/m^3), approximately eight times the RCS $ES_{adjusted}$ for a nominal 10-hour shift.

Closed cab road headers
Closed cab road header operators face a much reduced risk from both respirable dust and RCS, due to the operation of ventilating systems providing pressurised filtered air to the closed cabs. However, the very high geometric standard deviations (GDS) for both respirable dust and RCS (3.46 and 4.27) reflected that some of these were not operating optimally during the program. This was evidenced at various times by doors left open, and later by poor door seals. Equipment manufacturers' specifications for dust penetration were regularly exceeded until seal performance could be verified.

Shotcreters, roof bolters, drillers, fitters, boilermakers etc.
The respirable dust and RCS concentrations experienced by these remaining SEGs were, on average, much lower and all within the $ES_{adjusted}$ for the nominal 10-hour work shift operating in each location. However, the RCS GSD (mostly >3) for most SEGs indicate that there were still numerous excursions which were excessive needing management. In fact, 20 of 49 (41 percent) of this group still exceeded the RCS ES. Because of the use of RPE however, the personal exposures should all have been adequately controlled.

Controls

Ventilating systems
Direct dust extraction of the large amount of dust created in rock winning at a face is the single most important process for controlling the risks from both respirable dust and RCS. It reduces dustiness to a level where respiratory protection is able to work effectively in controlling the residual dust risks.

The main exhaust extraction ventilating system accompanying the road headers is usually a simple spiral wound trunk or galvanised trunk, approximately 1.5–1.6 metres in diameter. Ventilation was applied differently according to the number of headers operating in a drive, their relative dispositions to each other and the number of benches being simultaneously worked. Several examples are shown in Appendix A2. Thus a simple scenario would have one header with the extraction inlet as close as practicable (1.5–2 m) to a worked face. As the face advanced, this distance increased until a new section of duct could be installed. More elaborate systems were derived for multi-header operation; some were effective (Ventilation example 3), and some not so (Ventilation example 4). The potential for very high dust concentrations when the main exhaust extraction was inadequate was demonstrated, and for which only the half face piece positive pressure demand respirators would provide adequate additional protection.

The duct inlet was normally the simple end of the duct without either a baffle to prevent rear air entry or a bell curve entry to permit slow acceleration air flow. The air was filtered prior to discharge so that the air discharge could be environmentally acceptable in an urban area (often with a hospital 500–1000 metre distant). The in-line filtering meant that judicious use had to be made of water suppression of the dust. During some sampling programs the water suppression system was not always fully operational and during shotcreting procedures when small pieces of metal were being sprayed with the concrete, ventilation was not applied to the tunnel to protect the filtering mechanism from accidental puncture.

Generally, the residual respirable dust concentrations in the driveway from the face were low, and provided there was no work out-bye (or fresh-air side), typically this figure was below 0.5 mg/m^3. The high volume of air being drawn down the drive by the extraction system (measured between

50–70 m^3/sec) could provide a nominal air flow rate in the drive of >0.5 m/s. Tunnel air flows at different sites measured between 0.1 and 0.9 m/s with marked flow gradients across the tunnel.

Although significant volumes of air were being moved by these exhaust systems, the capture of dust at a face depended mostly on general movement of contaminated air and not on direct capture of dust by the duct operating as an exterior or capturing hood. Only when the road header operated on the same side as the exhaust inlet, and at a distance of no more than two metres from the duct inlet was the system able to act as a capturing hood.

Closed cab road headers with dust control filtering units
Some road headers were fitted with a combined air-conditioning and pressurised fine dust filtration unit. Where these were operating correctly, the dust concentration inside a closed cab could be adequately controlled to the point that additional RPE was not required. However, only 19 per cent of all road header measurements (open or closed cab) were low enough to have used no additional RPE. In practice, the pressurised dust filtration's effectiveness was easily bypassed as a result of leaving doors open for access and vision whilst still gaining significant air-conditioning benefits, and poor seals. Towards the latter half of the project, the sealing problems were addressed.

Respiratory Protective Equipment
All workers in the tunnel were required to wear the supplied RPE. Properly worn, the performance of the P2 disposable filter respirators would have proved adequate for minor exposed SEGs. In most instances, the nominal minimum protection factor of 10 provided by disposable P2 respirators would have sufficed also for the closed cab road header drivers.

For the closed cab road header operators using disposable P2 filtering respirators, there were only two (2) instances (~10 percent) where the P2 respirators would have provided inadequate protection against high levels of RCS.

For the open cab operators, the equipment mounted half-face respirator with continuous flow air line would have provided a nominal protection up to a factor of 50. Based on the worst observed outcome, the protection should still have been adequate, although that interpretation is based purely on an average exposure. DustTrak™ measurements revealed that peak dust concentrations could occasionally exceed the protective capacity of RPE with a protection factor of 50.

Conclusion and recommendations

Present and planned tunnelling operations for road and perhaps rail transport in the Brisbane metropolitan area are, and will all be, dusty operations in their commencement phases using road heading machines. The current survey has shown that RCS air concentrations to which workers are potentially exposed, and created principally by road heading machines, are excessive. Concomitant use of RPE and extraction ventilation is absolutely essential for all tasks around the face. From the personal samples obtained from all SEGs, 59 per cent exceeded an RCS $ES_{adjusted}$ of 0.07 mg/m^3. Contaminant concentrations measured on some shifts where there was little or no road header operation helped bring the overall average dust conditions down. Judged over the two year period of time that this program operated, the management of risk, on average, could nonetheless be judged as compliant.

Risk has been effectively controlled by the combination of both ventilation (extraction and cabin filtering) and the use of respiratory protection. Therefore it is paramount that the primary control provided by the extraction ventilation be constantly organised for optimal performance in order to permit the secondary RPE control to be effective There was little opportunity in this program for face ventilation to be constantly manoeuvred to track the cutting process and keep the point of dust generation inside the capture distance of the hood opening. However, in light of the very high dust concentrations produced, future tunnelling exercises could explore this concept.

The extent of adherence to RPE usage and the effectiveness of RPE fit testing or fit checking protocols were not assessed. The achievement of compliance in RCS exposure in many tasks comes at the cost of having to use personal protective equipment on a permanent basis. Reliance on the least acceptable of the methods in the control hierarchy is a trade-off for minimising the engineering effort otherwise needed to control the environment. A further point of concern is for those actual peak dust conditions in some situations where the dust extraction capture point is too remote to be immediately effective. In such situations, the protection factor of the RPE supplied (both disposable and reusable) can be temporarily grossly exceeded. Although average exposures may be seen to be compliant, peak exposures to RCS remain a concern for the development of disease due to the potential to temporarily overwhelm the respiratory system's defences.

In a legislative compliance assessment sense, the occupational health risks and their control are judged on a pragmatic use of Sections 27 and 27A of the *Workplace Health and Safety Act 1995* which deal with discharging obligations and managing risk where no regulation is made. This arises because the RCS to which workers are exposed is not subject to the *Workplace Health and Safety Regulation 2008* – Part 16 Hazardous Substances, simply because the silica does not fulfil the status of a hazardous substance because it does not come to the workplace accompanied by a material safety data sheet (Regulation S 198).

Resort to the Act circumvents having to use Regulation 348 which applies to obligations of a relevant person when atmospheric contaminants other than hazardous substances are involved. That regulation requires "*that the …employer must ensure that the level of the atmospheric contaminant generated from a process carried out in the conduct of the relevant person's business or undertaking is not more than the exposure standard for the atmospheric contaminant….*"

In an underground rock winning process, that condition simply cannot be attained without a prodigious engineering effort and there is thus no way to effectively comply with that regulatory provision.

Relevant persons in such tunnelling operations must keep dust levels and their means of control in constant review. Experience in this program revealed that closed cabin environments where the equipment was fitted with dust excluding devices showed some dust concentrations more than five times the adjusted exposure standard for RCS. Use of direct reading (eg DustTrak™) or similar monitoring devices set up to measure respirable dust are essential for the constant review of such work environments where the worker is presumed to be safe, and may consider that use of RPE is not essential. There are no visible signals in a darkened tunnel environment which will help workers to a true perception of risk of something that they cannot see.

Lastly, because of the potentially high levels of exposure, workers who make this kind of work a long-term occupation should be considered as candidates for health surveillance for RCS. Strictly, such health surveillance is not required under Queensland's current legislation, since the health surveillance provisions are restricted to those substances which are classed as "hazardous substances" under provisions of Regulation Section 198, though it is recommended in the *Tunnelling Code of Practice 2007*. With the advent of the nationally harmonised regulation on hazardous chemicals in 2012, that anomaly should be removed.

Further information

Further information is available from www.worksafe.qld.gov.au or by calling the WHS Infoline on 1300 369 915.

The following publications are available on the website:

- *Silica and the lung – fact sheet*
- *Silica –identifying and managing crystalline silica dust exposure - Information guide*
- *Silica – managing exposure in the workplace: Occupational Disease Strategy 2007–2010*
- *Workplace Health and Safety Act 1995*
- *Workplace Health and Safety Regulation 2008*
- *Hazardous Substances Code of Practice 2003*
- *Tunnelling Code of Practice 2007*
- *Tunnelling road header operations: dust conditions and their control - Summary report*

Appendix A1 - Dust concentrations among the 7 SEGs

SEG Operation	No.	Measurement	AM	ASD	GM	GSD	MVUE	LCL	UCL
Road header (open cab)	28	Resp. dust	4.84	4.95	3.39	2.35	4.73	3.33	8.61
		RCS	1.002	1.051	0.579	3.37	1.123	0.677	3.275
Road header (closed cab)	15	Resp. dust	1.708	2.46	0.84	3.46	1.74	1.165	3.507
		RCS	0.344	0.399	0.155	4.27	0.414	0.254	1.056
Shotcreter	8	Resp. dust	0.99	0.74	0.77	2.17	0.99	0.65	2.40
		RCS	0.094	0.119	0.047	3.54	0.09	0.047	0.741
Roof bolters, drilling rig operators & workers	21	Resp. dust	0.75	0.63	0.53	2.36	0.75	0.56	1.21
		RCS	0.142	0.163	0.067	3.93	0.157	0.094	0.450
Fitters, boilermakers and electricians	6	Resp. dust	2.42	2.65	1.16	4.17	2.50	1.11	118.6
		RCS	0.092	0.106	0.051	3.40	0.090	0.045	1.609
Drivers and crane operators	11	Resp. dust	0.51	0.64	0.31	2.82	0.49	0.30	1.44
		RCS	0.099	0.074	0.071	2.657	0.107	0.065	0.341
Supervisors	3	Resp. dust	0.33						
		RCS	0.065						

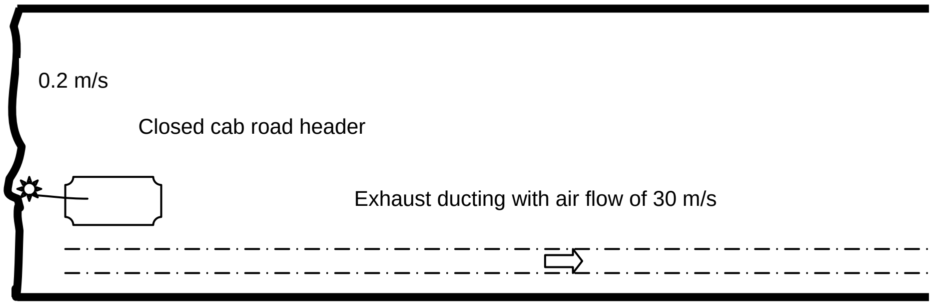
Note: Results of the respirable dust and RCS concentrations showing differently calculated means and confidence limits for all seven SEGS. RCS results are highlighted in pink.

All the following terms relate to the various dust concentration measurements

AM = arithmetic mean
ASD = arithmetic standard deviation
GM = geometric mean of the lognormal distribution
GSD = geometric standard deviation
MVUE = minimum variance unbiased estimate
LCL = 95% lower confidence limit of the lognormal distribution
UCL = 96% upper confidence limit of the lognormal distribution

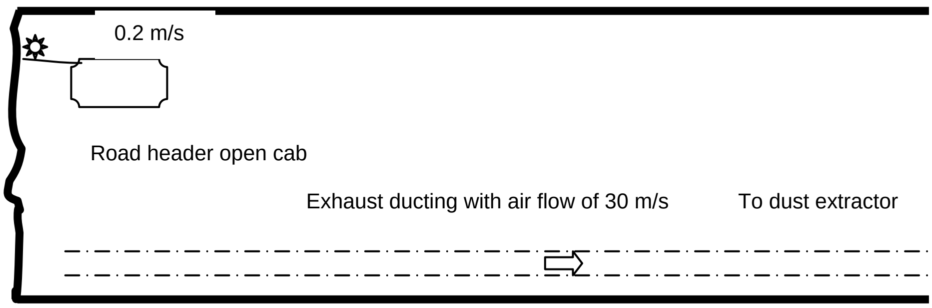
Most reliable information about the spread of results can be found by examining both the Geometric Means and their Geometric Standard Deviations.

Appendix A2 – Ventilation examples

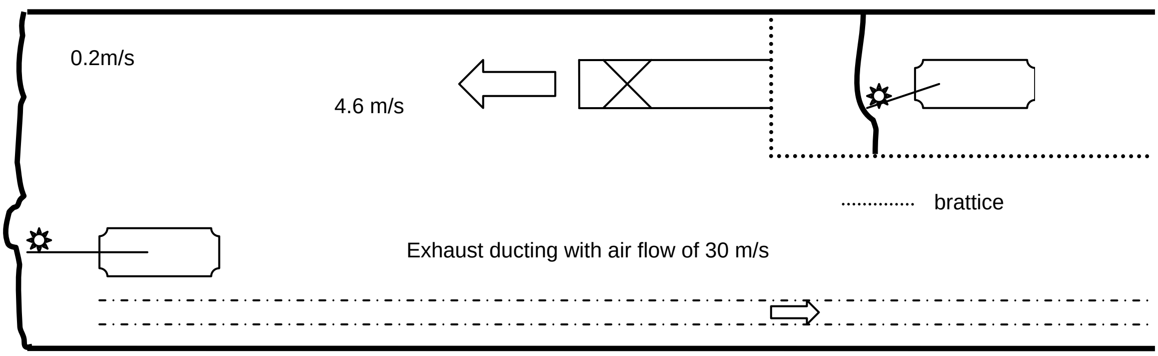


Ventilation example 1: Ideal situation of single road header operating with extraction ventilation brought to face

Mechanically generated dusts require a minimum velocity at the point of capture of between 2 and 3 m/s for the extraction to work ideally. For a duct of 1.6 m diameter, with a measured centreline velocity of 36 m/s, the maximum capture distance to maintain a velocity 2 m/s will be around 2 metres. Beyond 2 m, the dust will be extracted slowly as the air column moves towards the duct. From the distant side it may take up to one minute to clear the dust

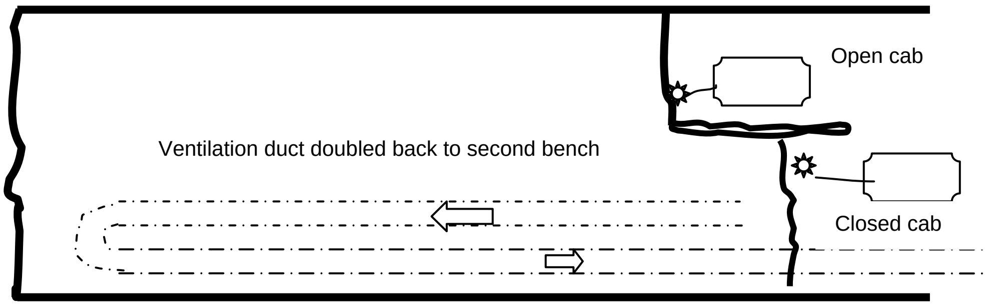


Ventilation example 2: Non-ideal situation with single road header operating with extraction ventilation on opposite side of tunnel



Ventilation example 3: Ideal situation with two road headers operating in same tunnel.

First (LHS) road header operating on advancing face, and second (RHS) road header operating on second bench within fully isolated (bratticed) enclosure fitted with in-line dust extractor and dust filtering unit X. This arrangement effectively prevents the dust load created by the second benching operation from contaminating the inbound operations at the forward face.



Ventilation example 4: Non-ideal situation with two road headers both engaged in second benching operations in near proximity to one another and relying on the one extraction point. The effective capture distance from the open end of the duct for mechanically generated dusts to be directly captured should not be significantly greater than 2 m.