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Evaluating Progress: Trends in respirable crystalline silica exposure in tunnel construction

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ABSTRACT: Silicosis remains the most prevalent work-related health condition reported among tunnel workers worldwide, highlighting the ongoing concern regarding respirable crystalline silica (RCS) exposure in the tunnelling industry. Advancements in engineering controls and work practices have been implemented to mitigate RCS exposure. This study analysed RCS exposure trends from 2016 to 2024 across tunnelling projects in New South Wales, Australia with the aim of evaluating the effectiveness of those measures in reducing exposure over time. Using exposure monitoring data from multiple tunnel construction projects, this analysis identifies trends in RCS levels across different workgroups, highlighting areas of progress as well as persisting challenges. The findings provide valuable insights into the effectiveness of current control strategies and pinpoints areas where additional engineering interventions are needed to further reduce exposure. Preliminary results indicate that while overall exposure levels have decreased in some tunnelling environments, certain workgroups remain at risk of high exposure to RCS. This research reinforces the need for continued innovation in engineering solutions, including improved ventilation and dust suppression technologies. By examining industry-wide exposure trends, this study aims to guide future engineering interventions, with the aim of ultimately creating a safer working environment for tunnel construction workers.

1 INTRODUCTION

Tunnel construction workers (TCWs) operate in environments that can be hazardous to their health. While various work-related diseases have been reported in TCWs globally, the literature indicates that important levels of respiratory disorders are frequently reported, silicosis being the most common. This emphasises silicosis as an on-going concern within the tunnelling sector (Cole and Driscoll 2025).

The primary risk factor for silicosis is cumulative exposure to respirable crystalline silica (RCS). Recognising the risks of RCS exposure, the Australian Tunnelling Society (ATS) established the Air Quality Working Group in 2017. The group developed standardised resources to add to the industry's body of knowledge to support the management of RCS (Cole 2019).

Several advancements in engineering controls and work practices have been implemented across various tunnelling projects to mitigate RCS exposure. These have ranged and included ventilation improvements, the increased use of enclosed heavy plant cabins, dust suppression, misting systems, mobile dust collectors for dust control, shrouds to better capture dusts at the source, improved housekeeping practices and real time monitoring (Sydney Metro 2020, Sydney Metro 2020, Sydney Metro 2020, Cole, Och et al. 2021, Fanning and Allan 2023). However, despite these advancements, challenges remain in effectively managing RCS exposure underground (Oliveira 2019).

Our research found that in the workforces that built several Queensland tunnels in the last decade, one in ten tunnel workers would develop silicosis if past exposure levels and controls exist (Cole, Carey et al. 2025), reinforcing the need to reduce exposure.

Airborne RCS measurements are routinely conducted by occupational hygienists across tunnel projects to assess workers exposure. Although this monitoring is common, researchers often have limited access to the data, making it difficult to evaluate whether exposure levels have improved, worsened, or remain unchanged over time. While tunnelling contractors retain custody of RCS monitoring reports, government agencies may also hold copies under certain circumstances. These may be obtained through contractual arrangements or as part of audit and assurance processes. In some cases, health and safety regulators request the reports to assist with compliance monitoring or enforcement.

When RCS data are held by government agencies, researchers can seek access through freedom of information (FOI) processes, with decisions based on public interest considerations. Additionally, the New South Wales Legislative Council can compel the production of documents from government agencies through an Order for Papers under Standing Order 52. Documents provided under this process are tabled in Parliament and become publicly accessible.

This study aimed to identify areas of progress and areas where additional engineering interventions may be needed to further reduce RCS exposure. It involved obtaining RCS exposure data that was collected during tunnel construction in New South Wales (NSW), Australia, between 2016 and 2024. The data was used to examine trends across multiple projects and work groups. This analysis focused on select work groups involved in three common tunnel construction methods: through tunnel boring machine (TBM), mined tunnelling, and cut and cover tunnelling.

2 METHOD

2.1 *Accessing RCS Data*

In conducting this research, applications were submitted to state and federal government agencies through their respective FOI legislative frameworks. In addition, the Australian Workers Union (AWU), which represents tunnel workers, was contacted to request voluntary access to existing datasets on air monitoring results for respirable dust and RCS in tunnelling. The AWU granted access to information they had previously obtained through their own FOI requests, which was used to support this study.

In late 2024, a request under Standing Order 52 led to the release of NSW government documents relating to RCS in air monitoring (Parliament of New South Wales 2024). These included data from multiple tunnel projects constructed since 2017, which were also accessed for this study.

2.2 *Analysing RCS Data*

The results of RCS and respirable dust exposure from personal exposure samples were reviewed and manually extracted into MS Excel. Each result was assigned a unique identifier for each tunnel project and tunnel site. The way that workers were categorised across each tunnel project was similar, but not identical. Reports containing qualitative information of worker activities performed during sample collection were used to categorise the exposure result by location, tunnelling method (e.g. TBM, mined tunnelling, cut and cover tunnelling) and work group. Duplicate records were identified and removed. Data were categorised into broad work group based on the qualitative descriptors provided.

Results were summarised by recording the number of samples (n) and geometric standard deviation (GSD). For each work group, the estimated arithmetic mean (AMest) and corresponding 90% credible interval (CI) was calculated using the Expostats toolkit, which applies Bayesian methods as described by Lavoué et al. (2018) (Lavoué, Joseph et al. 2018). Censored data was processed through ND Expo.

The geological conditions in the regions where tunnels were constructed varied in their crystalline silica content of the host rock. This variability contributed to wide GSDs in RCS data. To provide a more consistent comparison, GSDs were reported using respirable dust data only. Due to this variability, it was also considered that examination of changes over time would be better undertaken using respirable dust exposures rather than RCS levels.

Where datasets contained less than three results and/or less than three days of monitoring, they were excluded from this analysis. All data presented in this analysis do not consider the use of respiratory protective equipment (RPE) where it was used. Qualitative information contained in air monitoring reports were used to identify potential factors that may have contributed to elevated or decreasing levels of respirable dust and RCS.

3 RESULTS

RCS exposure data were available from 12 tunnel projects, with data spanning an eight-year period from 2016 to 2024. The information obtained included individual and summary exposure monitoring results, qualitative descriptions of work activities and various tables. Data formats varied and included hard copy paper files, electronic PDF documents, and MS Excel spreadsheets.

Tunnel projects used various construction methods, with TBM, mined tunnelling and cut and cover tunnelling being the most common. While the complete dataset comprised approximately 3,300 individual exposure results, this study focuses on the analysis of around 2,000 results. Data are presented by tunnelling method, with each project assigned a unique identifier to preserve anonymity.

3.1 *TBM Tunnelling*

Exposure data from workers constructing tunnels using TBMs were available from six projects. Figure 1 displays the AMest and CI for both respirable dust and RCS across each project.

Hard rock TBMs were used across all projects except for one (Project 6) which employed a mixed shield slurry TBM. Worker exposures on the mixed shield TBM were significantly lower than on hard rock TBMs. Mean RCS exposures across hard rock TBM projects ranged from 0.05 to 0.1 mg/m^3 with mean respirable dust exposures ranging from 0.22 to 0.53 mg/m^3.

Data were available from four projects for trend analysis; however insufficient data were available for TBM ring builders on Project 3. A general upward trend over time in respirable dust exposures for workers stationed on TBMs was identified for operators, ring builders and backend workers (Fig. 2). The most significant increases were observed among backend workers (these are the workers that extend services, manage conveyors, handle segments, and perform grouting tasks).

Several factors were identified as likely contributing to elevated levels of RCS in TBM environments. These included inadequate ventilation systems, which were observed to have air velocities below 0.5 metres per second (m/s) in areas where workers were present and therefore limiting the effective removal of airborne dust. The absence of proper sealing, filtration, and positive pressurisation in TBM operator cabins and crib rooms further reduced the effectiveness of containment controls. Instances were also reported where domestic-grade air purifiers were used to clean the air; although these units were not designed for industrial applications and provided limited benefit. In addition, housekeeping practices such as infrequent washdowns of TBMs allowed dust to accumulate and then become airborne when disturbed. Dust released from conveyor belts during operation was another common and significant source of RCS.

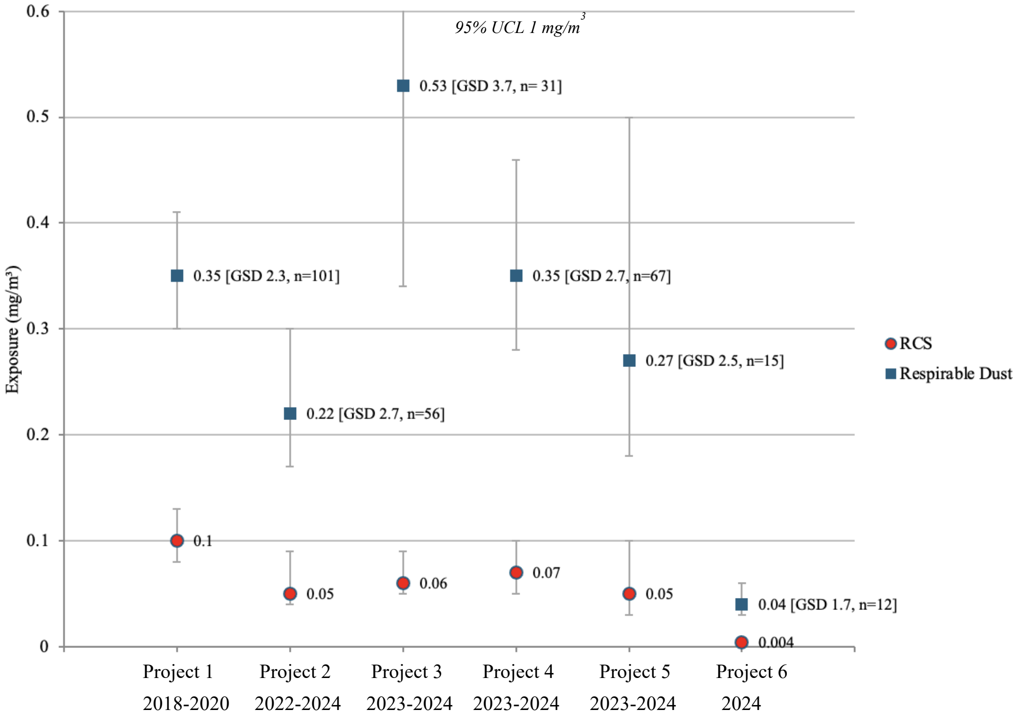

Figure 1. Respirable dust and RCS exposures to TBM workers.

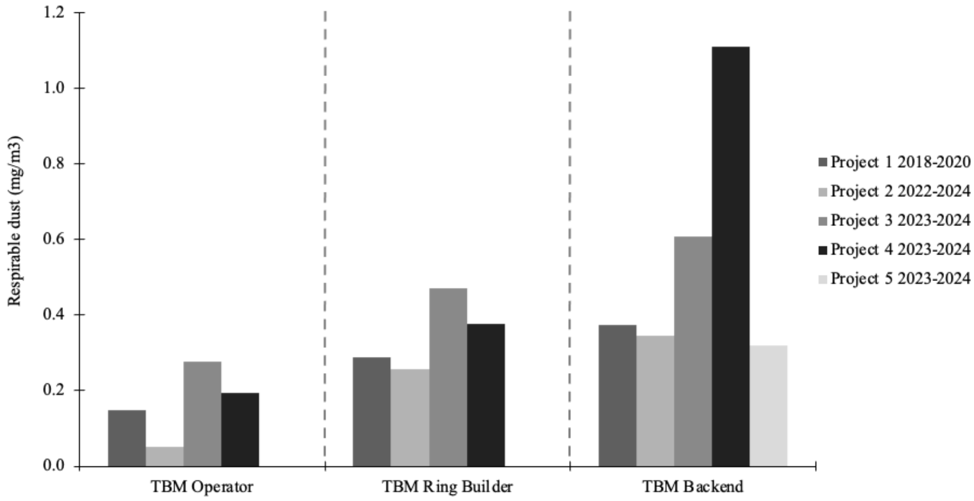

Figure 2. Mean (AMest) respirable dust exposures to workers on TBMs grouped by work group and project.

3.2 *Mined tunnelling*

Exposure data from workers constructing tunnels using mined methods were available from 12 projects. Figure 3 displays the mean (AMest) and CI for both respirable dust and RCS across each project. Mean RCS exposures ranged from 0.02 to 0.26 mg/m^3 with mean respirable dust exposures ranging from 0.22 to 0.70 mg/m^3 (Fig. 3). Note for one project (Project E) only summary exposure data by work group were provided, which prevented inclusion of the full dataset in Figure 3.

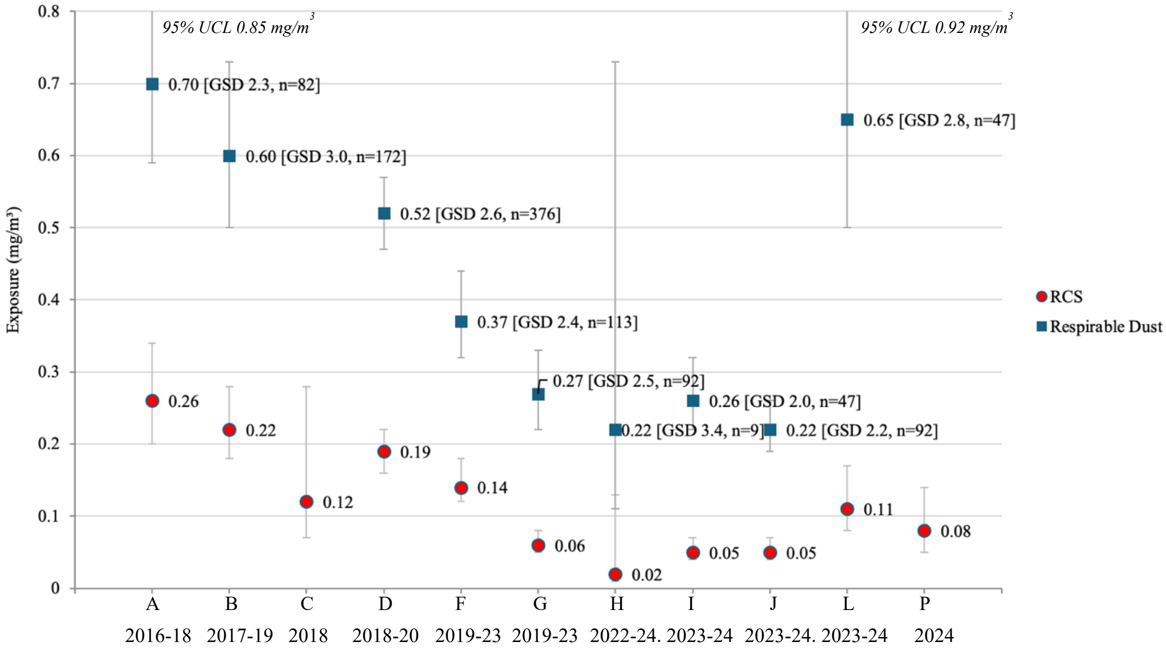

Figure 3. Respirable dust and RCS exposures to workers on mined tunnelling projects.

The highest exposures to workers on mined tunnel projects were of workers who operated roadheaders without cabins. Mean (AMest) RCS exposures were 5.1 mg/m^3 (CI 2.5-19) from a project constructed between 2019-2020. While insufficient data was available to enable trending, this level of exposure demonstrates significant exposures to RCS when this machinery is employed.

Other high exposed workers included those who operated roadheaders fitted with cabins, those who operated heavy plant, and workers on foot involved in excavation of the heading. These workers were involved in ground support, waterproofing, offsiding, or were otherwise classified as 'tunnellers'.

Data were available from 12 projects to trend exposures; however, only RCS data were available from Project C so respirable dust levels were estimated based on the crystalline silica content from nearby tunnel projects under construction. Insufficient data were available for roadheader and heavy plant operators from Project H or L. A downward trend in respirable dust exposures was identified for roadheader operators, heavy plant operators and workers on foot involved in heading excavation (Fig. 4).

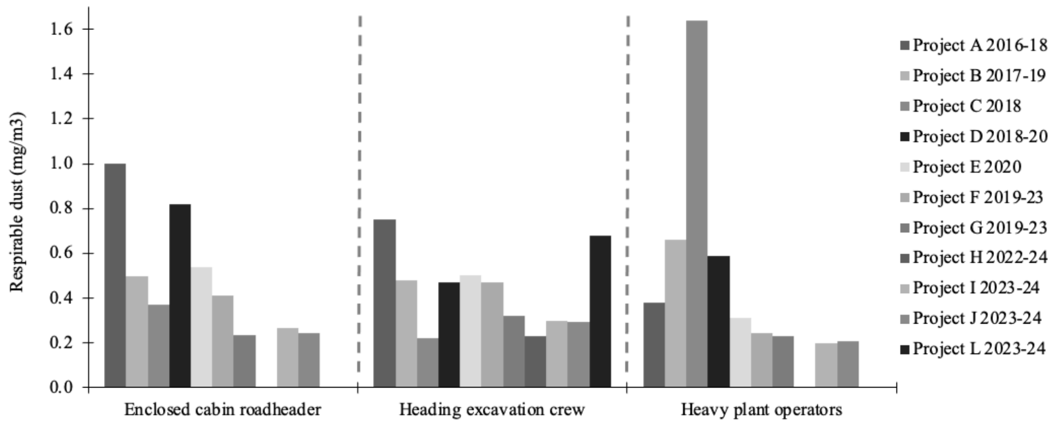

Figure 4. Mean respirable dust exposures to workers constructing mined tunnels grouped by work group and by project.

Although the data indicates a downward trend in exposures over time within mined tunnels, several challenges were evident in these environments. A common issue identified in reports was insufficient air velocity and/or extraction to effectively capture airborne dust generated during excavation. While extraction ventilation was available during roadheader operations where cabins were not used, its effectiveness was repeatedly limited. Reports also noted that extraction systems were not consistently extended following each cut or were only extended to the rear of the roadheader, allowing dust to accumulate around the machine. Elevated exposure levels were also observed during periods where multiple dust-generating activities occurred simultaneously, such as profiling in close proximity to benching operations.

Beyond roadheader operations, there was limited evidence of source-level dust extraction for heavy machinery. Water suppression systems were generally fitted to plant, though manual application by workers was also reported. Additional concerns included non-functional air-conditioning units in heavy plant, resulting in cabins being operated with doors and windows open, which compromised protection. Cabins were also reported to be affected by mud and settled dust. Over time, however, the use of sealed cabins fitted with positive pressure filtration systems became more common.

3.3 *Cut and cover tunnelling*

Exposure data from workers constructing tunnels using cut and cover methods were available from 6 projects. Figure 5 displays the mean (AMest) and CI for both respirable dust and RCS across each project. Mean RCS exposures ranged from 0.02 to 0.16 mg/m^3 with mean respirable dust exposures ranging from 0.18 to 0.25 mg/m^3 (Fig. 5).

Data were available from 6 projects for trend analysis; however, insufficient data were available for ground support workers from Project β and ε. When comparing respirable dust exposures, a downward trend was identified for ground support workers and those who operated heavy plant. However, an upward trend was identified for general labourers, who were primarily on-foot in the working area (Fig. 6).

In cut and cover tunnelling environments, fewer exposure control measures were observed compared with other tunnelling methods. Ventilation systems were rarely noted apart from the intermittent use of small air movers. While spray misters were used at times, they did not appear to effectively capture or remove airborne dust. Water suppression was applied in some instances, but its effectiveness was limited, particularly where air movement was restricted. The lack of localised dust control at the source allowed airborne dust to migrate beyond the immediate work area, exposing other workers. Similarly, water suppression systems fitted to plant equipment often did not sufficiently manage the volume of dust generated during operation. Inadequate housekeeping practices further contributed to dust accumulation in work zones.

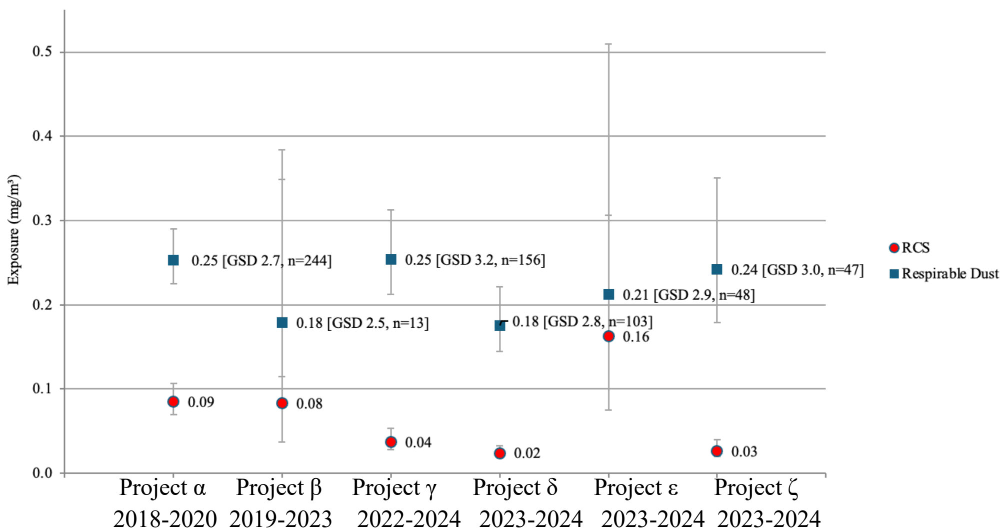

Figure 5. Respirable dust and RCS exposures to workers in tunnels built by cut and cover methods.

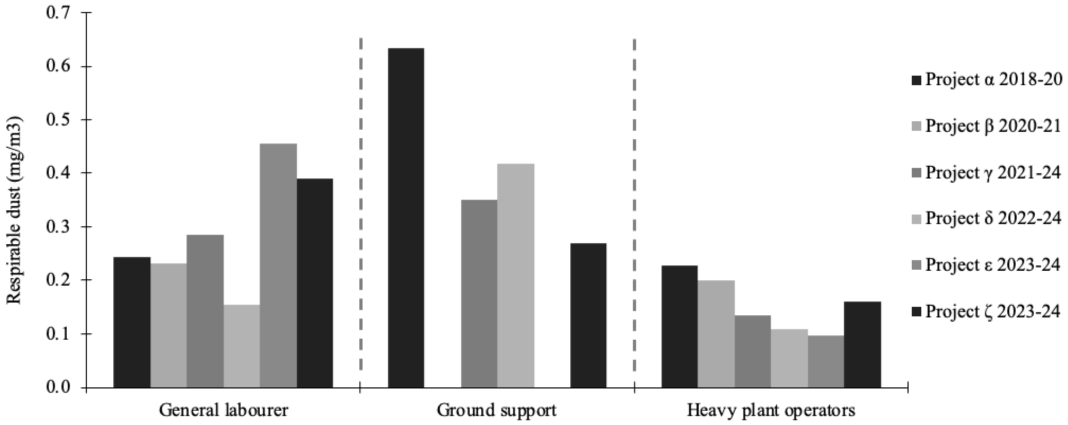

Figure 6. Mean respirable dust exposures to workers constructing cut and cover tunnels grouped by work group and by project.

4 DISCUSSION

Australia has experienced a significant shift in its approach to silicosis, largely due to a rise in cases linked to the stone benchtop industry. This surge in cases has sparked broader attention to silica exposure risks across multiple sectors, including tunnelling. During the period in which this data was collected, the National Dust Disease Taskforce was established, the WES was halved in 2020, and in 2024, the National Silicosis Prevention Strategy was approved alongside new crystalline silica regulations. These developments reflect heightened media, political, and regulatory focus on silica-related diseases, raising expectations for enhanced risk management in high-risk industries. For the tunnelling sector, this translates into increased scrutiny and a stronger imperative to prioritise engineering controls to ensure worker protection.

The results of this study indicate both progress and ongoing challenges in reducing TCW's exposures to RCS. Decreasing exposure levels were observed over time for select work groups in mined tunnels, as well as for ground support personnel and heavy plant operators in cut-and-cover projects. However, increasing exposure levels were identified among all workers on TBMs and among general labourers in cut-and-cover tunnelling.

A review of the commentary provided in exposure monitoring reports indicated that, while some control measures were in place, there remained a heavy reliance on RPE to protect TCWs from RCS exposure. Reports included commentary on whether RPE was being used, with recommendations often focused on measures low on the hierarchy of control. In many instances, where RPE was observed and exposure levels were estimated to be below the WES, there was little emphasis in reports on improving more effective, higher order controls. However, the hierarchy of control is founded on the principle that addressing hazards at their source and modifying the work environment is more effective than relying on individual behaviour. Engineering controls offer greater effectiveness and reliability compared to ongoing reliance on personal protective equipment (Lingard and Rowlinson 2004).

There were numerous instances where RPE was not effectively used over the assessed period. This included instances where its use was not mandated, the level of protection provided was inadequate, it had not been fit-tested, workers were not clean-shaven, or it was not worn when needed. These findings highlight the importance of prioritising higher-level interventions to more effectively manage RCS exposure and reinforces the continued need for engineering controls to further improve working conditions for TCWs across multiple tunnelling methods.

Given that RCS is a confirmed human carcinogen; all measures should be taken to minimise exposure to as low as reasonably practicable, regardless of whether exposures are below the WES.

There are some limitations to consider in this study. The available exposure data covered selected periods within each tunnel project, ranging from partial to broader phases of construction. Task-specific information was sometimes limited, meaning that results were assigned based on the authors' professional judgement. While common work groups and tunnelling methods are represented, data for all possible roles and construction approaches were not included. These limitations are considered unlikely to have introduced important bias into the study.

5 CONCLUSION

This study of exposure trends in tunnelling from 2016 to 2024 indicates both progress and ongoing challenges in improving conditions for TCWs. Decreasing exposure levels were observed over time for select work groups in mined tunnels, as well as for ground support personnel and heavy plant operators in cut-and-cover projects. However, increasing exposure levels were identified among all workers on TBMs and among general labourers in cut-and-cover tunnelling.

The data, supported by qualitative information contained in air monitoring reports, indicate that enhanced source control measures, improved ventilation and appropriate use of enclosures could provide improved protection for TBM workers. These findings also highlight the importance of integrated and fit-for-purpose dust control strategies across all aspects of TBM operations.

While exposure levels in mined tunnels showed a downward trend over time, further reductions could be achieved through more effective ventilation and dust extraction, particularly around roadheaders and during simultaneous dust-generating activities. The increased use of sealed cabins fitted with positive pressure filtration systems is a positive development in operator protection. In cut and cover tunnelling, more robust source control and ventilation measures could also reduce RCS exposure risks.

Overall, exposure levels highlight the continued need for engineering controls to further improve working conditions for TCWs across multiple tunnelling methods.

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