ICMM
International Council
on Mining & Metals

CONSIDERATIONS FOR THE ADOPTION OF REAL-TIME PARTICULATE MONITORING

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This brief provides a high-level overview of the considerations for the adoption of real-time particulate monitoring (RTPM) in the mining and metals industry. Although it is not a guidance document, it includes suggested principles, implementation maturity framework and case studies from ICMM member companies highlighting the industry's journey with RTPM. It aims to encourage the operationalisation of RTPM to reduce worker exposures to hazardous airborne particulates, to improve understanding of the benefits and the limitations of RTPM and ultimately seek the improvement of RTPM through an industry call to action.

Summary

Mining companies are challenged to effectively protect workers from harmful exposures to certain airborne particles and particulates. Based on the geology of the mined materials, dusts can be formed that can contain harmful levels of microscopic particles like silica, coal, lead, arsenic, alumina, asbestos fibres, or other elements that are dangerous to inhale. Similarly, processes such as diesel combustion can lead to diesel particulate matter being released into working areas. Overexposure to these particles and particulates can lead to a spectrum of negative health outcomes, from allergic reactions to asthma, chronic diseases such as black lung disease, silicosis, chronic obstructive pulmonary disease, asbestosis, cancers, and others. Both particles and particulates will be referred to as particulates throughout the rest of the document.

Mine operators work diligently to identify high risk activities, medically monitor at-risk workers, and implement protective controls. Sampling the air to identify, and quantify, the presence of harmful particulates is the primary tool used to mitigate where and when overexposures are likely to occur and validate exposure control effectiveness.

Traditional gravimetric analysis of sampled particulates is the standard way for estimating hazardous exposures and the method that most commonly meets regulatory compliance requirements. However, these sampling methods are typically conducted over several hours to make sure enough material is captured to be analysed, and results from analysis that both quantify and characterise the particulates can take days to receive. Since conditions present at the time of sampling may have changed, this time lag can delay the implementation of timely interventions to improve worker protections and can complicate the validation of control effectiveness.

Real-time particulate monitoring (RTPM) instruments are an important tool for airborne particulate monitoring. RTPM instruments use sensor technology to quickly detect and quantify airborne particulates. Since RTPM measures quickly, it is an effective tool for identifying uncontrolled or unexpected critical releases of hazardous particulates, pinpointing specific activities within job tasks that have a high likelihood of exposure. It could also be used to improve and confirm Similar Exposure Groups (SEGs), and for validating the effectiveness of existing controls.

Therefore, ICMM members believe **that RTPM is a proactive and effective tool for preventing hazardous airborne particulate exposures, mitigating associated risks, and validating controls.**

As ICMM member companies, we encourage collaboration and innovation to accelerate the industry towards a future of RTPM, that will help us to reach the goal of zero fatalities.

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Introduction

Mining companies understand that their greatest asset is their workforce and have made significant investments to improve the safety and health of workers, resulting in decreasing numbers of fatalities and injuries over the past decade.

However, mining companies continue to be challenged to effectively prevent and mitigate certain worker health risks, especially those associated with chronic respiratory illnesses such as silicosis, chronic obstructive pulmonary disease (COPD), coal workers pneumoconiosis, asbestosis. Preventing and controlling worker exposures to hazardous particulates is a top priority at mine operations – and in most jurisdictions a regulatory requirement.

In the 2019 ICMM publication *Fatality Prevention: eight Lessons Learned*, lesson 8*:* 'Prevention is better than cure' recognised that the burden of occupational disease in mining results in more fatalities (particularly those resulting from the inhalation of hazardous particulate material) than had been recognised in the past. It highlighted the need for different controls to prevent them compared to other fatal risks. The industry continues to apply critical control management (CCM) principles to reduce exposures, however, more needs to be done. Recognition of occupational diseases as a fatality risk that requires the same management as the safety discipline is gaining ground. Traditional modes of managing occupational health have been focused on consequences management (a focus on the disease) with less focus on managing the cause i.e. the control of health hazards in the workplace and the prevention of exposure.

To assist with the efficacy of CCM (to manage and verify controls to achieve effective implementation), quicker interventions are required when controls are shown to be failing or ineffective. It has been suggested that real-time (or as close to real-time as possible) monitoring of hazardous particulate material can be a source of this information.

This document lays out the background and reasoning for the use of RTPM at mining and metals operations based on the premise that RTPM is a proactive and effective tool for preventing hazardous airborne particulate exposures, mitigating associated risks, and validating controls. The overall aim is to encourage the operationalization of RTPM to manage particulate exposure controls and reduce worker exposures to hazardous airborne particulates, and to seek the improvement of RTPM technologies through an industry call to action. This call to action has ICMM encouraging collaboration and innovation to accelerate the industry towards a future of RTPM, that will help the industry to reach the goal of zero fatalities.

Background – purpose and history of particulate sampling

Gravimetric and optical detection analysis are the two primary methods used for particulate exposure assessment. Particulate sampling with gravimetric analysis is traditionally: the most prevalent method for estimating hazardous particulate exposures; the most commonly used method to meet national and regional regulatory compliance requirements; and the basis against which OELVs are set.

Current standards and Occupational Exposure Limit Values (OELVs)

Historically a variety of techniques and instruments have been used to assess exposure to particulates. International guidance on the general requirements for procedures used for the measurement of chemical agents in workplace atmospheres is provided by the International Organisation for Standardisation standard ISO20581, summarised in Table 1.

In most locations, national and local regulations prescribe permissible levels of hazardous particulates, with most occupational exposures benchmarked against established jurisdiction-specific occupational exposure limit values. These values are codified by regulatory bodies based on scientific organisations but can vary across the world.

Scope	General performance requirements for procedures for the determination of the concentration of gases, vapours, and airborne particulates in workplace atmospheres, and apply to all steps in the measuring procedure, including separate sampling and analytical method sand direct-reading instruments
Classification and Performance Requirements	Time-weighted average concentration
	Concentration variation, time/space
	Comparison with Occupational Exposure Limit Values (OELVs)
	Periodic Measurements
Test Method	Outline of testing protocols and uncertainty calculations
Validation Report	Test conditions, results obtained, measurement compliance

Table 1. Workplace air - General requirements for the performance of procedures for the measurement of chemical agents.

Importance of particulate size

Knowing the size of the particulates is essential in assessing risk as smaller particulates tend to go deeper in the lungs when inhaled and correlate to greater risk of disease. In workplace air sampling, size is defined as the aerodynamic diameter of the particulate. The reason aerodynamic diameter is used to measure a particulates size is that it accounts for both the physical size and its density. This is important when considering two particulates of the same size, but different densities, in that they will behave very differently when airborne.

To visualize this, imagine you have a wind tunnel and throw in two basketballs, one filled with air and the other filled with water. The behaviour of each basketball will clearly not be the same. This matters in our context because where particulates collect in the respiratory tract when inhaled correlates to the risk that those particulates pose to a worker's health.

Generally, larger, denser particulates, or 'inhalable' particulates (≤ 100 µm) will collect in the upper respiratory system like the nares and upper throat where they may be cleared or digested. Medium-sized particulates in the size of ≤40 µm or 'thoracic particulates' can penetrate to the bronchi and bronchioles. Smaller less dense particulates (≤ 15 µm) or 'respirable particulates' can traverse through the turns of the nares and upper throat and make it to the deep lungs, where they can be lodged into the alveoli and thus damaging the cells in the gas exchange region. The smallest, least most often dense particulates (≤ 0.5 µm) are the most complex because they behave more like gases then particulates, entering deep into the lungs where gas exchange occurs and potentially entering the blood stream, or exiting via exhaled breath. By understanding the aerodynamic diameter of airborne particulates an estimate can be made of where they may pose the most risk when inhaled. See ISO 7708 for more information on particulate size fraction definitions for health-related sampling.

Particulate composition and speciation

Size alone is not enough to fully assess risk from exposure to airborne particulates. Understanding the risk of hazardous particulates in the workplace also involves characterising the 'what, when, and how much' of miner exposures. Identification of what the dust consists of, called speciation, helps to narrow the list of potential health threats posed. Examples include silica, coal, beryllium, arsenic, lead, etc. Defining when the exposures occur, or during which activities, aids in mitigation so appropriate and effective controls are applied at the right time and in the right place. Lastly, quantifying the species of element or chemical correlates directly to exposure risk, allowing direct comparison to occupational exposure limits.

Particulate monitoring methods

Personal and area air sampling is the primary means used in occupational settings to characterise and quantify airborne particulates. Area samples represent a specific environment where miners may be present and correlates to the air quality of the general work environment. Personal samples are collected proximally to the breathing zone of a specific miner mimicking what is inhaled by that worker.

For worker risk management, particulate collection with gravimetric analysis and optical detection (see next section on real-time monitoring) are the two primary methods used for particulate air sampling.

Particulate collection with gravimetric analysis

The gravimetric method uses a calibrated pump to pull ambient air from the breathing zone through a size-selecting sampler that contains a collection substrate (in many cases a filter) sometimes held inside a plastic or metal sampler cassette. This complex apparatus is a challenge in the dynamic and harsh mining environment. When sampling is complete, the cassette is then sent to a laboratory for analysis. Size selective sampling methods with collection substrates allows for quantification and particulate type speciation, such as coal, lead, silica dust, or chrysotile fibres. Size selective sampling is typically conducted over hours and results take at least hours and in most cases days to provide the data needed to quantify exposures and measure existing control effectiveness. The environmental conditions present at the time of sampling may have changed by the time the data arrives, meaning that exposure mitigation and control validation decisions could be based on "old" data.

The benefits of this method are that it allows for the collection and characterisation of particulate speciation and size, and is a common methodology often used for regulatory compliance. Limitations and challenges associated with this technique include a time delay between sample collection and results, it can be a labour intensive and involve time-consuming processes, requires use of complex sampling apparatus, shipping, and handling of samples to the laboratory, and there is an inability to identify specific tasks or activities resulting in high exposures.

Real-time particulate monitoring

While particulate size selective sampling techniques are typically used in cases involving regulatory compliance, RTPM provides significant advantages for assessing hazardous exposures to miners where timely data generation enables more effective mine worker protections.

RTPM instruments function by drawing airborne particulates through a size selective pre-filter or impactor plate followed by exposure to one of two main categories of technologies:

Optical particulate counters, or spectrometers, measure by drawing a stream of particulates through a laser field with a light-scattering, or light-absorbing, detection sensor. The light scattering, or absorption, is then measured by the sensor and algorithms calculate measures of particulates mass or counts by size per volume of air (e.g., count/m^3; $\mu g/m^3$ per size classification). The instrument compares the detected particulates to benchmarks established during pre-sampling calibration of a known particulate density powder such as aluminium oxide. Over time advances in RTPM technology have resulted in improved particulate estimating algorithms and smaller components.

Photometers, also called nephelometers, measure airborne particulates by transmitting a light beam through the flow of airborne particulates towards a sensor. The sensor detects total amount of light reflected, or scattered, to calculate the particulate size and quantity.

Most field portable RTPM instruments are constrained to monitoring particulate sizes between PM2.5 and PM10, although a handful have been successful in detecting PM1 concentrations. Other major RTPM systems rely on alternative methods that use actual collection of material, which is then passed through filters known as impactors. These impactors are size specific, so the instrument sensors can measure a wider range of particulate sizes. The use of impactors is favoured in some operations due to the ability to retroactively run gravimetric testing on collected samples, whereas this ability is not an option when collecting data using scattered light. RTPM sampling methods can log results in one-second to one-hour intervals, which allows for the collection of large volumes of data that would otherwise be collected using gravimetric methods across 8-to-12-hour intervals.

RTPM use brings significant benefits to mine operators with many companies currently piloting or effectively using RTPM as a rapid analytical tool for understanding, and mitigating, respiratory risk. Benefits include:

1. Rapid and timely airborne particulate data that can be used to protect miners.
2. Effective tool in CCM used to validate the effectiveness of critical controls, mitigating airborne particulates where exposures have the potential for high-probability fatal outcomes.
3. Ability to identify and pin-point specific particulate emission sources.
4. Identification of specific activities within job tasks where overexposures occur, informing mitigation and control strategies.
5. Rapidly identify uncontrolled or unexpected critical releases of hazardous particulates.
6. Early warning of out-of-specification operations, enabling preventive maintenance before catastrophic failure of equipment.
7. Latest RTPM instruments are becoming small enough for use in personal dust sampling.
8. Validation of environmental and occupational dust controls.

However, there are challenges that continue to hamper getting the full roll-out and benefit of using RTPM that ICMM members would like to see addressed:

1. There is no standardisation of RTPM sensors, so comparing data across instruments is challenging.
2. Current RTPM technology does not support speciation of particulates and no RTPM instruments cover the entire size range germane to respiratory hazards (<0.5μm – 100μm).
3. Field-calibration of real-time particulate monitors is challenging.
4. RTPM data is not currently used for regulatory compliance.
5. Costs of purchase, maintenance, and required expertise to manage and discern data is high (median US$6K each, minimum US$10K per year, and US$150-250K per year, respectively).
6. Types of particulates detected, like silica, coal, diesel exhaust, alumina, lead, etc., cannot be differentiated.
7. Instrument interference from non-particulate aerosols, like water mist and vapor, is common.
8. Operational infrastructure requirements and dependency such as access to Wi-Fi communication, data storage capacity, etc.
9. Many RTPM instruments are often too large for workers to tolerate long-term personal sampling and the ruggedness of some instruments make them prone to breaking in the harsh work environments of mining.
10. There is currently no international standard (ISO-type standard) on real-time particulate monitoring.
11. If the density of the sampled aerosol fraction is not known beforehand, the result gained with the RTPM is only related to the density of the material the RTPM is calibrated to. In many cases this calibration factors can

be between 2 and 10 when assessing real workplace dusts.

RTPM and critical control management

RTPM provides significant benefits to health and safety management systems and can be a great tool within a critical control management (CCM) context.

CCM is a practical method of improving managerial control over rare but potentially catastrophic events by focusing on the critical controls. These sorts of events are called material unwanted events (MUEs). Examples of mining industry MUEs include underground fires, coal dust explosions and tailings dam failures. However, not all MUEs involve sudden events. For example, MUEs may also include the potential exposure of groups of workers to carcinogenic or other agent at harmful levels over a protracted period. These all have the potential to cause multiple casualties, but they can also affect the ongoing viability of a business. In other words, they represent a material risk to the business.

Prevention of MUEs requires specific attention at the highest level of an organisation alongside other material business risks. The CCM approach is based on:

- Having clarity on those controls that really matter – the critical controls.
- Defining the performance required of the critical controls.
- What the critical control must do to prevent the event occurring.
- Deciding what needs to be checked or verified to ensure the critical control is working as intended.
- Assigning accountability for implementing the critical control – who has to make it work.
- Reporting on the performance of the critical controls.

RTPM has the potential to play a crucial role in critical control management relating to respirable hazards.

For example, personal RTPM can help to pinpoint high exposure actions within tasks, and therefore allow targeted implementation or improvements to preventative controls where they are needed. Automated processes can make use of RTPM data where it can be used to warn of trending exposures nearing a set threshold, which enables timely corrective interventions to be made to mitigate overexposure

In addition, RTPM data can provide timely data about the effectiveness of controls and therefore prompt corrective or maintenance action to take place. An example of this is real-time monitoring of a workplace where a local exhaust ventilation (LEV) control is in place. An increase in detectable particulates could mean that the LEV is not performing to standard and may need repairing.

Principles for effective RTPM implementation

RTPM is an effective tool used to protect miners from hazardous airborne particulate exposures. To assist companies implementing RTPM programs, an RTPM Maturity Framework has been developed (see Table 2). This Maturity Framework is designed to help map a company's current position, motivate improvements, and evaluate progress along the way.

To aid in operationalisation of RTPM programs, companies guiding principles for RTPM use and examples of the current primary RTPM applications used by mine sites has been summarised.

1. CCM by validating airborne particulate mitigation effectiveness in environments with the potential for high-probability fatal exposures.
2. Identification of activities within job tasks where hazardous levels of particulate is suspected.
3. Rapid identification of uncontrolled or unexpected critical releases of hazardous particulates

RTPM provides significant benefit to health and safety management systems, such as measuring exposures in real time and critical controls mitigating high probability fatal exposure risks can be validated frequently. During personal monitoring, RTPM can pinpoint high exposure actions within tasks such that controls can be applied only where needed, at the high-risk actions and not the entire task. With RTPM, automated processes can be used to warn of trending exposures nearing a set threshold enabling mitigation before overexposure.

The eight guiding principles for effective RTPM use are listed here and summarised graphically in Figure 1.

1. Prepare for field work

- Define the objective of sampling
  - Anticipate particulate classification (silica, coal, alumina, etc)
  - Anticipate likely particulate size range of interest
- Using the sampling objective, schedule the order of sample locations
  - Identify uncontrolled critical releases of hazardous particulates
  - Identify specific activities within job tasks with high exposures
  - Validating the effectiveness of existing controls

- Assign roles and responsibilities to the sampling team
- Develop a sampling plan
  - Communicate sampling plan with personnel in the appropriate work areas
  - Communication, engagement and Change management Plan (for hygienist, supervisor, and employees in work areas)

2. Select the most appropriate RTPM instrument to meet the sampling plan objectives

- Ensure sensors and instrument selected will meet the objective of the sampling plan
- Set up the appropriate infrastructure to support sampling plan

3. Prepare the RTPM instrument and ancillary supplies

- Calibrate, charge, and confirm the RTPM instruments are in good working order
- Confirm internal data storage capacity sufficient based on anticipated sampling plan

4. Conduct field sampling

- Collect relevant control samples per the sampling plan, including background and blank samples
  - Utilise a chain of custody for all instruments and samples
  - Capture details of sampling activities, including:
    - Date and time of sampling
    - Description of the sampling environment
    - Personnel present and their job roles
    - Activities occurring prior to and during
    - Weather conditions
    - Temperature
    - Air speed and direction
    - Relative humidity
    - Barometric pressure
    - Additional details

5. Consider whether conditions and preliminary real-time data warrant implementing control measures now

- Use RTPM to validate control effectiveness

6. Extract data from the RTPM

- Extract via cloud-based platform is supported
- Download data from the RTPM instrument
- Confirm data format and adjust to allow for effective analysis
- Conduct data analysis in full consideration of field conditions
- Draw conclusions

7. Develop report

- Use data visualisations and annotated maps to make comparisons and identify trends
- Make data-driven recommendations

8. Communicate findings to impacted stakeholders

- Inform individuals in the sampled workplaces of results and recommendations.

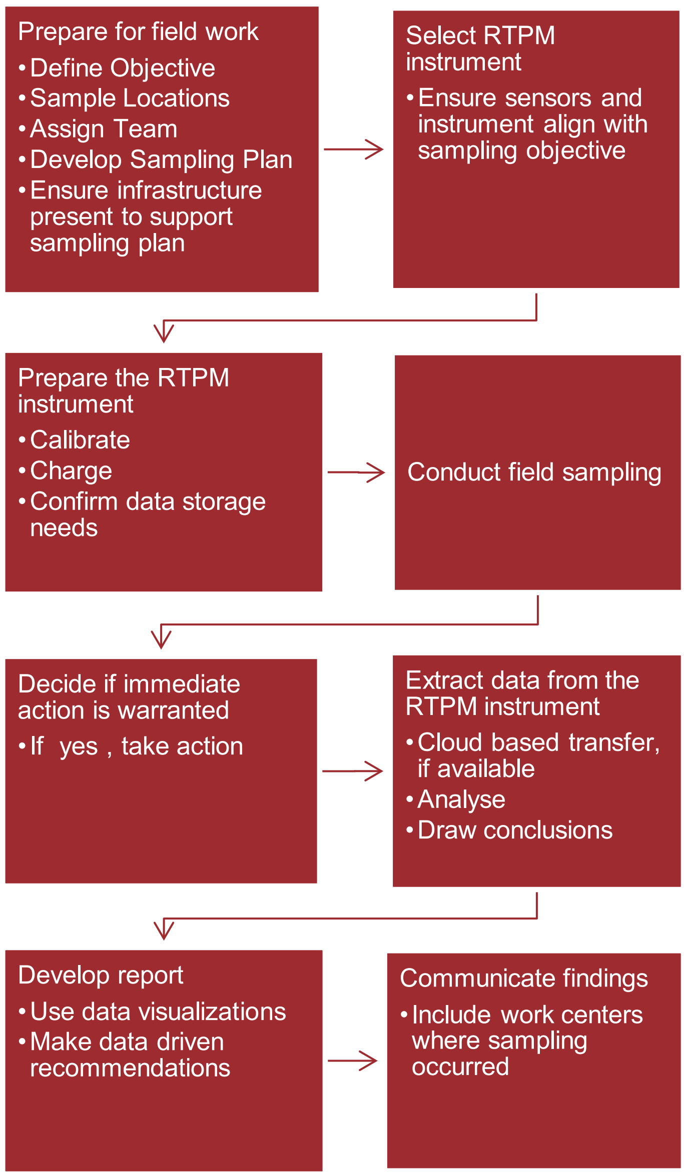

Figure 1. RTPM framework diagram

ICMM's RTPM vision

Health and safety has to be at the heart of all operations and processes. ICMM and its members share an unwavering commitment to improving health and safety performance, towards a goal of zero harm, with the priority of eliminating fatalities in the industry.

Mining presents various hazards that can be of significant consequence, but through effective risk management strategies, neither safety incidents nor the onset of occupational diseases should happen.

People have a right to go home safe and healthy to their families and their communities at the end of every day.

ICMM members believe that **RTPM is a proactive and effective tool for preventing hazardous airborne particulate exposures, mitigating associated risks, and validating controls.**

ICMM expects that RTPM will continue to expand in use across mine operations throughout the world. As the technology improves, RTPM will become smaller, more light-weight, less expensive, and have sufficient battery life that each miner can be fitted with an RTPM dosimeter that will alarm when ceiling, short-term limits, or full-shift time weighted average exposures to hazardous airborne particulates are approached.

RTPM call to action

Today RTPM is useful for health risk prevention and mitigation, but interest in (and a sense of urgency) is increasing. To meet the current worksite demands, ICMM members would like to see:

- Manufacturers developing the technology that enables compositional identification of particulates across the size spectrum using RTPM.
- Manufacturers developing the technological improvements in sensors and detectors that expand capabilities to simultaneously measure across broader size ranges (10 μm to > 1μm) and reduce interference from non-particulate aerosols, like water mist and vapor.
- Manufacturers improving ease of field calibration procedures.
- Mining companies continuing to work with the RTMP sector by piloting and using RTPM solutions.

RTPM case studies

The following case studies demonstrate the investment, and positive outcomes that mine operations are realising from RTPM utilisation. Highlights include:

- Early exposure warning
- Combining RTPM data with geolocation
- Early detection of equipment performance degradation motivating maintenance.

Case 1 – BHP

BHP is investing in a robust pilot study at 23 sites that evaluated RTPM technologies to deliver a scalable solution for minimising respiratory risks, increase situational awareness by combining real time data with geo location, inform decisions using a RTPM dashboard interface that allows dependable remote access, and enable automated rapid emergency notifications. Using both fixed and portable modalities, this ongoing study is currently validating real-time devices, airborne particulate monitoring, event storage, and reporting. Technologies being assessed include smart garments like safety vests with integrated sensors, geolocating, and two-way communication that can alarm for both the miner and hygienist when exceedances are detected. Additionally, sensors integrated into Internal Internet of Things (IIoT) frameworks coupled with Red Lion protocol converter (MODBUS to MQTT or Azure IoT) are being evaluated. The IIoT Hub is comprised of MQTT Mosquito Brokers and Ignition Sparkplug B making sensor data highly transportable across the network, resulting in real-time global data dashboard access. This study has so far identified RTPM instruments useful in identifying specific activities within tasks where high exposures occur, enabling implementation of pinpoint mitigation measures and control validation.

Case 2 – Vale

In the pursuit of reduced silica exposures, Vale evaluated three RTPM instruments, one for personal sampling and two for area monitoring as tools to mitigate airborne particulate exposure risk. The instruments were assessed for effectiveness for identifying dust generating activities and utility to rapidly identify overexposure events. The technology assessed includes the Nanozen Dustcount for personal sampling and TSI DustTrak and 3M EVM instruments for area monitoring. The instruments performed well and enabled exposure control validation. For sustainable RTPM program management and data interpretation a trained aerosol scientist or suitably capable industrial hygienist is required.

Case 3 – Alcoa

Alcoa evaluated four RTPM instruments. The study identified RTPM useful for validating critical control effectiveness, filter maintenance action levels, tracking and improving Similar Exposure Groups (SEGs), and early exposure warning in work areas when workers were present. Technologies evaluated included TSI DustTrak, TSI Sidepak, and FLIR Airtec (no longer in production). The instruments had effective data transfer, analysis, and plotting interfaces. RTPM limitations included significant and frequent maintenance requirements, lack of ruggedness, low tolerance by miners for personal sampling due to instrument size, and inability to use the data for regulatory compliance.

Case 4 – Freeport-McMoRan

Freeport-McMoRan evaluated three commercially available RTPM instruments and a prototype same-shift silica analysis tool under development for improved critical control monitoring for fatal risks. The instruments were used to identify sources of exposure, measure control effectiveness, guide priorities for dust control strategies. Technologies evaluated included TSI DustTrak, Thermo-Fisher pDR, Nanozen Dustcount, and NIOSH prototype same-shift silica monitor. Study found cross-sensitivity to non-dust aerosols, fog, and diesel particulate matter and that the RTPM instruments required re-calibration with changing geology across the particulate size range. Due to the bulky size of some instruments (other than Nanozen), miner tolerance for breathing zone sampling was low.

Case 5 – Teck

To build a business case for change for what is the biggest cause of premature deaths of miners, respiratory disease, Teck Resources invested more than US$1M in a robust, 12-month, RTPM pilot study. The study used personal RTPM instruments for identifying the activities that corresponded to the highest exposures, confirmation of critical controls, and prioritisation of interventions. The technology assessed included the Nanozen Dustcount combined with the NIOSH EVADE software. Confirmatory sampling was performed using Fourier Transform Infrared Spectroscopy (FTIR). RTPM was identified as a very effective tool for supporting data driven decision making that resulted in risk reductions.

Table 2. RTPM implementation maturity model

	Level 1 Unaware or Unable	Level 2 Exploratory	Level 3 Defined	Level 4 Adoptive	Level 5 Adaptive
Leadership	Company's primary airborne particulate exposure approach is focused on legislative compliance in the absence of leadership or commitment to improve.	Some initial leadership and commitment to real-time particulate monitoring demonstrated by leadership. Company is actively investigating real-time approaches to mitigate, monitor, and control airborne particulates.	Management demonstrates some level of leadership and commitment to airborne particulate control and RTPM. Company is actively pursuing RTPM technologies in design, operating procedures, and control validation. Limited utilisation at specific points within the operation.	Management demonstrates leadership and commitment to RTPM and airborne particulate exposure mitigation, control validation, and environmental monitoring. Demonstrated success in adoption of RTPM to achieve risk mitigation and hazard control objectives. RTPM data used to optimise operational designs and work practices.	Management demonstrates exceptional leadership and commitment to airborne particulate control and RTPM. Implemented leading industry practices in the design of critical controls for airborne particulate exposure elimination. Coupled with integrated use of RTPM digital data to optimise industry designs and monitoring of work practices.
Airborne particulate hygiene programme	No current agent-specific hygiene programme to eliminate, mitigate, and monitor airborne particulate exposures in real-time.	Airborne particulate programme exists with some elements of real-time particulate monitoring, mostly limited to a few measures and surveys (mostly outsourced services). Data management limited to simple post-sampling reports with no temporal, statistical, or trend analyses.	Company has a airborne particulate hygiene programme that incorporates RTPM. Programme not informed or based on findings of most recent (less than 24-months) most contemporary RTPM data or latest technology advancements.	Company has a airborne particulate hygiene programme that integrates RTPM technologies (within 24 months). The programme is based on airborne particulate risk assessment findings that eliminate, mitigate, and monitor particulate exposures. The programme has not been verified by a certified aerosol scientist or occupational hygienist within 24 months.	Company and sites have current airborne particulate hygiene programme with full integration of RTPM and in accordance with findings of the risk assessment to eliminate, mitigate, and monitor airborne particulate exposures. The programme has been verified by a certified aerosol scientist or occupational hygienist within 24 months.
Design guidelines	The operational standards and procedures are focused on minimal airborne exposure monitoring to meet legislative compliance only.	The operational standards and designs are focused on airborne particulate exposure prevention and mitigation based on legislative compliance as a minimum standard. Limited to no ad-hoc RTPM data used to inform standards and designs.	Airborne particulates are included in critical control matrices with Company defined administrative, engineering, design, and training standards.	Airborne particulate exposures are identified as a critical hazard with the company actively integrating all levels of control, including RTPM, to eliminate risk.	Airborne particulate exposures are identified as a key critical hazard with the company actively integrating all levels of controls, including RTPM, to exceed industry leading practices.

Critical control management	No system using real-time monitoring for the identification, measurement, and on-going maintenance of airborne particulate critical controls.	Some RTPM use as or in support of critical controls identified, but no system for ongoing monitoring maintenance of identified critical controls. No RTPM criteria for effective operation and maintenance of identified critical controls.	Company has a process to identify unwanted airborne particulate events and critical controls. Airborne particulate exposure hazards and associated priority unwanted event inventory present. A critical control RTPM framework not been defined. No defined action and response plans to rectify airborne particulate control failures.	Risk management process identifies airborne particulate-related unwanted events and critical controls. Airborne particulate hazards and priority unwanted events inventory current at individual operations. Airborne particulates included in the critical controls monitoring framework, and ongoing RTPM of critical controls is fully implemented. No defined action and response plans to rectify control failures.	Risk management process used for all airborne particulate-related unwanted events, critical controls, and risks. Airborne particulate hazards and priority unwanted events inventory current. Airborne particulates included in the critical controls monitoring framework, and ongoing RTPM of critical controls is fully implemented. Defined action and response plans present and outline how to rectify control failures.
Operational administrative controls	Operational administrative controls comply with legislative requirements as a minimum standard.	Fundamental operational administrative controls are defined and implemented across the operation.	Airborne particulate administrative controls are well defined and implemented across the operation. Coupled with RTPM for exposure response and control validation.	Administrative controls are integrated with engineering controls as an intervention for non-compliance. Coupled with continuous improvement in control efficiency that leverages RTPM technologies.	Administrative controls are integrated with engineering controls, including RTPM, to ensure real-time compliance with automated escalation and non-compliance intervention. Coupled with continuous improvement in operator behaviour programs in order to exceed industry leading practices.
Engineering and Technology controls	Activities are carried out in accordance with legislative requirements, applying operational standards that use basic technology like gravimetric sampling only.	Activities applied in accordance with legislative requirements and operational standards. Additional engineering controls use RTPM for specific exposure mitigation. Includes process to identify and review RTPM technologies for control validation.	RTPM integrated with engineering technology solutions have been implemented on critical pieces of equipment and key work areas, as defined by operational critical airborne particulate hazard standards.	Engineering technology including RTPM solutions has been installed across all critical locations and workplaces. Digital integration with administrative controls and mine design standards present.	Engineering technology including RTPM solutions has been installed across all critical locations and workplaces. Digital integration with administrative controls and mine design standards present. Actively supporting technology developments and data integration to improve industry leading practice.

Training and awareness	Insufficient aerosol science or industrial hygiene expertise to support real-time particulate monitoring programme. No education and training programme on airborne particulate exposures.	Education and training on airborne particulate monitoring limited to introductory aerosol sampling mostly focused on gravimetric methods. Limited records are kept of training conducted on airborne particulate sampling and data management. Training on RTPM use in exposure mitigation, monitoring, and control validation minimal.	An education and training programme on airborne particulate monitoring is present, but the programme is not competency-based and RTPM training is limited to basic functionality. Partial records are kept of training conducted. No RTPM data management training is provided.	The company has an appropriate competency-based education and training programme on airborne particulate hazards and control of exposures using RTPM and other technologies, but does not include the principles of aerosol science and related exposure health effects. Some means to identify exposures, limit health damage, and rudimentary data analysis are included. Records are kept of all training conducted on airborne particulate hazards and RTPM.	The company has an appropriate competency-based education and training programme on airborne particulate hazards and control of exposures using RTPM and other technologies, including the principles of aerosol science, advanced data analysis, and related exposure health effects. Some means to identify exposures or further limit health damage are included. Comprehensive records are kept of all training conducted, including training evaluation data.
Airborne particulate exposure incident management	No process to use real-time particulate measuring to report, investigate, and track airborne exposures and non-compliance events.	Airborne particulate exposure event reporting and investigations are limited in scope and breadth and conducted in isolation by health and safety practitioners.	All airborne particulate events and non-compliance is reported and investigated. The formal Incident Management Procedure is only partially developed and investigations are conducted in isolation by health and safety practitioners. Partial records are kept of the investigations.	The company has formal processes in place to report and investigate all airborne particulate events and non-compliance incidents. But not does not typically integrate behavioural and human performance improvement (HPI). All unwanted events are investigated as per the company incident management procedure, outcomes disseminated broadly, and detailed records kept.	The company has formal processes in place to report and investigate all airborne particulate events and non-compliance incidents, including HPI and behavioural inputs to root causes. All unwanted events are investigated as per the company incident management procedure, outcomes disseminated broadly, tracked for trends, and detailed records kept.