ICMM Mining with Principles

Diesel Particulate Matter (DPM) Good Practice Guide

Contents

Foreword

A most fundamental human need is to breathe fresh air. Yet, for millions of people working in underground mines across the globe, this is not a given. This Guide aims to change that.

Diesel is the energy source for most mining equipment today and will remain prevalent for years to come, even as zero emission alternatives are emerging. When burnt for energy, the fuel generates Diesel Particulate Matter (DPM), invisible airborne particles that are harmful to human health. Workers that are exposed to these can suffer long-term and far-reaching consequences including cancer, chronic respiratory disease, and cardiovascular complications – consequently affecting entire families and communities.

At ICMM, we believe that no job should compromise a person's health or their future. This is why in 2018, ICMM launched the Innovation for Cleaner, Safer Vehicles (ICSV) initiative, bringing together our member companies, original equipment manufacturers (OEMs) and technology suppliers to make mining equipment cleaner and safer.

ICSV is supporting acceleration in the development of zero emission haul trucks, which we anticipate will now be available by 2030, around a decade earlier than initially expected. It has also helped make those vehicles safer and avoid collisions with people, which is one of the leading causes of fatalities in mining.

In addition to reducing greenhouse gas emissions and improving the safety of vehicles, ICSV has had a focus on reducing exposure to DPM.

This Guide is a product of that work. It serves as both a call to action and a roadmap for meaningful change to reduce the exposure of our workers to these harmful elements. It builds on the shared leadership of ICMM members, who in 2024 pledged to protect workers in underground operations from DPM exposure through comprehensive management programmes.

This Guide empowers mining companies – regardless of commodity and location – with practical tools to assess risks, adopt cutting-edge technologies, and implement strategies that prioritise health, safety and sustainability.

For genuine progress we need to look beyond mere compliance with legislation and commit to ensuring that every worker – whether they are several kilometres underground or in a remote workshop – returns home safe and healthy each day. It's about fostering an industry that is not only resilient and productive but also holistically responsible.

This is our opportunity to lead with courage, act with compassion and create a future where breathing clean air is something everyone can count on.

Rohitesh Dhawan
President and CEO, ICMM

Introduction

01

Diesel-powered vehicles and equipment generate airborne Diesel Particulate Matter (DPM) emissions, which, with exposure to high concentrations in underground mining operations over time, can cause serious health issues among people working in these environments, including cancer. Classified as a carcinogen by the International Agency for Research on Cancer (IARC)[1], DPM has been linked to severe health effects, including respiratory and cardiovascular diseases, as well as an increased risk of lung cancer. Effective management of DPM is crucial for protecting people's health, as well as maintaining operational efficiency, regulatory compliance and safeguarding the long-term viability of mining companies.

This Guide provides a comprehensive framework for managing DPM in underground mining operations. It is designed to assist mining companies in developing and implementing robust DPM management plans that are both proactive and responsive, with a strong focus on health, safety and environmental responsibility.

The Guide contains five core elements:

— **Understanding DPM and health risks:** Detailed insights on the sources of DPM in mining operations, the associated health risks, and the regulatory standards that govern occupational exposure.

— **Business risks:** Exploration of the broader business risks associated with DPM exposure, including regulatory compliance challenges, financial implications, potential legal liabilities and reputational damage. The Guide highlights the importance of managing these risks.

— **Baseline assessment:** Step-by-step instructions for conducting a baseline assessment of DPM levels and sources within a mining operation. This assessment forms the foundation for developing targeted risk management strategies that prioritise high-risk areas and mitigate the health impacts of DPM.

— **DPM management strategies:** A detailed overview of strategies to monitor and manage exposure levels within established standards. This includes comprehensive monitoring methods, advanced emission control technologies and rigorous maintenance practices.

— **DPM management plan:** A framework for developing a comprehensive DPM management plan, incorporating steps to Define, Assess, Analyse, Control and Verify. This systematic approach ensures that DPM control measures are effective, sustainable, and enhance workplace safety and operational performance. A supporting flowchart provides clear guidance for implementing these control measures.

1. International Agency for Research on Cancer (IARC). (2012). 'IARC Diesel Engine Exhaust Carcinogenic'. Available at: https://www.iarc.who.int/wp-content/uploads/2018/07/pr213_E.pdf.

Understanding Diesel Particulate Matter (DPM) and Health Risks

02

DPM is a hidden but potentially serious hazard faced by workers in underground mining environments. This mixture of tiny particles can include harmful substances such as carbon, ash and toxic compounds, produced as a byproduct of combustion by diesel engines. In underground mines, where vehicles and equipment operate in confined spaces, DPM concentrations can increase significantly. These particles are so small that they can be inhaled deeply into the lungs, potentially causing serious health problems.

2.1 Sources of DPM

DPM is generated by diesel engines, which are widely used in mining due to their power and reliability. However, the level of emissions varies based on several factors, such as engine type, maintenance practices, and fuel quality. Older diesel engines, in particular, tend to emit higher levels of DPM, posing an even greater risk in underground operations where ventilation may be limited, and exposure is concentrated.

Other challenges posed in the underground setting:

— **Ventilation and air quality**
Maintaining air quality in underground mines is critical due to the accumulation of diesel emissions, heat and humidity.[2] Effective ventilation systems are essential to dilute and remove harmful contaminants.[3]

— **Limited space and mobility**
Confined spaces in underground mines limit machinery operation and worker movement, increasing congestion and accident risks.

— **Heat and humidity**
Underground mines often experience high temperatures and humidity, which exacerbate health risks and complicate the management of DPM.[4]

2. Azam, S., Liu, S., Bhattacharyya, S. and Zheng, S. (2024) 'Assessing the hazard of diesel particulate matter (DPM) in the mining industry: A review of the current state of knowledge', *International Journal of Coal Science & Technology*, Volume 11, article number 62. Available at: https://doi.org/10.1007/s40789-024-00707-8.
3. Yang, B., Yao, H., & Wang, F. (2022). 'A Review of Ventilation and Environmental Control of Underground Spaces'. *Energies*, 15(2), 409. Available at: https://doi.org/10.3390/en15020409
4. Chang, P.,, Xu, P. (2017): 'A review of the health effects and exposure-responsible relationship of diesel particulate matter for underground mines'. *International Journal of Mining Science and Technology*, 27(5), 831-838.Available at: https://www.sciencedirect.com/science/article/pii/S2095268617305839.

2.2 Health Impacts of DPM

DPM can be a significant health risk to the people working underground where exposure levels can be heightened due to confined spaces. The ultra-fine particles in DPM bypass the body's natural defences, reaching deep into the lungs and entering the bloodstream.

Immediate effects of DPM exposure can include eye irritation, coughing and respiratory discomfort, which are early warning signs of potential long-term damage. Prolonged exposure can lead to chronic respiratory conditions such as asthma and chronic bronchitis, significantly impairing workers' quality of life and ability to work. DPM is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) directly linking it to lung cancer.

In addition to respiratory harm, DPM exposure is associated with severe cardiovascular effects. The fine particles can cause systemic inflammation and oxidative stress, exacerbating conditions like hypertension and increasing the risk of heart attacks and strokes. For workers performing physically demanding tasks underground, these risks can lead to sudden and potentially fatal health crises.

Key health risks linked to DPM:

Cancer: DPM is a recognised carcinogen, particularly associated with lung cancer. In 2012, the International Agency for Research on Cancer (IARC), which is part of the World Health Organisation (WHO), classified diesel engine exhaust, including DPM, as a Group 1 carcinogen. This classification is based on substantial evidence linking DPM exposure to an increased risk of lung cancer. Studies, such as those conducted in underground mining environments, indicate that people exposed to high levels of DPM have a significantly higher risk of developing lung cancer compared to the general population.[5]

Respiratory issues: Short-term exposure to DPM can cause immediate health effects such as eye and respiratory tract irritation, presenting symptoms like redness, itching, coughing, throat irritation and shortness of breath. Long-term exposure can lead to more severe respiratory conditions, including chronic bronchitis and other chronic respiratory diseases. The fine and ultra-fine particles in DPM penetrate deep into the lungs and can cause sustained inflammation and damage to lung tissue over time.

Cardiovascular impacts: Prolonged exposure to DPM has been linked to various cardiovascular problems. Inhalation of DPM can induce systemic inflammation and oxidative stress, which are key mechanisms underlying cardiovascular diseases. People exposed to high levels of DPM are at an increased risk of developing conditions such as hypertension, ischemic heart disease and heart attacks.[6]

Other health impacts: Beyond the primary respiratory and cardiovascular concerns, DPM exposure is also linked to other health risks. The toxic compounds in DPM, such as polycyclic aromatic hydrocarbons (PAHs), can affect multiple organs and systems, potentially leading to various adverse health outcomes. Chronic exposure to DPM may also elevate the risk of bladder cancer among workers in high-exposure settings.[7]

5. Attfield et al., (2012). 'The Diesel Exhaust in Miners Study: A Cohort Mortality Study With Emphasis on Lung Cancer'. *Journal of the National Cancer Institute.* 104. 869-883. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3373218/pdf/djs035.pdf
6. Robert B. Hamanakam, R.B., Mutlu, G.M., (2018). 'Particulate Matter Air Pollution: Effects on the Cardiovascular System'. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC6250783/
7. Boffetta, P., Silverman, D., (2001) 'A Meta-Analysis of Bladder Cancer and Diesel Exhaust Exposure'. *Epidemiology.* 12(1). 125-130, Available at: https://journals.lww.com/epidem/fulltext/2001/01000/a_meta_analysis_of_bladder_cancer_and_diesel.21.aspx

2.3 Business Risks

In addition to the health impacts, DPM exposure presents a range of significant business risks. These risks extend beyond regulatory compliance and encompass reputational damage, financial implications, and potential legal liabilities. Companies operating in industries with high DPM exposure, such as underground mining, should recognise and proactively manage these risks. Addressing these risks through comprehensive DPM management strategies is an important step in safeguarding both people and the business.

2.3.1. Regulatory Compliance Challenges

To protect people's health, some countries have established Occupational Exposure Limits (OELs) for DPM, typically measured as elemental carbon. In some jurisdictions, these limits are becoming increasingly stringent as countries recognise the serious health risks posed by DPM exposure. However, there are still countries that have yet to implement OELs specifically targeting DPM, leaving a regulatory gap in addressing this critical issue.

Across the world, there are a variety of regulations mandating regular monitoring of worker exposure to ensure compliance with existing OELs.[8] When an exceedance of the exposure standard occurs, mine operators are typically required to notify relevant regulatory authorities, take corrective actions, conduct investigations, resample air quality after corrective measures, and review their principal hazard management plans. Additionally, maintaining records of monitoring and corrective actions is often mandated, with retention periods varying across jurisdictions.

Failure to comply with these regulations can lead to legal and financial consequences, including fines, sanctions and operational shutdowns. Many regulatory bodies are continuously lowering permissible exposure limits for DPM, driving companies to invest in advanced monitoring and control technologies. For example, the Organisation for Economic Co-operation and Development (OECD) emphasises the need for clear and enforceable OELs that are protective of worker health and feasible to implement, based on scientific, technical and socio-economic considerations.[9]

Non-compliance carries broader consequences beyond legal risks – it can erode a company's credibility and relationships with regulators. To avoid these pitfalls, companies should stay vigilant about regulatory updates and proactively enhance their DPM management practices. This includes implementing effective control strategies, regular monitoring and adopting available best practices in DPM management to meet or exceed regulatory standards. By doing so, companies can work towards a safer work environment, protect worker health and maintain operational continuity.

2.3.2. Financial Implications

Failure to effectively manage DPM exposure can create financial risks for companies, particularly over the long term. While direct links between DPM exposure and immediate absenteeism or turnover may not be as strong, the long-term health impacts of chronic exposure can lead to increased costs related to health surveillance, case management, and potential compensation or legal claims from affected people.

Investing in preventive measures and effective DPM management strategies can help mitigate these long-term financial risks by ensuring compliance with health regulations and reducing the likelihood of chronic health issues that could result in costly legal actions or compensation claims.

2.3.3. Compensation and Other Legal Claims

As a recognised respiratory irritant and causative agent for lung cancer, DPM exposure poses serious health risks, potentially providing a basis for compensation claims by affected individuals. Depending on jurisdiction, these claims may escalate to civil lawsuits based on a failure to maintain a safe and healthy work environment.

The threat of health-related class action suits is significant in industries with high DPM exposure, such as underground mining. Companies that fail to effectively manage DPM risks may face substantial legal repercussions. These lawsuits not only present the risk of significant financial liabilities but may also damage the company's reputation and trustworthiness, affecting long-term business viability.

8. Deveau, M. et al. (2015). 'The Global Landscape of Occupational Exposure Limits – Implementation of Harmonization Principles to Guide Limit Selection'. *Journal of Occupational and Environmental Hygiene.* 19(12), 127-144. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC4654639/
9. Organisation for Economic Co-operation and Development, (2023). 'Establishing Occupational Exposure Limits: Practices and Criteria'. 15-18. Available at: https://www.oecd-ilibrary.org/establishing-occupational-exposure-limits_901f4b5a-en.pdf?itemId=%2Fcontent%2Fpublication%2F901f4b5a-en&mimeType=pdf

Effective Management of DPM

03

Effective management of DPM is crucial to safeguarding the health and safety of everyone working in underground mining operations. Given the unique challenges posed by confined spaces in these environments, companies should establish a robust framework for assessing and controlling DPM exposure.

This section outlines the steps required to establish baseline DPM levels and identify key sources of emissions. These foundational activities are vital for developing targeted risk management strategies that prioritise high-risk areas and mitigate the impact of DPM on health. By systematically addressing these factors, mining operations can implement effective controls that improve air quality, enhance safety standards, and protect worker well-being.

3.1 Baseline Assessment of DPM Levels and Sources

A baseline assessment of DPM sources and workplace atmosphere levels is the first step in determining the presence and extent of the DPM hazard within mining operations. The following steps can help guide the design of a baseline assessment:

- **Identify DPM sources:** Focus on the optimisation of engine performance, minimising the generation of DPM.
- **Limit the release of DPM into the workplace atmosphere:** Focus on the destruction or capture of generated DPM prior to release into the workplace atmosphere.
- **Manage released DPM:** Evaluate the data to identify high-risk areas and job roles with the highest potential for DPM exposure. Prioritise these sources for control measures based on their emission levels and the frequency and duration of worker exposure.
- **Collect data:** Focus on collecting data to optimise and ensure adequate control of exposure to DPM within the workplace.
- **Provide Personal Protective Equipment (PPE):** Where residual risk of exposure to DPM remains, ensure workers are properly protected whilst continuing to manage and reduce exposure using the hierarchy of controls (see 6.4 – Figure 3).

Diesel equipment and exposure benchmarking checklist:

Effective management of DPM begins with a clear understanding of the performance and emissions of existing diesel equipment. Benchmarking is an important first step in this process, providing a foundation for all subsequent DPM reduction initiatives. By systematically evaluating your current fleet, you can identify high-emission equipment, prioritise upgrades, and implement targeted control measures that will maximise the impact of efforts to reduce DPM emissions.

This checklist can help you to benchmark existing diesel equipment:

- ☐ **Develop an equipment register:** Keep an updated list of all diesel equipment (make, model, year, specifications, location, maintenance).
- ☐ **Map service areas:** Document where each type of equipment operates to plan emission controls.
- ☐ **Test tailpipe emissions:** Perform emissions tests on all equipment.
- ☐ **Collect data:** Record emissions data consistently across machines.
- ☐ **Identify high-emission equipment:** Identify and prioritise high-emission equipment for upgrades or replacement.
- ☐ **Calculate emissions:** Determine total emissions output based on operating data (load, hours, fuel use).
- ☐ **Monitor high fuel use**: Track fuel use, focusing on high-consumption equipment.
- ☐ **Evaluate workplace exposure:** Measure DPM exposure in different work areas.
- ☐ **Analyse exposure time**: Analyse worker exposure duration to prioritise interventions.
- ☐ **Review operational patterns:** Review equipment usage patterns to plan emission control efforts.
- ☐ **Establish a health surveillance plan:** Set up a medical surveillance programme, including lung function testing, for workers potentially exposed to DPM.
- ☐ **Develop an emissions reduction plan:** Use data to create a reduction plan (scheduling, equipment upgrades, controls).
- ☐ **Install control technologies:** Install Diesel Particulate Filters (DPFs), Selective Catalytic Reduction (SCR) systems, and optimise operations.
- ☐ **Undertake continuous review:** Implement and enforce DPM standards in daily operations. Regularly audit and update the DPM management plan. Continually improve as new technologies and needs emerge.
- ☐ **Schedule area testing:** Periodically assess work areas for DPM using appropriate area sampling methods.
- ☐ **Monitor personal worker exposure:** Monitor workers' DPM exposure, especially near high-emission equipment, utilising methods such as NIOSH Method 5040.[10]

3.2 DPM Management Plan

Building on the baseline assessment of DPM levels and sources, the next step is to evaluate and summarise the existing measures currently in place to control DPM exposure within a mining operation. Assessing the effectiveness of these measures not only helps in identifying gaps but also guides the refinement of strategies to better protect health.

This section provides an overview of the key control measures that are typically employed, highlighting areas where improvements may be necessary to achieve optimal performance and compliance with health and safety standards.

Common DPM control measures in mining operations:

- **Employ engineering controls:** Ensure that the mine has a well-designed and properly maintained ventilation system to dilute and remove DPM from the air. Evaluate the system's capacity to handle peak emission periods and ensure continual operation.
- **Optimise fuel burn:** Oversee and manage the quality of fuels and lubricants used in OEM operations to minimise DPM emissions at the source, prior to the implementation of capture or reduction initiatives. Implement the use of low sulphur diesel and optimise the use of additives to reduce DPM levels within the workplace atmosphere.

10. NIOSH. (2003). *Diesel Particulate Matter (as Elemental Carbon) 5040.* National Institute for Occupational Safety and Health. Available at: https://www.cdc.gov/niosh/docs/2003-154/pdfs/5040.pdf.

— **Deploy emission control technologies:** Use DPFs and Diesel Oxidation Catalysts (DOCs) on equipment to reduce DPM emissions. Routine assessments and maintenance of these systems ensure they remain operational and effective.

— **Implement maintenance practices:** Implement rigorous maintenance schedules for all diesel-powered equipment to ensure efficient operation and minimise emissions. Regular inspections and timely replacement of engine parts help to maintain low emission levels.

— **Implement administrative controls:** Rotate workers to minimise individual exposure times in high-DPM areas and implement work practices that reduce emissions, such as minimising engine idling and optimising operational schedules.

— **Provide Personal Protective Equipment (PPE):** Provide appropriate PPE such as respirators to workers in high-exposure areas. Train workers on the correct use and maintenance of PPE to maximise its effectiveness.

3.3 Assess Control Efficacy

After evaluating existing DPM control measures, the next step in effective DPM management is the development and maintenance of a comprehensive DPM source inventory. This inventory serves as a foundational tool for tracking and managing the sources of DPM emissions within the mining operation. By systematically cataloguing equipment and monitoring emission data, mining operations can identify high-risk sources, analyse trends, and implement targeted improvements.

Steps to develop and maintain a DPM source inventory:

— **Catalogue and profile equipment:** Keep detailed records of all diesel-powered equipment, including make, model, age, emission rates and maintenance history and any changes to fuels and additives used. Regularly update the inventory to reflect any modifications in the equipment fleet.

— **Track emission data:** Record emission levels for each piece of equipment during routine operations and after maintenance activities. Use this data to identify trends and opportunities for improvement in emission control.

— **Monitor changes:** Document any modifications to equipment or operational practices that could impact DPM emissions. Ensure that these changes are reflected in the inventory and that their effects are monitored over time.

— **Ensure management of change:** Closely monitor the procurement of new equipment, fuels, or additives. Document any testing of new fuel types or additives as part of the comprehensive record-keeping system.

3.4 Identification of Gaps in Current DPM Management Practices

After establishing a comprehensive DPM source inventory, the next step in DPM management involves identifying gaps in existing practices. This process is vital to ensure that existing strategies not only comply with regulations but effectively minimise exposure risks. By systematically evaluating current practices, mining operations can work to pinpoint weaknesses and areas for improvement, leading to enhanced safety and operational efficiency.

Key steps to identify and address gaps in DPM management:

— **Review compliance:** Compare current practices against regulatory requirements and industry best practices to identify areas of non-compliance or opportunities for enhancement.

— **Evaluate technology and maintenance practices:** Assess the effectiveness of current emission control technologies and quality of their maintenance. Identify the availability of new or alternative technologies or enhanced maintenance practices that could improve DPM emissions control.

— **Implement training and awareness programmes:** Review the effectiveness of supervisor and worker training programmes on DPM risks and control measures. Ensure that all workers are aware of the hazards and are trained in best practices for reducing exposure.

— **Collect feedback and monitor improvement:** Collect feedback from workers on current DPM management practices and identify practical challenges they face. Use this feedback to refine and improve control measures and operational practices.

Occupational Exposure Limits for Elemental Carbon

04

Establishing clear exposure limits is a critical step to develop a robust DPM management plan, providing measurable benchmarks to safeguard worker health. Elemental Carbon (EC) is widely recognised as a reliable indicator for DPM due to its strong correlation with diesel emissions. By focusing on EC measurements, mining operations can effectively assess and control exposure to DPM, ensuring compliance with regulatory standards and safeguarding the health of those working underground.[11]

4.1 International Standards:

Several international bodies have set OELs for DPM, and others may do so in future. These guidelines serve as benchmarks for managing DPM exposure and highlight regional approaches to protecting worker health. Key examples include:

National Institute for Occupational Safety and Health (NIOSH):
NIOSH recommends an exposure limit of 0.1 mg/m^3 for DPM measured as Elemental Carbon (EC) in underground metal and nonmetal mines. This limit is intended to protect people from the adverse health effects associated with prolonged exposure to DPM.[11]

Australian Institute of Occupational Hygienists (AIOH):
AIOH recommends a guideline of 0.1 mg/m^3 for DPM measured as EC, with a more protective action level of 0.05 mg/m^3 to trigger investigation and improved controls. This action level is intended to ensure early detection of potential over-exposures and prompt implementation of corrective measures to protect worker health.[12]

11. Noll, J. D., et al. (2007). *Relationship Between Elemental Carbon, Total Carbon, and Diesel Particulate Matter in Several Underground Metal/nonmetal Mines*. National Institute for Occupational Safety and Health (NIOSH). Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC4487601/.
12. Minerals Council of Australia. (2021). *Submission on Safe Work Australia's Releases 2-14 Selected Substances WES*. Available at: https://minerals.org.au/wp-content/uploads/2023/01/MCA-Submission-on-SWA-Releases-2-14-selected-substances-WES-12-Feb-2021-final.pdf.

Strategies for Monitoring and Maintaining Exposure Levels within Set Standards

05

Effective management of DPM exposure in underground mining requires a comprehensive approach that includes consistent monitoring, rigorous maintenance and robust control measures.

This section outlines strategies which can be employed to manage DPM exposure through accurate monitoring, diligent maintenance of control systems, and the implementation of control measures that adhere to OELs.
By integrating these strategies, mining operations can create a safer working environment and work to maintain compliance with regulatory standards.

5.1 Monitoring Strategies

Accurate and consistent monitoring is the foundation of effective DPM management. This sub-section outlines various monitoring techniques that can be used to assess and manage DPM levels in underground mining operations. Employing these strategies enables mining operations to gather the necessary data to ensure that DPM exposure levels remain within safe limits, allowing for timely interventions when needed.

- **Regularly monitor air quality:** Implement both continuous and periodic air quality monitoring in critical areas of the mine using personal and stationary sampling devices. Ensure that these devices are capable of accurately measuring EC.
- **Implement exposure assessment programmes:** Conduct comprehensive exposure assessments, including baseline assessments and ongoing monitoring. Document exposure levels and compare them with the established OELs to identify any exceedances.
- **Utilise real-time monitoring:** Utilise real-time monitoring technologies to provide immediate feedback on DPM levels. This enables rapid response and corrective actions when exposure levels approach or exceed set limits.

5.2 Maintenance and Operational Strategies

Monitoring alone is insufficient to control DPM exposure; it should be complemented by effective maintenance strategies that ensure all control systems are functioning optimally.

This sub-section focuses on the maintenance practices which can be implemented to minimise DPM emissions and maintain a safe work environment. Proper maintenance of ventilation systems, equipment and operational practices are key components that support the ongoing effectiveness of DPM control measures.

- **Focus on ventilation management:** Ensure that ventilation systems are adequately designed, maintained and operated to provide sufficient airflow and dilution of DPM. Regularly inspect and clean ventilation ducts and filters to maintain optimal performance.
- **Maintain equipment:** Implement rigorous maintenance schedules for all diesel-powered equipment. Regularly service engines and exhaust systems to minimise emissions. Retrofit older equipment with advanced emission control technologies such as Diesel Particulate Filters (DPFs) and Diesel Oxidation Catalysts (DOCs).
- **Optimise operational controls:** Optimise operational practices to reduce DPM emissions. This includes minimising engine idling, reducing the number of diesel engines operating simultaneously in confined spaces, and scheduling high-emission activities during times when fewer workers are present.
- **Provide training and health surveillance:** Provide comprehensive training for everyone exposed to DPM on exposure control, including the use of PPE and best practices for minimising emissions. Establish health surveillance programs to monitor the health of people exposed to DPM, including regular medical examinations and lung function testing.
- **Implement leading practices:** Stay informed about the latest research and technological advancements in DPM control. Implement leading practices and innovative solutions to continually improve DPM management and reduce worker exposure.

Figure 1: DPM Control Strategies

5.3 DPM Control Strategies

After establishing robust monitoring and maintenance protocols, the next step is to implement comprehensive control strategies.

The following hierarchy can be used in designing a DPM control strategy:

— Prevention of DPM generation

— Prevention of DPM release

— Management of released DPM

— Information gathering for optimisation

This section will outline each of these steps.

5.3.1 Prevention of DPM Generation

The most effective approach to managing DPM is to prevent its generation at the source. This sub-section focuses on strategies to minimise the production of DPM by optimising the operation of diesel-powered equipment and utilising cleaner technologies and fuels.

By preventing DPM generation, mining operations can greatly reduce the overall burden of particulate matter in the working environment. Key strategies which can be used to prevent the generation of DPM at its source include:

— **Transition to electric mine vehicles and equipment:** Replace diesel-powered equipment with electric alternatives where feasible. EVs produce zero DPM emissions, thereby eliminating a major source of airborne particulates. They also reduce the need for extensive ventilation to manage exhaust pollutants, lower operational costs over time due to reduced fuel and maintenance needs and improve overall air quality in the mine.

— **Schedule regular engine maintenance and tuning:** Implement a rigorous maintenance schedule for all diesel-powered equipment to ensure engines are operating efficiently and combusting fuel completely. This reduces the production of DPM and other harmful emissions. Perform regular tuning and calibration of engines to optimise fuel combustion and minimise particulate output.

— **Utilise higher specification engines:** Invest in modern, high-specification engines designed to produce fewer emissions. These engines typically incorporate advanced technologies that enhance combustion efficiency and reduce DPM production. Upgrade older equipment to newer models with better emission control features.

— **Implement alternative fuel options:** Use Ultra-Low Sulphur Diesel (ULSD) to reduce sulphur content in the fuel to decrease sulphate particulate emissions. Implement the use of low-ash lubricants.

5.3.2 Prevention of DPM Release

If generating DPM cannot be entirely avoided, the next best option is to prevent its release into the air that people breathe.

Various exhaust gas after-treatment technologies and strategies can be employed to achieve this, such as:

— **Diesel Particulate Filters (DPFs):** Install DPFs on diesel-powered equipment to capture and oxidise particulate matter in the exhaust stream.

— **Diesel Oxidation Catalysts (DOCs):** Use DOCs to convert carbon monoxide, hydrocarbons, and some particulate matter into less harmful substances.

— **Selective Catalytic Reduction (SCR) systems:** Implement SCR systems to reduce nitrogen oxides (NO_x) which can form secondary particulate matter. These systems convert NO_x into harmless nitrogen and water vapour, significantly improving air quality.

5.3.3 Management of Released DPM

Once DPM is released into the environment, controlling its spread and reducing worker exposure is critical. Strategies for managing DPM after it has been emitted might include:

— **Improve ventilation systems:** Design and maintain effective ventilation systems in underground mines to dilute and remove diesel exhaust pollutants. Use ventilation controls such as auxiliary fans and ducting to direct airflow and remove contaminants from high-risk areas.

— **Minimise diesel-powered equipment use:** Optimise the deployment of diesel-powered equipment to minimise the number of units operating simultaneously in confined spaces. Implement fleet management practices that prioritise the use of low-emission equipment and reduce idling time.

— **Utilise enclosed cabins with High-Efficiency Particulate Air (HEPA) filters:** Equip machinery with enclosed cabins that use HEPA filters to capture DPM at the source, protecting operators from direct exposure. Regularly maintain and replace cabin filters to ensure effectiveness.

— **Utilise local extraction ventilation:** Where practical, use extraction ventilation to remove DPM in areas such as mobile workshops, or during high-emission activities.

— **Transition to automated operations:** Where practical use automation and access control to remove people from areas within the mine where DPM is released into the environment. Remote-controlled and autonomous options can be used in these situations.

— **Provide PPE:** Provide workers with appropriate PPE, such as respirators equipped with filters capable of capturing fine particulate matter and train them on correct use and maintenance.

5.3.4 Information Gathering for Optimisation

Continual improvement in DPM control requires systematic data collection and analysis to refine strategies and ensure effectiveness. This might include the following approaches:

— **Implement personal exposure monitoring:** Deploy personal monitoring devices to assess individual exposure and adjust work practices accordingly. Deploy personal monitoring methods such as NIOSH 5040 to assess personal exposure and adjust work practices accordingly. Identify high-risk worker groups (Similar Exposure Groups) and target them for enhanced controls.

— **Improve control measures using data insights:** Use the insights gained from the data analysis to evaluate and enhance existing control measures. This may involve implementing more effective engineering controls, revising administrative procedures, or providing enhanced PPE to reduce exposure levels within these high-risk groups.

— **Conduct regular audits and reviews:** Conduct regular audits to evaluate compliance with OELs and identify areas for improvement. Update practices based on audit findings and new research.

— **Plan for future advancements:** Stay informed about emerging technologies in diesel emission controls. Plan for the integration of new solutions that can further reduce DPM emissions. Anticipate regulatory changes by adopting innovative solutions and enhancing DPM management practices.

DPM Management Plan

06

A well-structured strategy and diligent implementation are crucial for effectively controlling DPM emissions in mining operations. Establishing a comprehensive DPM management plan helps to safeguard worker health, ensure regulatory compliance and improve operational efficiency.

This plan integrates all the elements outlined in this Good Practice Guide and follows a systematic approach through the steps of Define, Measure, Analyse, Control, and Verify.

This framework should be used in conjunction with sections 2 to 5 of this document to produce a management plan tailored to company management systems and operations.

Figure 2: Five-step DPM Management Plan

6.1 Step 1: Define

Clearly outline project parameters and ensure that all relevant aspects of the operation are considered. This step is also where a dedicated committee is formed to oversee the project, and a compliance review is conducted to ensure that all regulatory requirements are being met.

1. Capture the current situation:
- Conduct a comprehensive baseline assessment to understand the current levels of DPM emissions and worker exposure.
- Document all existing control measures, equipment specifications and operational practices.

2. Set project parameters:
- Define clear objectives and goals for DPM reduction, such as specific emission reduction targets and timelines.
- Set Key Performance Indicators (KPIs) to measure progress and success.

3. Establish the scope:
- Determine the full scope of the DPM management plan, including all relevant equipment, areas and processes within the mining operation.
- Ensure that the plan addresses all sources of DPM and includes measures to control and reduce emissions.

4. Form a committee:
- Assemble a dedicated committee with representatives from key internal stakeholder groups, including management, health and safety officers, maintenance personnel, and worker representatives.
- Assign roles and responsibilities to ensure accountability and effective communication.

5. Review compliance:
- Conduct a thorough review of current compliance with local, national and international regulations and standards related to DPM emissions.
- Identify any gaps in compliance and areas that require improvement.

6.2 Step 2: Assess

Systematically measure and collect data on current levels of DPM emissions and exposure. This phase focuses on gathering accurate and comprehensive information through various monitoring techniques, providing a foundation for identifying areas of concern and ensuring compliance with exposure limits.

1. Measure tailpipe emissions:
- Perform emissions testing on all diesel-powered equipment to quantify DPM emissions from each machine.

2. Track equipment utilisation:
- Track utilisation rates of all diesel-powered equipment to identify high-use machines that may contribute significantly to DPM emissions.
- Collect data on equipment operating hours, fuel consumption and maintenance schedules.

3. Implement personnel monitoring:
- Utilise personal monitoring devices to measure individual worker exposure to DPM using a methodology such as NIOSH 5040.
- Collect data on exposure levels during different tasks and in various work areas.

4. Implement area monitoring:
- Use collected data to pinpoint both groups of workers who experience high levels of DPM exposure – known as Similar Exposure Groups (SEGs) – and specific areas where DPM concentrations are consistently elevated or where significant exposure peaks occur.
- Leverage these data insights to enhance existing controls or implement new strategies. This may include upgrading ventilation systems, modifying work practices, adapting scheduling to minimise exposure during peak times, or introducing more effective filtration and emission reduction technologies.

6.3 Step 3: Analyse

Evaluate the data collected during the Assess phase to identify key sources of DPM emissions, prioritise risks and develop targeted control strategies. This phase focuses on turning raw data into actionable insights that guide decision-making and improvements in DPM management.

1. Develop equipment emission profiles:

— Analyse the collected emissions data to create a detailed profile for each piece of equipment.
— Identify high-emission equipment and prioritise them for upgrades or replacements.

2. Prioritise equipment and work areas:

— Rank equipment and work areas based on their contribution to overall DPM emissions and worker exposure.
— Focus initial improvement efforts on the highest-priority items to achieve the greatest impact.

3. Identify patterns and trends:

— Look for patterns and trends in the data to understand the factors contributing to high DPM levels.
— Use this analysis to inform targeted DPM reduction strategies and optimise resource allocation.

6.4 Step 4: Control

Take action to manage DPM. The hierarchy of control should be the foundation of any DPM management strategy, prioritising controls in the following order, as laid out in Figure 3:

1. Eliminate:

This is the most effective form of control and involves removing the source of DPM altogether. Strategies include replacing diesel-powered equipment with electric vehicles or implementing automation and remote operation technologies to reduce the need for diesel equipment.

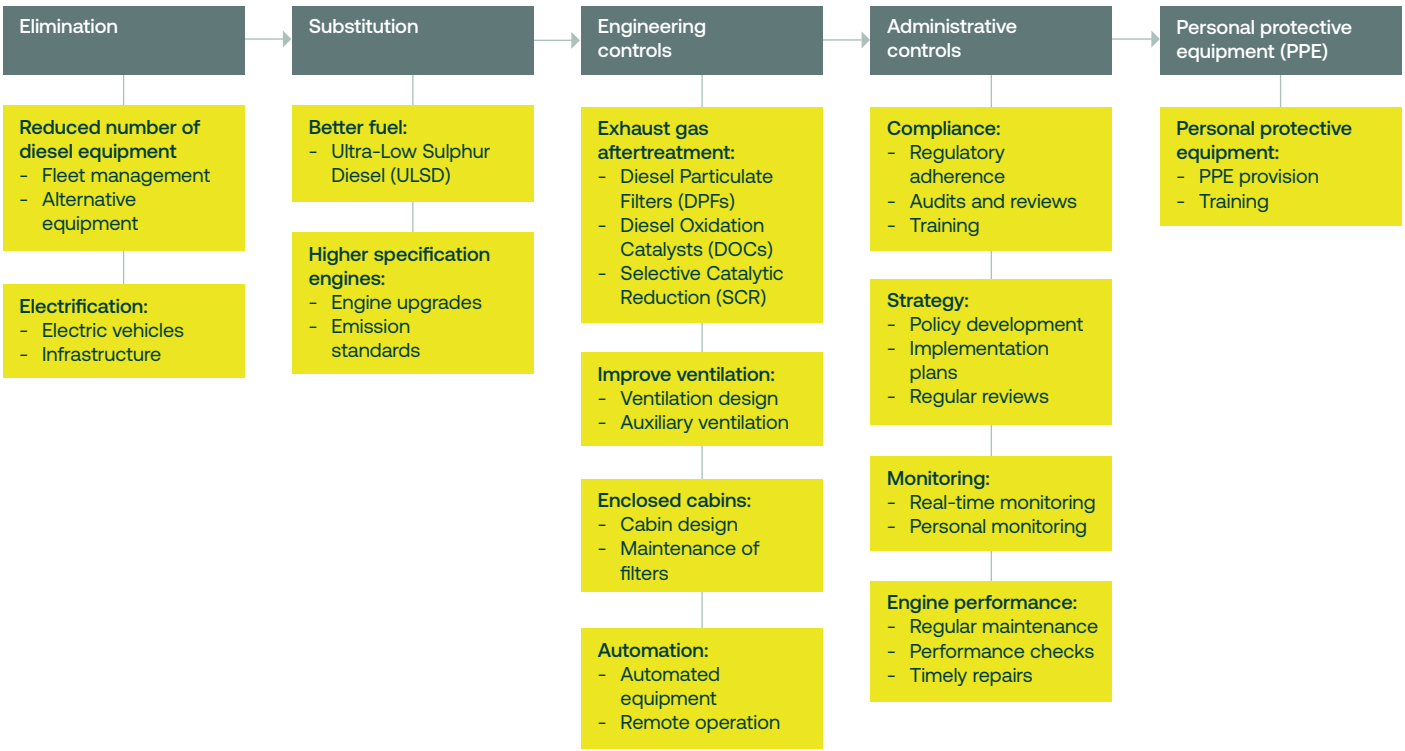
2. Substitute:

When elimination is not possible, replace high-emission diesel engines with lower-emission options. This can include using engines that meet higher emission standards or switching to fuels like Ultra-Low Sulphur Diesel (ULSD) or biodiesel blends, which generate fewer particulates.

3. Implement engineering controls:

These controls are designed to isolate people from the DPM hazard. Effective engineering controls may include:

Figure 3: Hierarchy of control for DPM



— Implementing technologies like Diesel Particulate Filters (DPFs), Diesel Oxidation Catalysts (DOCs) and Selective Catalytic Reduction (SCR) systems to capture or convert harmful emissions before they are released into the environment.
— Enhancing mine ventilation systems, including designing efficient primary and auxiliary ventilation to remove or dilute DPM from work areas.
— Using enclosed operator cabins with High-Efficiency Particulate Air (HEPA) filters to protect workers from direct exposure.

4. Implement administrative controls:
These involve changing the way work is performed to reduce exposure. This may include:

— Rotating shifts to minimise individual exposure time in high-DPM areas.
— Educating people on the risks of DPM and safe work practices.
— Regularly monitoring DPM levels with real-time and personal monitoring devices, conducting audits and reviewing control measures for effectiveness.

5. Provide PPE:
— PPE should be the last line of defence when other controls are not sufficient. This includes the provision of respirators with appropriate filters and ensuring people are trained in their correct use and maintenance.

6.5 Step 5: Verify

Verify the effectiveness of the DPM management plan. Once a DPM management plan is in place, companies should take steps to monitor progress and verify that controls are working. A good verification strategy should include the following steps:

1. Monitor efficacy:
Set cadence for periodic and systematic monitoring of emissions and controls, including refresher training.

2. Collect and use data:
Setup and use a DPM emissions register or data warehouse/data visualisation tools.

3. Set-up workflow triggers:
Utilise automation such as alarms and responses to enable real-time monitoring of emission levels in designated work areas.

Conclusion

07

DPM presents a serious health hazard in underground mining operations, posing significant risks to workers' well-being. Addressing this challenge goes beyond regulatory compliance – safeguarding the health of workers is the right thing to do. This Good Practice Guide provides a framework for managing DPM exposure, emphasising proactive and responsive measures, adherence to health and safety standards, and fostering a culture of continual improvement.

By understanding the origins and health impacts of DPM and implementing robust control strategies such as transitioning to electric vehicles, optimising ventilation systems, adopting emission control technologies, and developing detailed DPM management plans, responsible mining companies can create a healthier and safer work environment. The approach outlined, based on the Define, Assess, Analyse, Control and Verify steps, enables systematic risk management and the integration of leading practices into daily operations.

Adopting these strategies not only protects workers' health but minimises business risks, including regulatory non-compliance, financial liabilities and reputational damage. By prioritising employee well-being and taking decisive action to mitigate DPM exposure, mining and metals companies can take meaningful steps towards toward a more sustainable and responsible industry.

Appendix A: Glossary of Key Terms

Diesel Oxidation Catalysts (DOCs)
Exhaust aftertreatment devices that reduce emissions from diesel fuelled vehicles and equipment.

Diesel Particulate Filters (DPFs)
Devices fitted to diesel equipment to remove particulate matter from diesel exhaust.

Diesel Particulate Matter (DPM)
A complex mixture of organic compounds, sulphates, nitrates, metals and other toxins that form a cohesive layer on the particulate from diesel exhaust.

Elemental Carbon (EC)
Refers to inorganic forms of carbon, widely recognised as a reliable indicator for DPM due to its strong correlation with diesel emissions.

Nitrogen Oxides (NO_x)
A mixture of gases composed of nitrogen and oxygen released to the air from the exhaust of motor vehicles as well as other industrial processes, in the form of Nitric Oxide and/or Nitrogen Dioxide.

Occupational Health and Safety (OHS)
The discipline concerned with protecting the health and safety of workers.

Operational Exposure Limit (OEL)
The maximum airborne concentration of a substance to which a worker can be exposed over a time without suffering any harmful consequences.

Personal Protective Equipment (PPE)
Equipment, such as safety helmets, eye protection, respiratory protective equipment, and other equipment that will protect the user from health and safety risks at work.

Polycyclic Aromatic Hydrocarbons (PAHs)
Hazardous chemical compounds, consisting of carbon and hydrogen, which can pose significant health risks to those exposed to them.

Risk
The chance of something happening that will have an impact on objectives. It is usually measured in terms of event likelihood and consequences.

Selective Catalytic Reduction (SCR)
Systems which convert harmful nitrogen oxides in exhaust gas into water and nitrogen.

Similar Exposure Group
A group of workers who have similar exposure profiles for a particular hazard due to the similarity, frequency and nature of the work they perform

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