Considerations for the Establishment of a Corporate Occupational Exposure Limit for DPM

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Occupational Exposure Limits

- Management of worker exposure to airborne chemical agents in mining places a strong emphasis on the establishment of occupational exposure limits (OELs) for inhalation exposure
- OELs are a prescribed requirement under mining health and safety legislation in most world-wide jurisdictions
- There can be significant variance in OELs across jurisdictions for a particular agent, which is especially pronounced for several agents common to the underground mine environment

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Occupational Exposure Limits

- This presents challenges to the establishment of policy objectives for mining corporations that operate in multiple jurisdictions, specifically in the establishment of a common set of site-level occupational health & hygiene (OH&H) risk assessment practices.

The hierarchy of requirements can be summed up as the need to:

- meet local jurisdictional OEL requirements
- adopt the most stringent OEL in the jurisdictions where operations exist
- adopt the most stringent OEL in existence
- incorporate the recommendations of other agencies (ACGIH, AIOH, CCA/OCRC, etc.) in the establishment of corporate-wide OELs

Threshold Limit Values

- Many regulatory agencies incorporate ACGIH recommendations (TLVs®) in the establishment and revision of OELs
- TLV® is the airborne concentration of a chemical substance for which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effect
- TLVs® are established by scientific expert committee that review the current body of scientific data and stakeholder submissions that are pertinent to the determination of agent-specific critical effects and dose-response relationships for the working population, but do not consider economic or technical feasibility. (ACGIH, 2019).

ACGIH Review of DPM

- The ACGIH has reviewed but has not published a recommended Threshold Limit Value (TLV®) for diesel particulate matter:
  - In 1995/96, the ACGIH published a Notice of Intended Change (NIC) to introduce a TLV-Time Weighted Average (TWA) of 0.15 mg/m^3 as total DPM.
  - The NIC was revised in 1999 to a TLV-TWA of 0.05 mg/m^3 as total DPM
  - NIC was revised in 2001 to a TLV-TWA of 0.02 mg/m^3 as EC
  - NIC was ultimately withdrawn in 2003 without adoption.
  - Diesel exhaust remained on the ACGIH List of Chemical Substances and Other Issues under Study until 2006.

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6

MSHA

- The abbreviated MSHA Final Rule history for the DPM PEL in metal/nonmetal mines is as follows:
  - Jan. 2001 - Introduced an exposure limit of 400 µg/m^3 as TC based on a risk assessment conducted in 2001; full enforcement began in July 2003.
  - June 2005 - Changed the TC-based exposure limit to a comparable PEL of 308 µg/m^3 as EC.
  - May 2006 - Revises the DPM PEL to 160 µg/m^3 as TC; based on revisions to risk assessments of 2001 and 2005.
  - May 2008 - Commits MSHA to the continued use of TC as the parameter for a DPM PEL on the basis of excessive variance of the TC-to-EC ratio when TC < 230 µg/m^3.

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7

DPM OELs Worldwide

Table 1: Select OELs for Diesel Exhaust Particulates

Organization	OEL Name	8-Hour OEL
Mining Health and Safety Administration (MSHA)	Permissible Exposure Level (PEL)	160 µg/m^3 as TC
Ontario Ministry of Labour (MOL)	Time Weighted Average Limit (TWA)	400 µg/m^3 as TC, or 308 µg/m^3 as EC
Australia Department of Natural Resources and Mines (DNRM)	Exposure Limit	100 µg/m^3 as EC
New South Wales Department of Primary Industries (NSWDPI) – Mine Safety	Maximum Workplace Exposure Standard	100 µg/m^3 as EC
Australian Institute of Occupational Hygienists (AIOH)	Exposure Limit	100 µg/m^3 as EC
Western Australia Mining Industry Advisory Committee (MIAC)	Acceptable Limit	100 µg/m^3 as EC

Challenges to the Establishment of a DPM OEL

- There are several challenges to the establishment of a generally-accepted OEL for DPM:
  - Complexity of the composition of DPM
  - DPM Exposure assessment techniques
  - Influence of constantly changing emissions control technology and fuel formulations
  - Concurrence of other agents associated with chronic respiratory diseases

Composition of DPM

- Diesel exhaust emissions are complex mixtures of over 1,800 compounds in the form of gases, vapours and particulate matter.
- DPM consists of a predominantly submicron elemental carbon core, which accounts for approximately 75% of the total mass of diesel emissions.
- Other chemical constituents adhere or condense onto the carbon core surface immediately after formation, including at least 32 polyaromatic hydrocarbons (PAHs), 16 nitrogen-substituted PAHs (PNAs), sulphate and trace elements (USEPA, 2002).
- Some secondary particle formation can occur after tailpipe emission, through agglomeration with ash, additional organic compounds and sulphates.

DPM Assessment Techniques

- Assessment of inhalation exposure over the years has been based on the assessment of particle-based surrogate measures such as respirable particulate matter and respirable combustible dust
- In 1996, an industrial hygiene assessment technique (Birch and Cary, 1996) was developed that involved the collection of airborne DPM onto quartz fiber filters, followed by the determination of the elemental carbon fraction by high temperature volatilization in helium followed by chemical transformation into methane for chromatographic analysis.
- NIOSH validated and published method as *5040 – Diesel Particulate Matter (as Elemental Carbon)*.

DPM Assessment Techniques

- NIOSH Method 5040 was developed specifically for the mine environment and has become the predominant assessment technique for DPM. The method yields the elemental carbon (EC), as well as the organic carbon (OC) and total carbon (TC - the sum of EC and OC) content of the sample
- Method 5040 was revised and reissued by NIOSH in 2003 and 2016, resulting in methodology changes that have addressed several interferences and artifacts that occurred when assessing elemental carbon in the mine environment.
- Analytical instrumentation enhancements and the development of the SKC® DPM jeweled impactor cassette, used in conjunction with a respirable cyclone have significantly reduced previous sources of bias (error), such as uneven filter deposition, inclusion of concurrent organic vapours, and char formation (elemental carbon formed during the pyrolysis of the organic carbon fraction).

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12

Engine/Fuel Technological Advances

- The establishment of an OEL based on the chronic effects of a chemical agent is typically heavily reliant upon longitudinal and cohort studies
- Past sets of exposure data are culled for flaws in methodology and are then aligned with symptomatology and used to establish toxicological dose-based reference values such as NOAEL and LOAEL
- Advances in diesel engine/emissions control technology have resulted in changes in the composition of DPM tailpipe emissions
- Similarly, initiatives toward low sulphur fuels and the use of biodiesel have also contributed to the changing chemical profile of DPM emissions in the mine environment

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13

Concurrent Exposures

- A significant challenge to the establishment of toxic effect levels for DPM has been the inability to factor out the contribution from other inhalables with similar symptomatology and health effects.
- NSWDPI / AIOH reviewed a large dataset of epidemiological studies published between 1957 and 1999 to assess link between DPM exposure and lung cancer. A significant limitation was the absence of control of confounding factors (especially smoking), as well as inadequate statistical power and lack of accurate exposure estimates (TERA, 2004).
- Most of the non-cancer health effects associated with DPM inhalation exposure are related to particulate matter exposure in general

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Carcinogenicity

- It is a generally accepted fact that inhalation exposure to DPM is associated with lung cancer
- In 2012, IARC reclassified DPM as a Group I lung carcinogen, without indicating the degree of potency
- The predominant challenges to establishing a dose-response relationship between DPM exposure and lung cancer are:
  - Absence of actual large size population studies, especially over the long latency period of lung cancer
  - A lack of rigorous and historically valid exposure data
  - A lack of control over cigarette smoke as a lung cancer confounder

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Other Health Risk Exposure Thresholds

- The EPA has established a Reference Concentration (RfC) of 5 μg/m^3 as total DPM, for the non-carcinogenic critical effects of pulmonary inflammation and histopathology.
- The RfC is the estimated concentration of continuous inhalation exposure for the entire human population (including sensitive subgroups) associated with an appreciable risk of deleterious effects during a lifetime.
- The EPA RfC for DPM is based on a robust data set from rat inhalation studies which established a NOAEL of 0.144 mg DPM/m^3.
- When assumptions and uncertainty factors are adjusted for a non-sensitive working subpopulation and an occupational (versus continuous) exposure pattern, the estimated OEL equivalent is 140 μg/m^3 as total DPM (TERA, 2014).
- The EPA have not established a RfC for DPM on the basis of carcinogenic effects.

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16

Summary of DPM Dose-Response Relationships

- Although there is a correlation between DPM exposure and lung cancer in miners, a dose-response relationship based on human exposure data cannot be established.
- Similarly, dose-response relationships for non-carcinogenic effects in the mine environment cannot be defined based on existing occupational exposure data.
- Guidance is based on a management system approach for control of diesel engine pollutants. The OEL should represent an achievable threshold that represents an effective reduction of irritancy effects, and should result in a reduction of downstream cancer outcomes.
- In the absence of a "… defined universal dose-response relationship, experience has shown that when workplace exposures are controlled below 0.1 mg/m^3 as submicron EC, irritant effects decrease markedly" (AIOH, 2013).
- The stated basis for the MSHA PEL is the feasibility of attainment based on best and current control technology, and not on any specific adverse health effect

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17

Key Considerations for a Corporate OEL for DPM

1) EC Versus TC as the Basis for DPM Exposure Assessment

- The majority of OELs for DPM worldwide are on the basis of EC. The basic mechanism for the transport and inhalation uptake of most carcinogenic constituents of diesel exhaust is through elemental carbon particles as carrier. Therefore, an EC basis for exposure assessment would be consistent with the toxicological basis for carcinogenic effects.
- The present MSHA PEL for DPM is on the basis of TC, reportedly due to excessive variance in TC-to-EC ratio for existing occupational exposure data where TC < 230 $\mu g/m^3$.
- Enhancements to NIOSH 5040 sampling and analytical methodology over the years have been focused on the optimization of the assessment of EC, which has resulted in the elimination of many interferences and minimal variance in the TC-to-EC ratio

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18

Key Considerations for a Corporate OEL for DPM

2) Critical Effect Basis for a DPM OEL

- The TLV® as well as the OELs of other agencies/associations are established on the basis of the prevention of the occurrence of the first observable health effect on the basis of daily continuous exposure over a career.
- There is irrefutable evidence linking excessive DPM exposure to lung cancer. However, limitations in existing human exposure data for DPM in the mine environment prevents the determination of statistically reliable no effect levels or acceptable exposure risk for both carcinogenic and non-carcinogenic effects.

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19

Key Considerations for a Corporate OEL for DPM

3) Adoption of the Most Stringent Existing OEL

- Most existing OELs for DPM exposure are based on achievability through implementation of best emission and exposure control technology and practices, and not on the risk-driven occurrence of a particular health effect.
- In addition, the risk of developing lung cancer is indeterminate which warrants the implementation of ALARA (as low as reasonably achievable) management practices.
- Review the recommendations of OELs and threshold data of non-regulatory agencies that are uninfluenced by economics, technical feasibility or stakeholder interests.

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20

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21