Occupational Exposure Limit Evaluation: Diesel Particulate Matter

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Diesel Exhaust Particulates

1. Chemical Classification

Diesel exhaust is a complex and inhomogeneous mixture of gases, aerosols, and particulates resulting from the combustion of diesel fuel. Over 1,800 compounds have been identified in diesel exhaust (MSHA 2001). Diesel exhaust consists of gaseous and particle-phase emissions, whereas diesel particulate matter (DPM) consists of the particle phase compounds only and includes primary and secondary particle types.

The gaseous components of diesel exhaust include hydrocarbons, carbon monoxide (CO), carbon dioxide (CO₂), oxides of nitrogen (NO, NO₂), and sulfur dioxide (SO₂) (US EPA 2002). At least 32 polycyclic aromatic hydrocarbons (PAHs) and 16 nitrogen-substituted PAHs have been identified in diesel exhaust (US EPA 2002). Additional irritant gases such as aldehydes (particularly acrolein) can be present in diesel exhaust (MSHA 2001). Several of these components are known human or animal carcinogens and cause serious non-cancer effects, and include benzene, formaldehyde, acetaldehyde, 1,3-butadiene, acrolein, dioxin, PAH, and nitro-PAH, among others (US EPA 2002).

Primary DPM consist of a solid carbon core with absorbed organic and metallic compounds including carbonaceous matter and hydrocarbons, sulfate, and trace elements (among others) (MSHA 2001). DPM formed in the combustion process (primary particles) can undergo further transformation upon release into the atmosphere, including particle agglomeration and adsorption of additional ash, organics, and/or sulfates to the particle surface. These transformed particles are considered secondary particles (US EPA 2002). The carbon core is characterized as elemental or organic – elemental carbon has undergone pyrolysis and has been stripped of hydrogen while organic carbon can contain oxygen, nitrogen, and sulfur (US EPA 2002). Typically, the ratio of elemental carbon to other compounds in diesel exhaust is high (roughly 75% in particulate matter of ≤2.5 µm (PM₂.₅)) (US EPA 2002).

DPM are irregularly shaped and sized, and particles tend to become more irregular with increasing size. Most DPM is in the size range of respirable particles (<1 µm), but particle size is highly variable and depends on fuel type, engine type, and environmental factors (MSHA 2001). Roughly 90% of DPM is <0.03 µm in diameter (mode 0.02 µm), but due to their small size these particulates represent only 10% of the total particle mass (Kittelson et al. 2002, as cited in MSHA 2001; US EPA 2002). The majority of the remaining particle mass is made up of agglomerated and adsorbed compounds that range from 0.03-0.5 µm (Kittelson et al. 2002, as cited in MSHA 2001). The remaining mass consists of larger particles (>1 µm) which may be inhalable but are likely to deposit out of the air onto surfaces (Kittelson et al. 2002, Watts et al. 2009, as cited in MSHA 2001).

Particle density is an important factor when assessing inhalability/respirability, but is complex because of the irregularity of the agglomeration and size of the particles. Because of the small size of DPM, it is anticipated to behave more like an aerosol in the air and to deposit more deeply in the human respiratory tract as compared to larger aerosols. This can lead to an increased adverse response in exposed human workers.
2. Standard Exposure Limits

There are a number of occupational safety organizations that derive safe exposure limits for workers exposed to industrial compounds, including DPM. Of these organizations, five are typically investigated in detail when searching for available safe exposure limits and for information on human toxicity. These agencies and the values they derive are briefly described below.

2.1 ACGIH

The American Conference of Governmental Industrial Hygienists (ACGIH) derives threshold limit values (TLVs) through an independent body of experts who review the available data set, including published and peer-review literature of health effects. Health impairments evaluated vary from chemical to chemical, but can include irritation, narcosis, shortened life expectancy, adverse effects on reproductive health, and more, and will depend on the amount and type of available data. Emphasis is placed on minimal and no effect data, and on human studies. Exposure at or below the level of the TLV does not pose an unreasonable risk of disease or injury. These values are derived for use by industrial/occupational hygienists and are not for regulatory purposes. TLVs are airborne concentration limits for repeated worker exposure without the manifestation of adverse effects, but do not cover the entire range of human variability and therefore are not anticipated to protect sensitive individuals. TLVs are usually expressed as time weighted averages (TWAs) for exposure during an 8 hour workday for a total of 40 hours per week. This means that slight exceedances of the TLV are acceptable as long as the total TWA exposure is below the TLV. Provided that the TLV-TWA is not exceeded, overages of the TLV should not exceed 3 times the TLV for more than 30 minutes, and should never exceed 5 times the TLV.

2.2 NIOSH/OSHA

The National Institute for Occupational Safety and Health (NIOSH) derives Recommended Exposure Limits (REL) to help industrial hygienists and occupational health professionals control worker exposure to hazardous substances in the workplace. The Occupational Safety and Health Administration (OSHA) sets Permissible Exposure Limits (PELs) for this same purpose. NIOSH and OSHA work in a cooperative manner under the joint effort of the Standards Completion Program. Data are evaluated from many sources including internal NIOSH documents and other available published literature relevant to the chemical hazard. Once NIOSH develops a REL, it is then transmitted to OSHA and the Mine Safety and Health Administration (MSHA) for use in setting regulatory exposure guidelines. Many RELs are reported as TWAs for up to a 10 hour workday and a total 40 hour workweek. TWA OSHA PELs should not be exceeded at any time during an 8 hour workday during a 40 hour workweek. Exposure limits are reported as air concentrations.

2.3 German MAK Commission

The German Permanent Senate Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area (MAK Commission) proposes maximum workplace concentrations (MAK values). These include an evaluation of the toxicological effects related to occupational exposure and health. The MAK value is the maximum permissible air concentration in the workplace that does not affect worker health with repeated and long term exposure (8 hours per day, 40 hours per week). The MAK values are instilled as 8 hour TWAs, and are intended to protect against local irritation and adverse systemic effects. Substance specific excursion factors are also established. Chemicals are also evaluated
on the basis of carcinogenicity, reproductive effects, genotoxicity, and sensitization. The evaluation includes various exposure factors along with a robust evaluation of human and animal health effects data.

2.4 AIHA/OARS

The American Industrial Hygiene Association (AIHA) guideline foundation developed Workplace Environmental Exposure Levels (WEELs) until 2011. WEELs are developed for the protection of healthy workers and do not protect sensitive populations or workers with underlying health conditions. The Occupational Alliance for Risk Science (OARS) began housing and developing WEELs in 2013. The WEEL values are based on repeated daily exposures over a working lifetime, and are typically averaged over an 8 hour workday during a 40 hour workweek. The WEELs are intended to protect workers from both acute and chronic adverse health effects from occupational exposure to chemicals. Provided that the 8 hour TWA is not exceeded, overages of the WEEL should not exceed 3 times the 8 hour TWA for more than 30 minutes, and should never exceed 5 times the 8 hour TWA.

2.5 SCOEL

The Scientific Committee on Occupational Exposure Limits (SCOEL) advises the European Commission on workplace exposure limits and derives Occupational Exposure Limit Values (OELVs). The committee is a multidisciplinary group of experts that review all available information on a case by case basis for chemical evaluation prior to derivation of the OELV. These values are for airborne exposures and are to be used in a regulatory setting for the protection of workers for the working lifetime (up to 45 years) and their progeny (as the data allow). Values are reported as TWA concentrations for an 8 hour workday during a 40 hour workweek. These values are not intended to protect susceptible populations but are intended to protect against respiratory sensitization, or to at least note if the chemical is a sensitizer.

3. Existing Occupational Exposure Limit Guidance

A thorough search was conducted to identify all existing occupational exposure guidance values applicable to DPM. These values are listed in the below Table 1 and include the year of assessment, chemical type, guidance value, target population, and the source of this information. When data were lacking for occupational guidance values, additional values were identified for protection of the general population (See Appendix A). These values are evaluated below in Section 4.

<table>
<thead>
<tr>
<th>Organization, year</th>
<th>Chemical(s)</th>
<th>Name</th>
<th>Year</th>
<th>Guidance Value</th>
<th>Target Population</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine Safety and Health Administration (MSHA)</td>
<td>diesel particulate matter [measured as EC]</td>
<td>Permissible exposure limit (PEL)</td>
<td>2001</td>
<td>120 µg/m³ [8-hr TWA] *approximately equal to 0.16 mg/m³ TC</td>
<td>underground metal/nonmetal mines and underground coal mines</td>
<td><a href="http://www.msha.gov/01-995/Dieselpartmmn.htm#.U2eaOXZe_YA">http://www.msha.gov/01-995/Dieselpartmmn.htm#.U2eaOXZe_YA</a></td>
</tr>
<tr>
<td>Organization, year</td>
<td>Chemical(s)</td>
<td>Name</td>
<td>Year</td>
<td>Guidance Value</td>
<td>Target Population</td>
<td>Source</td>
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<tr>
<td>New South Wales Department of Primary Industries (NSWDPI) – Mine Safety (2008)</td>
<td>diesel particulate matter [measured as EC]</td>
<td>maximum workplace exposure standard</td>
<td>2008</td>
<td>100 μg/m³ [8-hr TWA] *approximately equal to 0.16 mg/m³ TC or 0.2 mg/m³ diesel particulate</td>
<td>workplace exposure (mine atmosphere)</td>
<td><a href="http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0011/419465/MDG-29.pdf">http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0011/419465/MDG-29.pdf</a></td>
</tr>
</tbody>
</table>

EC – elemental carbon; OC – organic carbon; TC- total carbon

$^*$ – Previous TWA values of 300 μg/m³ (EC - for tunneling and non-coal mining) and 100 μg/m³ (EC - for other applications) were withdrawn in 2007 because the epidemiological studies evaluated were based on exposures to emissions from older diesel engines. New diesel technology has changed the quality and quantity of diesel emissions significantly.
4. Data Analysis

For the DPM OELs evaluated here, the standard organizations (listed in Section 2) did not have occupational exposure limits (with the exception that the MSHA value is based on a NIOSH report). However, a number of additional safety values are available through multiple organizations. The key identified OELs (from Table 1) were those from the MSHA of 120 μg/m$^3$ and from a number of Australian organizations (AIOH, DNRM, MIAC, and NSWDPI) of 100 μg/m$^3$ (which used the same derived OEL value and adopted it across organizations). Due to a lack of additional OEL values a third, non-occupational, general population exposure limit was evaluated from the US EPA of 5 μg/m$^3$ (See Appendix A; Table 2). This third value was utilized to get a robust comparison of the different bases for the safe limit derivation and to help understand the higher OEL values as compared to the more conservative general population value. Once a comparison of values was completed and the most relevant value was recommended, an updated literature search was conducted from the date of the most recently derived value through the present to confirm that additional data were not available for use in either updating the recommended value or for derivation of a new value. This update is discussed below and documented in Appendix B.

4.1 OEL Basis

A number of Australian (AU) organizations applied identical guidance values that were adopted across agencies. Out of the four AU organizations listed (Table 1), the New South Wales Department of Primary Industries (NSWDPI) – Mine Safety (2008) guidance value derivation is detailed here. However, it should be noted that NSWDPI adopted the AIOH guidance value during their assessment, and many of the AU assessments build off of each other. Overall, a large dataset of epidemiology studies published between 1957 and 1999 was reviewed, and the impact of DPM on the development of lung cancer in workers was evaluated. A number of limitations were noted with these studies including inadequate statistical power, no control of confounding factors (smoking), and lack of accurate exposure estimates. Even with these limitations, most organizations that assessed the link of DPM exposure to lung cancer (US EPA, IARC, etc.) agreed that there is suggestive evidence that DPM causes lung cancer. However, the potency and strength of this association is still being debated. Most of the non-cancer adverse health effects were related to particulate inhalation and included eye, throat, and lung irritation, lightheadedness, nausea, cough, phlegm, and potential for chronic respiratory disease. NSWDPI reported that no defined dose-response relationship existed for exposure to DPM and development of these non-cancer effects. They also stated that because the concentration of DPM expelled varied wildly per engine, and that there was no identified NOAEL for humans exposed to DPM, the policy decision was to reduce engine emissions as low as possible to protect human health.

The NSWDPI value of 100 μg/m$^3$ (measured as elemental carbon; equivalent to 200 μg/m$^3$ for total DPM) was adopted on the basis of controlling irritation responses in humans, under the assumption that control of exposures to the 100 μg/m$^3$ level would be protective of irritation and also downstream consequences of exposure, such as systemic adverse effects and cancer effects. However, no single critical effect and/or critical study was reported. In fact, the support document states “the guideline is based on a management system approach for the control of diesel engine pollutants”. This guidance value is related to the total DPM expelled from diesel engines and the lack of technology available to further reduce atmospheric DPM emissions.
Because the most feasible way of measuring DPM is to measure the elemental carbon [EC] in the diesel particulates, almost all of the OELs listed in Table 1 are expressed in terms of the EC mass. (Note that this is the OEL for DPM, expressed as EC mass, not the OEL for pure elemental carbon. Because DPM includes adsorbed organic compounds in additional to the carbon, the DPM OEL may be lower than that for pure elemental carbon of the same size range.)

Overall, the guidance value suggested by the NSWDPI was adopted from AIOH, and is the same as that reported from the additional AU organizations (DNRM and MIAC). For example, AIOH states that while there is a lack of dose-response data for DPM, experience has shown that when exposures are controlled to a 100 μg/m³ level, irritant effects were significantly reduced. AIOH suggests that measures to reduce irritation are likely to reduce downstream lung cancer outcomes. The AIOH recommendation was based off of a few key publications: Criteria Bulletin No. 50 (NIOSH 1988), International Agency for Research on Cancer (IARC) cancer classification (IARC 1989), the Health Effects Institute (HEI 1995) meta-analysis of data from 1950-1980, Mines Safety and Health Administration (MSHA 2001), and the United States Environmental Protection Agency (US EPA) reference concentration (RfC) (US EPA 2002).

Two of these documents have been reviewed in this document – MSHA (2001) and US EPA (2002). The DNRM and MIAC also adopted the NSWDPI/AIOH guidance value.

The MSHA conducted a DPM risk assessment in 2001. The assessment preceded and was very similar to the AU assessments listed above, with the exception that MSHA noted that there were available exposure-response relationships showing adverse effects from DPM. Generally, MSHA concluded that DPM causes sensory and respiratory irritation, cardiovascular, cardiopulmonary, or respiratory-related premature death, and lung cancer. Due to lack of available data, MSHA was unable to quantify the risk of the first three of these effects, and so based the risk assessment on the development of lung cancer in exposed workers. At the time of the assessment, MSHA concluded that current miners were at an increased risk from high DPM exposure levels, and recommended a reduction in exposure to reduce this risk. Since the original 2001 ruling, a literature update has been conducted up through 2005 (published in 2006) that did not impact the original assessment. The MSHA stated that feasibility in mining scenarios was the main driver for the derived guidance value, and was not based on specific adverse health effects (other than reducing the risk of lung cancer). In fact, in the assessment update MSHA asserts that there are some irritant effects evident at the 100 μg/m³ level, but that it is only feasible to reduce DPM to this level based on current technology. Feasibility, as defined by the US Supreme court, refers to “capable of being done, executed, or effected”, and relates to available technology being able to “achieve a significant reduction in DPM”.

The US EPA guidance value for the general public was the most robust assessment in that it was based on a specified health effect and was not based on feasibility. The reference concentration (RfC) is defined by the US EPA as “an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime”. The critical effect identified was pulmonary inflammation and histopathology, as reported in the OEL values above. The basis of the inhalation RfC was a no-observed-adverse-effect-level (NOAEL) of 0.46 mg/m³ in exposed rats. A human equivalent concentration (HEC) for this effect level was calculated using a dosimetry model and was reported as NOAEL_{HEC} = 0.144 mg/m³. Uncertainty factors applied included 10 for variability and susceptibility in exposed human populations and 3 for the additional dynamic extrapolation from rats to humans that was not accounted for in the dosimetry model, for a total uncertainty factor of 30. The final derived value is 5 μg/m³.
4.2 Comparison of OELs

The US EPA value is protective of sensitive populations through the addition of an uncertainty factor of 10, so in order to compare to the two OELs (that are not protective of sensitive populations), removal of the 10x uncertainty factor provides a way to compare these values for protection of the same population. This means after removal of the 10x uncertainty factor for sensitive subpopulations to be applicable to worker scenarios, the RfC is increased to 50 μg/m$^3$. Also, the two OELs presented are taken as TWAs for the worker exposure scenario. An adjustment of the EPA general population value to the worker exposure scenario based on duration of exposure but that also takes into account breathing rate under occupational conditions compared with general population exposure gives a further rough estimate adjustment to 140 μg/m$^3$.\(^1\) Given this back extrapolation, the value for general population exposures as roughly estimated for worker exposures can be compared directly to the OELs. After completing the above adjustment, it appears that the three selected values are very similar, at 140 μg/m$^3$ (US EPA-OEL adjusted; as total DPM), 100 μg/m$^3$ (AIOH; as elemental carbon), and 120 μg/m$^3$ (MSHA; as elemental carbon). Because there is no adjustment to convert the US EPA total DPM limit to elemental carbon, it is likely that this value is higher than the elemental carbon value would be, given that it contains the additional components of diesel exhaust that are not included in either TC or EC measurements. In fact, when looking at the adjustment for the AIOH value for total DPM, it is similarly higher at 200 μg/m$^3$. Also, because the US EPA is protective below the threshold for effects, but the occupational guidance values state effects occur at the OEL, the expectation is that the US EPA value is more conservative than the OEL values.

As the basis for these values, all are anticipated to protect workers exposed for at least 8 hour workdays in a 40 hour workweek. All are based on controlling and minimizing irritation responses in humans at some level, and are expected to be mostly protective of these effects in workers, with the expectation that controlling irritant responses will help to control downstream effects, such as cancer. However, one difference worth noting is that MSHA states that adverse effects have been shown to occur at exposures below this safe level and that feasibility is the main driver of the assessment, while the AU organizations state that in an aside to feasibility, the dose-response is not defined.

5. Recommendations for use

The recommended DPM OEL is 100 μg/m$^3$ (measured as elemental carbon) from AIOH (200 μg/m$^3$ as DPM). The exceedances recommendation is also adopted: Provided that the OEL-TWA is not exceeded, overages of the OEL should not exceed 3 times the OEL for more than 30 minutes, and should never exceed 5 times the OEL. However, due to the nature of irritant effects, and the fact that irritation is exacerbated by increasing concentration, exceedances should be closely monitored to protect workers from irritation.

\(^1\) Exposure scenario for general population is 24 hours a day, 7 days a week. Exposure scenario for occupational population is 8 hours a day, 5 days a week. In order to account for both the difference in hours/day of exposure and differences between the breathing rate for a worker and the breathing rate for ambient exposure, the exposure is also adjusted based on the total volume inhaled during the exposure period. The US EPA assumes a volume of 10 m$^3$ during an 8 hour workday for occupational exposure (some OEL-deriving organizations use a different breathing rate), and 20 m$^3$ for 24 hour continuous exposure (assuming light activity) for environmental (ambient) exposure. Based on this, an adjustment to the general population exposure value of 50 μg/m$^3$ is 50*(20 m$^3$/10 m$^3$)*(7 days/5 days) = 140 μg/m$^3$. 
Because elemental carbon is a measurable exposure surrogate, this value is easily applied and monitored for worker exposure. Because of the uncertainty associated with back extrapolating a general population RFc to an OEL (as applied to directly compare the US EPA value to the OELs), the US EPA RFc is not recommended for adoption, but provides support that the AIOH value is likely protective of chronic (lifetime) exposures. Additionally, the OEL value from MSHA provides further support for the recommended OEL as the value falls in the same range as the others and is based off of a robust assessment.

Finally, an updated review of the literature was initially conducted from 2006-2014 to identify potential data available to update the OELs discussed herein (See Appendix B). 2006 was chosen as the starting year for the update since the MSHA conducted a literature search update through 2005 and published in 2006. While there were a large amount of available data on DPM exposure estimates and adverse health effects in exposed workers, this literature was largely unhelpful in updating the OELs based on feasibility. As such, the entire literature base was not fully evaluated for utility in updating the risk assessment. However, key publications were pulled out as potentially relevant. Also, because of this only 1 database (PubMed) was searched. A more accurate update for these OELs may be to search for technological advances in the ability to reduce DPM machine output in worker exposure scenarios; however this is outside the scope of this current work.

In summary, the recommended DPM OEL is 100 μg/m$^3$ (measured as elemental carbon) from AIOH (200 μg/m$^3$ as DPM) based on feasibility and for control of irritant responses and protection from downstream effects.
6. References


Appendix A. Existing General Population Exposure Limit Guidance

Table 2. General Population Guidance Values for Diesel Exhaust Particulates

<table>
<thead>
<tr>
<th>Organization, year</th>
<th>Chemical(s)</th>
<th>Name</th>
<th>Year</th>
<th>Guidance Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>California Environmental Protection Agency (CalEPA)</td>
<td>Diesel exhaust</td>
<td>Noncancer health value</td>
<td>1998</td>
<td>5 μg/m³</td>
<td><a href="http://www.arb.ca.gov/toxics/dieseltac/defnds.htm">http://www.arb.ca.gov/toxics/dieseltac/defnds.htm</a></td>
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<tr>
<td>U.S. Environmental Protection Agency (US EPA)</td>
<td>Diesel engine exhaust</td>
<td>Reference concentration (RfC)</td>
<td>2003</td>
<td>5 μg/m³</td>
<td><a href="http://www.epa.gov/iris/subst/0642.htm">http://www.epa.gov/iris/subst/0642.htm</a></td>
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<tr>
<td>International Programme for Chemical Safety (IPCS)</td>
<td>Diesel exhaust emissions</td>
<td>Non-cancer guidance values/Benchmark concentration</td>
<td>1996</td>
<td>5.6 μg/m³ 2 μg/m³ 3 μg/m³</td>
<td><a href="http://www.inchem.org/documents/ehc/ehc/ehc171.htm">http://www.inchem.org/documents/ehc/ehc/ehc171.htm</a></td>
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Appendix B. Literature Update

Table 3. Literature search update for DPM adverse effects in workers (2006-2014)

<table>
<thead>
<tr>
<th>Database searched</th>
<th>Search terms</th>
<th>Number of hits</th>
<th>Number of hits relevant to an OEL update?</th>
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<tbody>
<tr>
<td>PubMed</td>
<td>(((((diesel exhaust OR diesel particulate) AND (occupation* OR work*))))) AND  &quot;2006&quot;[Date - Publication] : &quot;3000&quot;[Date - Publication])</td>
<td>764</td>
<td>Not assessed</td>
</tr>
<tr>
<td>PubMed</td>
<td>(((((diesel exhaust OR diesel particulate) AND (occupation* OR work*))))) AND  &quot;2006&quot;[Date - Publication] : &quot;3000&quot;[Date - Publication]) AND exposure limit</td>
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<td>2</td>
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<tr>
<td>PubMed</td>
<td>(((((diesel exhaust OR diesel particulate) AND  &quot;2006&quot;[Date - Publication] : &quot;3000&quot;[Date - Publication])))) AND occupational</td>
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<td>Not assessed</td>
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<tr>
<td>PubMed</td>
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<td>8</td>
<td>0</td>
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<td>PubMed</td>
<td>diesel exhaust particulates occupational exposure limit</td>
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<td>0</td>
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Relevant Abstracts

Diesel exhaust in miners study: how to understand the findings?
Morfeld P.

Abstract
The Diesel Exhaust in Miners Study (DEMS) is an outstanding epidemiological project on the association between occupational diesel exhaust exposures, measured as long-term respirable elemental carbon (REC) estimates, and lung cancer mortality in a large cohort of US miners. Two articles published recently (Attfield et al. (J Natl Cancer Inst Epub, 2012), Silverman et al. (J Natl Cancer Inst Epub, 2012)) described the epidemiological findings. These papers are expected to have considerable impact on the evaluation of the carcinogenic potential of diesel exhaust, furthermore, on occupational and environmental limit value discussions related to diesel motor emissions and particle exposures. DEMS found remarkable exposure-response relationships between REC exposure estimates and lung cancer mortality - conditional on a pronounced effect of surface vs. underground work on lung cancer risk. If this risk factor is ignored the estimated REC-lung cancer association is attenuated substantially. The authors relied on this risk factor in their main analyses. However, this factor "surface/underground work" remained unexplained. The factor lead the authors to introduce unusual cross-product terms of location and smoking in adjustment procedures and even caused the authors to hypothesize that high REC exposures are protective against lung cancer excess risks due to smoking. To understand the reliability of these conclusions, we should ask basic questions about the data collection process in DEMS: Did the mortality follow-up procedures suffer from errors like those that affected the NCI formaldehyde cohort study? Are the REC and/or smoking data reliable, and are these data
collected/constructed in such a way that the procedures allow valid comparisons between surface and underground workers? Without clarifying the issues raised in this Commentary the Diesel Exhaust in Miners Study remains to be difficult to interpret.

Dose-response relationships between occupational exposure to potash, diesel exhaust and nitrogen oxides and lung function: cross-sectional and longitudinal study in two salt mines.
Lotz G¹, Plitzko S, Gierke E, Tittelbach U, Kersten N, Schneider WD.
Abstract
OBJECTIVE:
Several studies have shown that underground salt miners may have an increased incidence of chest symptoms and sometimes decreased lung function. Miners of two salt mines were investigated to evaluate relationships between the lung function and the workplace exposure. The effect of nitrogen monoxide (NO) and nitrogen dioxide (NO(2)) was investigated in view of the recent debate on European occupational exposure limits.

METHODS:
A total of 410/463 miners (mine A/mine B) were examined cross-sectional and 75/64% of the first cohort were examined after a 5-year period. Exposure was measured by personal sampling. Personal lifetime exposure doses of salt dust, diesel exhaust, NO(2) and NO were calculated for all miners. Dose-response relationships were calculated by multiple regression analysis. Each exposure component acted as an indicator for the complex exposure.

RESULTS:
Exposure response relationships were shown in the cross-sectional and longitudinal investigations in both mines. In the 5-year period, the adjusted (age, smoking, etc.) effect of the exposure indicators resulted in a mean decrease of FEV(1) between -18 ml/year (mine A) and -10 ml/year (mine B). The personal concentrations related to this effect were 12.6/7.1 mg/m(3) inhalable dust, 2.4/0.8 mg/m(3) respirable dust, 0.09/0.09 mg/m(3) diesel exhaust, 0.4/0.5 ppm NO(2) and 1.7/1.4 ppm NO (mine A/B). Exposure was related to symptoms of chronic bronchitis only in mine B.

CONCLUSION:
The effects found in both mines indicate that the mixed exposure can cause lung function disorders in salt miners exposed over a long time. Because of the high correlation of the concentrations it was not possible to determine the effects of a single exposure component separately or to recommend a specific occupational exposure limit. However, possible maximum effects associated with the mixed exposure can be evaluated in the ranges of concentrations of the individual substances in the mines.