Diesel Exhaust

Need to monitor exposure and further reduce occupational exposure limit

Dr. Kevin Hedges (COH, CIH)

Occupational Hygienist (OHCOW)

khedges@ohcow.on.ca

http://www.ohcow.on.ca/
Weight of the evidence or Wait for the Evidence?
Protecting Underground Miners from Diesel Particulate Matter

“It doesn’t look to me like it could do any chromosomal damage.”
Diesel emission what does it consist of?

Diesel particulate matter (DPM)
- Organic carbon (PAH, Nitroarenes)
- Elemental carbon
- Sulphate
- (other trace)

Vapours
- Organic carbon (ie. aldehydes)
- Other organics

Gases
- Carbon monoxide (CO)
- Carbon dioxide (CO$_2$)
- Nitric oxide (NO)
- Nitrogen dioxide (NO$_2$)

International Agency for Research on Cancer (IARC) (2013) Monograph 105

“Diesel engine exhaust is carcinogenic to humans (Group 1)”
So what is the big deal?

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Year</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEI&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1999</td>
<td>Evidence not strong enough</td>
</tr>
<tr>
<td>ACGIH&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2002</td>
<td>Recommended 0.02mg/m&lt;sup&gt;3&lt;/sup&gt; (measured as REC)</td>
</tr>
<tr>
<td>ACGIH&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2003</td>
<td>Recommended limit withdrawn</td>
</tr>
<tr>
<td>MSHA&lt;sup&gt;3&lt;/sup&gt;</td>
<td>2008</td>
<td><strong>Evidence becoming stronger</strong> - Effective date for Occupational exposure limit (OEL) in the US for underground metal / non-metal 0.16mg/m&lt;sup&gt;3&lt;/sup&gt; (TC) ~ 0.12 (REC)</td>
</tr>
<tr>
<td>IARC&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2012</td>
<td><strong>Strong evidence</strong> – IARC monograph – confirmed carcinogen.</td>
</tr>
<tr>
<td>NCI / NIOSH&lt;sup&gt;4&lt;/sup&gt;</td>
<td>2010 - 2013</td>
<td>Study findings support a much lower OEL which may have a significant impact on UG mining.</td>
</tr>
<tr>
<td>HEI&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2013</td>
<td>Expert panel established</td>
</tr>
<tr>
<td>HEI&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2014 6 March</td>
<td>Workshop held in Boston – open to public, academia, regulators, industry and engine manufacturers.</td>
</tr>
<tr>
<td>HEI&lt;sup&gt;1&lt;/sup&gt;</td>
<td>November 2015</td>
<td>Expert panel review released. <strong>Strong evidence!</strong> Likely significant impact especially in UG mining!</td>
</tr>
</tbody>
</table>
The Diesel Exhaust in Miners Study (DEMS) studied a cohort of more than 12,000 male U.S. non-metal miners; and the Trucking Industry Particle Study that examined a cohort of about 31,000 male workers employed in the unionized U.S. trucking industry.
Overall Panel Conclusions

- Both studies were well-designed and conducted according to high standards of epidemiological research.
- Both studies addressed many of the deficiencies that had limited earlier studies for quantitative risk assessment.
- The results and data from both the Truckers and the DEMS can be usefully applied in quantitative risk assessments.
- The uncertainties within each study should be considered in deriving and characterizing an exposure-response relationship.
- The detailed evaluations of these studies by the HEI Panel and other analysts have laid the groundwork for a systematic characterization of the exposure-response relationship and associated uncertainties.
Relative risks were estimated using exposures lagged 15 years in Silverman et al. (2012) and 5 years in both the Garshick et al. (2012a and Steenland et al. (1998), based on the best model fit in each study. The authors presented sensitivity analyses to lag choices in supplemental material, available online. Elemental carbon was measured as REC in DEMS, as SEC in Garshick et al. (2012a), and as EC in Steenland et al. (1998). SOURCE: Vermeulen R, Silverman DT, Garshick E, Vlaanderen J, Portengen L, Steenland K. 2014b. Exposure–response estimates for diesel engine exhaust and lung cancer mortality based on data from three occupational cohorts. Environ Health Perspect 122:172–177. doi: 10.1289/ehp.1306880.
### Health effects

<table>
<thead>
<tr>
<th>Health effects</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung cancer</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Acute adverse respiratory health outcomes</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Chronic adverse respiratory health outcomes</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Acute adverse cardiovascular health outcomes</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Immunological effects</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Bladder cancer</td>
<td>Suggestive</td>
</tr>
<tr>
<td>Chronic adverse cardiovascular health outcomes</td>
<td>Suggestive</td>
</tr>
<tr>
<td>Reproductive and developmental effects</td>
<td>Suggestive</td>
</tr>
<tr>
<td>Central nervous system effects</td>
<td>Suggestive</td>
</tr>
<tr>
<td>based on acute neurophysiological symptoms in overexposed workers</td>
<td></td>
</tr>
</tbody>
</table>
The Occupational Cancer Research Centre (OCRC) (2017)

The Occupational Cancer Research Centre recommends reducing personal exposure to \(0.02 \text{ mg/m}^3\) measured as elemental carbon.

More than a **10-fold reduction** from the current ON mining limit

Reg. 854: MINES AND MINING PLANTS 183.1 (4)

The current regulatory occupational exposure limit (OEL) does not offer an acceptable level of protection!

To put it in context!

Canadian Cancer Statistics 2015

Burden of cancer attributable to occupational diesel engine exhaust (DEE) exposure in Canada (1961 – 2001) ~ 1.4 million workers exposed

Exposure period 1961 - 2001

<table>
<thead>
<tr>
<th>Gender</th>
<th>Attributable fraction % Lung Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>4.92</td>
</tr>
<tr>
<td>Female</td>
<td>0.29</td>
</tr>
<tr>
<td>Overall</td>
<td>2.70</td>
</tr>
</tbody>
</table>

1 in 20 men and about 1 in 37 overall

1Joanne Kim, 2Cheryl E Peters, 2Chris McLeod, 3Sally Hutchings, 3Lesley Rushton, 1Manisha Pahwa, 1,4Paul A Demers. 1Occupational Cancer Research Centre, Toronto, ON, Canada; 2University of British Columbia, Vancouver, BC, Canada; 3Imperial College London, London, UK; 4University of Toronto, Toronto, ON, Canada
This shows that there is a relatively high (excess) risk from relatively low exposures.
What about UG mining?
EXPOSURES - Source IARC Monograph 105 p.96
Relative risks were estimated using exposures lagged 15 years in Silverman et al. (2012) and 5 years in both the Garshick et al. (2012a and Steenland et al. (1998), based on the best model fit in each study. The authors presented sensitivity analyses to lag choices in supplemental material, available online. Elemental carbon was measured as REC in DEMS, as SEC in Garshick et al. (2012a), and as EC in Steenland et al. (1998).

Underground miners face high risk of lung cancer death from diesel exhaust exposure: study

By the National Reporting Team’s Jessicah Mendes
Updated 17 Nov 2016, 9:45pm

Diesel exhaust could be causing fatal lung cancer in underground miners at a rate up to 38 times the accepted occupational risk, according to a new study.

It shows underground production workers, including diesel loader operators and shotcreters, face the highest risk — and researchers are calling for strict controls to limit their exposure.

The study, published in Occupational and Environmental Medicine, marks the first phase of a landmark investigation sponsored by the National Health and Medical Research Council.

Using Department of Mines and Petroleum data from 2003 to 2015 and other studies, it modelled the average levels of exposure among employees in a range of occupations on Western Australian mine sites.

It then estimated the number of lung cancer deaths caused by those levels with stark results.

"If somebody were to be exposed as an underground miner, we saw that that person would be exposed to on average 44 micrograms per cubic metre (ug/m3)," lead investigator Dr Susan Peters from the University of Western Australia told the ABC.

PHOTO: Underground miners face a higher risk of lung cancer due to exposure to diesel exhaust. (Supplied: Newcrest Mining)

RELATED STORY: Black lung disease no longer contained to underground mining

RELATED STORY: Mine industry risks still very real, support group says

RELATED STORY: WHO confirms diesel fumes carcinogenic

MAP: WA

Key points:

- There is no national occupational standard for exposure to diesel emissions
- Researchers are calling for exposure limits to diesel to be lowered
- Diesel exhaust is the second most common cause of cancer after UV exposure

The flow of air must reduce the concentration of toxic substances in diesel exhaust emissions to prevent exposure of a worker to a level in excess of the limits prescribed under section 4 of Regulation 833 of the Revised Regulations of Ontario, 1990 (Control of Exposure to Biological or Chemical Agents) made under the Act. O. Reg. 265/15, s. 11.

(5) The flow of air must,

(a) reduce the time-weighted average exposure of a worker to total carbon to not more than 0.4 milligrams per cubic metre of air; or
(b) reduce the time-weighted average exposure of a worker to elemental carbon, multiplied by 1.3, to not more than 0.4 milligrams per cubic metre of air.
What does this mean?

This limit is 3 times higher than other international occupational exposure limits (OEL) such in the US and Australia.

Is this acceptable?
Dr. Rob McDonald VP Health and Hygiene, BHP Billition.

Australian Institute of Occupational Hygienists (AIOH), plenary December 2016.

• “Significant lag that exists between regulatory action and the level of science that informs health risk”.

• “Should be managing exposure to diesel exhaust to as low as technically feasible”.

• Interim target to be managing diesel exhaust to $0.03\text{mg/m}^3$ TWA 8-hrs measured as elemental carbon.

https://www.youtube.com/watch?v=n_iFh-BsECo&feature=youtu.be&a
Management of Diesel Emissions
## Controlling Diesel Particulate Matter in Underground Mines

### More Effective

**Elimination**
- Reduce or eliminate diesel particulate emissions before they enter the workplace air.

**Substitution**
- Replacing or repowering old equipment
  - Newer engines must meet much stricter emissions regulations. Replacing an engine or a piece of equipment with a newer model will significantly decrease emissions. The level of reduction depends on the old and replacement equipment.

**Engineering Controls**
- Aftertreatment systems
  - A variety of different aftertreatment systems are available. Emissions reductions depend on the type of filter chosen, as well as the engine and load. Particulate reductions can range from 20-95%.

**Administrative Controls**
- Preventive maintenance
  - Maintenance keeps all parts of the engine, as well as any emissions control systems, functioning optimally. Poorly maintained engines can produce significantly more emissions than an engine in good condition.

**Personal Protective Equipment (PPE)**
- Idling technology
  - Idling technology works by automatically turning off the engine when the vehicle idles. The emissions reductions will be greater for equipment that spends a high proportion of time idling.

### Average Reductions

<table>
<thead>
<tr>
<th>Average particulate matter exposure reductions based on published data</th>
<th>Less effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50%</td>
<td></td>
</tr>
<tr>
<td>50-85%</td>
<td></td>
</tr>
<tr>
<td>85-99%</td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

Varied/Unknown: ?

### Proactive Controls

- Alternative Energy
  - Involves replacing diesel equipment with alternatives such as electric.

- Rebuilding engines
  - Manufacturers often offer upgrade kits that can be incorporated into an engine rebuilt to improve emissions.

### Reactive Controls

- General ventilation
  - General ventilation dilutes emissions by bringing clean air into the area. The reductions vary depending on the volume of air provided. It also helps reduce ambient air concentration of non-diesel hazards, as well as helping with temperature control.

- Enclosed cabs
  - When properly functioning, enclosed cabs protect the operator, but do not protect the surrounding workers.

- Tele-operating
  - Tele-operation allows the operator to be in a safe location, such as a filtered control room on the surface. Reductions in exposure can be up to 100% if the operator is completely removed from the site. Other workers may still be exposed if they enter the work area, or if emissions circulate to other areas of the mine.

- Scheduling and site planning
  - Control the number of diesel engines operating in an area. Schedule workers during times when fewer diesel engines are working.

- Monitoring emissions
  - An emissions monitoring program is critical for ensuring that diesel controls are functioning properly.

### Reactivity Controls

- Operator training
  - Training can include driving skills, how to recognize maintenance issues, proper use of diesel control technologies, and the health effects of diesel exhaust.

- Respirators
  - PPE should be used as a last resort, and is not a replacement for other controls. The concentration of diesel exhaust in the air should still fall below the regulatory limit. When used, respirators should be fit-tested, and training should be provided to wearers.

### Hierarchy of Controls

1. Elimination
2. Substitution
3. Engineering Controls
4. Administrative Controls
5. Personal Protective Equipment (PPE)

### More Effective

- Physically remove the hazard
- Replace the hazard
- Isolate people from the hazard
- Change the way people work
- Protect the worker with Personal Protective Equipment

### Less Effective

- Towards a cancer-free workplace

Reproduced with permission from OCRC
GE and BHP Billiton announce global partnership to improve efficiency and reduce emissions in the mining sector


Using battery powered vehicles ie. battery powered scoop used underground.
https://gereports.ca/breathing-easier-underground/

We have the technology!
 ✓ Nominate a champion.
 ✓ Establish a team.
 ✓ Measure the tail pipe emissions by carrying out a baseline assessment.
 ✓ Measure and monitor personal exposures.
 ✓ Ensure that there is an emissions based maintenance program.
 ✓ Have a short and longer term strategy.

Reduce / eliminate emissions from the engines!

Engage with experts:

Canadian resource: Sean McGinn
http://www.mknizdfactors.com
It is important to continually review and lower limits - this drives exposure reduction and continuous improvement
Can it be measured?

<table>
<thead>
<tr>
<th>Raw exhaust monitoring</th>
<th>Personal exposure monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Yes but ensure that measurement is precise and accurate
Ensure precision and accuracy

Diesel ChekMate® Mark II
E.R.P Engineering Pty Ltd.
Australian guideline (NSW MDG 29)

4.1 GASEOUS EXHAUST EMISSIONS

When tested in accordance with SECTION 5 Monitoring of Diesel Engine Pollutants the raw exhaust gas of the diesel engine shall;

a) not exceed the limits specified in Table 3 below, and
b) be compared against the baseline limits as specified in Table 4 below.

<table>
<thead>
<tr>
<th>Description</th>
<th>CO (ppm)</th>
<th>NO (ppm)</th>
<th>NO₂ (ppm)</th>
<th>NOₓ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type testing of new engines for underground coal mines without methane injection</td>
<td>-</td>
<td>900</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>(0.09%)</td>
<td></td>
<td></td>
<td>(0.01%)</td>
<td></td>
</tr>
<tr>
<td>Type testing of new engines for underground coal mines with methane injection</td>
<td>-</td>
<td>900</td>
<td>100</td>
<td>1,000</td>
</tr>
<tr>
<td>(0.09%)</td>
<td></td>
<td></td>
<td>(0.01%)</td>
<td></td>
</tr>
<tr>
<td>In-service engines in underground coal mines</td>
<td>-</td>
<td>900</td>
<td>100</td>
<td>1,000</td>
</tr>
<tr>
<td>(0.09%)</td>
<td></td>
<td></td>
<td>(0.01%)</td>
<td></td>
</tr>
<tr>
<td>Engines in other underground environment</td>
<td>1,100</td>
<td>900</td>
<td>100</td>
<td>1,000</td>
</tr>
<tr>
<td>(0.09%)</td>
<td></td>
<td></td>
<td>(0.01%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 – Raw exhaust gas limits for diesel engines operating in underground environments

Notes:
1. Based on the coal legislation

“In NSW Australia Where “failed” must be withdrawn from use underground”
Nitrogen dioxide:
Caution there may be an increase in nitrogen dioxide after installing a diesel oxidation catalyst (DOC).

NIOSH note

“The concentration of nitrogen dioxide should also be monitored before and after the DOC. A history of this data should be stored to assess the activity of the DOC in increasing the concentration of this compound”.


See also MSHA: HEALTH HAZARD ALERT Underground Coal Mines Increased Nitrogen Dioxide (NO2) Emissions

30
Need to understand what the exposures are by carrying out a baseline exposure assessment for diesel particulate matter (DPM) measured as total and elemental carbon.
NIOSH 5040
Important - Occupational Exposure Limits are not fine dividing lines between safe and unsafe exposure.

The case of Claude Fortin (Lavery Lawyers 18 Feb 2013)

Mining Companies and Occupational Disease: Regulatory Standards Are Not The Test

On December 17, 2012, the Quebec Superior Court upheld a decision which could have far reaching consequences.

Despite safety measures implemented by those companies

In this decision, the superior court supported that an employee, who had been diagnosed with lung cancer, was suffering from an “occupational disease” even though the level of contaminants to which he was exposed fell below regulatory standards.

This was a first!

Can exposures be lowered for underground mining in Canada?
Occupational exposure limit in ON TC 0.4 (0.31 EC)

Resources
Information, research, and technology transfer:

Diesel technology forum
http://www.dieselforum.org/

Canadian Mining Industry Research Organization
Diesel Emission Evaluation Program
http://www.camiro.org/mining/diesel-emission-evaluation-program

The Australian Coal Industry’s Research Program (ACARP)

Centers for disease control and prevention (CDC / NIOSH)
http://www.cdc.gov/niosh/mining/topics/DieselExhaust.html

Mining Diesel Emissions Council (MDEC)
http://www.mdec.ca/

CanmetMINING, Natural Resources Canada
http://www.nrcan.gc.ca/mining-materials/green-mining/8178
Resources (continued)
Information, research, and technology transfer:


Queensland Australia Mining
QGN 21 Guidance note for management of diesel engine exhaust in metalliferous mines Mining and Quarrying Safety and Health Act 1999 January 2014, Version 1

Western Australia Mining

NSW Australia Mining
Guideline for the management of diesel engine pollutants in underground environments 2008
Resources (continued)
Information, research, and technology transfer:

MKNIZD Factors Inc.
http://www.mknizdfactors.com

E.R.P Engineering Pty. Ltd.

MSHA
https://arlweb.msha.gov/01-995/dieselpartmnm.htm
https://arlweb.msha.gov/s&hinfo/diesel.htm
https://arlweb.msha.gov/s&Hinfo/toolbox/tbcover.htm
https://arlweb.msha.gov/s&hinfo/deslreg/dreg.htm

National Institute for Occupational Safety and Health (NIOSH)
Mining / Topic: Diesel Exhaust
https://www.cdc.gov/niosh/mining/topics/dieselexhaust.html

Occupational Safety and Health Administration (OSHA)
Diesel Exhaust
https://www.osha.gov/SLTC/dieselexhaust/
Previous presentations:

Memorial University of Newfoundland (MUN) SafetyNet
Diesel fumes – how hramfull are they? (December 2015).
https://www.youtube.com/watch?v=Gruu8iyZJps&feature=youtu.be

Occupational Health Clinics for Ontario Workers Inc (OHCOW).
Diesel Exhaust Occ-tober (October 2016).
https://youtu.be/zCoBdAvjhgl