Control of Diesel Particulate Matter
Exposures in Underground Stone Mines in the United States

Lansdowne Resort
Leesburg, Virginia
September 25 – 26, 2008
• History and background
• Regulation
• DPM Controls
• Compliance history
Rudolf Diesel
1858 - 1913

Diesel engine patented in Germany by Rudolf Diesel in 1892
Diesel engines are the workhorses of underground metal and nonmetal mining.

- 190 Mines
- 8,000 Diesel Units
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190 Mines

8,000 Diesel Units

\[ \bar{x} = 42 \text{ units/mine} \]
Diesel Particulate Matter (DPM) consists of:

- Solids, liquids, and vapors;
- Burned and unburned hydrocarbons; fuel, lube oil;
- Oxides of sulfur, nitrogen;
- Metal fragments, metal oxides, acids, salts, ash, other substances

2,000+ identified compounds

- Nucleation mode – 5 to 50 nm
- Agglomeration mode – 50 nm to 1 µm
Health Effects of DPM

- Due to particle size, DPM particles are respirable in size
  - Can reach the deep lung (alveoli)
Health Effects of DPM

- Principal adverse health effects
  - Sensory irritations and respiratory symptoms serious enough to distract or disable miners
  - Immunologic effects (allergenic responses and asthma-like symptoms)
  - Premature death from cardiovascular, cardiopulmonary, or respiratory causes
  - Lung cancer
Many agencies and organizations regard DPM as hazardous to human health.

<table>
<thead>
<tr>
<th>Year</th>
<th>Organization</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>US EPA</td>
<td>Likely human carcinogen</td>
</tr>
<tr>
<td>2001</td>
<td>ACGIH (proposal)</td>
<td>Suspected human carcinogen</td>
</tr>
<tr>
<td>2001</td>
<td>US Dept of HHS</td>
<td>Reasonably anticipated to be a human carcinogen</td>
</tr>
<tr>
<td>1998</td>
<td>CARB</td>
<td>Toxic air contaminant</td>
</tr>
<tr>
<td>1996</td>
<td>World Health Org</td>
<td>Probable human carcinogen</td>
</tr>
<tr>
<td>1989</td>
<td>IARC</td>
<td>Probable human carcinogen</td>
</tr>
<tr>
<td>1988</td>
<td>NIOSH</td>
<td>Potential occupational carcinogen</td>
</tr>
</tbody>
</table>
MSHA Rulemaking Background and Timeline

**1960’s to present**  DPM epidemiological and occupational exposure studies

**1980’s**  Interagency task forces evaluated DPM health risks, DPM sampling, and DPM control technologies

**Mid-1990’s**  MSHA DPM rulemaking initiated

**October 1998**  MSHA issues Proposed Rule

**January 2001**  MSHA issues Final Rule

- DPM limit phased in over 5 years
  - Total Carbon surrogate for DPM
  - Interim Limit of $400_{TC} \mu g/m^3$; Final Limit of $160_{TC} \mu g/m^3$
  - Control of exposures by engineering or work practices
- Special Extensions to Final Limit
- Overexposure prompts requirement for Control Plan
- “Best Practice” standards for fuel, maintenance, engines, training, and recordkeeping
MSHA Rulemaking Background and Timeline

**January 2001** Legal challenges to Final Rule; USWA intervenes in litigation

**February 2001** Parties agree to negotiations

**July 2001** Enforcement of “Best Practice” standards (fuel, maintenance, engines, etc.)

**July 2003** Enforcement of Interim DPM Limit

**June 2005** Final Rule creates interim permissible exposure limit (PEL), other changes

**May 2006** Final Rule creates 3-step Final DPM PEL, changes to PPE and Special Extensions

**February 2007** US Court of Appeals upholds DPM Final Rules
Current MSHA MNM DPM Rule

- Permissible exposure limit (PEL) of $160_{TC} \mu g/m^3$ (shift weighted average full shift personal sample, analyzed per NIOSH method 5040)
- Mine operators may apply for Special Extension of the PEL based on technological or economic infeasibility (1 year duration, renewable)
- Exposures controlled via engineering and/or administrative means. If compliance infeasible using engr/admin controls alone, supplemental respiratory protection required
  - Respiratory protection program, medical evaluations
  - Medical transfers with pay retention
  - Job rotation **not allowed** as a means of compliance
Current MSHA MNM DPM Rule

- Low sulfur (500 ppm) fuel required and fuel additives must be registered with US EPA
- Engine maintenance
  - Approved engines in approved condition
  - Emission-related components to manufacturers’ spec
  - Emission controls in effective operating condition
  - Maintenance tagging
  - Mechanic qualifications
- Engines either Approved or meet EPA PM limits
- DPM training annually
- DPM exposure monitoring
- DPM recordkeeping
DPM Regulations Outside the US

EU Member States

- Engine emission standards similar to US EPA
- Occupational exposure limits (OEL) established on state-by-state basis
- Germany - $300_{EC} \, \mu g/m^3$ for tunneling/non-coal mining
  - diesel particulate filters mandatory

Non-EU European states

- Switzerland - Engine emissions based on EU limits
  - OEL of $100_{EC} \, \mu g/m^3$ for mining/tunneling
  - diesel particulate filters mandatory

Canada

- Engine emission standards harmonized with US EPA
- Several Provinces have adopted 1.5 mg/m$^3$ (RCD)
# US EPA vs. EU Non-Road Diesel Engine Emission Standards

<table>
<thead>
<tr>
<th>HP</th>
<th>US EPA (Tiers 2, 3, and 4)</th>
<th>EU (Stages III and IV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-75</td>
<td>0.22 (2008) 0.022 (2013)</td>
<td>19-37 0.45 (2007)</td>
</tr>
<tr>
<td>50-100</td>
<td>0.30 (2004)</td>
<td>37-75 0.30 (2008)</td>
</tr>
<tr>
<td>50-75</td>
<td>0.22 (2008) 0.022 (2013)</td>
<td>37-56 0.019 (2013)</td>
</tr>
<tr>
<td>100-175</td>
<td>0.22 (2003)</td>
<td>75-130 0.22 (2007)</td>
</tr>
<tr>
<td>75-175</td>
<td>0.015 (2012)</td>
<td>56-130 0.019 (2012)</td>
</tr>
<tr>
<td>175-750</td>
<td>0.15 (2001-2003) 0.015 (2011)</td>
<td>130-560 0.15 (2006) 0.019 (2011)</td>
</tr>
</tbody>
</table>
Available Control Strategies

1. Ventilation
2. Environmental Cabs
3. Administrative Controls
4. Diesel Engines
5. Engine Maintenance
6. Biodiesel Fuel
7. DPM Exhaust Filters
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Emission Reduction
Exposure Controls
Available Control Strategies

1. Ventilation
2. Environmental Cabs
3. Administrative Controls
4. Diesel Engines
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7. DPM Exhaust Filters

Most MNM mines were able to attain consistent compliance with Interim DPM PEL
Available Control Strategies

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Most MNM mines were able to attain consistent compliance with Interim DPM PEL.

Additional controls will be needed at many mines to meet Final DPM PEL.
## Available Control Strategies

1. Ventilation
2. Environmental Cabs
3. Administrative Controls
4. Diesel Engines
5. Engine Maintenance
6. Biodiesel Fuel
7. DPM Exhaust Filters

Almost all mines will require a combination of controls to attain compliance.
Effectiveness of DPM Controls

- Ventilation – DPM reduction depends on nature of upgrade - improvement roughly proportional to airflow increase
  - Doubling airflow *could* cut DPM conc. 50%

- Environmental cabs  50 - 80% reduction
  - 800 µg/m³ reduced to 400 - 160 µg/m³ in cab
  - Some workers *can’t* work inside cab

- Administrative or work practice controls - DPM reduction depends on mine conditions and work practices employed
Effectiveness of DPM Controls

- Low emission engines - effect depends on engines - 95+% reduction possible
  - Example: Pre-”Tier” engine replaced by Tier 2 engine could reduce DPM up to 95%
    - 800 µg/m³ reduced to 40 µg/m³
    - Reductions of 25% to 40% more typical

- Engine maintenance – depends on many factors - results vary widely
  - A few mine operators have implemented “emissions-based maintenance”
Effectiveness of DPM Controls

- Alternate fuels - effect depends on fuel blend, engines, etc. - results vary
  - 50% bio-diesel fuel reduces DPM 20-40%
    - 800 µg/m³ reduced to 640 µg/m³ to 480 µg/m³
  - 100% biodiesel fuel reduces DPM 50-80%
    - 800 µg/m³ reduced to 400 µg/m³ to 160 µg/m³
  - OCC recommended to reduce OC
- DPM exhaust filters - 80 to 99% efficient
  - 80% efficiency reduces 800 µg/m³ to 160 µg/m³
  - 99% efficiency reduces 800 µg/m³ to 8 µg/m³
Summary Comparison of DPM Controls

<table>
<thead>
<tr>
<th>Environ</th>
<th>Clean</th>
<th>B100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cab</td>
<td>Engines</td>
<td>Fuel</td>
</tr>
</tbody>
</table>

Maximum EC Reduction (pct)

- Q 50%
- Environ Cab
- Clean Engines
- B100 Fuel
- DPM Filters
## MSHA Compliance Sampling
### Comparing Results From ’03-’04 to ’07-’08

<table>
<thead>
<tr>
<th>Total Carbon Concentration</th>
<th>July ‘03 to July ‘04 N = 811</th>
<th>May ‘07 to May ‘08 N = 608</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 100 µg/m³</td>
<td>28.1%</td>
<td>44.6%</td>
</tr>
<tr>
<td>&lt; 200 µg/m³</td>
<td>55.7%</td>
<td>71.8%</td>
</tr>
<tr>
<td>&lt; 300 µg/m³</td>
<td>73.1%</td>
<td>86.3%</td>
</tr>
<tr>
<td>&gt; 400 µg/m³</td>
<td>15.6% (49 mines)</td>
<td>8.1% (29 mines)</td>
</tr>
<tr>
<td>&gt; 600 µg/m³</td>
<td>5.1% (25 mines)</td>
<td>3.6% (12 mines)</td>
</tr>
</tbody>
</table>
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Thank You