



# Diesel Exhaust Emissions – Health Effects

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## Modern Underground Mining

- 10,000+ tons per day hoisted to surface
- Heavily mechanized
- Multi-level parallel ventilation networks (energy intensive)
- Diesel is usually the largest ventilation stress factor
- Diesel used for haulage, drilling, maintenance, personnel transportation, supervision, etc.



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# Diesel Emissions Composition

- Particulate (DPM)
  - Elemental carbon
  - Organic carbon
  - Sulphates
  - Metals & ashes
- NO, NO<sub>2</sub>, SO<sub>2</sub>, CO, CO<sub>2</sub>, H<sub>2</sub>O
- Aldehydes, hydrocarbons





## Diesel Exhaust

- Complex mixture of thousands of chemicals
- Gases and fine particles
- Over forty air contaminants recognized as toxic, carcinogenic or reproductive and developmental hazards





## Substances in Diesel Exhaust Listed by the California Air Resources Board as Toxic Air Contaminants

### acetaldehyde

acrolein

aniline

antimony compounds

### arsenic

benzene

beryllium compounds

biphenyl

bis[2-ethylhexyl]phthalate

1,3-butadiene

cadmium

chlorine

chlorobenzene

### chromium compounds

### cobalt compounds

cresol isomers

cyanide compounds

dibutylphthalate

dioxins and dibenzofurans

ethyl benzene

### formaldehyde

hexane

### lead (inorganic)

### manganese compounds

### mercury compounds

methanol

methyl ethyl ketone

naphthalene

### nickel

4-nitrobiphenyl

phenol

phosphorus

POM, including PAHs

and their derivatives

propionaldehyde

selenium compounds

styrene

toluene

xylene isomers, mixtures

o-xylenes

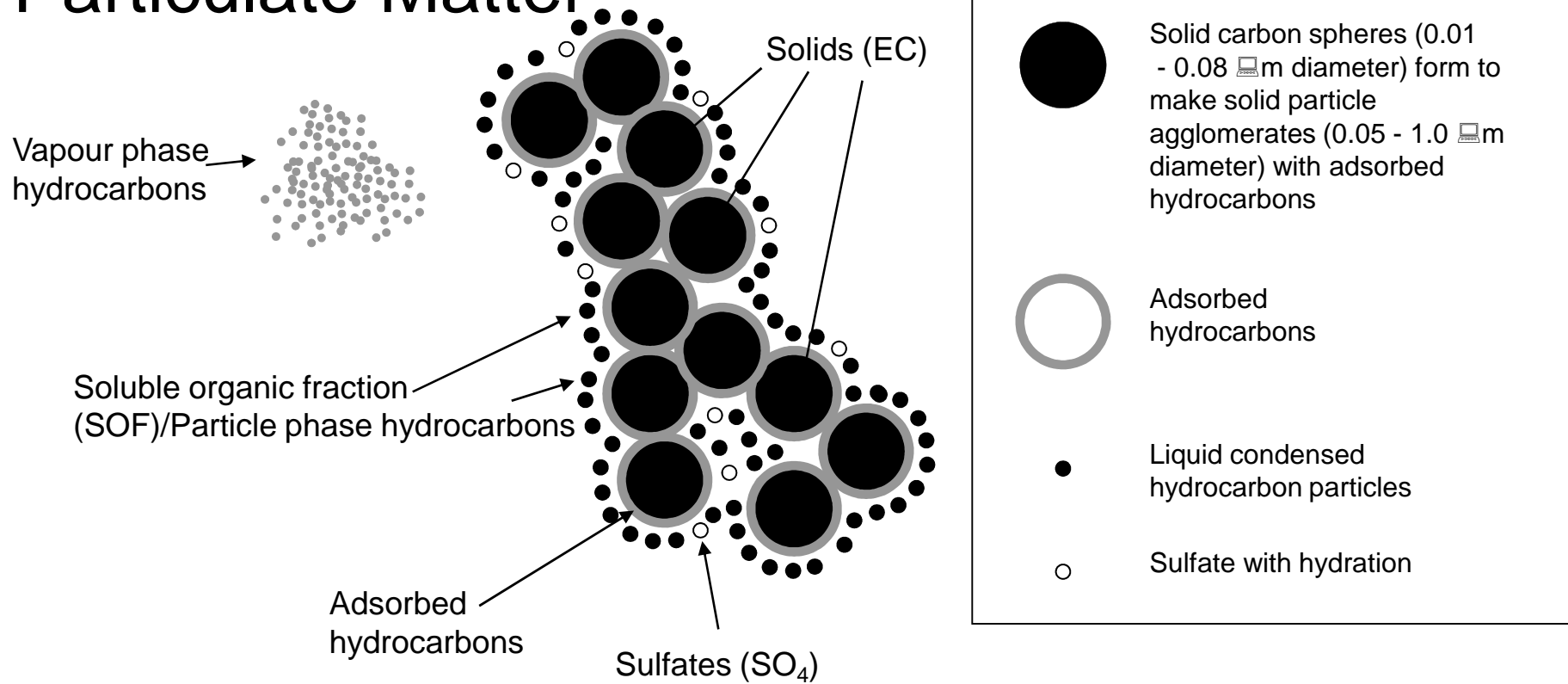
m-xylenes

p-xylenes





# Particulate Matter



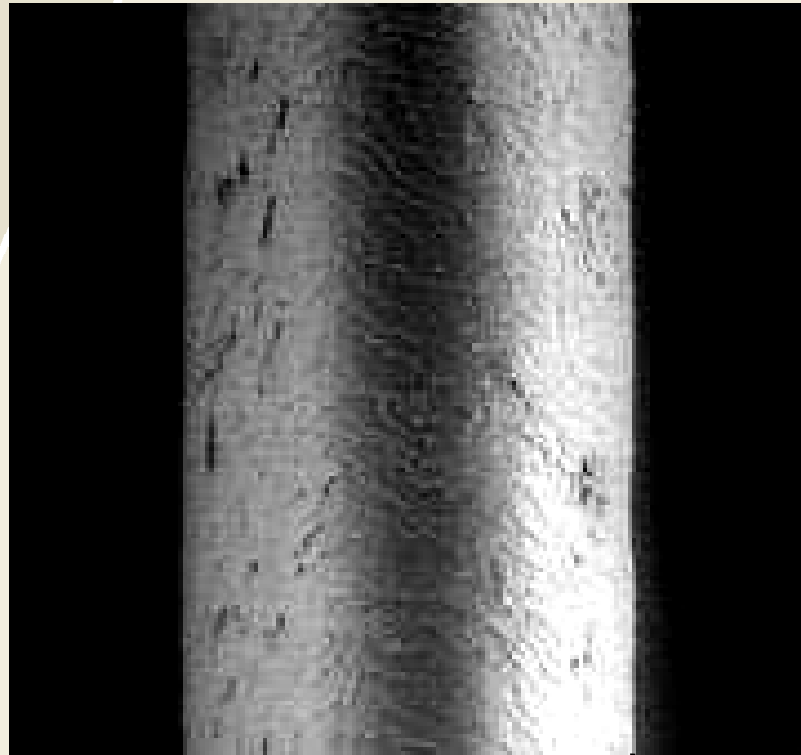
Reproduced from HEI's Diesel Exhaust: A critical Analysis of Emissions, Exposure, and Health Effects



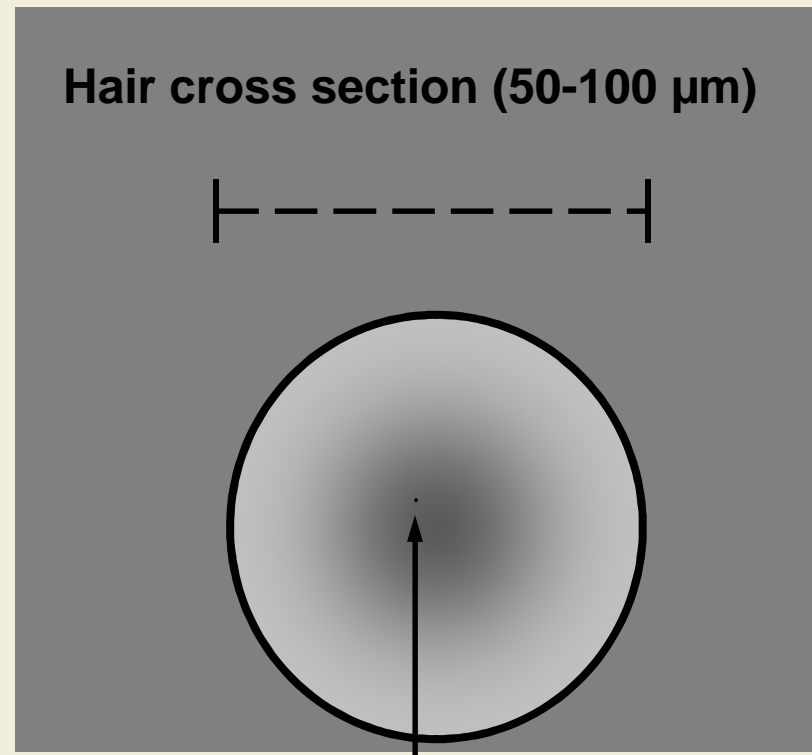
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**Human Hair**  
**(50-100  $\mu\text{m}$  diameter)**



**Hair cross section (50-100  $\mu\text{m}$ )**

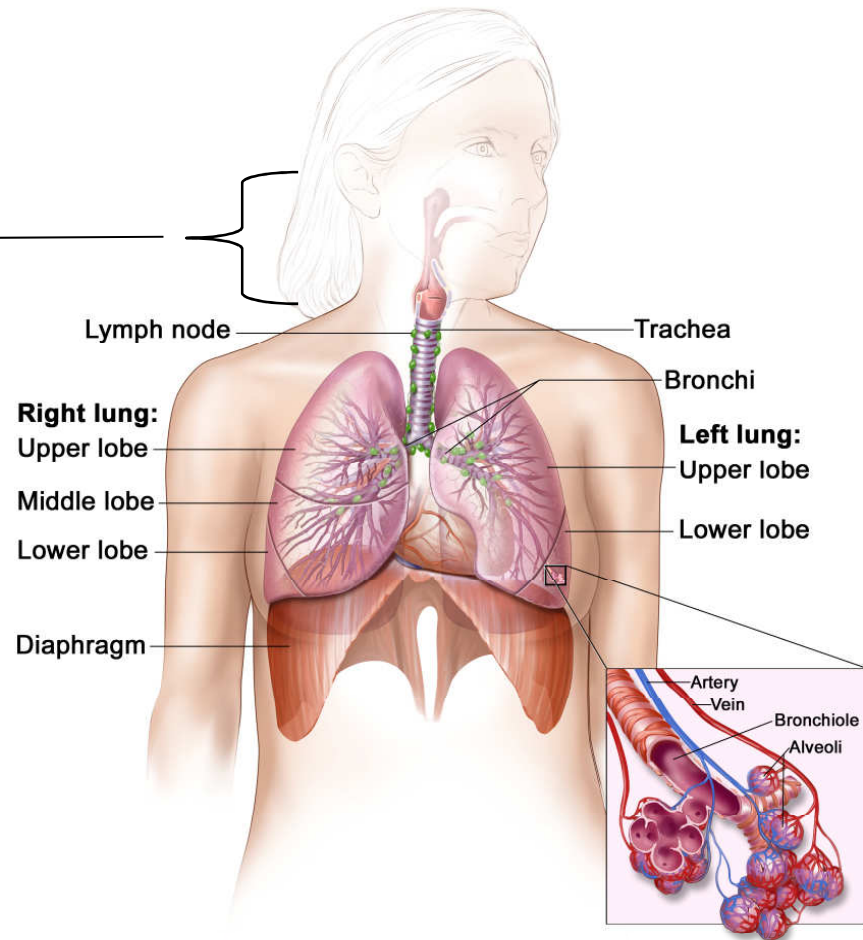
**PM0.1 (0.1  $\mu\text{m}$ )**





## Where they go...

- Nose and throat remove particles greater than  $10\ \mu\text{m}$
- Trachea and upper bronchi remove particles  $2.5\ \mu\text{m}$  to  $10\ \mu\text{m}$
- Particles between  $0.1\ \mu\text{m}$  and  $2.5\ \mu\text{m}$  are deposited in bronchioles and alveoli
- Particles less than  $0.1\ \mu\text{m}$  reach all areas of lung and to some degree diffuse into body tissues



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## What does it mean?

- Whether we're talking about solids, gases or vapours, almost every component of diesel exhaust finds a way to interact with our bodies at the level of the bloodstream or the tissues





# Physical and Chemical Nature of Diesel Exhaust

- Four potential levels of threat
  - Carcinogenic
  - Toxic
  - Fine particulate
  - Oxides of nitrogen





## Threat Levels 1 and 2

- Cancer
  - Lung
  - Bladder
- Toxins
  - Nervous
  - Endocrine
  - Reproductive
  - Immune
  - Liver
  - Kidney





## Threat Level 3

- Fine Particulate Matter
  - Premature death
  - Increase respiratory illnesses
  - Exacerbates asthma
    - Number of symptom days
    - Attacks
    - ER visits
    - Hospitalization

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## Threat Level 4

- Nitrogen oxides
  - Increased ozone, smog
  - Increase in respiratory illnesses
  - Decrease in lung function





## Non-cancer Health Effects from Short-term Exposure

- Acute irritation
- Respiratory symptoms (e.g., cough)
- Nausea
- Compromised pulmonary function
- Increase in biochemical markers associated with allergy
- Asthma exacerbation

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## Non-cancer Health Effects from Long-term Exposure

- Greater cough and phlegm
- Asthma induction
- Animals also show decreased resistance to infection, increased chronic lung inflammation and tissue changes

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# Cancer Risk Assessments of Diesel Exhaust

- 1988 - National Institute for Occupational Safety and Health (NIOSH): potential occupational carcinogen
- 1989 - International Agency for Research on Cancer (WHO): probable human carcinogen
- 1990 - State of California: known to cause cancer
- 1995 - Health Effects Institute and 1996 – WHO: consistency in showing weak association between exposure to diesel exhaust and lung cancer

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## Cancer Risk Assessments of Diesel Exhaust (cont.)

- 1998 - California EPA (Staff Recommendation): may cause an increase in the likelihood of cancer
- 1998 - California Air Resources Board: diesel particulate emissions are a toxic air contaminant
- 1998 – U.S. National Toxicology Program: diesel exhaust particulate is reasonably anticipated to be a human carcinogen
- 2002 - U.S. Environmental Protection Agency: likely to be carcinogenic to humans by inhalation at environmental levels of exposure

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## Particulate Exposure Standards

- Daily average  $35 \mu\text{g}/\text{m}^3$  –  $\text{PM}_{2.5}$  (U.S. EPA)
- Annual average  $15 \mu\text{g}/\text{m}^3$  –  $\text{PM}_{2.5}$  (U.S. EPA)
- Occupational exposure limits (DPM in mines):
  - Canada  $1500 \mu\text{g}/\text{m}^3$
  - Québec  $600 \mu\text{g}/\text{m}^3$
  - Ontario  $400 \mu\text{g}/\text{m}^3$
  - USA  $160 \mu\text{g}/\text{m}^3$





## Percentage of DPM Samples in Excess of Various Occupational Exposure Limits – 2008 Canadian Underground Mine Data (700 samples)

Exposure limit ( $\mu\text{g}/\text{m}^3$ )	% of samples in excess of limit (Total Carbon)
1500 (Canada)	0
600 (Québec)	2
400 (Ontario)	7
160 (USA – MSHA)	57





## What can we conclude from all this

- Because of a lack of research, a causal link between DPM exposure in humans and the more serious long-term health effects has not been demonstrated, but...
- Particulate matter and DPM are known contributors to increased hospital admissions, ER visits, asthma attacks, lost workdays, and premature death.
- Animal research together with epidemiological studies in humans suggest a causal relationship between occupational diesel exhaust exposure and lung cancer
- Concentration levels in mines are in the range that environmental agencies would consider high for general population exposure
- Everyone agrees that less exposure is better
- Underground, you can run but you can't hide...

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# Solutions Toolbox for Mining

- Control at the source
- Modern engines
- Certification for U/G mine engines
- Emissions based maintenance
- Exhaust treatment
- Clean or alternative fuels
- Alternative energy (hybrids, hydrogen)
- Regular sampling and monitoring
- Ventilation
- Training/technology transfer
- Regulation



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## Acknowledgements

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*Thank you...*