Diesel Exhaust: Health Effects and Research Needs

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Outline

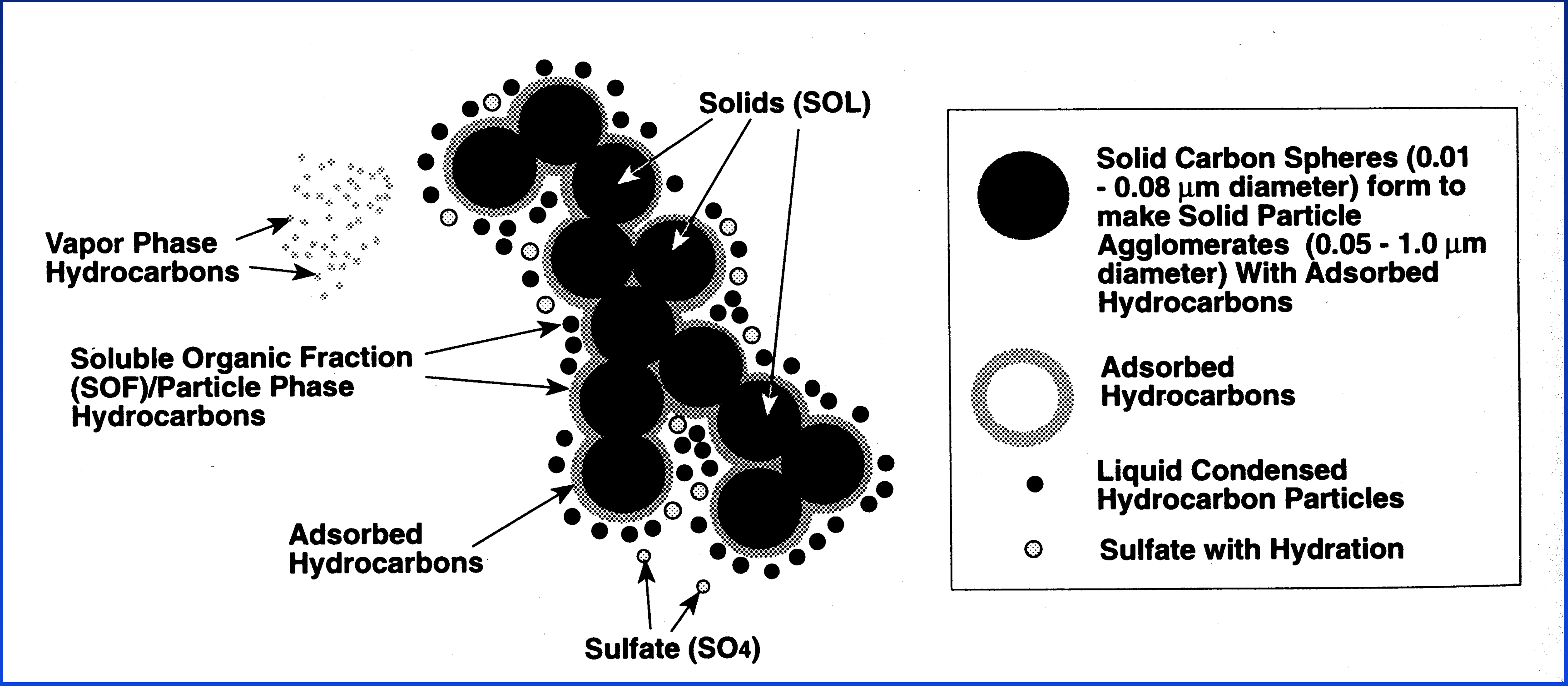
- What is diesel exhaust?
- How is exposure assessed?
- What exposure levels have been reported?
- What are the potential health effects?
  - Non-cancer
  - Cancer
- Are these health effects unique to diesel or properties of all inhaled (ambient) particles?
- Current research

Diesel Exhaust Composition

- Vapor Phase
  - Carbon Monoxide
  - Carbon Dioxide
  - Sulfur Dioxide
  - Nitrogen Oxides
  - Aldehydes
  - Hydrocarbons
  - PAH Compounds
- Particulate Phase
  - Elemental Carbon
  - Sulfates
  - Hydrocarbons
  - PAH Compounds

PAH= Polycyclic Aromatic Hydrocarbons

Diesel Particle



Health Effects Institute, 1995

Particulate Phase

- Particles have adsorbed hydrocarbons and PAH compounds
- PAH compounds cause mutations/chromosomal alterations in laboratory test systems
- Size favors inhalation and deposition into lower region of the lung
- Older diesel engines produce more particles by weight than newer engines, but newer diesels may produce finer particles

Diesel Exhaust Contributes to Ambient Particulate Matter

- Total Suspended Particulates (TSP)
- Respirable particles: < 10 µm
  - Coarse particles: 2.5-10 µm
  - Fine particles: < 2.5 µm ($PM_{2.5}$)
  - Ultrafine particles: < 1.0 µm ($PM_{1.0}$)
  - Diesel exhaust 0.05-1.0 µm
- Contribution of diesel to ambient particles varies

Sources of $PM_{2.5}$ - PM_{10}

- Crustal particles:
  - Mechanically generated from agriculture, mining, construction, road traffic and related sources
- Organic particles
  - Biological origin

Sources of $PM_{2.5}$

- Combustion particles
  - Motor vehicles (diesel, gas)
  - Burning of coal, fuel oil, wood, food
- Crustal particles
  - Finely ground airborne road dust and soils

How is Diesel Exhaust Exposure Assessed?

- Job title
- PM_{10} or $PM_{2.5}$
- Elemental carbon (EC) in particles < 1.0 μm
- Source apportionment: EC and assessment of associated organic chemical profile
  - Provide estimates of diesel and non-diesel EC

Measurements in Various Exposure Settings

Exposure Setting	Measurement	µg/m^3
25 underground metal/non-metal mines 1988-97	Mostly EC	**68 - 1835**
11 surface mines (coal/non-coal) 1988-97	Mostly EC	**19 – 160**
Railroad workers (various jobs) 1981-83	Respirable*	**39 - 130**
Truck terminals/diesel forklifts (1988-1989)	EC	**27.2**
Railroad workers (various jobs) 1996	EC	**1.9 – 21.0**
Truck mechanics (1988-1989)	EC	**12.1**
City truck drivers/Road drivers (1988-1989)	EC	**4.0/3.8**
Harlem streets, July 1996	EC $PM_{2.5}$	**1.5 – 6.2** **36.6 – 47.1**

*cigarette adjusted

Area Levels of Elemental Carbon, μg/m³

Trucking Industry Study, October 1999

Area	Urban		Rural	
	N	GM	N	GM
Terminal Dock*	16	4.2	8	0.6
Yard (Upwind)	6	2.2	7	0.3

*$PM_{2.5}$ = 53 μg/m³ (mean) on dock

Marine Dock Exposure

- Ro-ro ferry, Great Britain (Groves and Cain, 2000)
  - Elemental Carbon GM = 37 $\mu g/m^3$ (GSD 2.5)
  - 20 personal samples

- Ro-ro ship stevedores, Sweden (Dahlqvist and Ulfvarson, 1996)
  - Study conducted in 1987; respirable dust (AM/SD)
  - <u>Ship 1</u>: 80 (+/-20) $\mu g/m^3$ <u>Ship 2:</u> 250 (+/-40) $\mu g/m^3$

Human Health Effects Overview

- Odor and Irritant
- Allergic Response
- Respiratory Symptoms: Acute and Chronic
- Pulmonary Function: Acute Exposure
- Pulmonary Function: Chronic Exposure
- Lung Cancer (best studied)
- Other Cancers (weak evidence)

Early Diesel Research

Odor and Irritant Effects

- Odor: focus of early research
- Old diesel: black smoke with characteristic odor
- Reports in miners, bus garage workers, stevedores
- Specific constituent unknown
- Newer diesels: less black smoke, but also depends on maintenance and operating characteristics

Highway Diesel Exhaust

Methods Allergic and Lung Inflammatory Response: Experimental

- Nasal studies in humans:
  - Particles with and without pollen sprayed in nose
  - Washings to assess chemical mediators of allergy
- Lung studies in humans:
  - Controlled diesel exposure followed by lung lavage
  - Assess cellular and chemical response in lavage fluid
- Studies with cultured human airway cells

Assessment of Lung Function and Respiratory Symptoms: Experimental Methods

- Pulmonary Function
  - FEV_1 = Volume exhaled in 1 second
  - FVC = Volume between total lung capacity and residual volume
- Standardized respiratory symptom questionnaire
- Acute effects: Assess work shift changes
- Chronic effects: Assess lung function attributable to long-term exposures

Allergic Response: Summary

- Grass pollen can bind to diesel particles
- Diesel particles sprayed in nose results in production of nasal IgE
- Ragweed + diesel particles = greater ragweed response than ragweed alone
- Nasal challenge with diesel particles result in nasal inflammatory response
- Particles without organic compounds = less response
- Diesel particles result in release of markers of inflammation from cultured human airway cells

Pulmonary Function: Bronchial Changes

- 15 nonsmoking volunteers, no asthma or allergies
- 300 µg/m^3 whole diesel exhaust for 1 hour
- No change in FEV_1 and FVC
- Lavage: increase in inflammatory cells and other inflammatory markers
- Bronchial biopsies: inflammatory changes

Salvi et al. *Am J Respir Crit Care Med* 1999; 159: 702-709.

Acute Health Effects: Bus Garage

- 232 male workers in four garages
- Workers ≥ 310 μg/m^3 respirable particles reported more cough, itchy or burning eyes, chest constriction, wheeze, difficulty breathing
- No significant shift related changes in FEV_1
- Smoking and age adjusted

Gamble J et al. *Environ Res* 1987; 42:201-214.

Acute Health Effects: Miners

- 150 underground coal miners - diesel/non-diesel
- Diesel mine respirable dust = 2.0 $\pm$ 1.7 mg/m^3
- Non-diesel mine respirable dust = 1.4 $\pm$ 1.5 mg/m^3
- Similar shift related changes in both groups

Ames RG et al. *Am Rev Respir Dis 1982;* 125: 39-42.

Acute Health Effects: Stevedores

- 23 stevedores exposed to diesel truck exhaust after 10 days off work
- No control group
- Respirable dust 130 - 590 $\mu g/m^3$ (?contribution of diesel)
- Shift related changes in FEV_1 and FVC

Ulfvarson et al. *Scand J Work Environ Health* 1987; 13: 505-512.

Acute Health Effects: Children

- Lung function testing in 1,092 children who lived near highways
- 4% reduction in FEV_1 and FVC per 10,000 trucks/24 hours - within 300 meters
- Weaker relationship between reduced function and automobile traffic
- Adjusted for parental smoking, gas cooking

Brunekreef et al. Epidemiology 1997; 8: 298-303.

Chronic Health Effects

- Five studies in surface and underground coal, potash, and salt miners, and bus garage workers
  - Cross sectional studies of active workers, many with short-term exposure
  - One five year longitudinal study
- Diesel exhaust not specifically measured
- No consistent association between exposure and pulmonary function

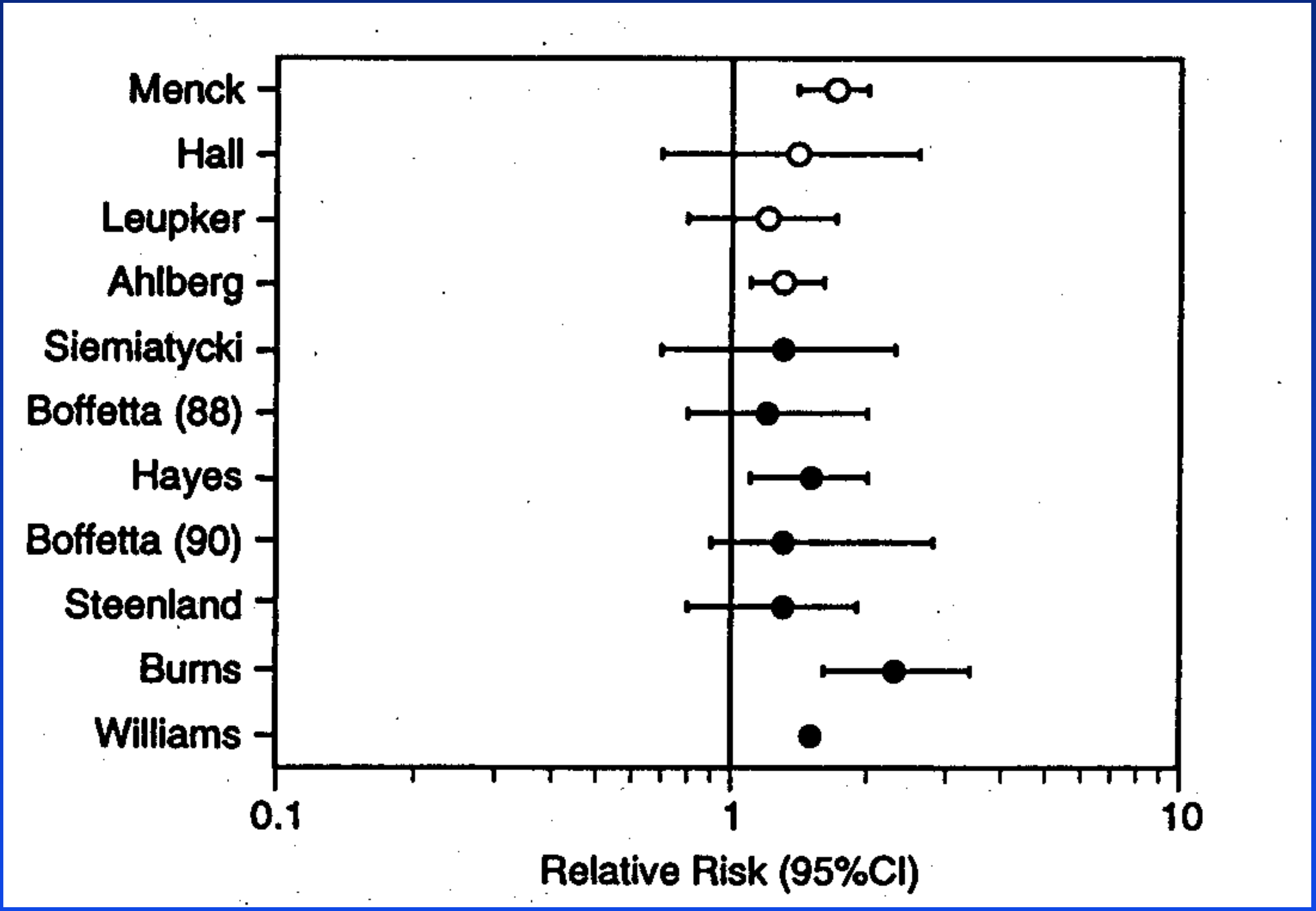
Lung Cancer
Summary Of Results In Animals

- Dose related increase in lung tumors at high levels of diesel exhaust exposure (3500 μg/m^3) in rats
- Results can be reproduced by inhalation of other insoluble particles without associated organics
- Relevance to humans occupationally exposed at lower concentrations is uncertain

Lung Cancer
Epidemiological Studies in Humans

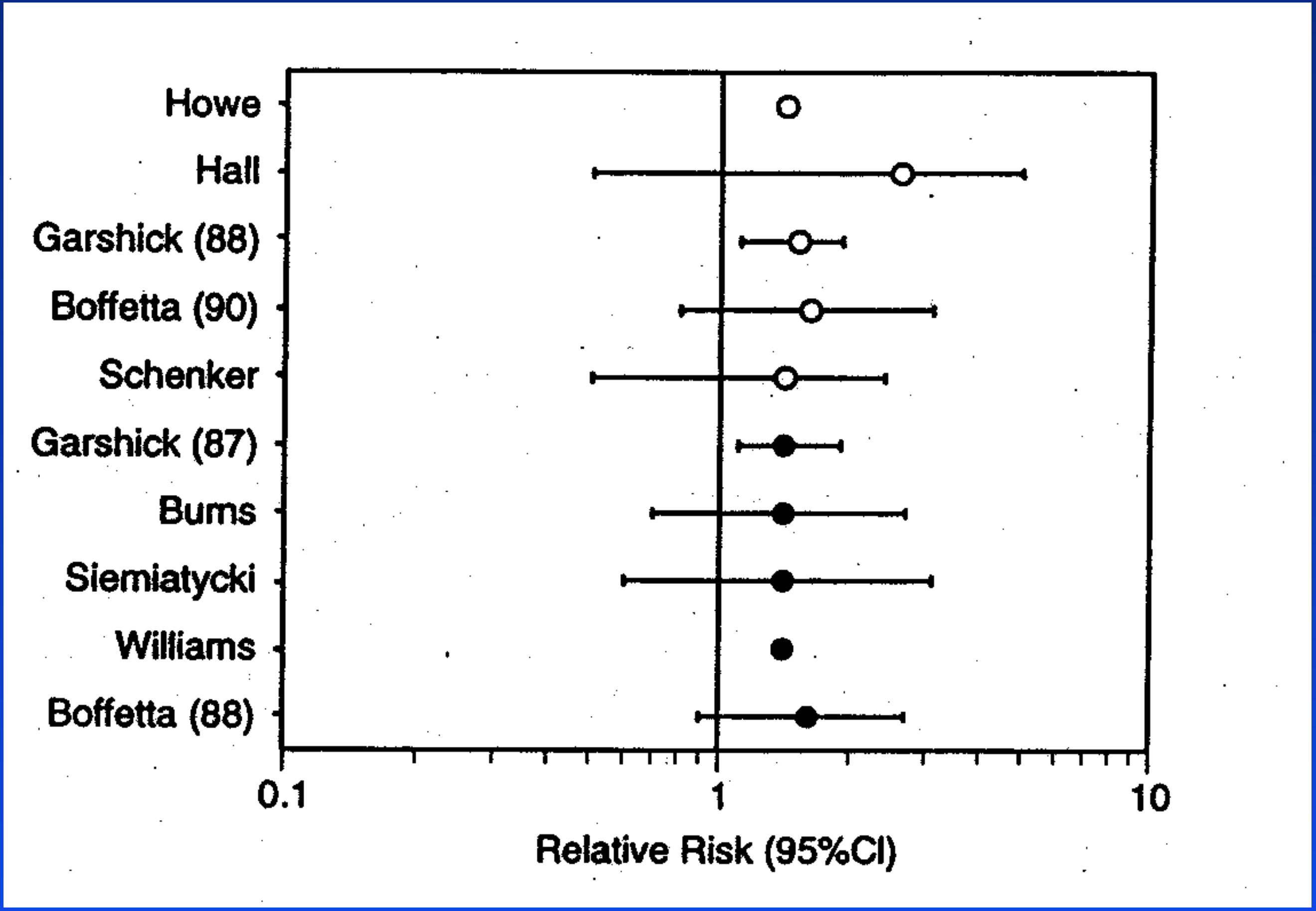
- >30 studies
- Truck Drivers
- Railroad Workers
- Bus Garage And Transport Workers
- Dock Workers
- General Population Groups

Truck Driver Studies



solid circle = smoking adjusted open circle = smoking unadjusted

Railroad Worker Studies



solid circle = smoking adjusted   open circle = smoking unadjusted

Epidemiological Studies With Quantitative Exposure Assessments
Used to validate exposure assignments

- Teamsters Union (Steenland et al. 1990)
  - Case-control study of retired workers who died in 1982-1983
  - Elevated risk in long haul drivers (mainly diesel) and pick-up and delivery (gas) drivers
  - Extent of diesel exposure uncertain
- U.S. Railroad Workers (Garshick et al. 1987, 1988)
  - Case-Control Study - 1981-1982
  - Retrospective Cohort Study – 55,407 workers 1959-1976
  - RR exposures 1950's-1970's

Railroad Workers Studies

- Case-control study
  - Odds ratio = 1.41 (1.06, 1.88) for 20 years of work
  - Smoking adjusted
- Retrospective cohort study
  - Relative risk= 1.45 (1.11, 1.89) in workers with greatest potential for exposure
  - Dose – response controversial
  - Mortality update through 1996 nearly complete

Conclusions: Lung Cancer Epidemiological Studies

- Consistently elevated lung cancer risk
- Risk unlikely explained by cigarette smoking
- Exposure Related Uncertainties
  - Job title and exposure not directly linked to job title
  - Dose and duration of exposure uncertain
- Study Design Related Uncertainties
  - Few studies with long-term follow-up and none with well characterized exposure over years

*Health Effects of PM**
Effects associated with a 10 µg/m^3 rise in PM$_{10}$

- >150 studies
- Cardiovascular mortality: 1.4%
- Cardiovascular hospital admissions 0.8%
- Respiratory mortality: 3.4%
- Respiratory hospital admissions
  - Asthma: 2% COPD: 2.5% Pneumonia: 1.5%
- Effect driven by PM$_{2.5}$ rather than by larger particles
- Biologic mechanism under study

*Adapted from Pope & Dockery, 1999

Chronic Exposure and Mortality

Most vs Least Polluted City, Smoking Adjusted

	Six Cities $PM_{2.5}$	ACS $PM_{2.5}$	ACS SO_4
All Mortality	1.26 (1.08-1.47)	1.17 (1.09-1.26)	1.15 (1.09-1.22)
Cardio-pulmonary	1.37 (1.11-1.68)	1.31 (1.17-1.46)	1.26 (1.16-1.37)
Lung cancer	1.37 (0.81-2.31)	1.03 (0.80-1.33)	1.36 (1.11-1.66)
All others	1.01	1.07	1.01

Association of Fine Particulate Matter from Different Sources with Daily Mortality in Six U.S. Cities

% Increase in Daily Deaths (95% CI) with 10 μg/m³ Increase in $PM_{2.5}$

Crustal (Si)	-2.3 (-5.8, 1.2)
Motor (Pb)	3.4 (1.7, 5.2)
Coal (Se)	1.1 (0.3, 2.0)

Laden et al. *Environ Health Perspect* 108:941-947, 2000.

Cardiovascular Effects of PM

- Preliminary studies suggest $PM_{2.5}$ related to
  - Implantable defibrillator discharge
  - Abnormal heart rate control
  - Increased risk of myocardial infarction
- Efforts underway to understand biologic mechanisms

Health Effect Summary

- Diesel Studies
  - Potential to influence the development of allergy
  - May induce inflammatory changes in human airway
  - Probable elevated lung cancer risk
  - Dose-response and mechanisms uncertain
- PM Studies
  - Elevated mortality/morbidity due to respiratory/cardiac causes
  - Fine particles associated with lung cancer mortality
  - Mortality related to $PM_{2.5}$ from gasoline powered sources in one study

Conclusions

- Considerable data indicates adverse health potential of diesel exhaust and PM
- Effects of low level exposures to diesel difficult to characterize
- Diesel contributes to PM
- Studies characterizing fine and ultrafine PM and associated health effects are needed

Research Study: Trucking Industry Particle Study

- Cooperative efforts of 4 national LTL carriers and Teamsters Union
- Assess lung cancer mortality in 55,750 trucking company workers 1985-2000
- Characterize current exposure
  - $PM_{2.5}$, EC, source apportionment
- Estimate previous exposures
- Funded by National Cancer Institute 2001-2006