Overview of Particulate Matter in California

November 18, 2004
Outline of Presentation - Part 1

- Particulate matter primer
- Health impacts
- Exposure and toxicity considerations
- Future directions
Particulate Matter Primer
What is Particulate Matter?

A complex mixture that may contain:

- Soot
- Smoke
- Metals
- Elemental and Organic Carbon
- Nitrates
- Sulfates
- Acids
- Pollen
- Vegetation
- Dust
- Water
- Tire Rubber
Common Terms Used in Describing PM

- **Origin**
  - Primary (directly emitted)
  - Secondary (formed in the atmosphere)

- **Size Distribution**
  - Coarse (2.5 to 10 μm) (primary)
  - Fine (2.5 μm and less) (primary + secondary)
  - Ultrafine (0.1 μm and less) (primary + secondary)

- **Measurement**
  - PM$_{10}$ (ultrafine + fine + coarse)
  - PM$_{2.5}$ (ultrafine + fine)
  - PM$_{10-2.5}$ (coarse)
How Small is PM?

- Human Hair: 60 µm diameter
- PM$_{10}$: 10 µm
- PM$_{2.5}$: 2.5 µm
Measurement of Particulate Matter

- Particles are captured onto a filter
- Mass of PM measured as micrograms per cubic meter ($\mu g/m^3$) of air

One grain = 60 $\mu g$
Sources of Particles

**Gas-to-particle Conversion (Secondary PM)**
- fuel combustion
- livestock
- sewage
- biogenic hydrocarbons

**Directly Emitted (Primary PM)**
- fuel combustion
- mechanical abrasion (brake wear, tire wear)
- road dust (paved, dirt)
- agricultural activities
- fugitive dust
- biological (pollen, fungi)
- sea salt
- meat cooking
How is Secondary PM Formed?

Photochemical Reactions in the Atmosphere

Ozone Chemistry

\[ \text{NO}_x \rightarrow \text{Nitric acid} \]  
- or Polluted Fog

\[ \text{SO}_2 \rightarrow \text{Sulfate salts} \]  
- or Ozone Chemistry

Low T, High RH

\[ \text{Nitrate salts} \rightarrow \text{ammonium nitrate} - \text{ammonia} \]  
- sodium nitrate - sea salt

\[ \text{organic nitrate} - \text{organic gases} \]  

High RH

\[ \text{Ozone Chemistry} \rightarrow \text{Condensible Organics} \]  

- [aromatics (eg, PAHs), alkenes]
Distribution of Mass by Particle Size

<table>
<thead>
<tr>
<th>Diameter (μm)</th>
<th>Relative Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>Urban</td>
</tr>
<tr>
<td>0.01</td>
<td>Ambient</td>
</tr>
<tr>
<td>0.1</td>
<td>Freeway</td>
</tr>
<tr>
<td>1</td>
<td>Coarse</td>
</tr>
</tbody>
</table>

- Urban
- Ambient
- Freeway

- Soil Dust
- Pollen
- Fungi
- Brake Wear
- Tire Rubber

- Ultrafine
- Fine
- Coarse
Health Impacts:

Particulate matter accounts for most of the serious health effects linked to ambient air pollution.
Particle Size and Health

Respiratory Deposition as a Function of Particle Size

Coarse PM is mostly deposited in upper respiratory track.
Ultrafine and Fine PM are deposited throughout the respiratory track.
Types of Health Studies

Epidemiologic Studies
- Investigate responses in populations
- Types:
  - Time-series -- acute effects
  - Longitudinal -- long-term effects
  - Intervention -- effects of control programs

Mechanistic Studies
- Investigate biological mechanisms or responses
- Types:
  - Cellular
  - Animals
  - Humans
## Vulnerable Populations

<table>
<thead>
<tr>
<th>Group</th>
<th>Type of Evidence</th>
<th>Strength of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly with heart/lung disease</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Asthmatics</td>
<td>yes</td>
<td>emerging</td>
</tr>
<tr>
<td>Children</td>
<td>yes</td>
<td>emerging</td>
</tr>
<tr>
<td>Infants</td>
<td>yes</td>
<td>emerging</td>
</tr>
<tr>
<td>Neonates</td>
<td>yes</td>
<td>emerging</td>
</tr>
<tr>
<td>Diabetics</td>
<td>yes</td>
<td>emerging</td>
</tr>
</tbody>
</table>
Long-term PM$_{2.5}$, PM$_{10}$ and sulfate exposure is associated with death in older adults with cardiopulmonary disease

- **American Cancer Society study (Pope et al., 1995, 2002)**
  - Over 550,000 adults from 151 U.S. cities
  - Followed for 16 years
  - 1.5 year average loss in life expectancy between least and most polluted cities (14 years per premature death)
  - Increased risk of lung cancer mortality

- **Harvard Six-Cities study (Dockery et al., 1993)**
  - Over 8000 adults
  - Followed for 14 to 16 years
Mortality Risk and Long-term PM

Harvard Six-Cities Study

From Dockery et al., 1993
Death Risk and Short-term PM

Percent Increase in death per 10 µg/m³ PM10
(90 cities, results for day after PM10 event)

European studies out to 40 days find 2-4 times the death rate.
Analysis of 20 largest cities found no threshold for death from PM10.
Health Benefits of PM Control

Intervention Studies

Winter Hospital Admissions for Children

Other Interventions
- CHS relocation (improved lung function growth)
- Dublin coal ban
- Erfurt, Germany reunification
- Hong Kong sulfur reduction

Ongoing

An Opportunity?
- Diesel retrofits
## Ambient Air Quality Standards

(\(\mu g/m^3\))

<table>
<thead>
<tr>
<th></th>
<th>Annual</th>
<th>24-Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>California</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM(_{10})</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>PM(_{2.5})</td>
<td>12</td>
<td>--</td>
</tr>
<tr>
<td><strong>National (current)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM(_{10})</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>PM(_{2.5})</td>
<td>15</td>
<td>65</td>
</tr>
<tr>
<td><strong>National (under review)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM(_{10-2.5})</td>
<td>13-30</td>
<td>30-75</td>
</tr>
<tr>
<td>PM(_{2.5})</td>
<td>12-15</td>
<td>30-50</td>
</tr>
</tbody>
</table>
Selected Examples of Health Benefits from Attaining State PM Standards

Meeting the California annual standards estimated to prevent, per year, about:

• 6,500 deaths
• 3,100 cardiovascular and 2,900 respiratory hospitalizations (over 65)
• 1,000 asthma hospitalizations (under 65)
• 389,000 incidences of lower respiratory symptoms (ages 7-14)
• 2,800,000 million lost work days
• Others (ER visits, asthma exacerbation)

Based on 18.5 (PM2.5) and 33.1 (PM10) μg/m³ population-weighted annual-average exposure in 2000.
## Adverse Health Effects from Diesel PM Exposure

*(annual number of cases)*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Cases</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung Cancer (TAC)</td>
<td>270 (95% upper limit)</td>
<td></td>
</tr>
<tr>
<td>Mortality (PM$_{2.5}$)</td>
<td>2000</td>
<td>(or 3000 95% upper limit)</td>
</tr>
</tbody>
</table>

Based on 1.8 µg/m$^3$ population-weighted annual-average exposure in 2000. Lung cancer has a 90% mortality rate.
Particle exposure and toxicity considerations are a logical way to prioritize emission reductions.
Controlling Ambient Air Impacts: Mass vs. Health

• Current control programs assess emissions reductions
  – “A ton is a ton”

• For health impacts need to consider
  – Human exposure
  – Toxicity of particles
Exposure

• Total exposure for a population depends on:
  – Total mass emitted
  – Size of particles
  – Meteorology/dilution
  – Proximity effects
  – Population density
  – Ventilation rates

• Exposure impact can vary by 100-fold
PM Toxicity

- PM toxicity can vary
- Measured as toxic effect per PM mass
- Determined from human, animal, and cell culture studies
- Different animals, protocols makes comparisons difficult
Diesel and Gasoline Potency

Relative Potencies - Cytotoxicity

Adapted from Seagrave et al. (2002)

WG = White smoke emitter, gasoline (n=1)
BG = Black smoke emitter, gasoline (n=1)
HD = Diesel black smoke emitter (n=1)
D = Diesel (n=3)
30 = tested at 30 deg F
G = gasoline (n=5)
What’s on the Horizon?
Air Pollution Research Directions

• Toxicity ranking of PM sources
  – ARB - traffic, wood smoke
  – HEI/USEPA - systematic protocols
  – HEI - Advanced Collaborative Emissions Study

• Mechanisms of PM toxicity
  – NIEHS/USEPA - neonates, diabetics
  – ARB - ultrafine PM
Ultrafine PM in Ambient Air

• Definition -- PM up to 0.1 µm

• Sources
  – Diesel- and gasoline-powered vehicles
  – Meat cooking and wood/biomass combustion
  – Secondary formation from heavy hydrocarbons

• High levels near sources

• Health findings
  – May be associated with death and disease
  – Pass into the circulatory system
  – Induce cellular damage
Health Effects Summary

- PM responsible for most of the serious health effects known from exposure to ambient air pollutants
- Annual-average standards most important to attain
  - U.S. EPA standards not health-protective
- Exposure and toxicity of particles appear to vary
- Future research includes health effects of ultrafine particles