Current Status of the National Ambient Air Quality Standards in the US

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Objective

• To provide an overview of the US national ambient air quality standards (NAAQS), which are set by the US Environmental Protection Agency (EPA), focusing on current knowledge of particulate matter (PM)
  • Atmospheric chemistry and physics
  • Conventional measurements
  • Exposure-dose-response relationship
  • Novel measurements
Air pollution system

Anthropogenic sources
- Automobile exhaust
- Coal burning
- Diesel exhaust
- Industrial emissions
- Tobacco smoke
- Wood burning

Natural sources
- Animals
- Dust storms
- Oceans
- Plant/tree emissions
- Volcanoes
- Wildfires

Transformations
- Adsorption
- Coagulation
- Evaporation
- Heterogeneous chemistry
- Homogeneous chemistry
- Nucleation
- Photochemistry

Sampling
- Bulk aerosols
- Effects on receptors
  - Gas molecules
    - In situ
    - Off-line
- Real-time
- Remote
- Single particles

Receptors
- Animals
- Building surfaces
- Earth surfaces
- Humans
- Plant/trees
- Rivers/lakes

Control

Transportation

Effects on receptors

Impact of air pollution

- Human health effects
  - Human morbidity and mortality
  - US EPA primary standard—“public health”
- Environmental effects
  - Animals, vegetation, crops, soil, water, buildings, visibility, weather, climate, etc.—“public welfare”
  - US EPA secondary standard
### US national ambient air quality standards

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide (CO)</td>
<td>9 ppm (8 hr average)</td>
</tr>
<tr>
<td></td>
<td>35 ppm (1 hr average)</td>
</tr>
<tr>
<td>Ozone (O₃)</td>
<td>0.12 ppm (1 hr average)</td>
</tr>
<tr>
<td></td>
<td>0.08 ppm (8 hr average)</td>
</tr>
<tr>
<td>Nitrogen dioxide (NO₂)</td>
<td>0.053 ppm (annual mean)</td>
</tr>
<tr>
<td>Sulfur dioxide (SO₂)</td>
<td>0.03 ppm (annual mean)</td>
</tr>
<tr>
<td></td>
<td>0.14 ppm (24 hr average)</td>
</tr>
<tr>
<td></td>
<td>0.50 ppm (3 hr average)</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>1.5 µg·m⁻³ (quarterly mean)</td>
</tr>
<tr>
<td>Particulate (PM₁₀)</td>
<td>50 µg·m⁻³ (annual mean)</td>
</tr>
<tr>
<td></td>
<td>150 µg·m⁻³ (24 hr average)</td>
</tr>
<tr>
<td>Particulate (PM₂.₅)</td>
<td>15 µg·m⁻³ (annual mean)</td>
</tr>
<tr>
<td></td>
<td>65 µg·m⁻³ (24 hr average)</td>
</tr>
</tbody>
</table>
Key milestones in US air quality standards for PM

• 1971—promulgation of total suspended particulates (TSP) standard, which measures “total” PM mass concentration

• 1978—promulgation of particulate Pb standard

• 1987—promulgation of PM$_{10}$ standard

• 1997—promulgation of revised PM$_{10}$ standard and introduction of PM$_{2.5}$ standard (also a revision of the O$_3$ standard)
Recent developments in US air quality standards for PM

- 1997—promulgation of PM$_{2.5}$ and revision of PM$_{10}$
- 1998—PM$_{2.5}$ standard challenged in court
- 1999—US Court of Appeals remanded PM$_{2.5}$ standard back to EPA for revision
- 2001—US Supreme Court decision
  - EPA has the right to promulgate a PM$_{2.5}$ standard
  - Compliance costs should not be considered
  - PM$_C$ should replace PM$_{10}$
Complexity and diversity of atmospheric PM

• Physical characteristics
  • Size distribution (aerodynamic, physical, etc.)
  • Concentration (mass or number)
• Chemical characteristics
  • Composition (chemical or elemental)
  • Acidity/alkalinity
• Temporal characteristics
• Spatial characteristics
Physical and chemical characteristic of atmospheric PM

Fine particles

Sources
Combustion
High temperature processes
Gas-to-particle conversion

Formation
Coagulation
Condensation
Nucleation

Composition
Ammonium
Carbon (elemental)
Carbon (organic)
Nitrate
Sulfate
Metals
Water

Accumulation mode

Coarse particles

Sources
Combustion
High temperature processes
Gas-to-particle conversion
Rain and fog droplets

Formation
Coagulation
Condensation
Nucleation
Evaporation

Composition
Ammonium
Carbon (elemental)
Carbon (organic)
Nitrate
Sulfate
Metals
Bioaerosols
Water

Sources
Soil
Tire dust
Brake pad dust
Road dust
Sea
Plant and animal detritus

Formation
Abrasion
Crushing
Resuspension
Whitecapping

Composition
Metals
Metal oxides
Silicon
Sea salt
Bioaerosols
Water

Sources
Combustion
High temperature processes
Gas-to-particle conversion

Formation
Coagulation
Condensation
Nucleation
Evaporation

Composition
Ammonium
Carbon (elemental)
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Sources
Soil
Tire dust
Brake pad dust
Road dust
Sea
Plant and animal detritus

Formation
Abrasion
Crushing
Resuspension
Whitecapping

Composition
Metals
Metal oxides
Silicon
Sea salt
Bioaerosols
Water

Particle diameter (µm)

Ultrafine mode

Accumulation mode

Coarse mode

10^{-2} 10^{-1} 10^{0} 10^{1}
Particle size distribution by different PM properties

Chemical characteristics of atmospheric PM

Particle-bound water as a function of humidity

Temporal characteristics

Noble et al. manuscript in preparation.
Atmospheric PM homogeneity

"Average" particles

"Unique" particles

Single atmospheric particles

Conventional PM monitoring

• Sample collection—filtration
• Physical characteristics
  • Size specific
  • Mass concentration
• Chemical characteristics—non-specific
• Temporal characteristics—24 h integrated sampling
• Spatial characteristics—PM measurement networks
US nationwide trend in ambient PM$_{10}$ concentration

Annual mean PM$_{10}$ concentration in 1999

Fitz-Simons et al. Analyses of 1999 PM data for the PM NAAQS review; 2000.
PM$_{2.5}$ standard

- Measurement performed by a federal reference method (FRM) or federal equivalent method (FEM)
- FRM explicitly specified
  - Design-based criteria
  - Performance-based criteria
- Improved quality control (QC)
- Increased sample precision
Annual mean PM$_{2.5}$ concentration in 1999

Fitz-Simons et al.  Analyses of 1999 PM data for the PM NAAQS review; 2000.
Instrumental schematic $\text{PM}_{10}$ and $\text{PM}_{2.5}$

$\text{PM}_C = \text{PM}_{10} - \text{PM}_{2.5}$
PM\textsubscript{C} data by subtraction of PM\textsubscript{2.5} from PM\textsubscript{10}

Vanderpool et al. manuscript in preparation.
Annual mean $\text{PM}_C$ concentration in 1999

Fitz-Simons et al. Analyses of 1999 PM data for the PM NAAQS review; 2000.
Some (of the many) remaining uncertainties

• “Major” uncertainties
  • What is the causal agent in PM for the observed health effects?
  • What is the injurious biological mechanism?

• “Minor” uncertainties
  • What should be done about particulate water?
  • What should be the temporal resolution of the ambient measurements?
PM research priorities from National Research Council

- Investigate ambient levels vs. personal exposure
- Assess hazardous PM components
- Develop measurement and analysis tools
- Determine exposure to susceptible subpopulations
- Develop source-receptor measurement tools
- Develop modeling tools
- Examine combined effects of gaseous copollutants
- Study mechanisms of injury
Considerations for personal exposure determination

- Time spent in each microenvironment
  - Outdoor
  - Home
  - Office
  - Public buildings
- PM concentration in each microenvironment
  - Indoor sources
  - Building ventilation
Sequence of exposure

- sources emission
- transfer, dispersion of the pollutants, transformation
- contact with human: exposure
- internal dose biologically effective dose
Microenvironment exposure-dose relationship

source A → ME A → time fraction → Personal Exposure (integrated) → Internal dose/biologically effective dose

source B → ME B → time fraction

source n → ME n → time fraction
Indoor vs. outdoor concentrations

Influence of activity on indoor PM concentration

Novel research techniques for real-time measurements

• Physical characteristics
  Instrument dependent—size, concentration, *etc.*

• Chemical characteristics
  Instrument dependent—nitrate, metals, *etc.*

• Temporal characteristics
  Instrument dependent—real-time (<1 h)

• Spatial characteristics
  Currently, single prototype instruments
Aerosol time-of-flight mass spectrometry

Real-time measurement of nitrate-containing particles

Real-time measurement of brushfire particles

Real-time measurement of sea salt particles

Conclusion

• US Supreme Court decided that EPA has the right to promulgate PM standards

• Air quality standards should be based on most current scientific knowledge
  • Atmospheric chemistry and physics
  • Conventional measurements
  • Exposure-dose-response relationship
  • Novel measurements
Future directions of ambient PM monitoring

• US national ambient air quality standards
  • PM\textsubscript{10}—will be phased out of NAAQS
  • PM\textsubscript{2.5}—will remain a standard
  • PM\textsubscript{C}—will “replace” PM\textsubscript{10} standard
• EPA “PM Health Center” program
• EPA “PM Supersites” program
  • Characterize ambient PM
  • Conduct methods testing
Partial reference list

- **US national ambient air quality standards**

- **Particulate matter sampling**