Health effects of particle emissions - impact on metrology
HEALTH EFFECTS OF PARTICLE EMISSIONS - METROLOGY

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This paper reviews the latest work on the health effects of particles in the ambient environment, and as vehicle combustion emissions. New data are considered within a matrix linking sources to exposure to dose to toxicology mechanisms to health effects to population health. These data are evaluated in the context of economics, existing and future legislation, and measurement.

For sources, there appears to be a consensus that diesel emissions be considered as 2 separate modes, a carbonaceous accumulation mode based around 100 nm mobility diameter, and a nucleation mode based around 20 nm mobility diameter, comprising sulphate and hydrocarbon. For gasoline emissions there is evidence for a hydrocarbon particle (droplet) mode at high speed. For other combustion emissions, a mixture of C, sulphate / nitrate, hydrocarbon and organic carbon is observed.

Advances in real-time particle monitoring as number, area and mass are such that short-term events can readily be measured (and located using GPS technology) improving mechanisms for measuring personal and population exposure.

Studies of acute toxicity show good evidence for a role of particle-bound metals in inflammation, and some evidence for a role for ultrafines for blood clotting effects, heart rate variability and inflammation. Similarly, there is some evidence for linking heart rate variability and exposure to fine sulphate particulate.

Chronic toxicity for Diesel particles has been re-evaluated in the US and Germany. There is good evidence that diesel particles at high exposure can cause cancer in rats. However, these occur at levels causing ‘rat lung overload’. Human studies (mainly acute) remain limited and ambiguous.

Recent epidemiologic evidence has focussed a re-analysis by the US Health Effects Institute of the 6 Cities and Pope / ACS studies. In general, the re-analysis reports robust associations of mortality with fine particles, sulphate and sulphur dioxide, with relative risk ratios for particles as per original data. For combustion emissions, new work has been reported by Wichmann and Peters showing a strong association of cardiac effects with particle number and NOx. For Diesel particles USEPA and HEI have published reviews of Diesel toxicity, with Germany setting a occupational exposure (MAK) standard for Diesel exposure.

Economic studies remain ambiguous with reports of air pollution costs of up to 1.7% GDP in developed countries. However, the impacts and costs of chronic exposures (cohort studies) outweigh the acute effects which have driven public health policy, with overall public health cost dependent on exacerbation of ‘less sick’ groups to ‘at risk’ groups. The costs of less serious impacts (restricted activity, symptom days) or days of, may be greater than those of more serious effects such as acute respiratory or cardiovascular hospital admissions.
In conclusion, particle emissions measurement is currently at a more sophisticated level than equivalent air quality monitoring with a need to develop common measurement parameters across disciplines before new legislation can be promoted.
Health effects of particle emissions - impact on metrology

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Structure

- **Particles and Health**
  - exposure / dose / toxicology / epidemiology
  - economics
  - legislation timeline

- **Measurement Issues**
  - particle size / particle composition / alternative metrics
  - sampling / measurement / calibration
  - metrology community input
Framework

Sources of Airborne Particulate Matter or Gaseous Pre-cursors

Emissions, Transformations & Transport

Indicator In Ambient Air (e.g. Mass, No. Concentration)

Time-activity patterns
Indoor exposure
Sources & sinks

Personal Exposure

Dose to target tissues

Deposition, Clearance, Retention, Metabolism

Human Health Response

Mechanisms of Damage & Repair
Sources

- **Diesel emissions**
  - two distinct modes
  - sulphate / hydrocarbon based nucleation mode (5-20 nm)
  - C based accumulation mode (60-200 nm)
- **Gasoline emissions**
  - hydrocarbon based mode at high speed
- **Stationary / other sources**
  - mixture of C, sulphate / nitrate, hydrocarbon, organic carbon

From Kittelson, 1999
Sources / Personal exposure

- Improved real-time measurement technologies & GPS mapping improving & discriminating personal exposure
- Particle # : to 1 s averaging with CPC
- PAH : to seconds averaging with Nanomet / PAS
- Particle mass : 1 minute averaging for new PM$_{2.5}$ mass monitor
Particle Dose

![Graph showing particle dose efficiency vs. particle diameter](image)

- **Deposition Efficiency**
- **Particle Diameter (um)**
- **Total**
- **Alveolar**
- **Bronchi**
- **Head**
Relative particle dose

- Nucleation and accumulation modes show significant penetration to alveoli (AI)/ terminal bronchioles (bb) / bronchi (BB)
- Relative dose enhanced for surface area and number modes
- Relative dose to lung regions from equivalent mass of 10 nm (nuc) / 100 nm (acc) particles

<table>
<thead>
<tr>
<th></th>
<th>BB</th>
<th>bb</th>
<th>AI</th>
</tr>
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<tbody>
<tr>
<td>Mass</td>
<td>5.4</td>
<td>3.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Surface Area</td>
<td>540</td>
<td>360</td>
<td>80</td>
</tr>
<tr>
<td>Number</td>
<td>5400</td>
<td>3600</td>
<td>800</td>
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</table>
Toxicology Mechanisms

**Acute toxicity**
- Good evidence for role of particle-bound metals e.g. Fe Cu V for inflammation
- Limited evidence for role of ultrafines for blood clotting effects, heart rate variability & inflammation
- Limited evidence for HRV / sulphate
- Significant research underway at US Particle Research Centres

**Chronic toxicity - Diesel**
- Good evidence that diesel particles at high exposure can cause cancer in rats.
- However these occur at levels causing ‘rat lung overload’
- Human studies limited and ambiguous (mainly acute)
- No-effect level of 5 µg/m³ proposed by USEPA
Epidemiology

$PM_{10} / PM_{2.5}$

- HEI re-analysis of 6 Cities and Pope / ACS studies published
- NMMAPS data available
- Re-analysis reports robust associations of mortality with fine particles, sulphate and sulphur dioxide
- RR ratio for particles as per original data

Combustion emissions

- Wichmann, Peters studies in Erfurt and other Euro centres - strong association of cardiac effects with P#, NOx
- EPA / HEI reviews of Diesel toxicity
- MAK standard for Diesel exposure
Economics

- Direct and indirect costs are significant fractions of GDP even allowing for uncertainty (e.g. WHO report of 1.7% GDP)
- Re-valuation of ‘life quality reduces ‘value’ of chronic susceptible sub-group
- The impacts and costs of chronic exposures (cohort studies) outweigh the acute effects which have driven public health policy
- Overall public health cost dependent on exacerbation of ‘less sick’ groups to ‘at risk’ groups
- The costs of less serious impacts (restricted activity, symptom days) or days of, may be greater than those of more serious effects such as acute respiratory or cardiovascular hospital admissions
Legislation

Emissions timeline
- Euro III, IV, V projected forward to 2008
- US standards to 2007
- Reviews in 2002/2003
- Role of after-treatment
- Is particle number legislation?:
  - necessary - if so, when?
  - Definable - if so, what?
  - practical - if so, how?

Ambient timeline
- ‘New’ PM$_{10}$ and PM$_{2.5}$ legislation under review
- Review process in 2002 / 2003
- Forward projections to 2010 imply cleaner air but from emissions reductions
- Need for discriminated epidemiology and toxicology mechanisms
## Summary of markers

<table>
<thead>
<tr>
<th>Metric</th>
<th>Data</th>
<th>Evidence</th>
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<tbody>
<tr>
<td>PM Mass</td>
<td>Epidemiology</td>
<td>Consistent association between PMx and reported health effects - a useful unifying PM measure</td>
</tr>
<tr>
<td>PM Particle Size</td>
<td>Epidemiology, Dosimetry, Toxicology</td>
<td>Indications from Epidem. and Tox. that fine PM$_{2.5}$ is more potent than coarse PM on a mass concentration basis (although ambient composition will vary). Finer particles penetrate more readily into lungs, cells and through tissue barriers</td>
</tr>
<tr>
<td>PM Surface Area</td>
<td>Toxicology</td>
<td>Finer particles have greater surface area per unit of mass; Oberdorster data implies toxicity for a known material is consistent with available surface area</td>
</tr>
<tr>
<td>Ultrafine PM</td>
<td>Epidemiology, Dosimetry, Toxicology</td>
<td>Growing recent epidemiological database suggesting that this fraction may be of importance. Toxicology – inflammatory response on ultrafine exposure. Particle number concentration is also a metric of interest</td>
</tr>
<tr>
<td>Metals &amp; Compounds</td>
<td>Toxicology</td>
<td>Have cytotoxic and inflammatory properties. The &quot;metals hypothesis&quot; associated with the soluble metal fraction of ROFA and may be related to the ability of these metals to catalyze production of free radicals in tissues. Utah epidemiology data</td>
</tr>
<tr>
<td>Acids</td>
<td>Toxicology</td>
<td>Human effects observed in laboratory but significant neutralising capacity in lung</td>
</tr>
<tr>
<td>Organics</td>
<td>Toxicology</td>
<td>Compound-specific effects – particular concern for lung cancer</td>
</tr>
<tr>
<td>Biogenic Particles</td>
<td>Toxicology</td>
<td>Biogenic particles of concern thro’ infectivity, cytotoxicity, inflammatory potential, allergenicity</td>
</tr>
<tr>
<td>Sulphate / Nitrate</td>
<td>Toxicology</td>
<td>Human effects observed in laboratory; under-reported in ambient measurements</td>
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<tr>
<td>Peroxides</td>
<td>Toxicology</td>
<td>Plausible toxicology route but ambient concentration low</td>
</tr>
<tr>
<td>Elemental Carbon</td>
<td>Epidemiology, Toxicology</td>
<td>Soot has irritant, mutagenic, and carcinogenic properties that vary with delivered dose and the properties of the sorbed materials. It is plausible that it could exert both short-term (irritant) and long-term (carcinogenic) effects.</td>
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<tr>
<td>Cofactors</td>
<td>Epidemiology</td>
<td>Significant differences in health markers for different gaseous co-pollutants with location</td>
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Conclusions

- Particle emissions measurement currently at more sophisticated level than air quality monitoring
- Validation of data across a broad shared user base offers ‘clout’ in assessment of environmental, health and product impact
- Require route to show measurement potential to other disciplines (AQ, toxicology, epidemiology)
- Common measurement parameters required across disciplines before new legislation can be promoted