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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.

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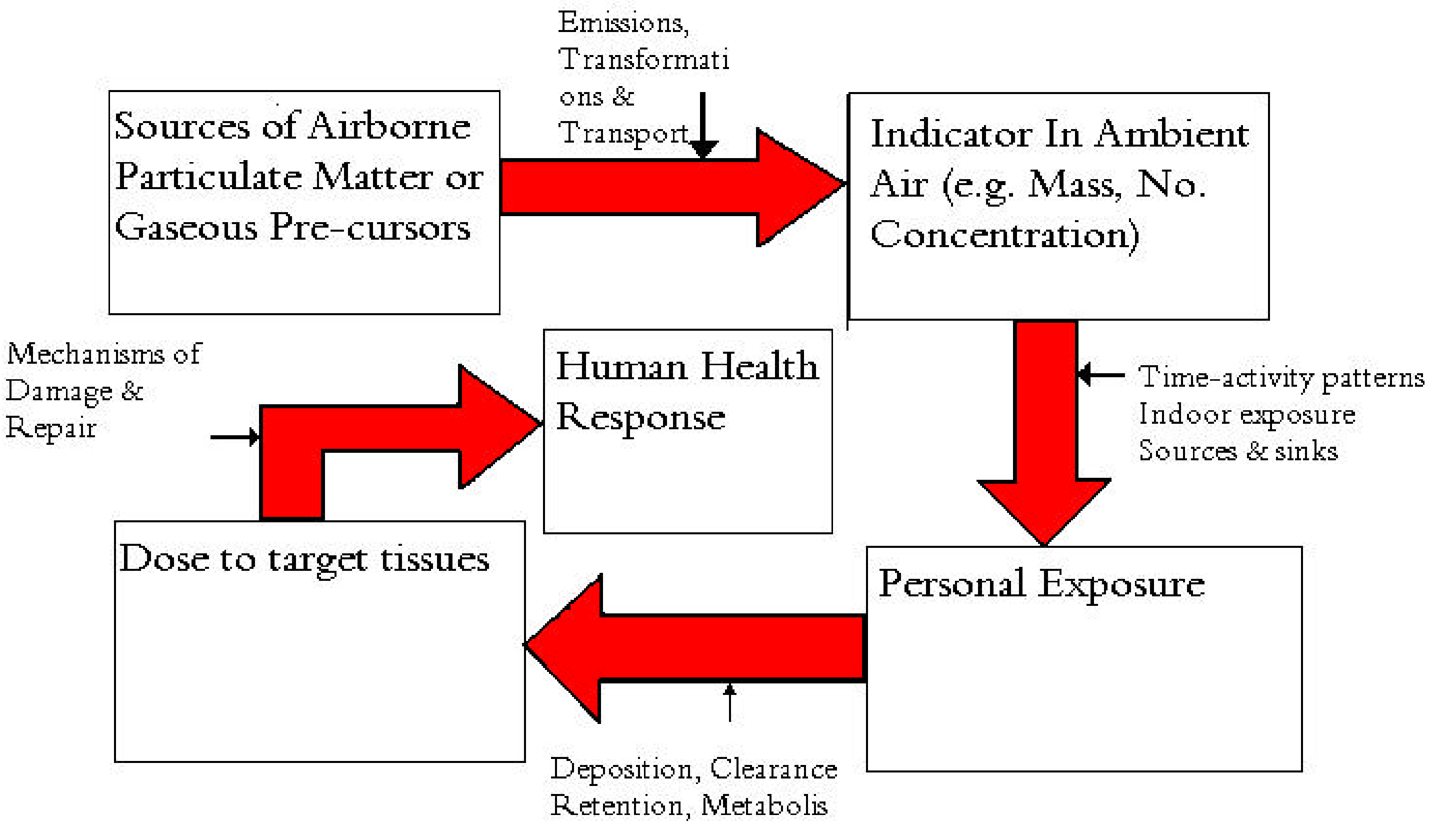
AEA TECHNOLOGY
ENVIRONMENT

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

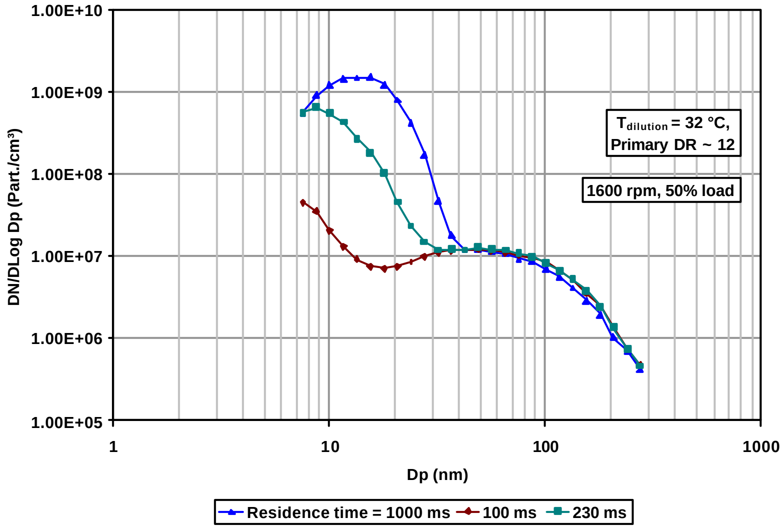
Framework



Sources of Airborne Particulate Matter or Gaseous Pre-cursors
Emissions, Transformati ons & Transport
Indicator In Ambient Air (e.g. Mass, No. Concentration)
Time-activity patterns
Indoor exposure
Sources & sinks
Personal Exposure
Deposition, Clearance Retention, Metabolis
Dose to target tissues
Mechanisms of Damage & Repair
Human Health Response

Sources

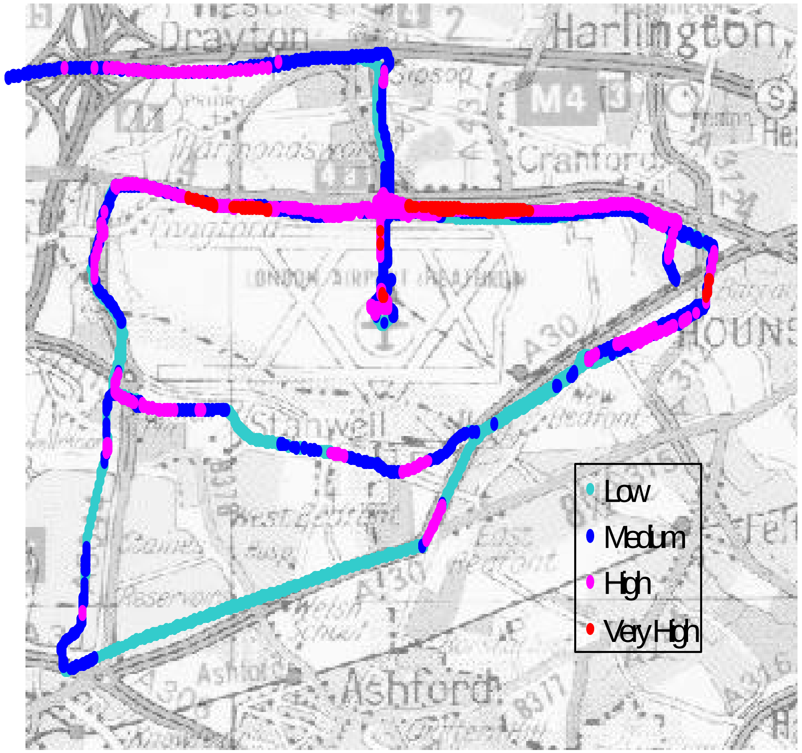
- Diesel emissions
  - two distinct modes
  - sulphate / hydrocarbon based nucleation mode (5-20 nm)
  - C based accumulation mode (60-200 nm)
- Gasoline emissions
  - hydrocarbon based mode at high speed
- Stationary / other sources
  - mixture of C, sulphate / nitrate, hydrocarbon, organic carbon



From Kittelson, 1999

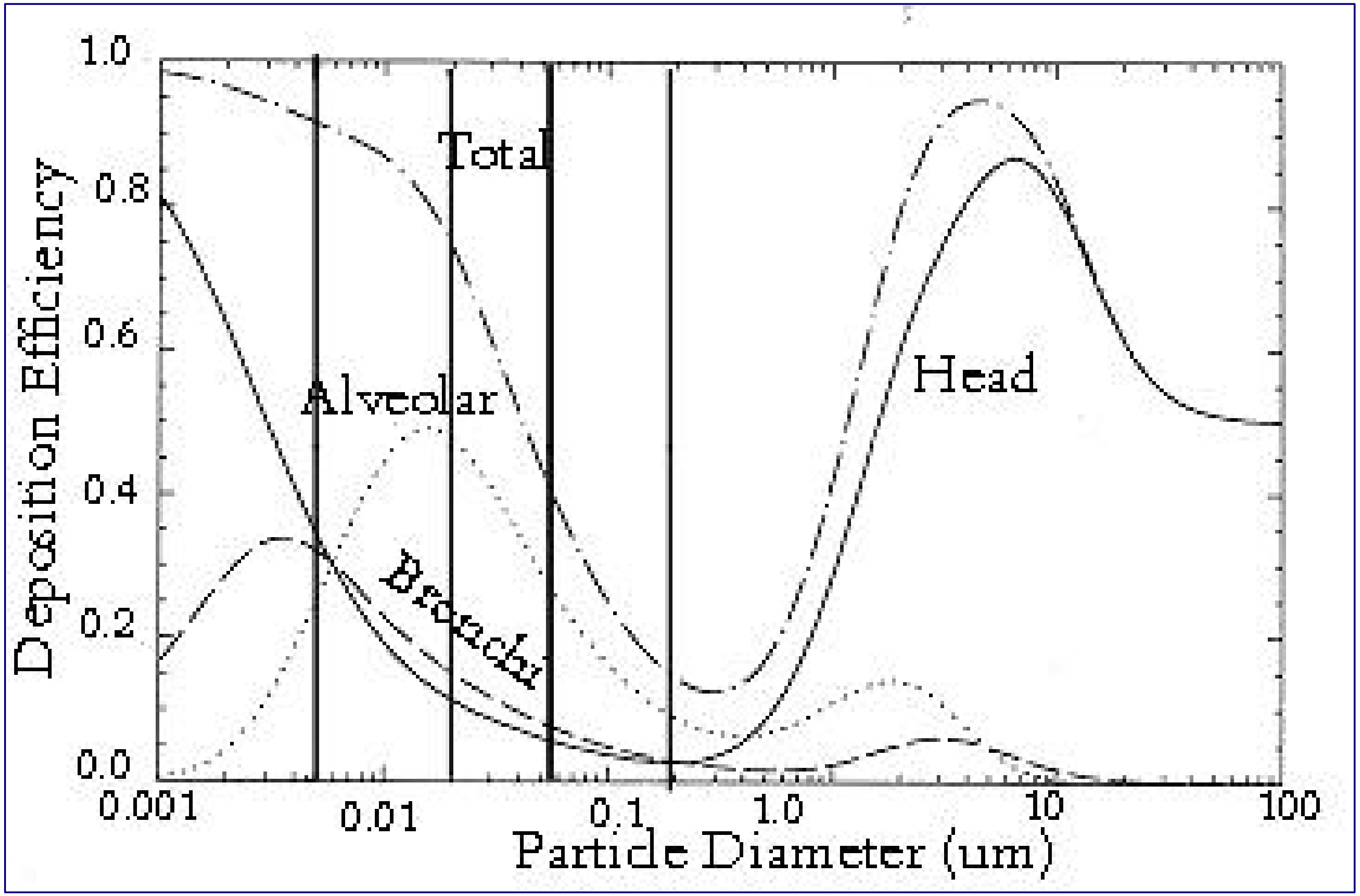
Sources / Personal exposure

Particle Number Mapping - Heathrow Airport



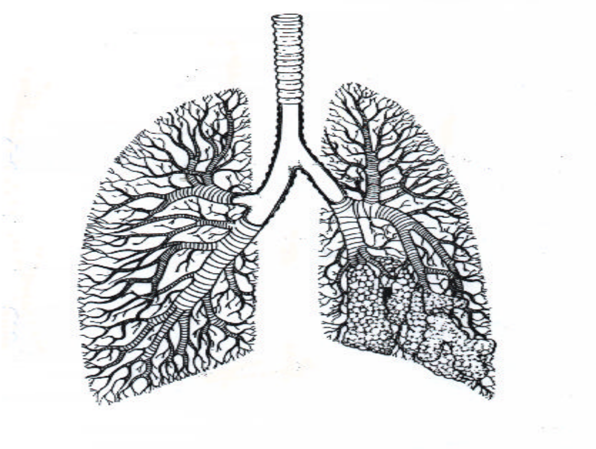
- Improved real-time measurement technologies & GPS mapping improving & discriminating personal exposure
- Particle # : to 1 s averaging with CPC
- PAH : to seconds averaging with Nanomet / PAS
- Particle mass : 1 minute averaging for new $PM_{2.5}$ mass monitor

Particle Dose



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



	BB	bb	AI
Mass	5.4	3.6	0.8
Surface Area	540	360	80
Number	5400	3600	800

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

Metric	Data	Evidence
PM Mass	Epidemiology	Consistent association between PMx and reported health effects - a useful unifying PM measure
PM Particle Size	Epidemiology Dosimetry Toxicology	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
PM Surface Area	Toxicology	finer particles have greater surface area per unit of mass; Oberdorster data implies toxicity for a known material is consistent with available surface area
Ultrafine PM	Epidemiology Dosimetry Toxicology	Growing recent epidemiological database suggesting that this fraction may be of importance. Toxicology – inflammatory reponse on ultrafine exposure Particle number concentration is also a metric of interest
Metals & Compounds	Toxicology	Have cytotoxic and inflammatory properties. The "metals hypothesis" 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
Acids	Toxicology	Human effects observed in laboratory but significant neutralising capacity in lung
Organics	Toxicology	Compound-specific effects – particular concern for lung cancer
Biogenic Particles	Toxicology	Biogenic particles of concern thro' infectivity, cytotoxicity, inflammatory potential, allergenicity
Sulphate / Nitrate	Toxicology	Human effects observed in laboratory; under-reported in ambient measurements
Peroxides	Toxicology	Plausible toxicology route but ambient concentration low
Elemental Carbon and Soot	Epidemiology Toxicology	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.
Cofactors	Epidemiology	Significant differences in health markers for different gaseous co-pollutants with location

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