Photo and map removed for copyright reasons.

Photo taken in Donora PA at noon, Oct. 29 1948 (Pittsburgh Post-Gazette).
Map showing Donora approximately 25 miles south of Pittsburgh.

What's the dose-response?
Early epidemiologic / biostatistical studies:

from England: excess **mortality** when avg. airborne concs. of:
"smoke" > 750 μg/m³
$SO_2$ > 0.25 ppm

What about excess **morbidity**?

"Diary" studies with *chronic bronchitics* in London[1]:

Correlated daily symptoms with daily pollutant levels.
NOELs seemed to be:
"smoke" = 250 μg/m³ (24-hr. avg.)
$SO_2$ = 0.19 ppm (24-hr. avg.)

[1] Lawther, PJ *et al.*, *Environ. Res.* 10:355-67, 1975.

# National Ambient Air Quality Standards (NAAQS)

The Clean Air Act, which was last amended in 1990, requires EPA to set **National Ambient Air Quality Standards** for pollutants considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. ***Primary standards*** set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. **Secondary standards** set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings.

The EPA Office of Air Quality Planning and Standards (OAQPS) has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" pollutants. They are listed below. Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air ($mg/m^3$), and micrograms per cubic meter of air ($\mu g/m^3$).

## National Ambient Air Quality Standards

| POLLUTANT | STANDARD VALUE * | | STANDARD TYPE |
|---|---|---|---|
| **Carbon Monoxide (CO)** | | | |
| 8-hour Average | 9 ppm | ($10\ mg/m^3$) | Primary |
| 1-hour Average | 35 ppm | ($40\ mg/m^3$) | Primary |
| **Nitrogen Dioxide ($NO_2$)** | | | |
| Annual Arithmetic Mean | 0.053 ppm | ($100\ \mu g/m^3$) | Primary & Secondary |
| **Ozone ($O_3$)** | | | |
| 1-hour Average | 0.12 ppm | ($235\ \mu g/m^3$) | Primary & Secondary |
| 8-hour Average | 0.08 ppm | ($157\ \mu g/m^3$) | Primary & Secondary |
| **Lead (Pb)** | | | |
| Quarterly Average | $1.5\ \mu g/m^3$ | | Primary & Secondary |
| **Particulate (PM 10)** *Particles with diameters of 10 micrometers or less* | | | |
| Annual Arithmetic Mean | $50\ \mu g/m^3$ | | Primary & Secondary |
| 24-hour Average | $150\ \mu g/m^3$ | | Primary & Secondary |
| **Particulate (PM 2.5)** *Particles with diameters of 2.5 micrometers or less* | | | |
| Annual Arithmetic Mean | $15\ \mu g/m^3$ | | Primary & Secondary |
| 24-hour Average | $65\ \mu g/m^3$ | | Primary & Secondary |
| **Sulfur Dioxide ($SO_2$)** | | | |
| Annual Arithmetic Mean | 0.030 ppm | ($80\ \mu g/m^3$) | Primary |
| 24-hour Average | 0.14 ppm | ($365\ \mu g/m^3$) | Primary |
| 3-hour Average | 0.50 ppm | ($1300\ \mu g/m^3$) | Secondary |

very new; not yet enforced...

* Parenthetical value is an approximately equivalent concentration.

➔ *Thousands* of other airborne substances not regulated *via* NAAQS

## U.S. EPA PM NAAQS

1971: Total suspended PM (TSP; $PM_{40}$)

1987: $PM_{10}$ (inhalable)

1996: $PM_{10}$ and $PM_{2.5}$

**$PM_{2.5}$**

15 $\mu g/m^3$, annual average standard

(average of **three years** of **quarterly means** of 24-hour measurements).

65 $\mu g/m^3$, 24-hour standard

(**98th** percentile of 24-hour measurements)

Figures removed for copyright reasons.

Source: Figures 2, 14 and 15 in Lighty, Veranth, and Sarofim. "2000 Critical Review -- Combustion Aerosols: Factors Governing Their Size and Composition and Implications to Human Health." *Journal of the Air and Waste Management Association* 50 (September 2000).

Four graphs removed for copyright reasons.

"Size and chemical species distributions of particles from specific sources."
Catalyst-equipped gasoline-powered engines
Non-catalyst-equipped gasoline-powered engines
Medium-duty diesel vehicles
Cigarette smoke

# Concentrations of solvent vapors or other gases in air: by volume (parts per million [billion]); by mass (mg [µg] per m³)

Convert between ppm and mg/m³ using the following approaches. Combining equations from the Ideal Gas Law and Dalton's Law of Partial Pressures yields an equation for the ready conversion of these units:

Ideal Gas Law $PV = nRT$

Dalton's Law $\frac{P_s}{P_T} = \frac{n_s}{n_T}$

$P_s$ = Partial pressure of solvents (atm)
$P_T$ = Total atmospheric pressure (1 atm)
$n_s$ = Number of moles of solvents
= Weight (wt.) of S/molecular weight (MW) of S

$n_T$ = Total number of moles
$V$ = Volume (m³)
$R$ = Gas constant (0.082 atm/°K mol)
$T$ = Temperature (298°K = 25°C)
$C_s$ = Concentration of S (weight of s/volume)

$$P_sV = n_sRT$$

$$P_s = \frac{n_sRT}{V}$$

$$P_s = \frac{C_s}{MW_s} 24.45$$

$$\frac{P_s}{P_T} = \frac{n_s}{n_T} \text{(ppm)} = \frac{C_s}{MW_s} 24.45$$

$$\text{ppm} = \frac{C_s}{MW_s} 24.45$$

## Types and Sources of Air Pollutants

Mobile sources: motor vehicles, airplanes

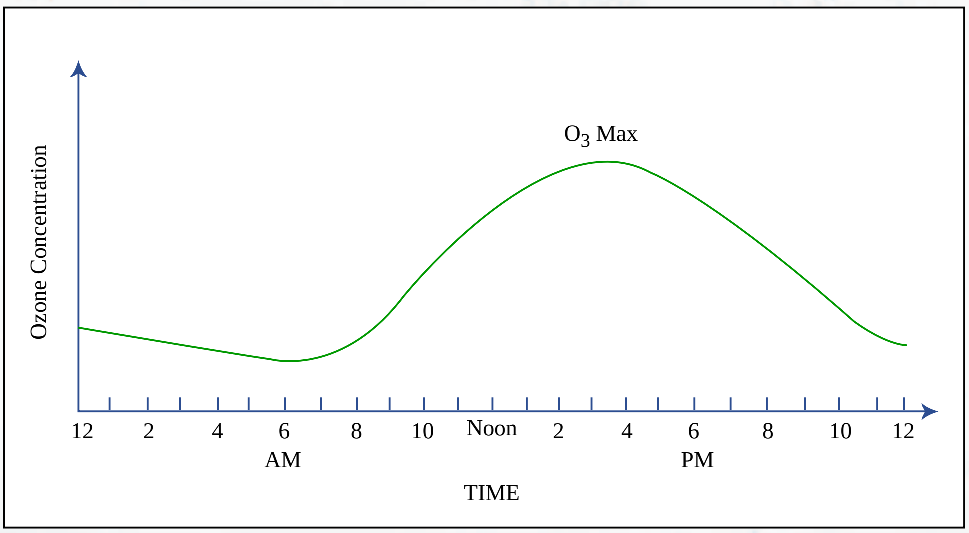
Stationary sources: power plants, factories, refineries

Primary pollutants: enter the atmosphere directly.

Secondary pollutants: form through atmospheric chemical reactions *e.g.*:

$2\ SO_2 + O_2 \longrightarrow 2\ SO_3$
$H_2O + SO_3 \longrightarrow H_2SO_4 \quad (NH_4^+, Na^+)$

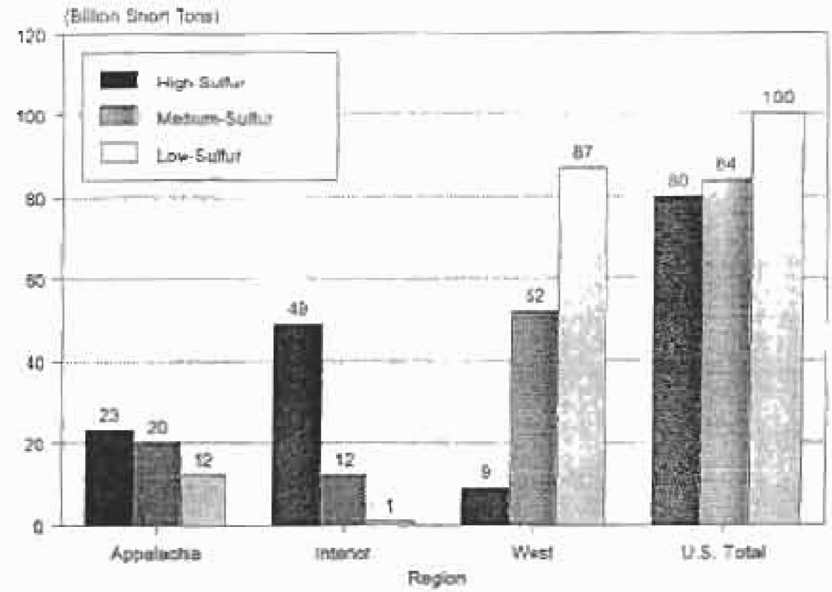
$O_3$ from VOC, $NO_x$ (NO and $NO_2$), $OH^-$, sunlight




Natural sources: vegetation: pollens, terpenes; fire, blowing dust, sea spray, volcanoes

Figure by MIT OCW.

Figure ES1   Estimates of Recoverable Coal Reserves in the United States by Sulfur Content and Region as of January 1, 1992




Source: Energy Information Administration estimates.

Estimated emissions to air, U.S., since 1940.

Graph removed for copyright reasons.

Concentration, ppm, CO, 8-hr. avg. (NAAQS = 9 ppm)

**Are current concs. of criteria pollutants safe?**

Concentration, ppm, $SO_2$, annual avg. (NAAQS = 0.030 ppm)

Concentration, $\mu g/m^3$, $PM_{10}$, annual avg. (NAAQS = $50 \mu g / m^3$)

Three graphs removed for copyright reasons.

Graphs removed for copyright reasons.
Figures 1 and 2.

Figure 1 and 2. Age-, sex-, and race-adjusted population-based mortality rates for 1980 plotted against mean sulfate air pollution levels for 1980. Data from metropolitan areas that correspond approximately to areas used in perpective cohort analysis.

Figure from: Pope, C. A. III.; Thun, M. J.; Namboodiri, M. M.; Dochery, D. W.; Evans, J. S.; Speizer, F. E., and Heath, C. W. Jr. "Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults." *American Journal of Respiratory and Critical Care Medicine* 151 (1995): 669-674.

Figure removed for copyright reasons.
Figure 4 in Pope, C. A., et al. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." *JAMA* 287, no. 9 (March 6, 2002): 1132-1141.

# NYPA's small, gas-fired power plants

The Supreme Court of the State of New York determined that the New York Power Authority was remiss in not "addressing the health impacts of $PM_{2.5}$ emissions" of 11 small (< 44 MW) natural gas-powered turbine electric generator units. (July 2001)

The Court noted that NYPA had quantified "$PM_{2.5}$ emissions by assuming that all $PM_{10}$ emissions were $PM_{2.5}$ emissions and concluded that the individual and cumulative impacts of such emissions by the purposed facilities would be insignificant [*e.g.* max. impacts < 2% of $PM_{2.5}$ std]." But the Court found that such an analysis was inadequate.

The Court wrote:

"Particulate matter is a nonthreshold pollutant."

and

"In light of the undisputed potential adverse health effects that can result from $PM_{2.5}$ emissions, we conclude that NYPA failed to take the requisite 'hard look' at this area of environmental concern."

Figures removed due to copyright reasons.
Please see:
Figures 2 and 6 in Dominici, F., et al. "A Report to The Health Effects Institute: Reanalyses of the NMMAPS Database." *Johns Hopkins University*, October 31, 2002.

Jamie Robins (2001) writes:

> I believe that, in an observational study, every two variables have an unmeasured common cause, and thus there is always some uncontrolled confounding. . . . As epidemiologists, we should always seek highly skeptical subject-matter experts to elaborate the alternative causal theories needed to help keep us from being fooled by noncausal associations.

From: "Data, design, and background knowledge in etiologic inference." *Epidemiology* 2001 May;12(3):313-20

## 3 Possibilities:

Deaths associated with ambient $PM_{2.5}$ are:

1. Caused entirely by PM : Easily controlled ↕ Uncontrollable

2. Partially caused by PM
   Partially confounded by other causes →→→ Pollution
   ↘↘↘↘ Non-pollution

3. Entirely confounded

Are current levels of ambient PM in fact toxic?

Does this question even make sense?

How can it, since $PM_{2.5}$ refers to *hundreds of thousands* of different things?

Differences in:

Size/Shape
Solubility/biopersistence
Chemical composition/pH
Biologic/Immunologic properties

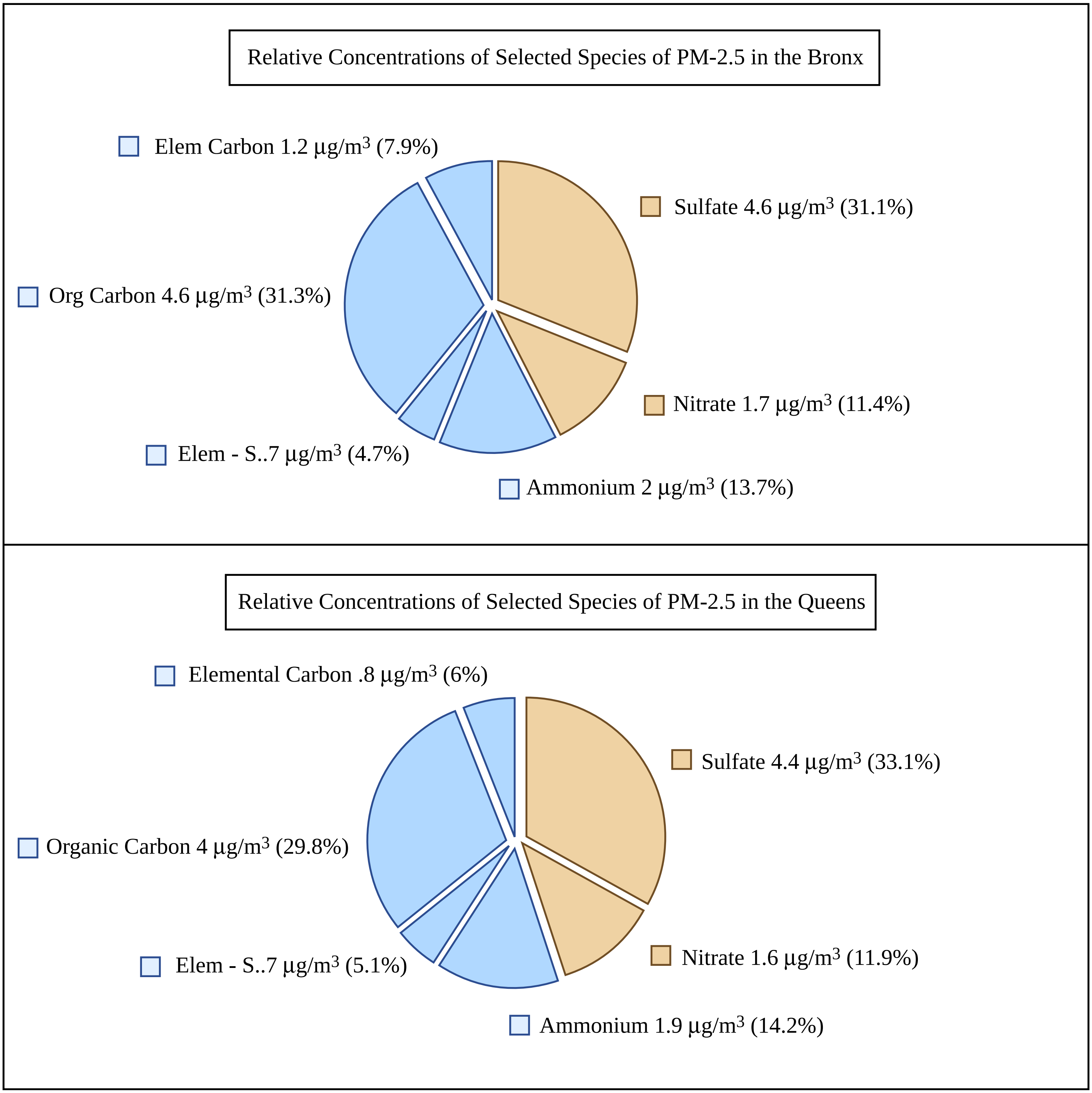



Figure by MIT OCW.

## Secondary PM from gas-to-aerosol conversion of $NO_x$ and $SO_2$ emissions

- Visibility concerns
- Health concerns?
  - sulfuric acid-layered ZnO / ozone (Mary Amdur)
  - "ordinary" sulfates?

  Ammonium sulfate and ammonium nitrate are water-soluble
  Virtually all metal nitrates soluble
  Most metal sulfates also soluble (except Ca, Pb, Hg, few other salts)

Amdur (1986):

> " . . . an air quality standard based on "suspended sulfate" without further characterization would be entirely inappropriate; the term is toxicologically meaningless."

## Inhaled $SO_4^{2-}$: Is it toxic at moderate levels?

1. Most bronchodilator medications used to treat asthma (such as albuterol, metaproterenol, and terbutaline), are supplied as the sulfate salts.

2. Each puff from a standard inhaler supplies a metered 100 $\mu$g of albuterol sulfate, supplying some 20 $\mu$g of sulfate.

3. Assume a person breathes in 2 L of air along with each puff of an inhaler.

4. Thus, 20 $\mu$g of sulfate per 2 L of air = 10 $\mu$g of sulfate per L of air, = 10,000 $\mu$g of sulfate per $m^3$ of air.

5. Is there evidence that this concentration causes harm?

6. Mildly acidic sulfate salts have been tested in several systems; inhaled concentrations below several hundred micrograms per cubic meter are NOAELs.

Inhaled $SO_4^{2-}$: Is it *carcinogenic* at moderate levels?

| Chronic Cancer Bioassays of Inorganic Sulfate Salts | | | |
|---|---|---|---|
| Sulfate salt | vehicle | test species | result |
| Aluminum potassium sulfate | water | mouse<br>rat | negative |
| Beryllium sulfate | water | mouse<br>rat | negative |
| Sodium sulfate | food | mouse | negative |
| Vanadyl sulfate | water | mouse | negative |
| Zirconium (IV) sulfate | water | mouse | negative |

**Case-crossover studies**

1. Drew Levy, Lianne Sheppard, *et al.* (2000)

**Hypothesis:** Risk of cardiac arrest = f [ambient PM]

**Subjects**: 362 cases of cardiac arrest in Seattle, 1988-94

**Air pollution data**: nephelometry, $PM_{2.5}$, $PM_{10}$, $SO_2$, CO, $O_3$, temp.

**Results:** Nonpositive. Point estimates suggested that as ambient concentrations of PM *increased*, relative risk of cardiac arrest *decreased*.

For an increase of 19.3 *u*g $PM_{10}/m^3$,
relative risk of cardiac arrest = 0.868
(95% c.i. = 0.744 - 1.012)

Case-crossover studies

2. Peters, Dockery, *et al.* (2001)

**Hypothesis**: Risk of myocardial infarction
= f [ambient PM]

**Subjects**: 772 cases of m.i. in Boston, 1995-96

**Air pollution data**: $PM_{2.5}$, carbon black, $SO_2$, CO, $O_3$,

**Results:** Positive.

For an increase of 25 *u*g $PM_{2.5}/m^3$ 2 hrs. prior,
relative risk of m.i. = 1.48
(95% c.i. =1.09 - 2.02)

For an increase of 20 *u*g $PM_{2.5}/m^3$ 24 hrs. prior,
relative risk of m.i. = 1.69
(95% c.i. = 1.13 - 2.34)

But these case crossover studies have not measured behavioral/emotional factors known to precipitate/increase risk of m.i.

Consider a case-crossover analysis performed as part of the Stockholm Heart Epidemiology Program (SHEEP) Möller *et al.*, (1999)

**Hypothesis**: Triggering of myocardial infarction
= f [anger]

**Subjects**: 699 cases of m.i. in Stockholm County, 1993-4

**Data on "hostile behavior" and symptoms in days/hours prior to m.i.**: gathered through detailed, structured interviews (interviewers blind to hypotheses)

**Results:** Strongly positive.

During 1 hour after an episode of anger, relative risk of m.i. = 15.7
(95% c.i. = 7.6 - 32.4)

Thus, if daily/hourly fluctuations in traffic/other activities that increase ambient PM also increase anger, the latter could confound associations between the former and m.i.

Figure removed for copyright reasons.

See Phillips, D. P. et al. "The Hound of the Baskervilles effect: natural experiment on the influence of psychological stress on timing of death." *BMJ* 323 (2001): 1443-1446.

## Allergens Present in Paved Road Dust in Los Angeles

| Allergens (Common Names) |
|---|
| Cladosporium mold |
| sycamore |
| Russian thistle |
| lambs quarters |
| mountain cedar |
| white elm |
| white pine |
| white ash |
| white oak |
| alder |
| mugwort |
| alternaria mold |
| meadow fescue grass |
| dog dander-epithelium |
| perennial rye grass |
| olive |
| western ragweed |
| Italian cypress |
| cat dander-epithelium |
| Bermuda grass |
| brome grass |
| house dust mite |
| natural rubber latex |
| timothy grass |

from: Miguel, A.G., Cass, G.R., Glovsky, M.M., and Weiss, J. (1999). *Environ. Sci. Technol.* 33:4159-4168.

Biologic aspects of Particles/Nanoparticles

Viruses:

Sizes: 20 - 250 nanometers
Shapes: two basic - icosahedron (capsid with 20 triangular faces); helix
Constituents: various proteins; nucleic acids
Types: some 3,600 named species in some 164 genera
Properties: benign - virulent

Some Diseases Caused by Viruses

| Animals | Plants | Humans |
|---|---|---|
| Rabies | Tobacco mosaic disease | Common cold and flu |
| Foot and mouth disease in cattle | Tomato bushy stunt | German measles and mumps |
| Newcastle disease in chickens | Maise dwarf | Chickenpox |
| Distemper in dogs | Alfalfa mosaic disease | Mononucleosis |
| Cowpox | Sugar beet curly top | Cold sores, hepatitis, warts |
| Influenza in cows, horses, and sheep | Dwarfism in rice | Herpes and AIDS |

**Bacteria:**

Sizes: 50 - 1,000 nm (Some agglomeration in air: most airborne bacteria clumps $\leq$ 8,000 nm)
Shapes: many: cocci, rods, ovoids, spirochetes, filaments
Types: about 5,000 named species in some 800 genera
Properties: benign - virulent

- Role of microorganisms/infection/inflammation in atherosclerosis/other chronic diseases?

- Methods for counting airborne microorganisms are inadequate.

**Bacteria:**

Sizes: 50 - 1,000 nm (Some agglomeration in air: most airborne bacteria clumps ≤ 8,000 nm)
Shapes: many: cocci, rods, ovoids, spirochetes, filaments
Types: about 5,000 named species in some 800 genera
Properties: benign - virulent

- Role of microorganisms/infection/inflammation in atherosclerosis/other chronic diseases?

- Methods for counting airborne microorganisms are inadequate.

Figures removed for copyright reasons.

Table 1, Figures 1 3 and 5, in Stieb, D. M., et al. "Meta-analysis of time-series studies of air pollution and mortality: effects of gases and particles and the influence of cause of death, age, and season." *J Air Waste Manag Assoc* 52, no. 4 (2002 April): 470-84.

See Gordon, T., et al. "Effects of Concentrated Ambient Particles in Rats and Hamsters: An Exploratory Study." *Health Effects Institute Research Report* 93, (2000). http://www.healtheffects.org/Pubs/st93.htm.

**What have toxicologic studies with concentrated ambient particles (CAP) revealed?**

No peer-reviewed reports of CAP-induced deaths.

None of the inhaled CAP exposures reviewed in the draft CD appear to have seriously affected healthy *or compromised* animals; many of the slight effects observed are reversible within 18-24 hrs.

Some of the noted changes, such as recruitment of neutrophils, are the normal and appropriate responses of a functioning immune system. Moreover, they may represent responses to the antigenic, "natural" portion of airborne $PM_{2.5}$

Sizable fractions of airborne PM contain biochemicals: Miguel, Cass, *et al.* (1999) report 1 - 6 $\mu g/m^3$ protein in ambient air; Taylor *et al.* (2002) find "fragmented pollen cytoplasm in the size range 0.12 to 4.67 microns" which "were loaded with group 1 allergens."

CAP studies so far have provided (i) little evidence that moderate levels of $PM_{2.5}$ produce or significantly aggravate disease, and (ii) little support for susceptibility factors, such as age or pre-existing disease.

Animal models of cardiopulmonary disease seem to be difficult to control and reproduce, and may need validation with simpler materials than CAP, so that the observed variability in responses can be better understood.

Do current concentrations of particulate matter (PM) in air in the United States *cause* disease and death?

The Dutch equivalent of a draft CD for PM noted (Netherlands Aerosol Programme, 2001, p.108):

> From the standpoint of dose, there appears to be little coherence between epidemiological and toxicological studies. While the former show association of increased mortality/morbidity with acute exposure PM at ambient concentrations below the current standards, the latter show associations of biological responses with PM atmospheres, both concentrated ambient PM and PM surrogates, *only* at orders of magnitude higher than ambient levels. . . . a number of toxicological studies with concentrated ambient PM have shown *no obvious relationship between exposure concentration and response.*