AIR POLLUTION

CE 326 Principles of Environmental Engineering

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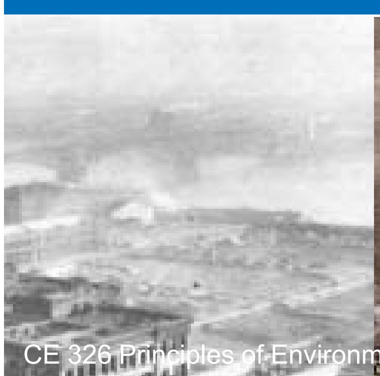
January 18, 2008

Air Pollution Factoids

- Americans make the equivalent of 3 M______ round trips to the moon each year in their automobiles.
- National air quality levels have shown significant improvements over the last 20______ years in the U.S.
- Since 1970, aggregate emissions of the six principal pollutants have been cut by 48____%, while the gross domestic product has increased 164%, energy consumption has increased 42_____%, and vehicle miles traveled has increased 155_______%.
- 170_____ million tons of pollution are emitted into the air each year in the U.S.

Air pollution Episodes

- Meuse Valley, Belgium, 1930 – zinc smelters, 60 deaths
- Donora, Pennsylvania, 1948 – 23 deaths over Halloween weekend
- London, England, 1952 – 4000 deaths




L'Indépendance Belge 6-12-1930

Le grand jour !

Trente-neuf personnes meurent mystérieusement à Engis et Flémalle

Depuis jeudi matin toute une région prise dans un épais brouillard, vit dans les transes

De Standaard 7-12-1930

De Maasvallei, de "Vallei van den Dood"

REEDS 64 PERSONEN WERDEN OP GEHEIMZINNIGE WIJZE UIT HET LEVEN GERUKT. — OOK VEEL VEE IS IN DE WEIDEN OMGEKOMEN. — ZIT DE MIST VOL GIFTIGE GASSEN? — DOKTERS EN GELEERDEN TRACHTEN HET TRAGISCH RAADSEL OP TE LOSSEN

Le Peuple 6-12-1930

UNE CATASTROPHE EXTRAORDINAIRE ENDEUILLE LA VALLEE DE LA MEUSE DEPUIS JEMEPPES A ENGIS

Quarante-trois personnes périssent dans le brouillard sous l'influence de gaz délétères

Le Soir 12-12-1930

Le tragique mystère de la Vallée de la Meuse

DE NOUVELLES AUTOPSIES

Liége, 10 décembre.

Le Soir 11-12-1930

Le Brouillard homicide

UNE COMMUNICATION DU GOUVERNEMENT

M. JASPAR, premier ministre, devant la Chambre debout, présente les condoléances du gouvernement aux familles des victimes du brouillard dans la vallée de la Meuse.

De Standaard 8-12-1930

Doodende mist in de Maasvallei

IN HET GEHEEL ZOUDEN ER 63 SLACHTOFFERS ZIJN. — ER ZIJN NOG HONDERDE ZIEKEN, DIE EVENWEL GEEN GEVAAR LOOPEN NU DE MIST WEG IS. — EEN SOORT SPAANSCHE GRIEP? — HET OORDEEL VAN DE GELEERDEN. — H. M. DE KONINGIN HEEFT ZICH TER PLAATSE BEGEVEN.

Un mystérieux « brouillard-tueur » sème la panique dans la vallée mosane : déjà soixante-cinq morts

Belgium's Poison Fog Cases Likened to the 'Black Death'

Special Cable to THE NEW YORK TIMES.

LONDON, Dec. 5.—The suggestion that the Belgian fog deaths may be due to some form of plague was advanced tonight by Professor J. B. S. Haldane, prominent Cambridge scientist.

"It seems like something in the nature of the Black Death to me," he told The Daily Mail tonight. "I don't think it can be caused by war gas, because the deaths occurred in different villages. They have been having floods in that district lately and that may be responsible."

The Black Death was the name given in the Middle Ages to the bubonic plague, which was responsible for millions of deaths in the fourteenth century in various parts of Europe.

1930

FOG BROUGHT DEATH ONLY TO OLD AND ILL

Toll of 70 in Belgian Towns Laid to Natural Causes as Menace Passes Away.

PEASANTS STILL IN TERROR

Many Credit Malignant Force —Authorities the World Over Speculate on Phenomenon.

Special Cable to THE NEW YORK TIMES.

BRUSSELS, Dec. 6.—While it is asserted by some medical authorities that the appalling number of deaths attributed to the dense fog in Belgium of the last three days were due in reality only to natural causes, the peasants refuse to relinquish the theory of poison. They point to the great numbers of cattle killed as supporting their belief.

Upward of seventy persons are reported dead, while the hospitals of Liége are choked with victims.

A conference of Red Cross doctors held today in Engis, one of the stricken villages, was unable to submit a report for want of definite evidence. In a conference here at the

BELGIAN FOG DEATHS LAID TO POISONOUS GAS

Doctor Who Performs Autopsy Unable to Identify It— Brussels Inquiry Today.

Special Cable to THE NEW YORK TIMES.

BRUSSELS, Dec. 8.—The deaths caused by the fog in the Meuse Valley were ascribed to a poisonous gas by Professor Firket, who performed an autopsy upon several victims today in Liége. He said, however, that he had been unable to determine exactly what gas had wrought the havoc.

"It is neither any known form of war gas, nor a gas such as might be derived from an ammonia explosion," he said. "We rather incline to the theory that it had its origin in some industrial accident, which resulted in the release of noxious gas."

Scientists investigating the incident agree that such a noxious gas could be carried by the fog. At the same time, no progress has been made by the authorities in discovering information concerning any such accident, and for the moment the mystery remains unsolved.

An inquiry will be held here tomorrow by the Cabinet of Ministers to seek a solution of the mystery.

LONDON, Dec. 8 (AP).—The mysterious "death fog" of the Meuse Valley in Belgium, which last week claimed more than threescore human lives, was not due to any communicable disease, in the opinion of Belgium health authorities, and they so informed the British Ministry of

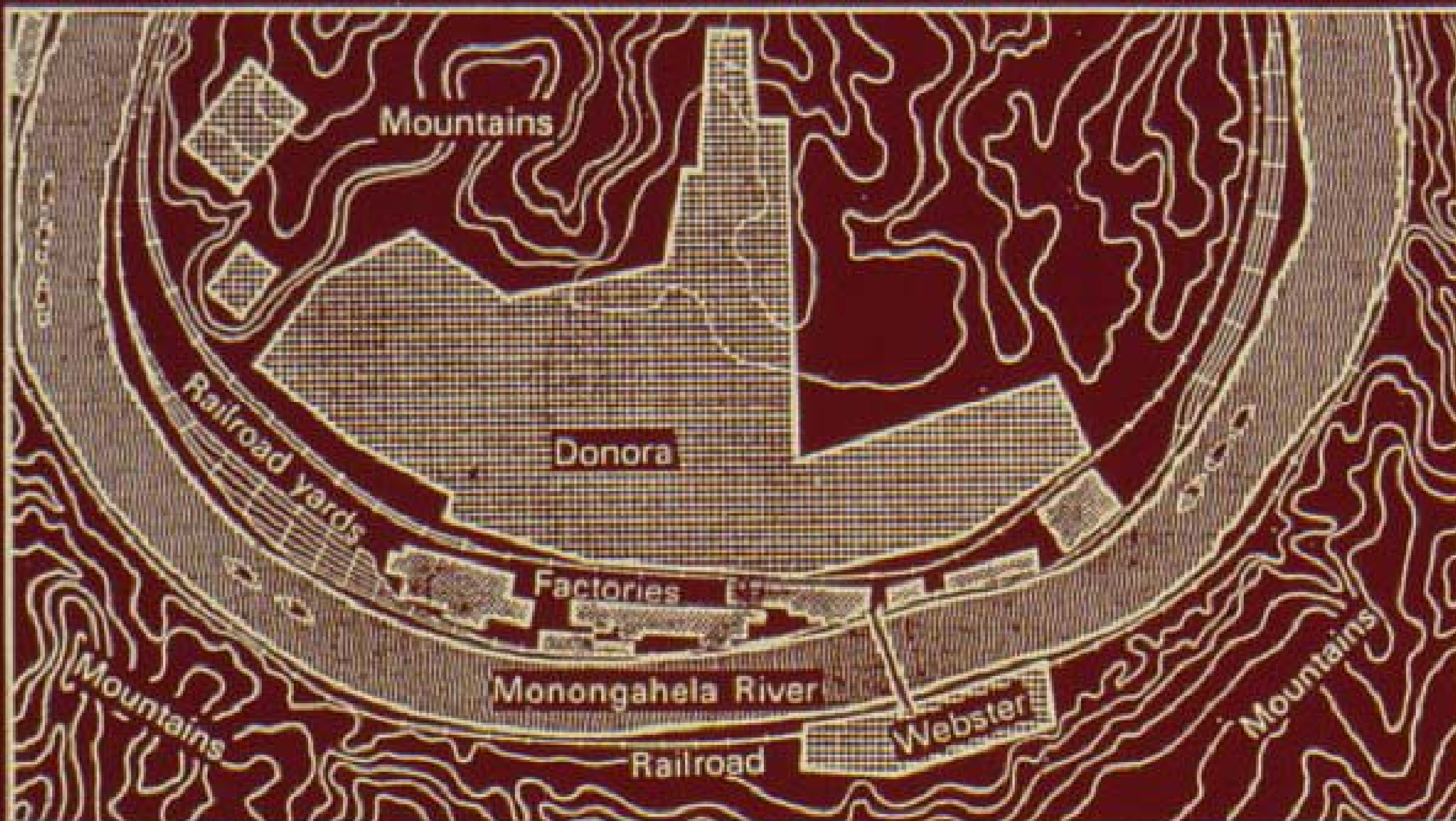


Fig. 1-2. Environs of Donora, Pennsylvania. Horseshoe curve of Monongahela River is surrounded by mountains. Railroad tracks are located on both sides of the river. Low-lying stretch of Monongahela Valley between railroad and river is natural trap for pollutants.

Donora, PA

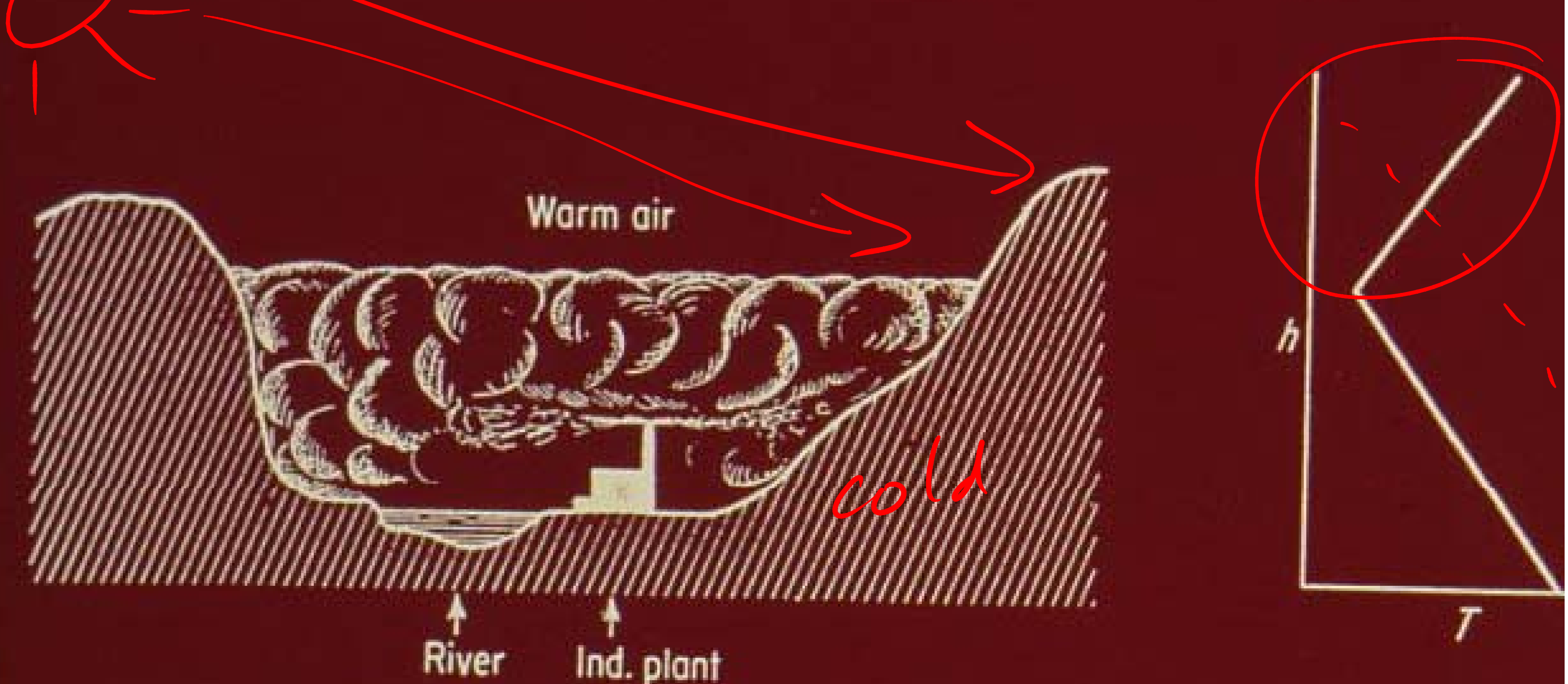
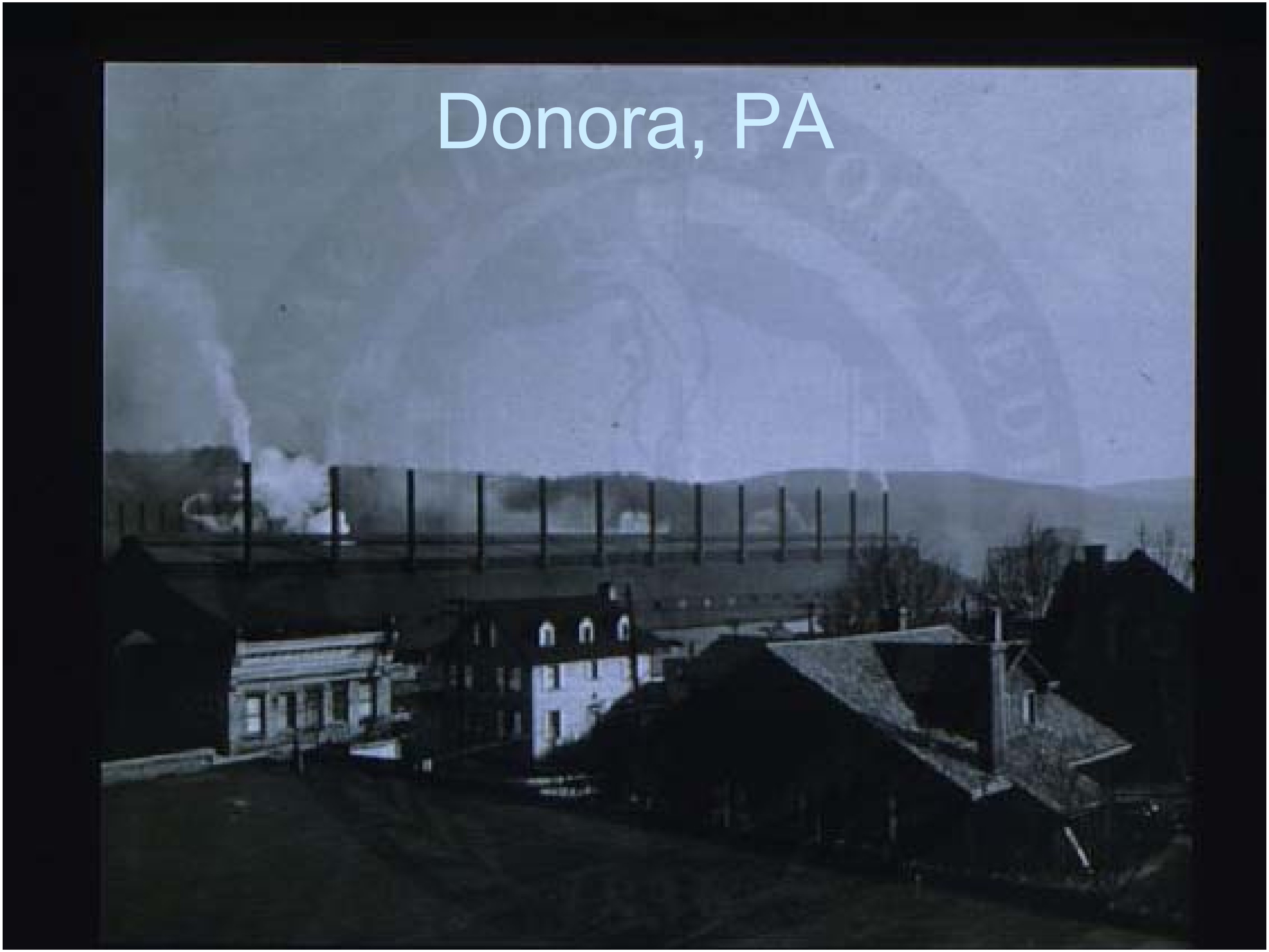


Fig. 4–9 Fumigation of a valley floor caused by an inversion layer that restricts diffusion from a stack.

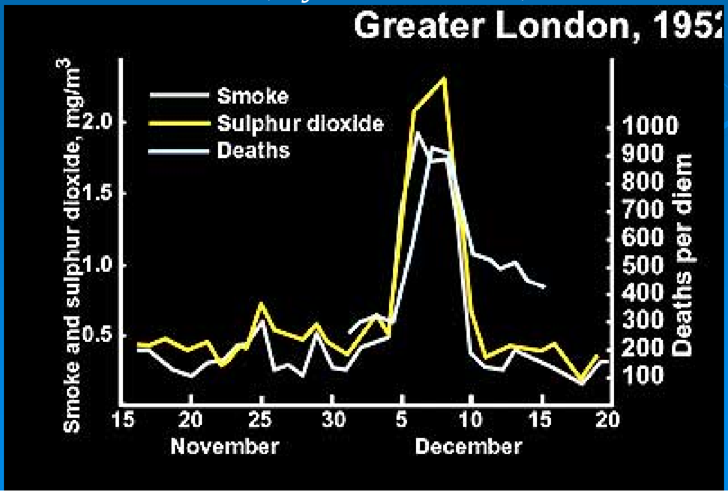
Donora, PA



"Night at Noon." London's Piccadilly Circus at midday, during a deadly smog episode, this time in the winter of 1955.
Credit: 'When Smoke Ran Like Water', by Devra Davis, Perseus Books

Central London during the killer smog, December 1952. At this point, visibility is less than 30 feet. During the height of the smog, people could not see their own hands or feet, and buses had to be led by policemen walking with flares.
Credit: 'When Smoke Ran Like Water', by Devra Davis, Perseus Books

Research by Rutgers University's Paul Lioy and others shows that as the amount of smoke and pollutants in the air shot up during the week of Dec. 5, 1952, so did the death rate in greater London. Estimates say the smog killed anywhere from 4,000 to 11,000 people.
Credit: Paul Lioy, Rutgers University



Smog: Sulfur Dioxide, Acidic Aerosols and Soot (particulates)

TABLE 1.1 Some Incidents of Excess Deaths Associated with Smog[a]

Year	Place	Number of excess deaths
1930	Meuse Valley, Belgium	63
1948	Donora, Pennsylvania	20
1952	London	4000
1962	London	700

[a] From Firket (1936), Wilkins (1954), Roueché (1965), and Cochran *et al.* (1992).

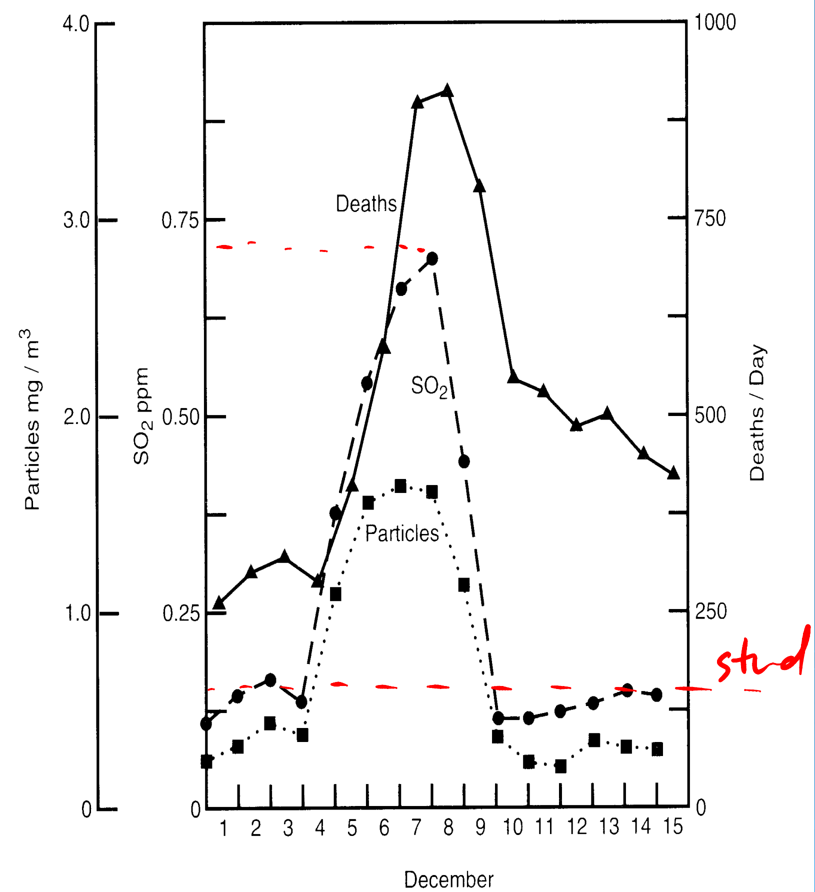


FIGURE 1.2 Concentrations of SO_2 and "smoke" as well as the death rate during the 1952 smog episode (adapted from Wilkins, 1954).

Air Pollution Factoids

- Approximately __146__ million people live in counties where monitored air in 2002 was unhealthy at times because of high levels of at least one of the six principal air pollutants
- the vast majority of areas that experienced unhealthy air did so because of one or both of two pollutants - __ozone__ and __particulate__________, PM_{10}
- Clean Skies legislation currently being considered would mandate additional reductions of __70__% from current emission levels from power plants through a c_ap___ and t_rade_____ program
- Of the six pollutants (NO_X, Ozone, SO_X, PM_{10}, CO, lead) ground level __ozone__ has been the slowest to achieve reductions

Primary vs. secondary pollutants

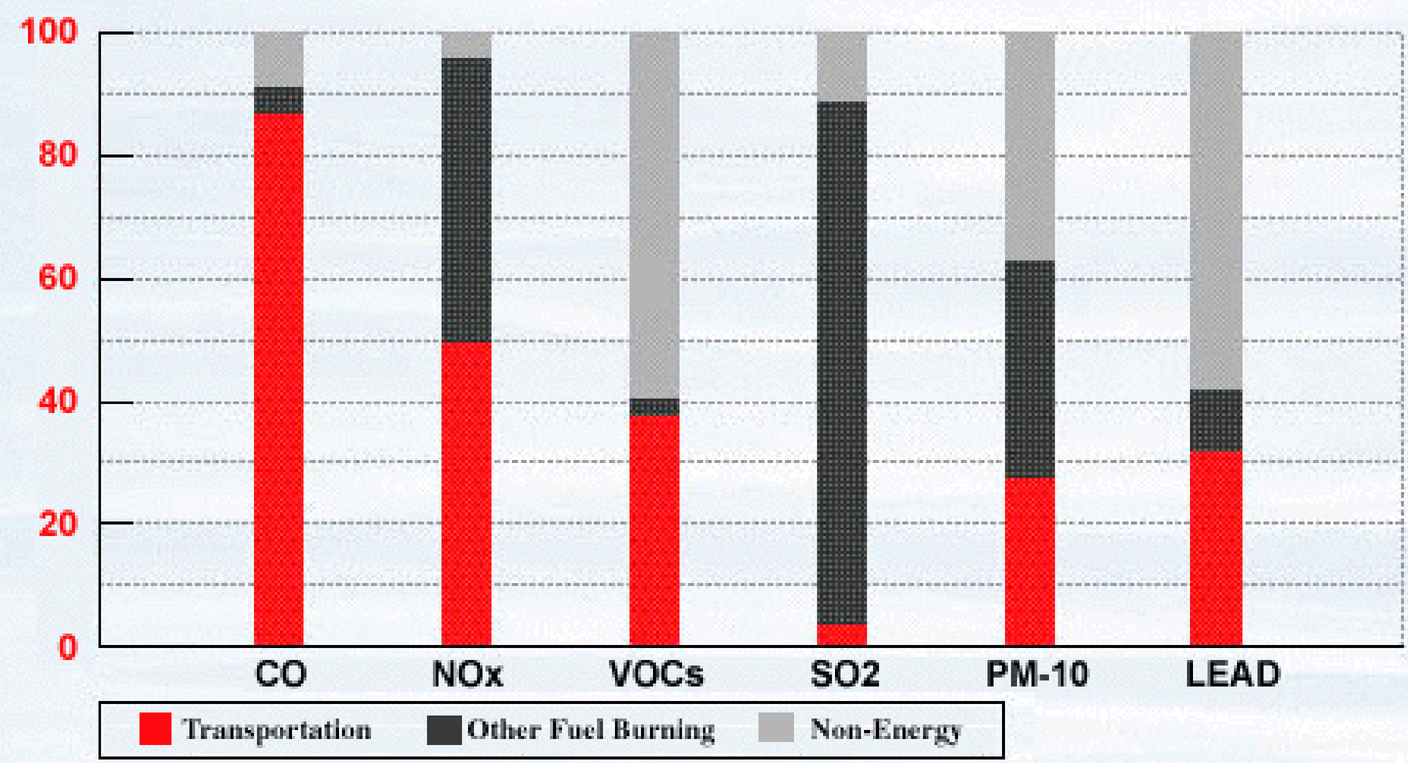
- **Primary pollutant** - discharged directly into the atmosphere (e.g., automobile exhaust)
- **Secondary pollutant** - formed in the atmosphere through a variety of chemical reactions (e.g., photochemical smog)

Stationary vs. mobile sources

- **Stationary Sources**
  - Contribute approximately 40% of total air pollution
    - 98% of SO_X,
    - 95% of particulates,
    - 56% of total hydrocarbons,
    - 53% of NO_X, and
    - 22% of CO

Stationary vs. mobile sources

- **Mobile Sources**
  - Contribute approximately 60% of total air pollution
    - 78% of CO,
    - 47% of NO_X,
    - 44% of total hydrocarbons,
    - 5% of particulates, and
    - 2% of SO_X



Source: WRI Estimate Based on Data from "National Air Quality and Emissions Trends Report, 1995," 1996, EPA 454/R-96-005

See: National Emissions Inventory from EPA

Effects of air pollution

- Damage to human health and welfare
- Damage to vegetation and animals
- Damage to material and structures
  - Abrasion
  - Deposition and removal
  - Direct chemical attack
  - Indirect chemical attack
  - Electrochemical corrosion
- Damage to the atmosphere, soil, and water

Air Pollution Effects

Statue damaged by acid rain

Melon leaves damaged by ozone

Feedlot

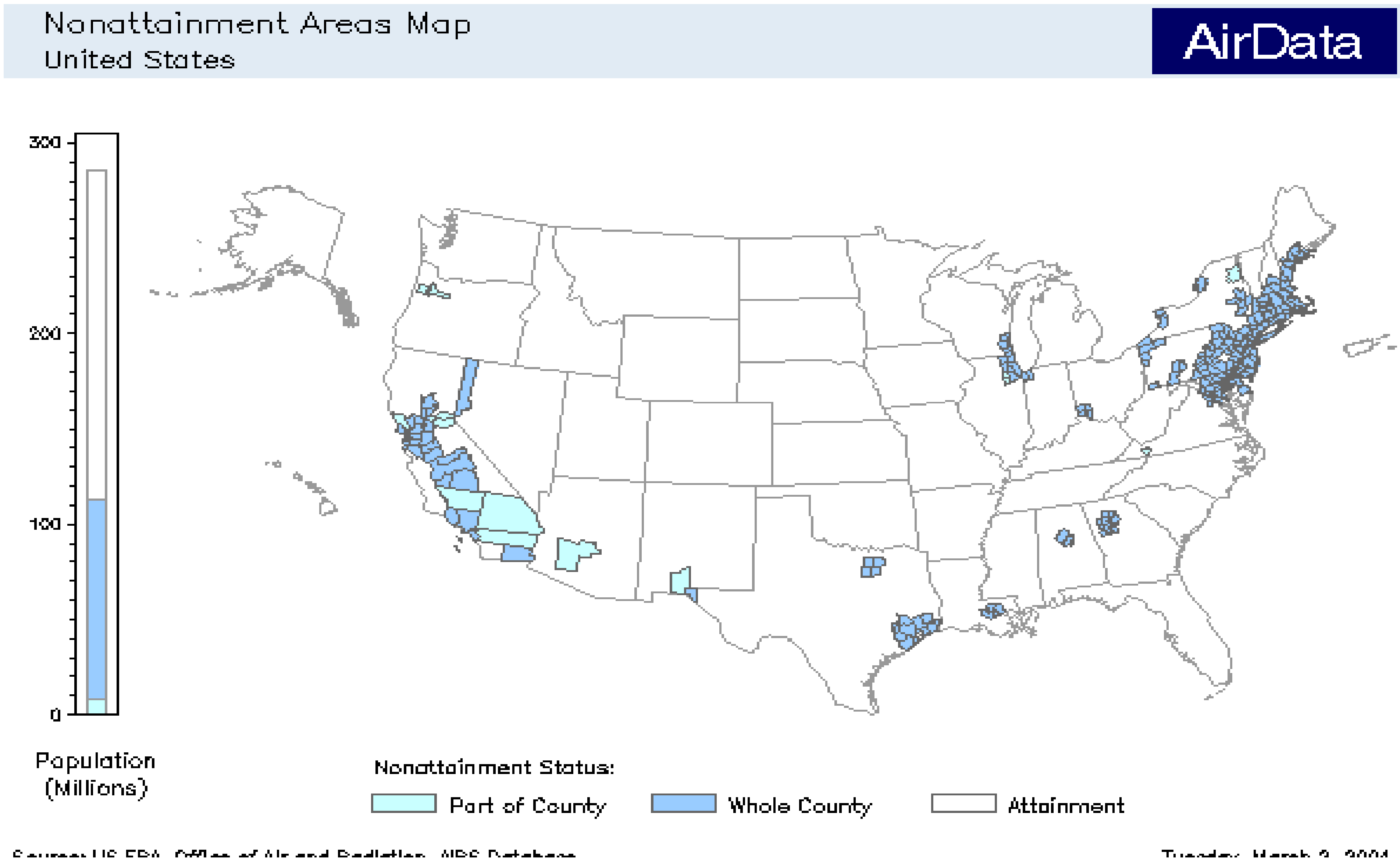
Definitions

- c riteria pollutant – pollutant that is regulated based on health or environmental criteria
- NAAQS - National Ambient Air Quality Standards - revised in 1987, set air quality standards.
- SIP – State Implementation Plan to achieve air quality standard
- AQR – ~~Air Quality~~ Region – areas that have air quality that meets primary standards is classified as an attainment area, if not, then it's a non-attainment area.
- NESHAPs – National Emissions Standards for Hazardous Air Pollutants
- MACT – Maximum Achievable Control Technology
  - also BACT – best available control technology) – the best available control equipment that is technologically feasible and is currently available.
- NSPS – New Source Performance Standards

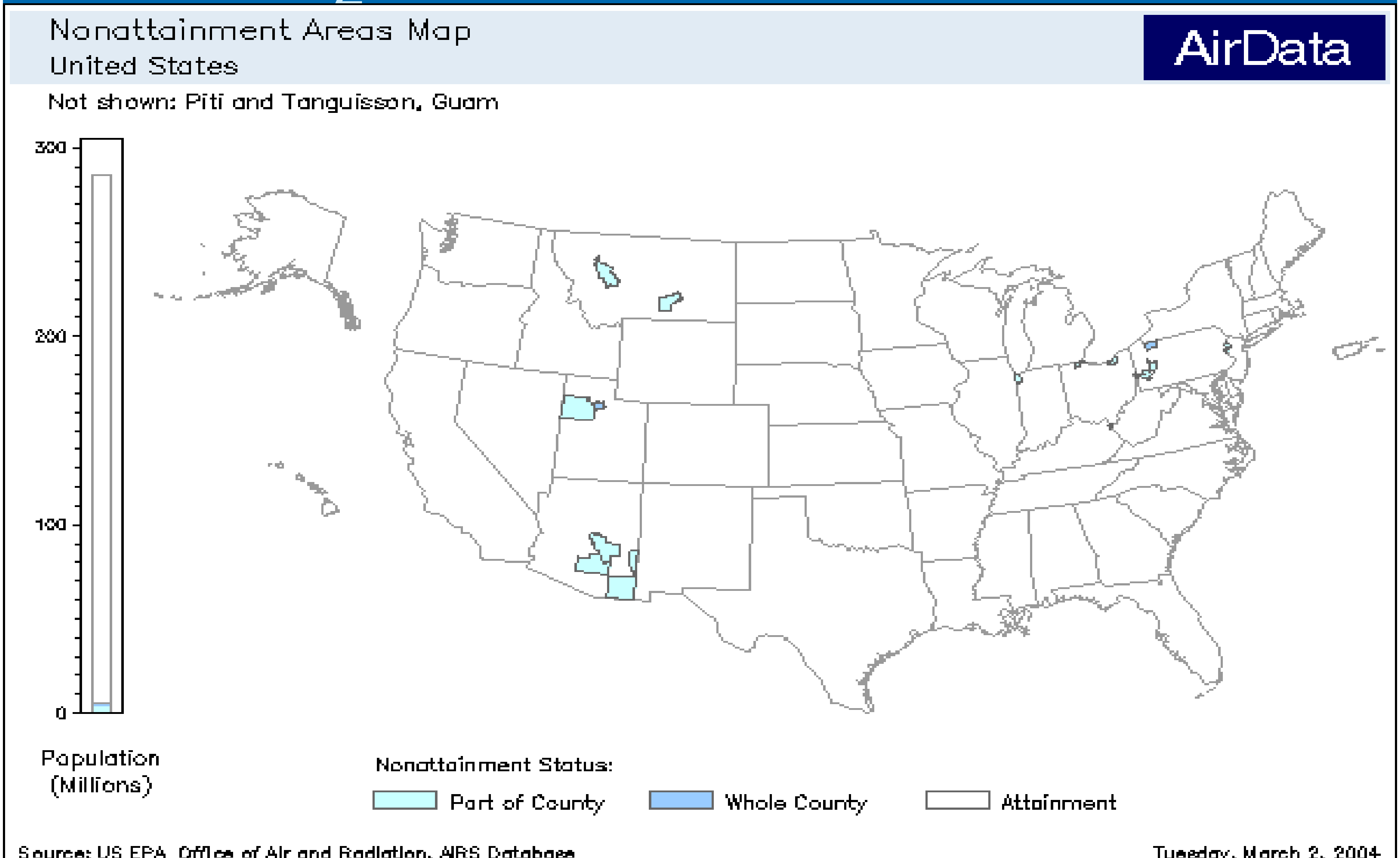
Seven Major Pollutants of Concern

1. Particulates
2. Sulfur Oxides (SO_X)
3. Ozone
4. Nitrogen Oxides (NO_X)
5. Carbon Monoxide (CO and other hyrdrocarbons)
6. Volatile Organic Compounds (VOCs)
7. Lead (& others: mercury, other inorganic metals, radon, HCl)

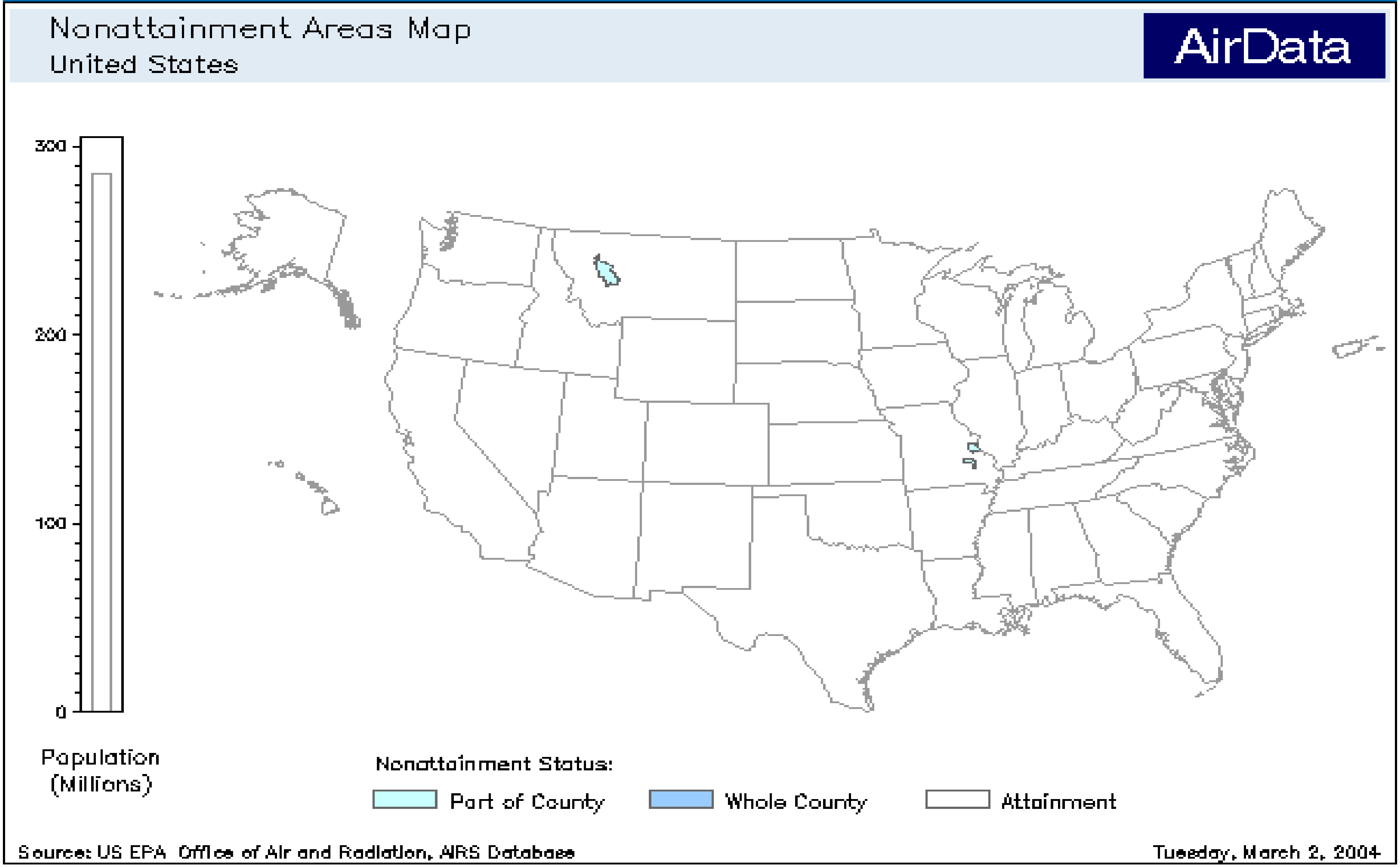
Ozone Nonattainment Areas



SO_2 Nonattainment Areas

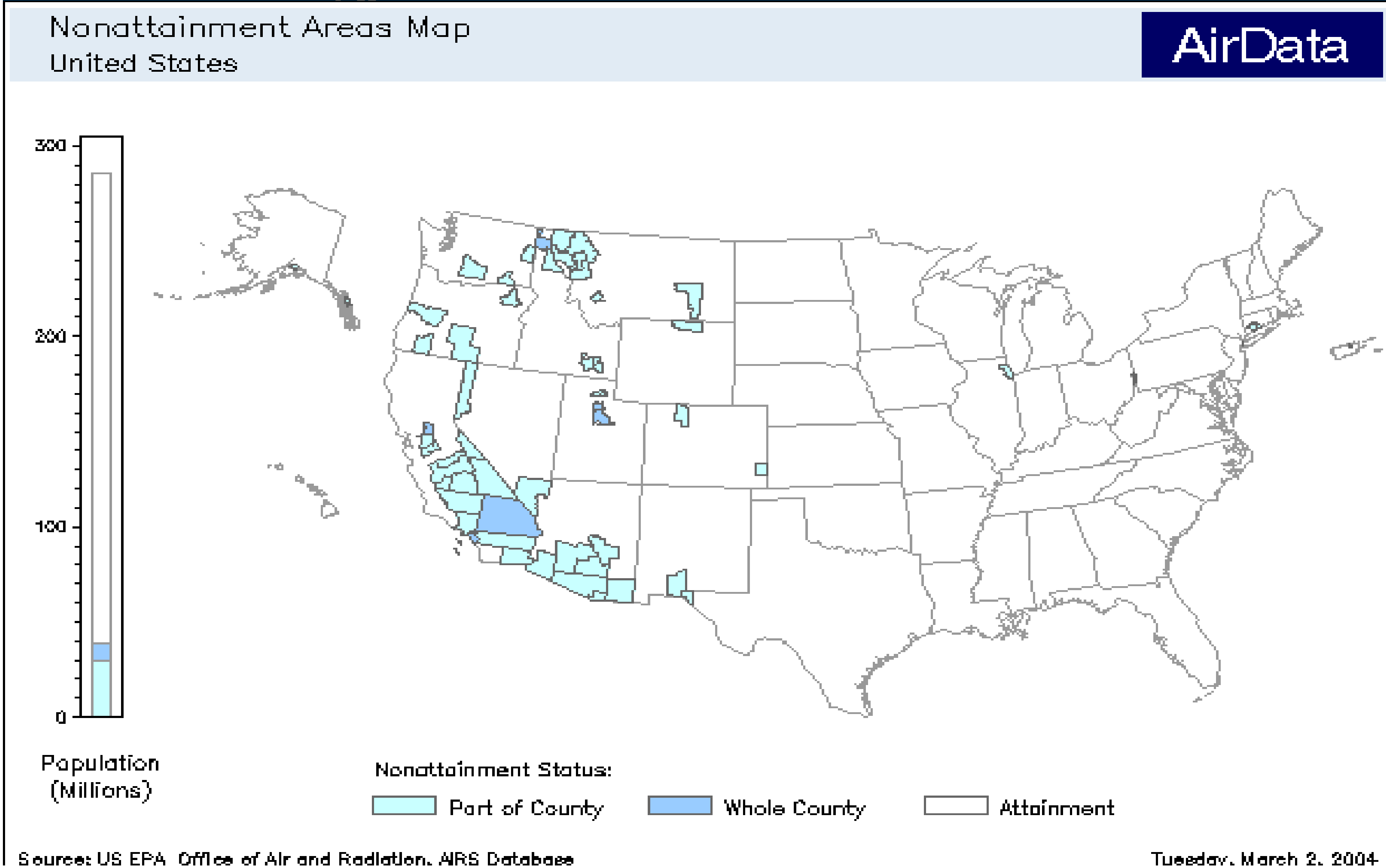


Lead (Pb) Nonattainment Areas

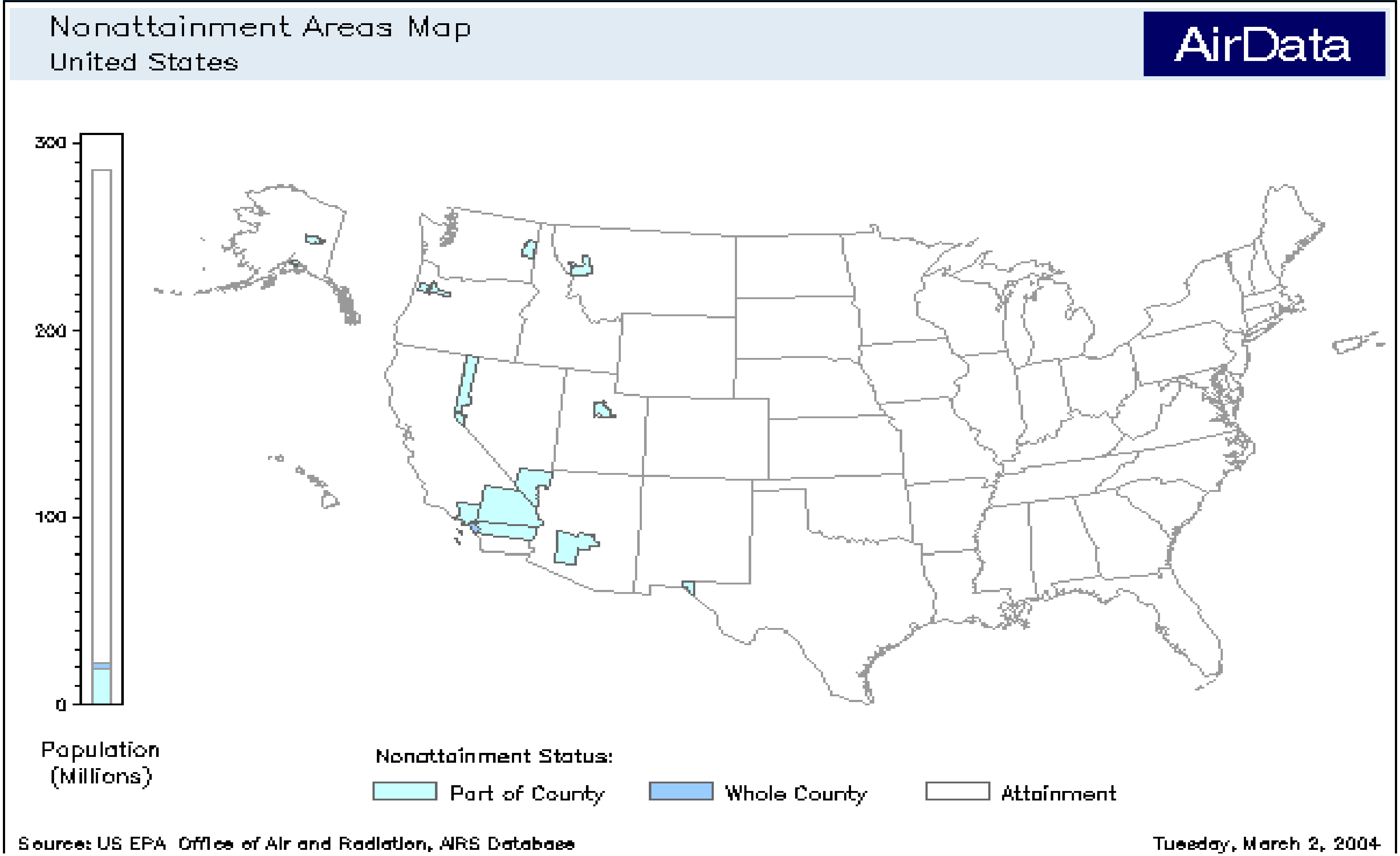


PM 2.5

PM_{10} Nonattainment Areas



CO Nonattainment Areas



Particulates

- released directly into the air
- largely a result of stationary sources
- a nearly ubiquitous urban pollutant.

"Although particulate levels in North America and Western Europe rarely exceed 50 micrograms of particulate matter per cubic meter (µg/m^3) of air, levels in many Central and Eastern European cities and in many developing nations are much higher, often exceeding 100 µg/m^3 (http://www.wri.org/wr-98-99/urbanair.htm)."

Size of Particulates

- $PM_{2.5\text{-}100}$: 2.5 to 100 µ in diameter, usually comprise smoke and dust from industrial processes, agriculture, c and road traffic, plant pollen, and other natural sources.
- $PM_{2.5}$: particles less than 2.5 µ in diameter generally come from combustion of fossil fuels.
- vehicle exhaust soot, which is often coated with various chemical contaminants
- fine sulfate and nitrate aerosols that form when SO_2 and nitrogen oxides condense in the atmosphere.
- largest source of fine particles is coal-fired power plants, but auto and diesel exhaust are also prime contributors, especially along busy transportation corridors.

Health Effects

- small particulates most damaging (PM2.5)
- $PM_{2.5}$ aggravate existing heart and lung diseases
- changes the body's defenses against inhaled materials, and damages lung tissue.
- Elderly, children and those with chronic lung or heart disease are most sensitive
- lung impairment can persist for 2-3 weeks after exposure to high levels of $PM_{2.5}$
- chemicals carried by particulates can also be toxic

National Ambient Air Quality Standards (NAAQS)

Criteria Pollutants	Standard Type	Avg. Time	Conc.	Health Risks and Concerns	Anthropogenic Sources	Natural Sources
Carbon monoxide	Primary	8 h 1 h	9 ppm 35 ppm	carboxy-hemoglobin (blood)	incomplete combustion from mobile and stationary sources	intermediate in breakdown of methane by hydroxyl radicals (OH·)
Hydrocarbons (measured as CH_4)	Primary	3 h	240 ppb	photochemical smog	incomplete combustion from mobile and stationary sources	see graph
Lead	Primary	24 h 3 month	18 ppb 6 ppb	CNS	leaded gasoline (obsolete?), smelters and refineries	volcanic activity and soils
Nitrogen dioxide	Primary	annual 1 h	53 ppb 250 ppb	health risks, visibility (NO_2 has a brown color)	high temperature combustion	bacterial processes in soil release nitrous oxide N_2O
Ozone	Primary	1 h 8 h	120 ppb 80 ppb	eye irritation, breathing difficulties	formed in nitrogen oxide photolytic cycle (NO_X + sunlight)	
Sulfur dioxide	Primary	annual 24 h	30 ppb 140 ppb	respiratory disease	sulfur in fuel	sulfur released in biological processes
Sulfur dioxide	Secondary	3 h	500 ppb	plant damage, material damage		
Total suspended particulates (TSP)	Primary	annual 24 h	75 $\mu g/m^3$ 150 $\mu g/m^3$	visibility and respiratory effects	combustion of fossil fuels and industrial activity	soil, sea salt, sand, forest fires, volcanoes
Particulates (PM_{10})	Primary	annual 24 h	50 $\mu g/m^3$ 365 $\mu g/m^3$	visibility and respiratory effects		
Particulates ($PM_{2.5}$)	Primary	24 h	65 $\mu g/m^3$	visibility and respiratory effects		

Sulfur Oxides

- Sulfur Oxides (SO_X, mainly SO_2)
- emitted largely from burning coal, high-sulfur oil, and diesel fuel.
- usually found in association with particulates
- SO_2 is the precursor for fine sulfate particles (separating the health effects of these two pollutants is difficult)
- SO_2 and particulates make up a major portion of the pollutant load in many cities, acting both separately and in concert to damage health.
- concentrations are higher by a factor of 5 to 10 in a number of cities in Eastern Europe, Asia, and South America, where residential or industrial coal use is still prevalent and diesel traffic is heavy
- major component of acid rain

Health Effects

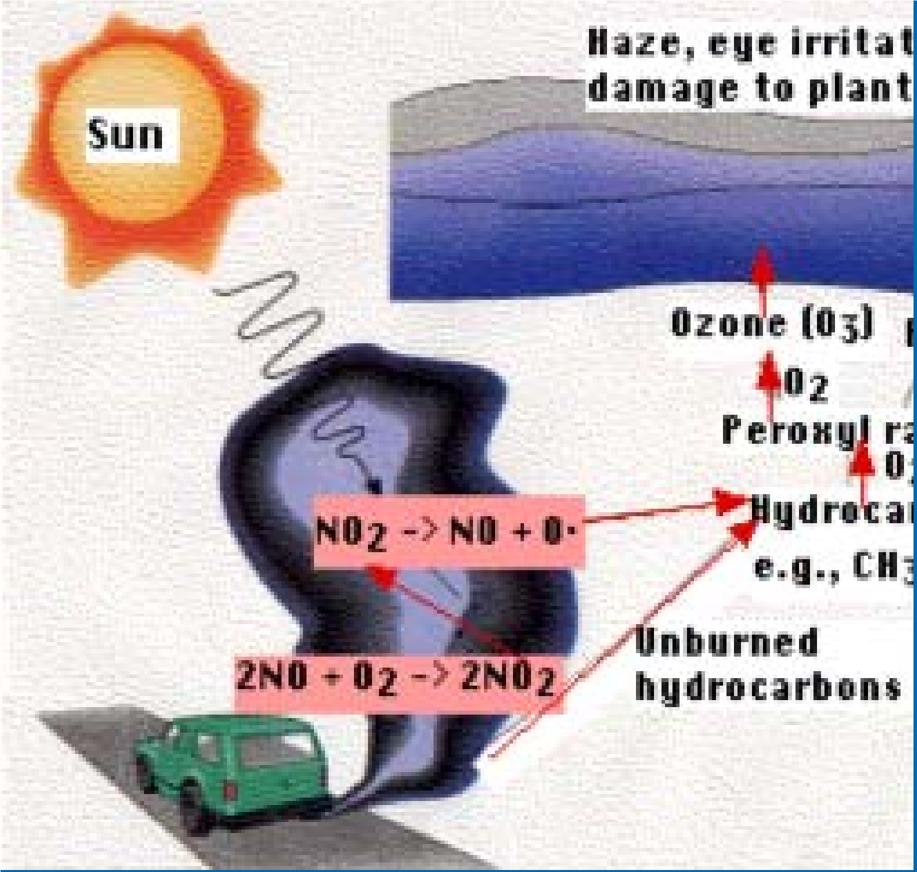
- SO_2 affects people quickly, usually within the first few minutes of exposure
- SO_2 exposure can lead to the kind of acute health effects typical of particulate pollution.
- Exposure is linked to an increase in hospitalizations and deaths from respiratory and cardiovascular causes, especially among asthmatics and those with preexisting respiratory diseases
- severity of these effects increases with rising SO_2 levels, and excercise enhances the severity by increasing the volume of SO_2 inhaled and allowing SO_2 to penetrate deeper into the respiratory tract
- Asthmatics may experience wheezing and other symptoms at much lower SO_2 levels than those without asthma.
- When ozone is also present, asthmatics become even more sensitive to SO_2 indicating the potential for synergistic effects among pollutants

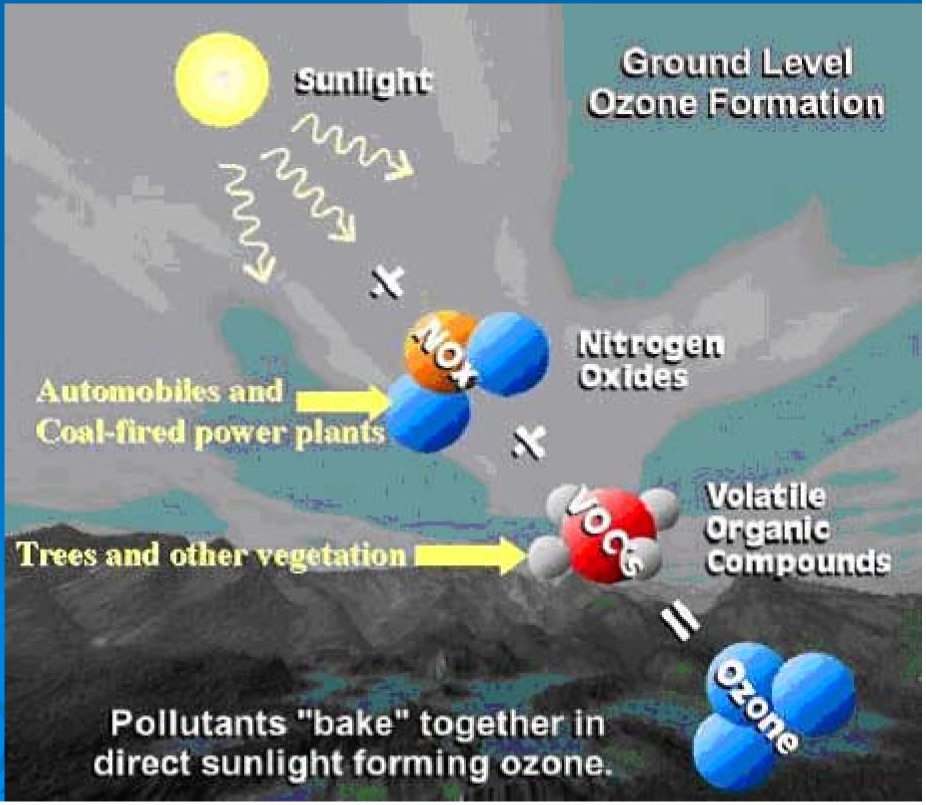
Ozone

- major component of photochemical smog
- formed when nitrogen oxides from fuel combustion react with VOCs
- sunlight and heat stimulate ozone formation, peak levels occur in the summer.
- widespread in cities in Europe, North America, and Japan as auto and industrial emissions have increased. Many cities in developing countries also suffer from high ozone levels, although few monitoring data exist
- powerful oxidant, can react with nearly any biological tissue.

Ozone

- concentrations of 0.012 ppm can irritate the respiratory tract and impair lung function, causing coughing, shortness of breath, and chest pain.
- Exercise increases these effects, and heavy exercise can bring on symptoms even at low ozone levels (0.08 ppm).
- ozone exposure lowers the body's defenses, increasing susceptibility to respiratory infections
- As ozone levels rise, hospital admissions and emergency room visits for respiratory illnesses such as asthma also increase.
- hospital admissions rise roughly 7 to 10 percent for a 0.05 ppm increase in ozone levels.
- in 13 cities where ozone levels exceeded U.S. air standards, the American Lung Association estimated that high ozone levels were responsible for approximately 10,000 to 15,000 extra hospital admissions and 30,000 to 50,000 additional emergency room visits during the 1993-94 ozone season


Haze, eye irritat
damage to plant
Sun
Ozone (O3)
O2
Peroxyl ra
Hydrocar
e.g., CH
NO2 -> NO + O·
2NO + O2 -> 2NO2
Unburned
hydrocarbons


Sunlight
Ground Level
Ozone Formation
NOx
Nitrogen
Oxides
Automobiles and
Coal-fired power plants
VOCs
Volatile
Organic
Compounds
Trees and other vegetation
Ozone
Pollutants "bake" together in
direct sunlight forming ozone.

Nitrogen Oxides

- principal precursor component of photochemical smog
- component of acid rain (NO_X is oxidized to NO_3^- in the atmosphere, NO_3^- reacts with moisture to form nitric acid H_2NO_4)
- formed inadvertently due to high temperature of combustion of atmospheric nitrogen

Carbon Monoxide

- Hemoglobin has an affinity for CO that is 200 to 250 times its affinity for oxygen
  - this reduces its affinity for oxygen, disrupts release of oxygen.
- Blood level of 0.4% is maintained by CO produced by body.
- Blood is cleared of 50% of CO in 3-4 hours after exposure.
- Global emissions of CO are 350 million tons per year, 20% from mobile sources.
- CO concentration in cigarette smoke is ~400 ppm.
- 24% of emergency room patients complaining of flu-like symptoms in one study showed carbon monoxide poisoning

Volatile Organic Compounds (VOCs)

- contribute to ozone generation
- many are subject to NESHAPS (benzene from gasoline vapors)
- significant industrial emissions (e.g., perchloroethylene from dry cleaners)
- many are carcinogenic or suspected carcinogens

Other Air Pollutants

- Lead
- Mercury
- other inorganic metals
- Radon

Note Title 1/18/2008

Homework problems 7: 2, 5, 7, 10, 15 starting on page 635 - 637

$PV = nRT$ $R = 8.3143 \frac{Pa \cdot m^3}{K \cdot mole}$

Find volume of 5.2 kg of CO_2 @ 152 kPa and 315 K

$V = \frac{nRT}{P} = \frac{n\ 8.3143\ (315)}{152,000}$

$n = \frac{5.2\,kg}{44\,g/mole}$

$= 118.2$ mole

$= 2.04\ m^3$

Ex. Convert SO_2 80 $\mu g/m^3$ to ppm 25 °C 101,325 Pa

$$V = \frac{nRT}{P} \qquad n = \frac{80 \times 10^{-6}\ g}{64\ g/mole} = 1.25 \times 10^{-6}\ \text{mole}$$

$$V = \frac{1.25 \times 10^{-6}(8.3143)(273+25)}{101,325} \times 10^{6} = 0.03056\ \text{ppm}$$

Dalton's Law of partial pressures:

$$P_T = P_1 + P_2 \ldots P_n$$

$$= n_1 RT/V + n_2 RT/V + n_n RT/V$$