AIR POLLUTION:
What Should Be Done?

by

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(*Neither Dr. Phalen nor his wife have financial relationships with any commercial entities that provide products or services discussed in this presentation*)

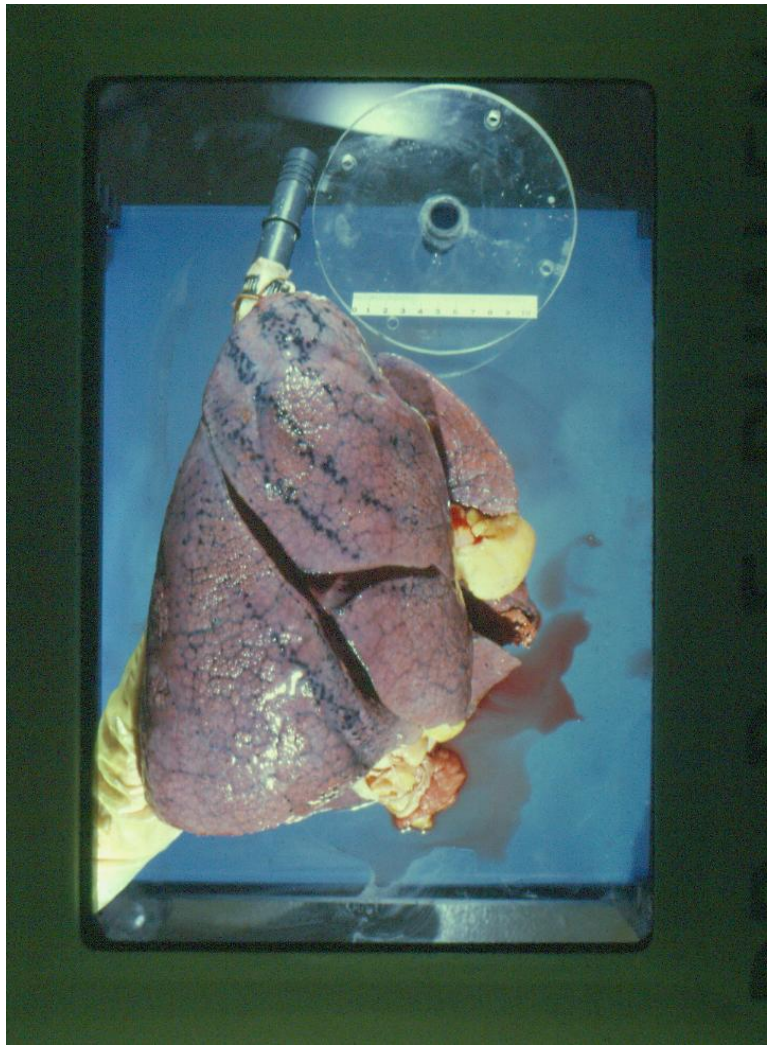
OBJECTIVES

- **IMPROVE UNDERSTANDING OF PARTICLE INHALATION**
- **DISCUSS THE SOURCES OF PARTICULATE AIR POLLUTION**
- **CHALLENGE SOME HEALTH-RELATED ASSUMPTIONS**
- **PRESENT SOME LESSONS LEARNED AND RECOMMENDATIONS**

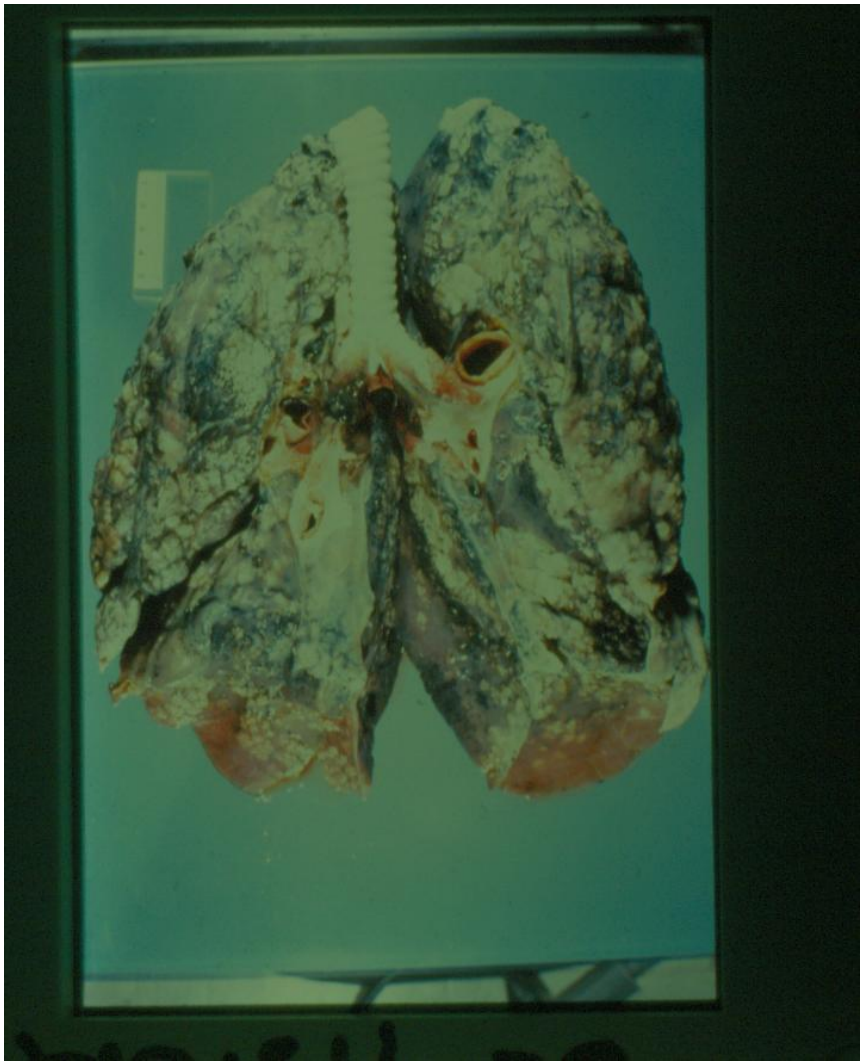
OUTLINE

- **AEROSOL BASICS**
- **EPA REGULATION OF PM**
- **SOURCES & CHARACTERISTICS OF PM**
- **CHALLENGES TO DOGMA**
- **MORE RECENT DEVELOPMENTS**
- **KNOWNS, UNKNOWNS & LESSONS**
- **CONCLUSIONS**
- **REFERENCES**

HEALTHY LUNG – MALE AGE 60 YEARS



SMOKER’S LUNG – FEMALE AGE 62 YEARS



AEROSOL BASICS

- **AN AEROSOL IS A RELATIVELY STABLE SUSPENSION OF SMALL (LIQUID, SOLID, ETC.) PARTICLES IN A GAS (USUALLY AIR).**

- **AEROSOL PARTICLES RANGE IN DIAMETER FROM 0.001 TO 100 MICROMETERS.**

  THE EYE CAN JUST RESOLVE ABOUT 70 MICROMETERS.

  THE OPTICAL MICROSCOPE CAN RESOLVE 0.2 MICROMETER.

  THE ELECTRON MICROSCOPE CAN RESOLVE ABOUT 0.001 MICROMETER (IN THEORY 0.00001 MICROMETER).

PARTICLE MOTION
(TIME TO MOVE 2 METERS)

DIAMETER (MICROMETERS)	SEDIMENTATION	DIFFUSION
100	8 SEC	1 MO
10	11 MIN	12 DAYS
1	16 HRS	3 DAYS
0.1	27 DAYS	14 HRS
0.01	11 MOS	3 HRS
0.001	10 YRS	11 MIN

EXPOSURE RATES

EXPOSURE ROUTE	MASS/DAY (GM)	VOL/DAY (L)
AIR	13,000	11,000
WATER	1,700	1.7
FOOD	1,600	1.6

INHALED AEROSOL DEPOSITION

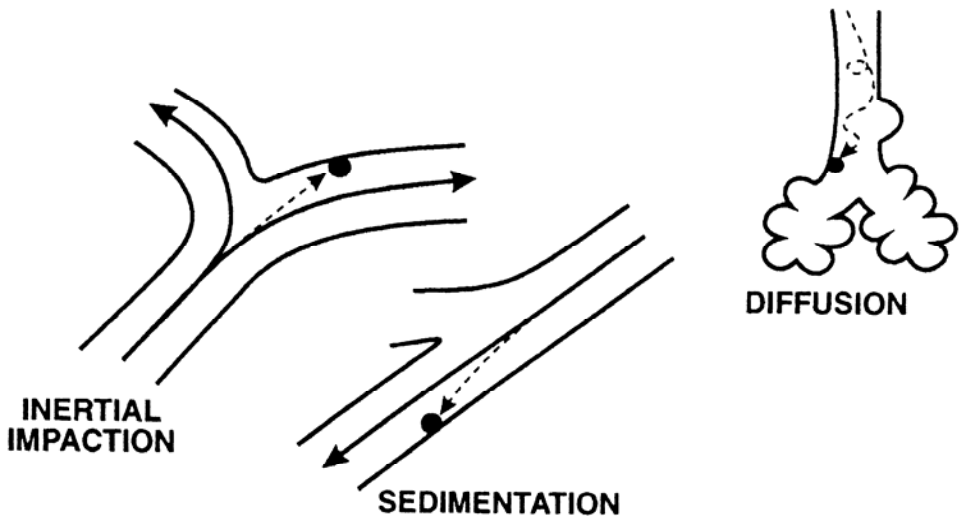
- **DEPOSITION OCCURS WHEN A PARTICLE TOUCHES THE AIRWAY SURFACE (THE STICKING COEFFICIENT = 1.0)**

- **AEROSOL PARTICLES TOUCH SURFACES WHEN THEY MOVE OUT OF THE AIR STREAM DURING INHALATION, BREATH-HOLDING OR EXHALATION**

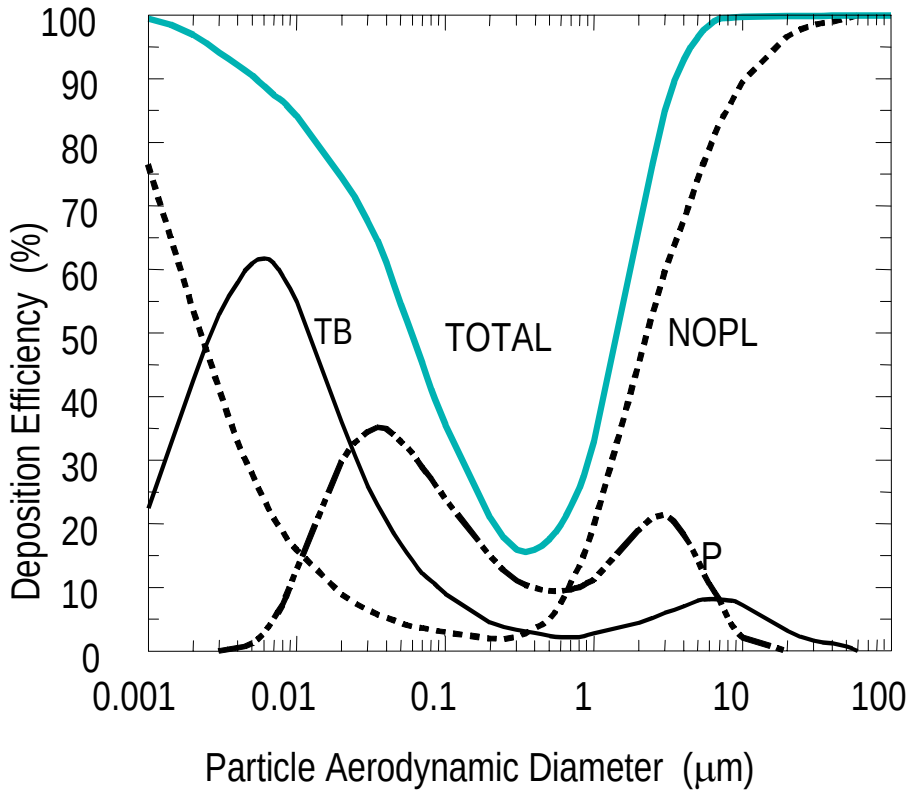
- **DEPOSITION MECHANISMS INCLUDE:**

  SEDIMENTATION
  DIFFUSION
  IMPACTION
  INTERCEPTION
  ELECTROSTATIC
  THERMOPHORETIC
  ETC.

THREE PARTICLE DEPOSITION MECHANISMS
(ASSUME STICKING COEFFICIENT = 1.0)

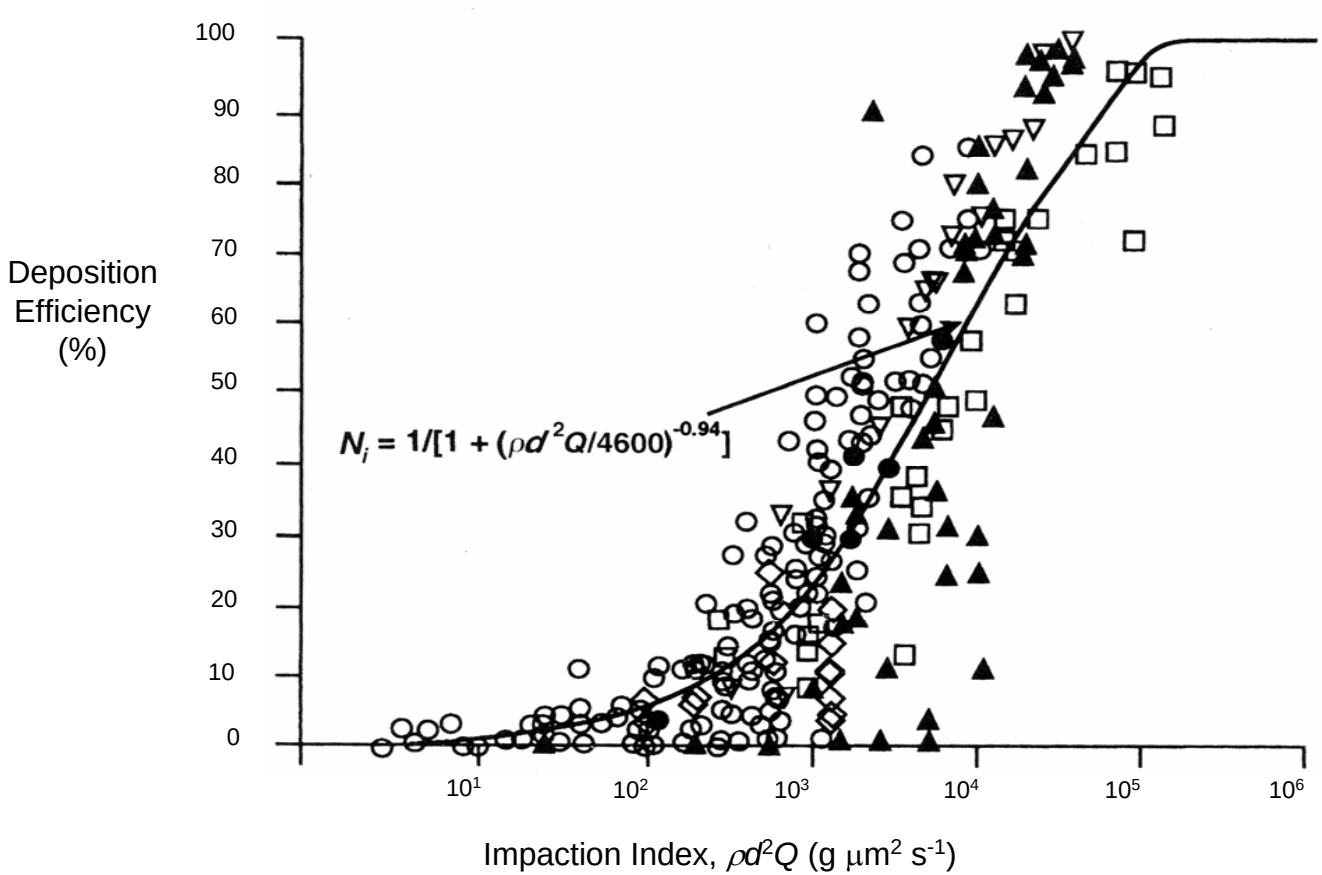


AEROSOL DEPOSITION CURVES



- **APPLIES TO THE "REFERENCE" MAN**
- **APPLIES TO IDEAL AEROSOLS**
- **CURVES AVAILABLE FOR VARIOUS BODY SIZES AND VENTILATORY STATES**
- **ADAPTED FROM NCRP, 1997**

AEROSOL DEPOSITION VARIABILITY IN THE NASAL REGION OF HUMANS (FROM YU AND SOONG, 1981)



CLEARANCE OF DEPOSITED PARTICLES

- **NASOPHARYNGEAL REGION**
  - **MUCOCILIARY**
  - **DISSOLUTION**
  - **SNEEZING, ETC.**

- **TRACHEOBRONCHIAL REGION**
  - **MUCOCILIARY**
  - **COUGHING**
  - **DISSOLUTION**

- **PULMONARY REGION**
  - **MACROPHAGES**
  - **EPITHELIAL UPTAKE**
  - **LYMPHATIC DRAINAGE**
  - **DISSOLUTION**

1993 PRESS HEADLINES & ARTICLES

Studies Say Soot Kills Thousands a Year

STUDIES SAY SOOT
KILLS UP TO 60,000
IN U.S. EACH YEAR

CALL TO REDIRECT EFFORTS

Little Is Spent on Particles That Harm Mostly Young, Elderly

and Those with Asthma

A pollution that may be the most deadly gets the least attention.

Scientists find particles are fatal even when under the legal limit.

EPIDEMIOLOGIC ASSOCIATIONS FOR INCREMENTS IN DAILY PARTICULATE MASS

(POPE et al., 1995)

- **MORTALITY UP FOR EACH 10μG/M^3 PM10**

  TOTAL: **1% (NOW O.28%)**

  RESPIRATORY: **3%**

- **HOSPITAL ADMISSIONS & VISITS UP FOR EACH 10μG/M^3 PM10**

  RESPIRATORY: **1%**

  ASTHMATICS: **3%**

- **OTHER ASSOCIATIONS FOR EACH 10μG/M^3 PM10**

  ASTHMATIC ATTACKS: **+3%**

  COUGH: **+2.5%**

  L.R.T. SYMPTOMS: **+3%**

  U.R.T. SYMPTOMS: **+0.7%**

  LUNG FUNCTION: **-0.1%**

- **ACUTE & CHRONIC FINDINGS CONSISTENT**
- **SEEN BY MANY INVESTIGATORS IN MANY CITIES**

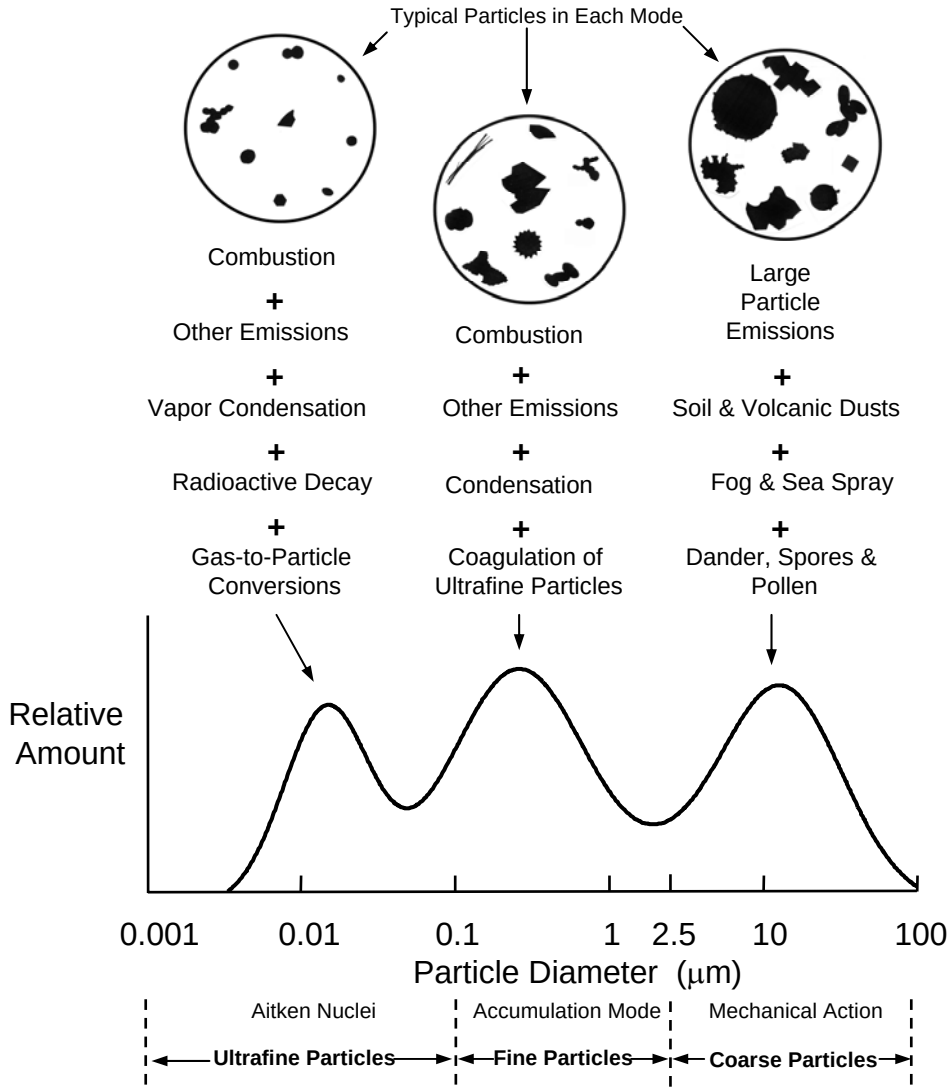
CHALLENGES TO EPI FINDINGS

- **THE RELATIVE RISK IS VERY SMALL**
- **THE ABSENCE OF CLINICAL PLAUSIBILITY**
- **SEASON & WEATHER ARE LARGE CONFOUNDERS**
- **NO DOSE-RESPONSE IS ESTABLISHED**
- **PM10 COULD BE A SURROGATE FOR REAL CULPRITS**
- **THE MODELS CAN OVERESTIMATE EFFECTS OF AN INDIVIDUAL POLLUTANT IF A COMBINATION IS THE CAUSE**

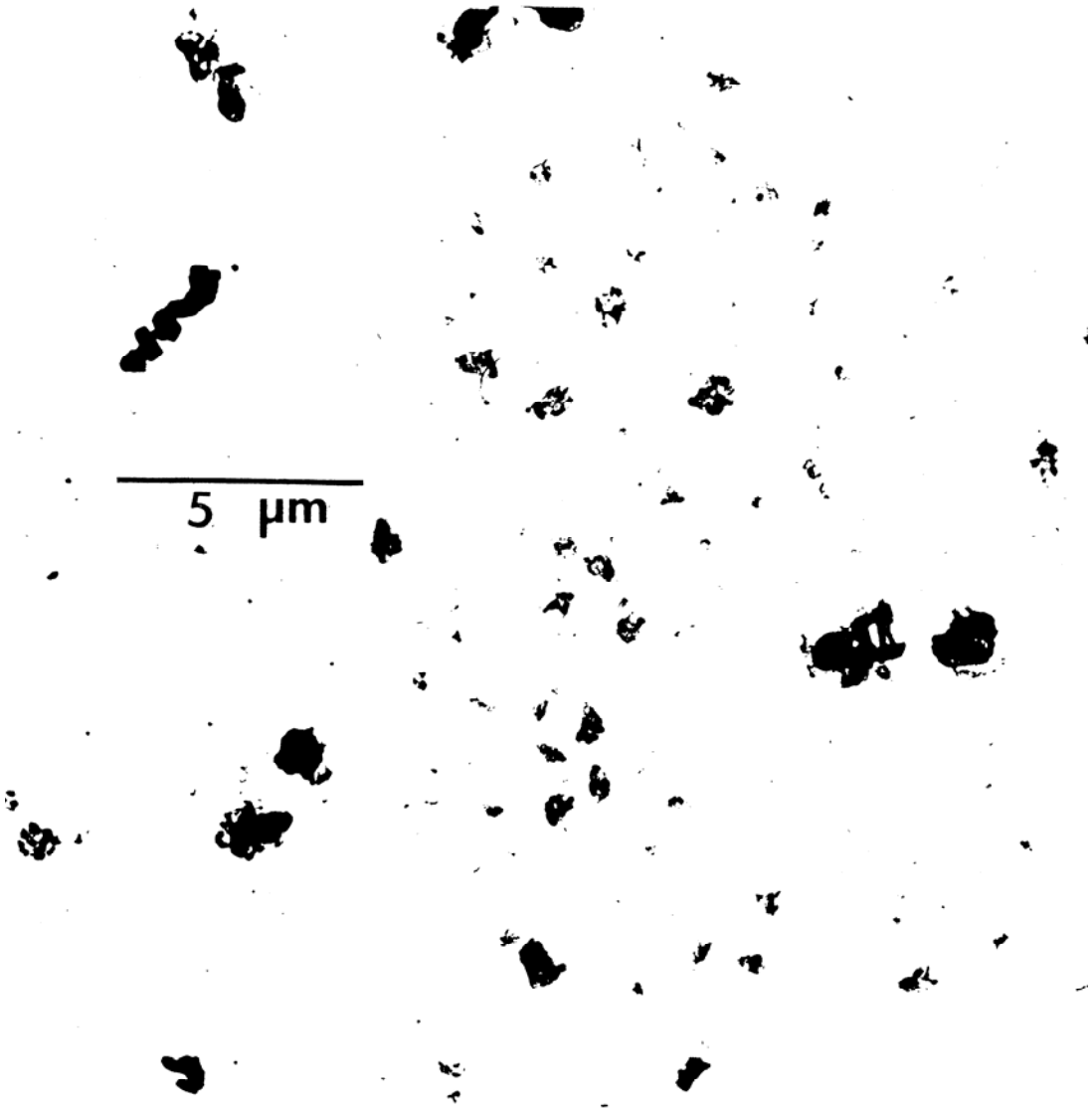
AIR QUALITY STANDARDS FOR PM

Criteria Pollutant	24 Hour Standard ($\mu g/m^3$)	Annual Standard ($\mu g/m^3$)
PM_{10}	150	revoked
$PM_{2.5}$	35	15

ATMOSPHERIC PM (PHALEN, 2002)



EM VIEW OF PM



PARTIAL LIST OF PROBLEMATIC PM CONSTITUENTS, COMPONENTS & PROPERTIES

- **COARSE PM MASS**
- **FINE PM MASS**
- **ULTRAFINE PM COUNT**
- **PM SURFACE AREA**
- **REACTIVE METALS**
- **METAL OXIDES**
- **SILICA**
- **CARBON**
- **ORGANICS**
- **ACIDS**
- **OXIDANTS**
- **COMBUSTION PRODUCTS**
- **SULFATES**
- **NITRATES**
- **MICROORGANISMS**
- **SPORES**
- **POLLENS**
- **INSECT PROTEINS**
- **ANIMAL PROTEINS**
- **PLANT PROTEINS**
- **TEMPERATURE**
- **HUMIDITY**
- **THE MIX**
- **GASES**
- **INDOOR POLLUTANTS**
- **BEHAVIORAL FACTORS**
- **CHANGES IN LEVELS**

PM CHARACTERISTICS THAT PRODUCE ADVERSE HEALTH EFFECTS

Characteristic	Mechanism	Particle Sources
Ultrafine Size	Increased Airway Permeability, Inflammation	Combustion, High-Temperature Processes, Reactive Gases and Vapors
Silica Content	Inflammation, Macrophage Injury, Cell Killing	Soil, Sandblasting, Ore Recovery
Acidity	Mucus Secretion, Impaired Mucus Clearance, Bronchoconstriction	Combustion of Sulfur-Containing Fuels, Internal Combustion Engines
Biogenic Aerosols	Bronchoconstriction, Inflammation, Infection	Plants, Animals, Fungi, Bacteria, Viruses
Metals and Highly Reactive Species	Inflammation, Cell Killing	Fuel Combustion, Industrial Processes, Soil, Photochemistry
Oxidative Properties	Cell Damage	Combustion Products, Industrial Processes, Soil, Photochemistry
Mixtures	Various	Various

NON-PARTICLE EXPLANATIONS OF ASSOCIATIONS BETWEEN HEALTH AND PM

Pathway	Potentially Susceptible
Meteorology	Persons with Advanced Lung and Heart Disease
Elevated Indoor Exposures Related to PM Episodes	Asthmatics, Bronchitics, Emphysemics, Young Children, Elderly, Immunocompromised, Cardiac Patients
Gaseous Pollutants (CO, SO_2, NO_X, Volatile Organics)	Cardiac Patients, Asthmatics, Others with Advanced Lung Disease
Panic or Fear of Air Pollution	Cardiac Patients, Asthmatics, Other Groups with Fragile Health

SOME PARTICLE SOURCES

I. ANTHROPOGENIC

- **COMBUSTION OF FUELS**
- **ATOMIZATION OF PRODUCTS**
- **RESUSPENSION OF DUST**
- **COMMINUTION OF SOLIDS**
- **CONDENSATION OF VAPORS**

II. NON-ANTHROPOGENIC

- **MICROORGANISMS**
- **ANIMALS (SKIN, FUR, ETC.)**
- **PLANTS (SPORES, POLLEN, ETC.)**
- **WATER SPRAY**
- **WIND EROSION OF SOIL**
- **CONDENSATION OF VOLATILES**
- **SMOKE**

III. SECONDARY PARTICLES

- **GAS TO PARTICLE PRODUCTS**
- **REACTION PRODUCTS**
- **AGGREGATES AND AGGLOMERATES**

SOURCES OF PM AND ASSOCIATED BENEFITS

Sources	Emissions	Benefits
Farming and Dairying	Dust, Diesel exhaust, Ammonia, Sprays, Biogenic aerosols	Without affordable food and milk, malnutrition and starvation become realities. Ammonia neutralizes air acidity.
Electric Power Generation	Fly ash, Metal-containing aerosols, Sulfur-containing particles, Various gases and vapors. (Nuclear plants are essentially free of air pollutants.)	Affordable and reliable electricity is needed for heating, air conditioning, food preservation and other survival- and economic-related activities.
Diesel Engine Operation	Fine particles, Gases, Vapors	Cost-effective diesel engines are essential for the operation of heavy trucks, trains, ships, and farm, mining and construction equipment. They are important to human health and prosperity.
Manufacturing	Coarse and fine particles, Gases, Vapors	Goods such as food, clothing, medications and machinery are essential to survival.
Miscellaneous Combustion	Fine and ultrafine particles, Gases, Vapors	Waste reduction, manufacturing, transportation, electric power generation and other essential activities depend on fuel combustion.
Miscellaneous Spraying	Fine particles, Gases, Vapors	Paints, pesticides, disinfectants, etc. are important for protecting valuable goods and controlling disease.

DEVELOPMENTS

- **EPA PROPOSES NEW PM STANDARDS**
- **CONGRESSIONAL HEARINGS ON OZONE AND PM STANDARDS**
- **NATIONAL ACADEMY OF SCIENCES COMMITTEE FORMED TO DEFINE RESEARCH AGENDA**
- **RESEARCH AGENDA STARTED**
- **NATIONAL PM RESEARCH CENTERS ESTABLISHED**
- **U.S. SUPREME COURT UPHOLDS EPA'S RIGHT TO SET STANDARDS**

NRC COMMITTEE'S FINAL REPORT

- **REVIEWED 1998 TO MID-2002 PROGRESS**
- **A MAJOR DEFICIENCY IS THAT THE HAZARDOUS PM COMPONENTS ARE STILL UNKNOWN**
- **PROGRESS HAS BEEN SUBSTANTIAL**
- **SUSCEPTIBLE POPULATIONS INCLUDE DIABETICS, OLDER ADULTS AND PROBABLY ASTHMATICS, COPD PATIENTS AND THOSE AT RISK FOR CARDIOVASCULAR DISEASE**
- **MAJOR POTENTIAL MECHANISMS ARE OXIDATIVE STRESS AND INFLAMMATION (CARDIOVASCULAR AND PULMONARY)**
- **EPIDEMIOLOGIC MODEL DEVELOPMENT IS NEEDED (EFFECT OF MEASUREMENT ERRORS AND MULTI-COMPONENT EXPOSURES)**

NRC FINAL REPORT: 2

- **SEVEN REMAINING HIGH PRIORITY CHALLENGES**
  1. **RELATING EMISSIONS TO EXPOSURES**
  2. **EFFECTS OF MIXTURES**
  3. **IMPROVED AIR QUALITY MONITORING**
  4. **LONG TERM EXPOSURE EFFECTS**
  5. **IMPROVED TOXICOLOGY STUDIES (INHALATION, AND RELEVANT DOSES)**
  6. **MULTI-COMPONENT RATHER THAN SINGLE POLLUTANT NAAQS FOCUS**
  7. **INTEGRATION ACROSS DISCIPLINES**
- **STRONGER TOOLS ARE NEEDED FOR SYNTHESIZING NEW INFORMATION**
- **CONTINUED INVESTMENT AND INDEPENDENT MONITORING AND GUIDANCE ARE NEEDED**
- **“MUCH IS STILL TO BE LEARNED.”**

PM LITERATURE UPDATE

- **OVER 40 PUBLISHED REVIEWS**
- **HUNDREDS OF ARTICLES IN LAST 5 YEARS**
- **SELECTED QUOTES**

"…to inform future regulatory discussions on control strategies, a systematic research effort is required to develop a better understanding of the health effects of different components of the PM mixture and the mechanisms of PM effects." HEI, 2002

"…the impact of hazards other than pollution (both social and environmental), which are common… shorten the lifespan so much that the contribution of pollutants to the decline in life expectancy cannot be detected." Kozlov, 2004

"…the whole body of knowledge supports the role of PM as a type of pollution with great influence on human health." Englert, 2004

QUOTES: 2

"PM10 was a significant predictor of mortality when controlling for gaseous pollutants…" Schwartz, 2004

"…there is evidence consistent with publication bias, so limited confidence may be placed on summary estimates of effect." Ward and Ayres, 2004

"…available evidence is compatible with either a small adverse effect of particulate air pollution on fetal growth and duration of pregnancy or with no effect." Glinianaia et al., 2004

"…results indicate that equal masses of PM can induce disparate lung injuries suggesting that particle components may be relevant in assessing health effects…" Ghio, 2004

QUOTES: 3

"This synthesis (of 109 studies) leaves little doubt that acute air pollution exposure is a significant contributor to mortality." Stieb et al., 2002

"Mental stress during daily life, including reported feelings of tension, frustration and sadness, can more than double the risk of myocardial ischemia in the subsequent hour." Gullette et al., 1997

"Reductions in respiratory and cardiovascular death rates in Dublin suggest that control of particulate air pollution could substantially diminish daily death." Clancy et al., 2002

"These findings provide no compelling evidence that short-term increases in relatively low concentrations of outdoor air pollutants have an adverse effect on individuals at risk of cardiac arrhythmias." Vedal et al., 2004

THE BIG QUESTIONS: PARTICULATE AIR POLLUTION

- **WHO WITHIN THE POTENTIALLY SUSCEPTIBLE GROUPS DIES OR IS SERIOUSLY HARMED?**
- **WHAT SUBSTANCES ARE LIKELY TO CAUSE THIS HARM? (AND IN WHAT FORMS, AMOUNTS & MIXTURES?)**
- **ARE THE PARTICLES REALLY CAUSAL, OR ARE THEY SURROGATES?**
- **WILL CONTROL OF PM MASS MEASURABLY IMPROVE HUMAN HEALTH?**
- **WHAT METRIC SHOULD BE USED TO VERIFY ACCEPTABLE PM LEVELS?**
- **WILL ANY LEVEL BE LOW ENOUGH TO PREVENT ALL HARM?**
- **COULD TIGHTENED AIR QUALITY CRITERIA FOR PARTICLES PRODUCE EXCESS DEATHS FROM OTHER CAUSES? (MANUFACTURERS, ECONOMISTS & EPIDEMIOLOGISTS MUST COLLABORATE ON THIS)**

TOXICOLOGY

OUR BASIC TENET – IS IT IN QUESTION?

- **"ALL SUBSTANCES ARE POISONS: THERE IS NONE WHICH IS NOT POISON. THE RIGHT DOSE DIFFERENTIATES A POISON FROM A REMEDY."**

  PHILIPPUS AUREOLUS THEOPHRASTUS BOMBASTUS VON HOHENHEIM-PARACELSUS (1493-1541)

- **"PARACELSUS'…VIEWS… REMAIN AN INTEGRAL PART OF THE PRESENT STRUCTURE OF TOXICOLOGY."**

  GALLO, M.A. & DOULL, J. CASARETT AND DOULL'S TOXICOLOGY: THE BASIC SCIENCE OF POISONS, FOURTH EDITION, PERGAMON, 1991, CH. 1.

BUT, WHAT IF:

- **VARIATIONS IN ENVIRONMENTAL QUALITY ARE ESSENTIAL FOR MAINTAINING NORMAL DEFENSE MECHANISMS, AND THUS GOOD HEALTH IN MOST HUMANS, AND**

- **SUCH VARIATIONS, NO MATTER HOW TINY, WILL ALWAYS TRIGGER SOME MORBIDITY AND MORTALITY?**

- **AS THE AIR GETS CLEANER, THE SENSITIVITY OF THE POPULATION TO VARIATIONS MAY INCREASE, PRODUCING ADDITIONAL RISKS.**

SOME IDEAS THAT CAN BE QUESTIONED

- **LESS POLLUTION IS BETTER**
- **A SAFE POLLUTANT LEVEL CAN BE FOUND**
- **ADVERSE & NON-ADVERSE EFFECTS ARE SEPARABLE**
- **ANY RISK OR STRESS IS BAD**
- **PROTECTING SENSITIVES PROTECTS EVERYONE**
- **SMALL RISK X LARGE POPULATION = HARM**
- **ISOLATING RISK FACTORS MAKES SENSE**
- **ISOLATING POPULATIONS AT RISK MAKES SENSE**
- **THE LATEST SCIENCE IS THE BEST SCIENCE**
- **NATURAL CHEMICALS ARE SAFER THAN ANTHROPOGENIC CHEMICALS**

EFFECT OF VARIOUS FACTORS ON AVERAGE HUMAN LIFESPAN

Factor	Effect on lifespan
Residence	
Gambia	26 Years Lost
United States	12 Years Added
Japan	14 Years Added
Moving to Missouri from California	2.5 Years Lost
Occupation / Education	
U.S. President (assassination)	5.1 Years Lost
Firefighter	3.5 Years Lost
Coal Miner	3.2 Years Lost
Educator	3.1 Years Added
Primary School Dropout	2.2 Years Lost
College Degree	2.2 Years Added
Lifestyle / Environment	
Alcoholic	11 Years Lost
Unmarried Male	9.6 Years Lost
Male, Relative to Female (USA)	7.7 Years Lost
Living in Poverty (USA)	6.9 Years Lost
Unmarried Female	4.4 Years Lost
Cigarette smoker (average for male & female)	3.5 Years Lost
35% Overweight (average for male & female)	2.6 Years Lost
Driving Small Instead of Large Car (USA)	70 Days Lost
One Pound Overweight	34 Days Lost
Air Pollution (USA Average)	23 Days Lost
Natural Radiation Exposure (USA)	8 Days Lost

WHAT IS KNOWN?

- **EPIDEMIOLOGY**
  Something associated with short-term PM changes and long-term levels consistently correlates with adverse human health effects.

- **PM POLLUTANTS**
  PM is the only regulated air pollutant that is not chemically-specific. PM is always associated with gas/vapor co-pollutants and behavioral events. Control of one PM component can elevate others.

- **TOXICOLOGY**
  Toxicology only describes adverse effects of agents; all agents are toxic. The potentially lethal PM components at ultra low doses are elusive.

- **NEEDED RESEARCH**
  A massive worldwide effort is underway. The questions are becoming more focused. Assimilation of results is a challenge.

WHAT IS UNKNOWN? - 1 -

- **WHO, WHAT & HOW?**
  Who specifically is being harmed is still vague, as is what properties of PM are most harmful. Also, the potential mechanisms of injury comprise a large list.

- **THE METRIC**
  The "metric" is jargon for a specific measurable PM property that, when sufficiently reduced, will eliminate, or greatly reduce, adverse health effects. The "metric" is elusive, but it does not appear to be PM mass. Other PM properties including count, chemistry, mixtures, gases, and temporal exposure factors must be considered.

- **EPISODES**
  More research is needed to understand how PM episodes differ from "normal" levels with respect to chemistry, size distributions, etc.

- **PERSONAL EXPOSURES**
  Each exposure to PM is unique – except for Siamese twins. Additional research on potentially vulnerable populations/individuals is needed.

WHAT IS UNKNOWN? - 2 -

- **EFFECTS OF CONTROL MEASURES**

  Depending on the specific control actions, there is evidence that human health can be improved. However, the confounding effects of air chemistry, standard of living, and changing lifestyle need to be better understood.

- **TRADEOFFS**

  Controlling PM levels unavoidably impacts food production, transportation, the costs of electrical power and the general economy. A holistic approach aimed at maximizing human health and welfare must be developed. Resources are limited, and changes in production/lifestyle can require decades.

RECOMMENDATIONS - 1 -

- **RESEARCHERS**
  - **Increase communication across disciplines.**
  - **Integrate research into a larger picture.**
  - **Develop better tools that are practical.**
  - **Communicate the limitations/uncertainties associated with one's work.**
  - **Don't generate/support unrealistic public fears.**

- **REGULATORS**
  - **Consider tradeoffs more thoroughly.**
  - **Realize the plasticity of physiological systems.**
  - **Attempt to optimize human health rather than eliminating all risk.**
  - **Consider the time scales required for solidifying knowledge and altering technology.**
  - **Be more holistic and sophisticated in analyzing issues.**

- **LEGISLATORS**
  - **Give up on legislating away all harm.**
  - **Strive to maximize human health and well being.**
  - **Appoint well qualified top-level administrators.**
  - **Read Chapters 8 & 9 in *The Particulate Air Pollution Controversy*.**

RECOMMENDATIONS - 2 -

- **THE PUBLIC**
  - **Understand how science and industry further human health.**
  - **Give science and industry time to work.**
  - **Support quality training of needed experts.**
  - **Listen to the qualified experts.**
  - **Abstain from exerting uninformed pressures via litigation.**

- **INDUSTRY**
  - **Continue to work on safer, cleaner products and processes.**
  - **Perform/support research on your products and processes.**
  - **Anticipate environmental and health trends.**
  - **Educate scientists, regulators, legislators & the public on your importance.**
  - **Stop blaming the "other guys" for pollution.**

LESSONS LEARNED

- **TIME**

  The time scales of science, industry, culture and regulation must be brought into better harmony – because the world has to work.

- **SCIENCE**

  New problems require new thinking, methods, and modes of coordination, otherwise, science will be irrelevant to their solution.

- **HEALTH**

  So many factors influence public health that simple analyses/solutions may do more harm than good. A practical, flexible, informed, open infrastructure must be supported and maintained.

- **CULTURE / HUMAN NATURE**

  Being narrowly focused on individual problems is inferior to taking a more thoughtful, patient and holistic approach.

CONCLUDING NOTES

- **SOMETHING ASSOCIATED WITH PM & PM CHANGES IS ADVERSELY AFFECTING HEALTH**
- **WHAT, WHO & HOW ARE UNCLEAR**
- **IS IT POSSIBLE TO PREVENT THE PREMATURE DEATHS OF THE VERY SUSCEPTIBLE?**
- **THE ONGOING RESEARCH EFFORT IS PRODUCTIVE**
- **WILL THE PM ISSUE EMERGE IN WORKPLACES & OTHER INDOOR ENVIRONMENTS?**

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