University of Maryland Baltimore County - UMBC

Phys650 - Special Topics in Experimental Atmospheric Physics (Spring 2009)

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Introduction to Atmospheric Aerosols:

Definition: Aerosols are suspended particulate matter (liquid or solid) – suspended in a fluid. In terms of atmospheric aerosols, this fluid is air. The Atmospheric Aerosol size distribution extends many orders of magnitude, from nm up to hundreds of microns.

Some Motivations to Study Aerosols

- Health Effects
- Property Damage
- Visibility
- Cloud Formation and Modification
- Climate Effects
- Transport of Nutrients

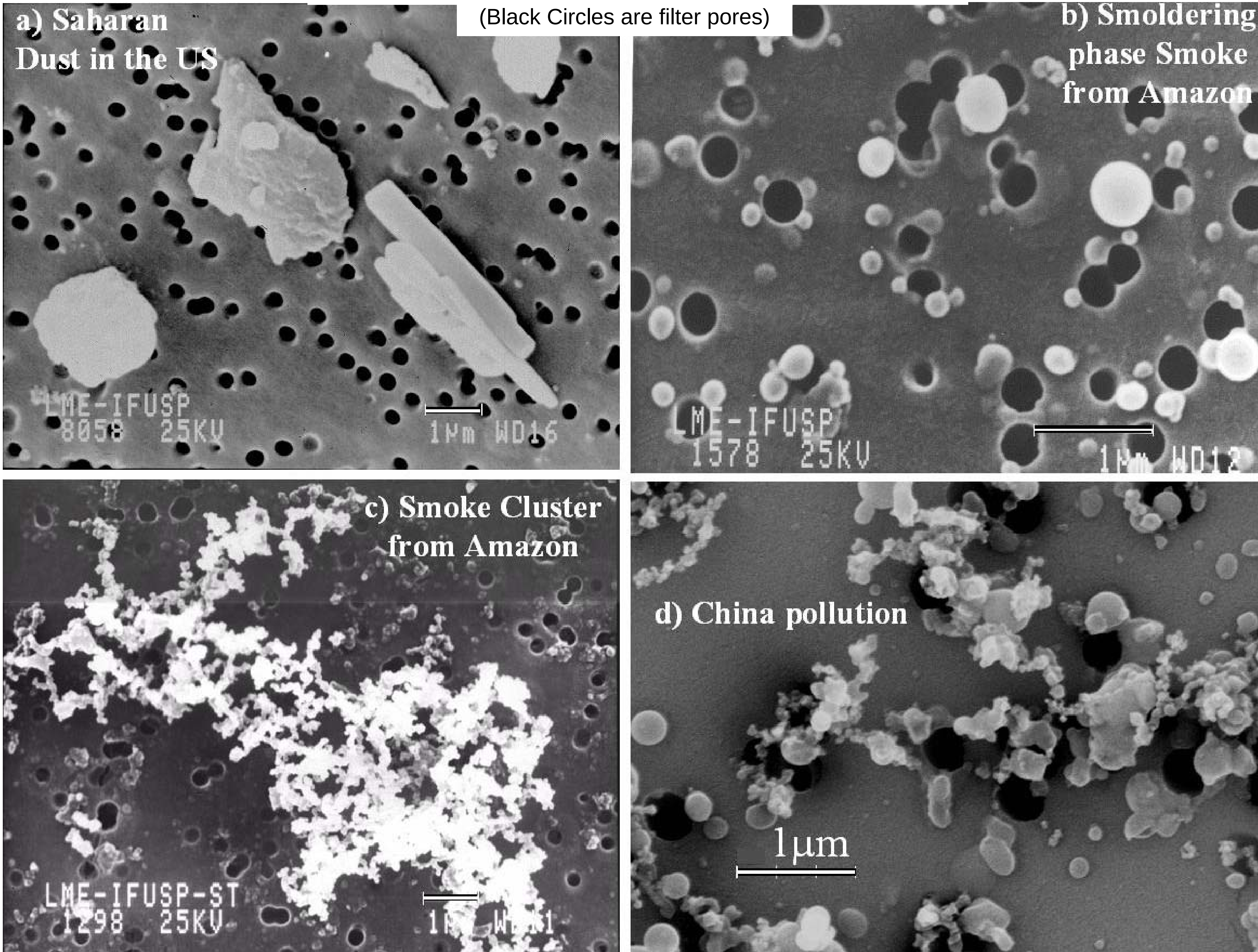
Amazon in the Wet and Dry Season

Clear day
Visibility ~ ??? km
N_{CN} ~ 500 cm^{-3}
BC ~ 0.2 $\mu g\ m^{-3}$

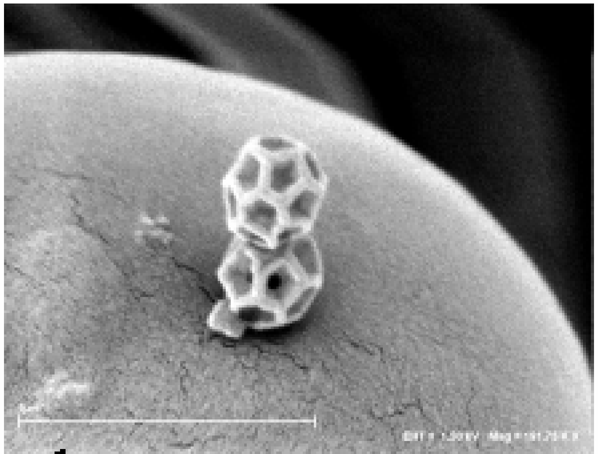
Smoke haze
Visibility ~ 800 m
N_{CN} ~ 10000 cm^{-3}
BC ~ 7 $\mu g\ m^{-3}$

Scanning Electron Microscopy of Aerosols:

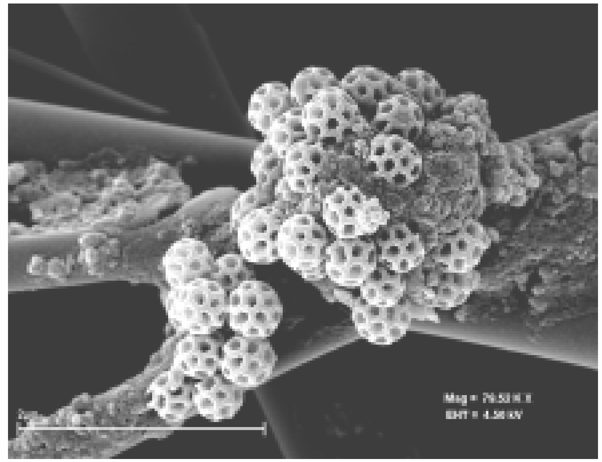
(Black Circles are filter pores)



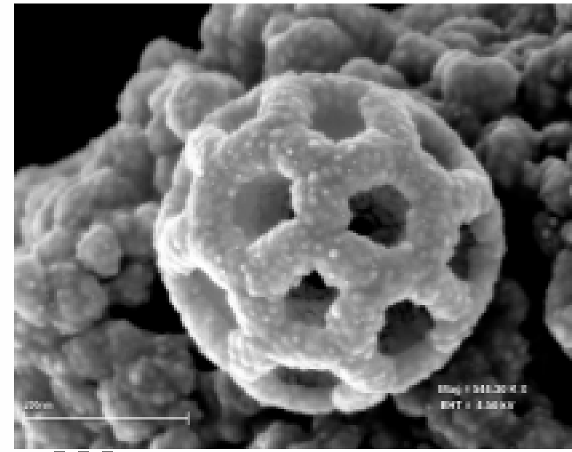
Natural biogenic aerosol particles



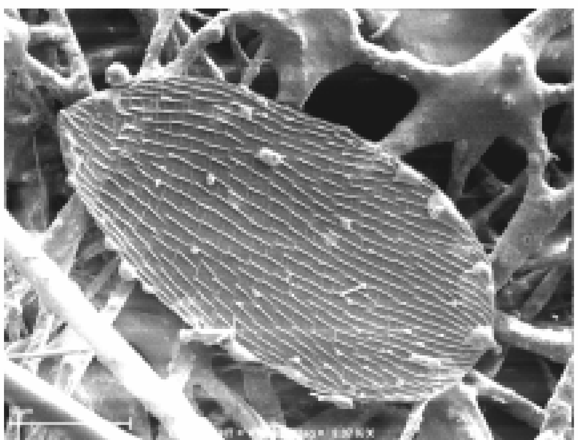
1 μm



2 μm

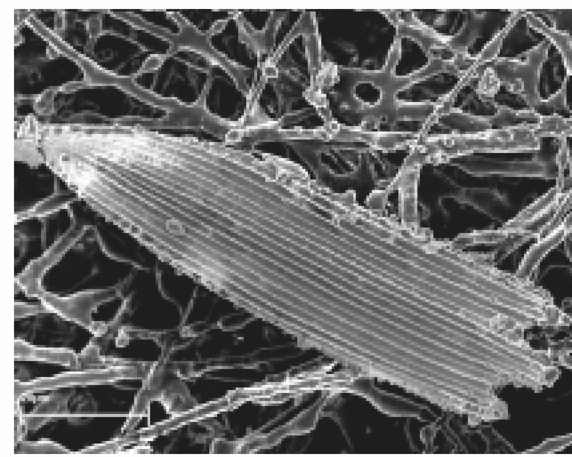


200 nm



10 μm

2 μm



20 μm

EPMA photos from Gunther Helas, MPIC

These notes are based on the following references:

- Aerosol Technology, Properties, Behavior, and Measurement of Airborne Particles, William C. Hinds, 1982, John Wiley & Sons, Inc.

- Atmospheric Chemistry and Physics of Air Pollution, John H. Seinfeld, 1986, John Wiley & Sons, Inc.

- ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences

- Prof. Colin O'Dowd Aerosol Course Presentation

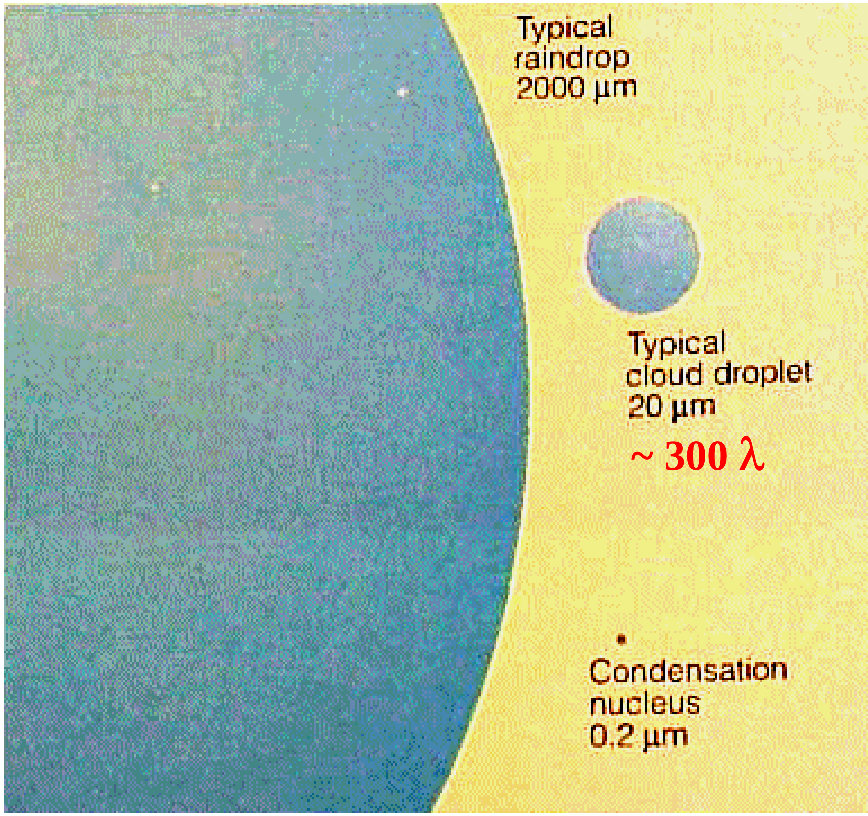
Molecular Mean Free Path: AVG distance between collisions

$$\lambda = \frac{<c>}{\sqrt{2}N\pi\sigma^2 <c>}$$

For air, at 20C and 1 atm:

λ = 0.066μm

Typical Size Scales



Note the different scale for each figure.

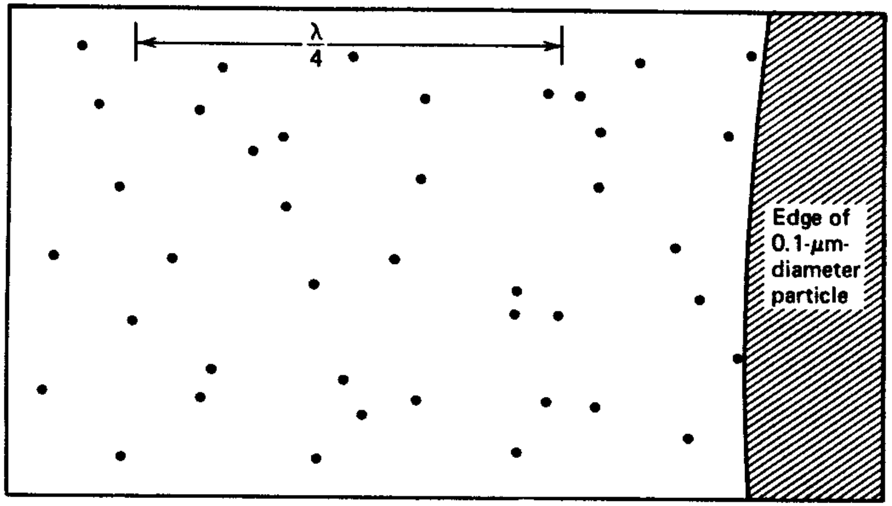


Figure 2.4 Relative size and spacing of air molecules at standard conditions.

Adapted From ENV 6130 Course on Aerosol Mechanics by Prof. Chang-Yu Wu, University of Florida, Department of Environmental Engineering Sciences

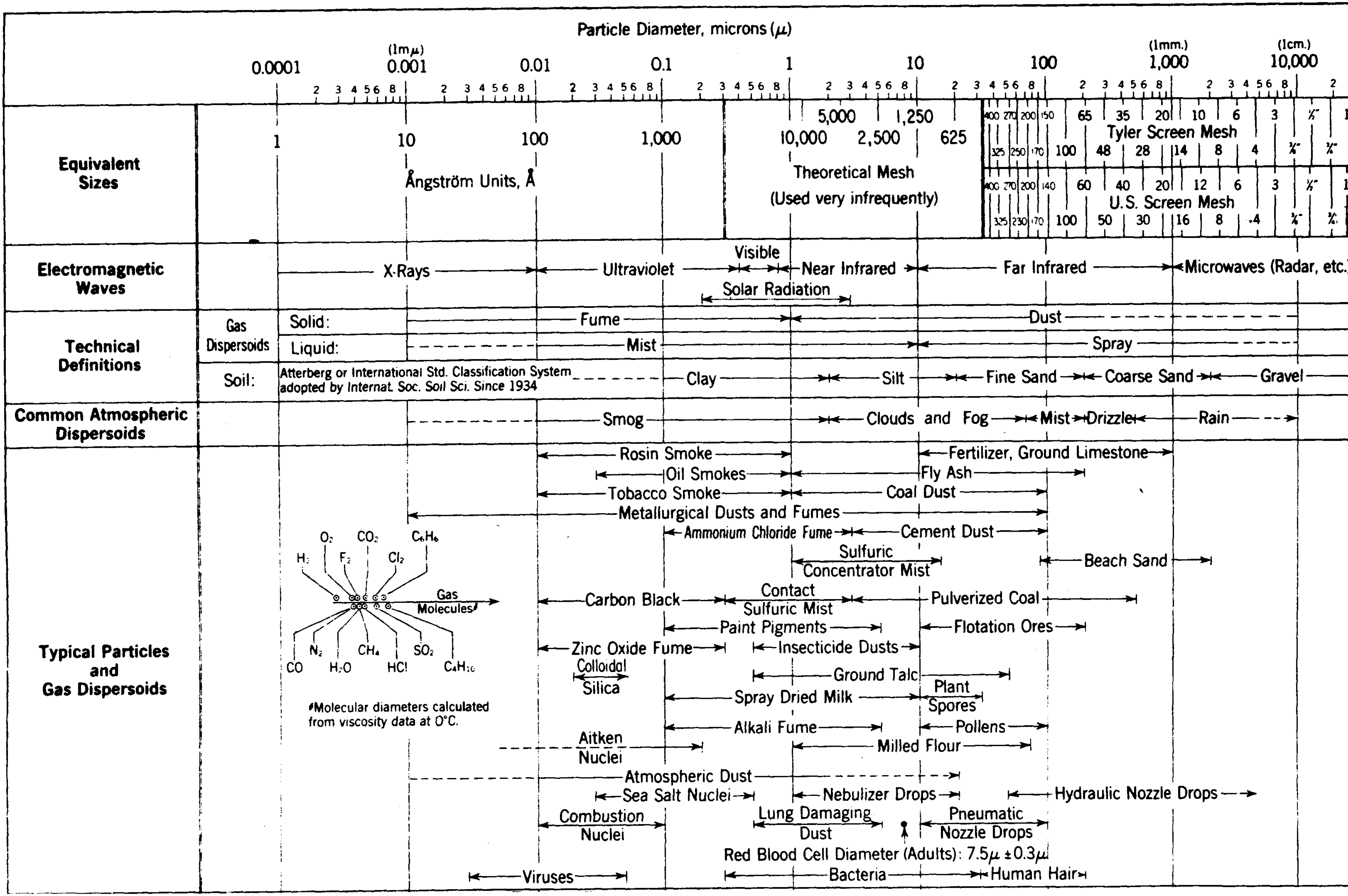


Figure 1. Particle size ranges for aerosols. Reprinted courtesy of SRI International, formerly Stanford Research Institute.

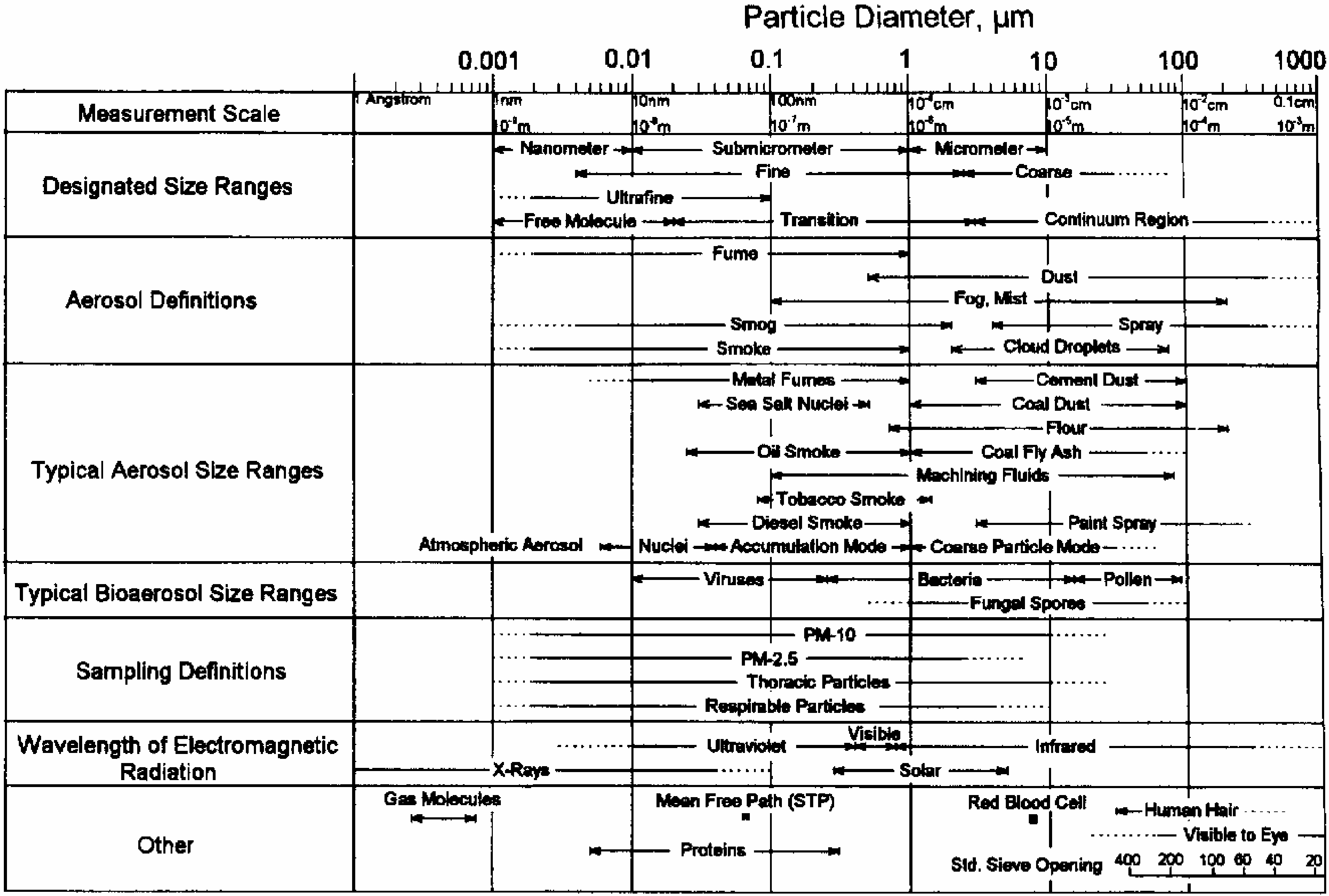
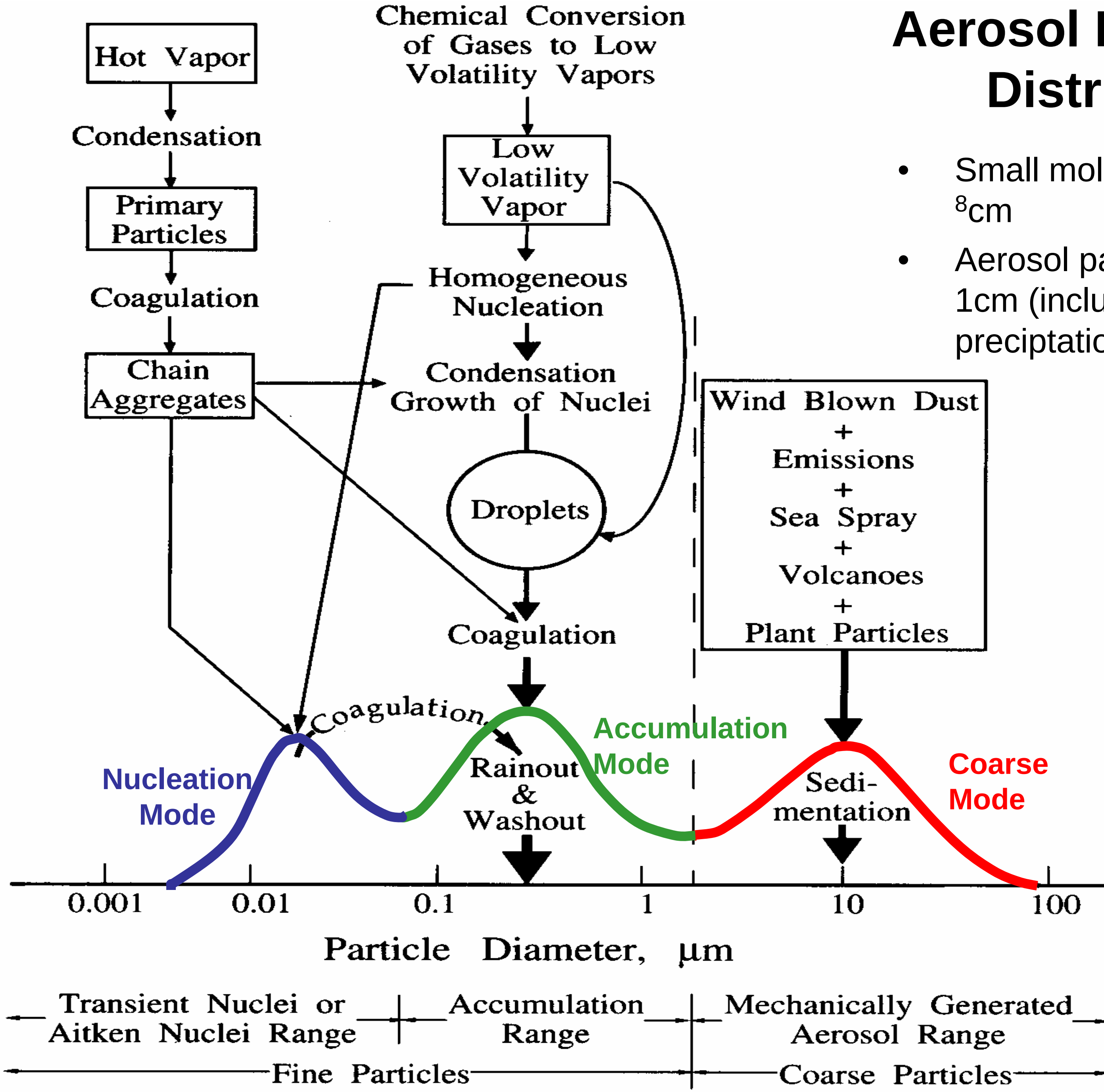


FIGURE 1.6 Particle size ranges and definitions for aerosols.

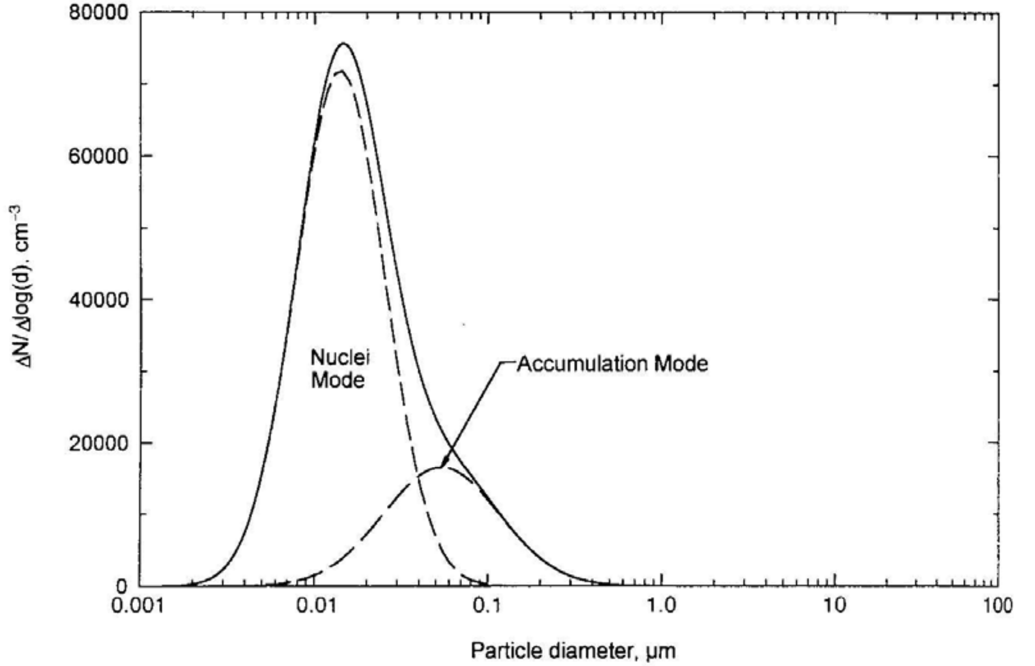
Aerosol Particle Size Distributions

- Small molecule or atom ~ 10^{-8}cm
- Aerosol particles ~10^{-7}cm to 1cm (including cloud and preciptation droplets, and hail)

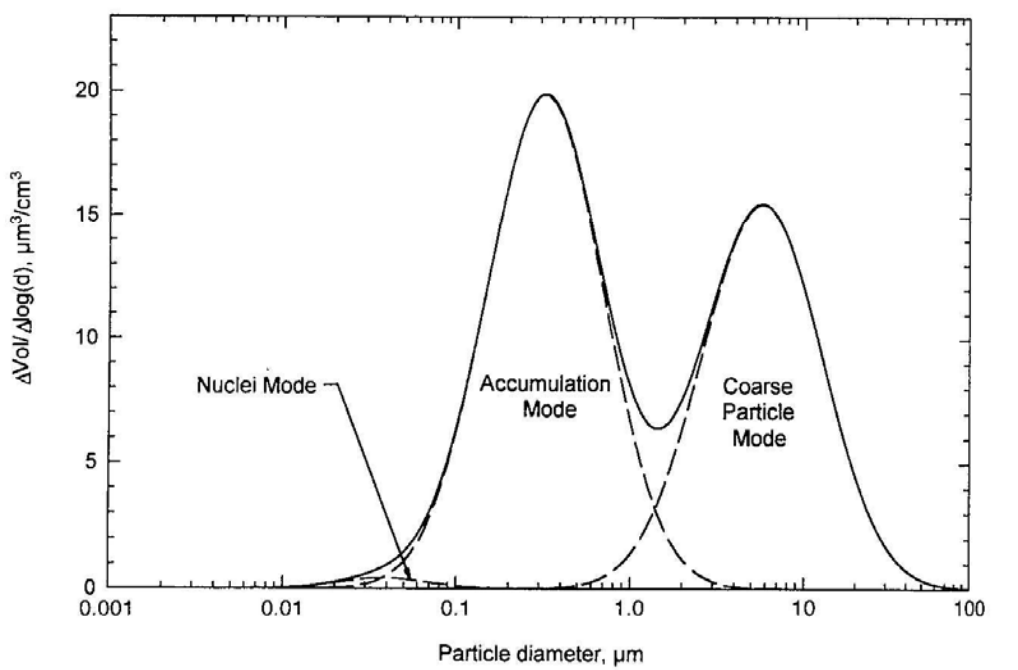


Extracted from Seinfeld and Pandis 1998

- Diffusion
- Coagulation
- Sedimentation
- Scrubbing
- Condensation
- Reaction
- Generation
  - Mechanical
  - Chemical



(c)



(d)

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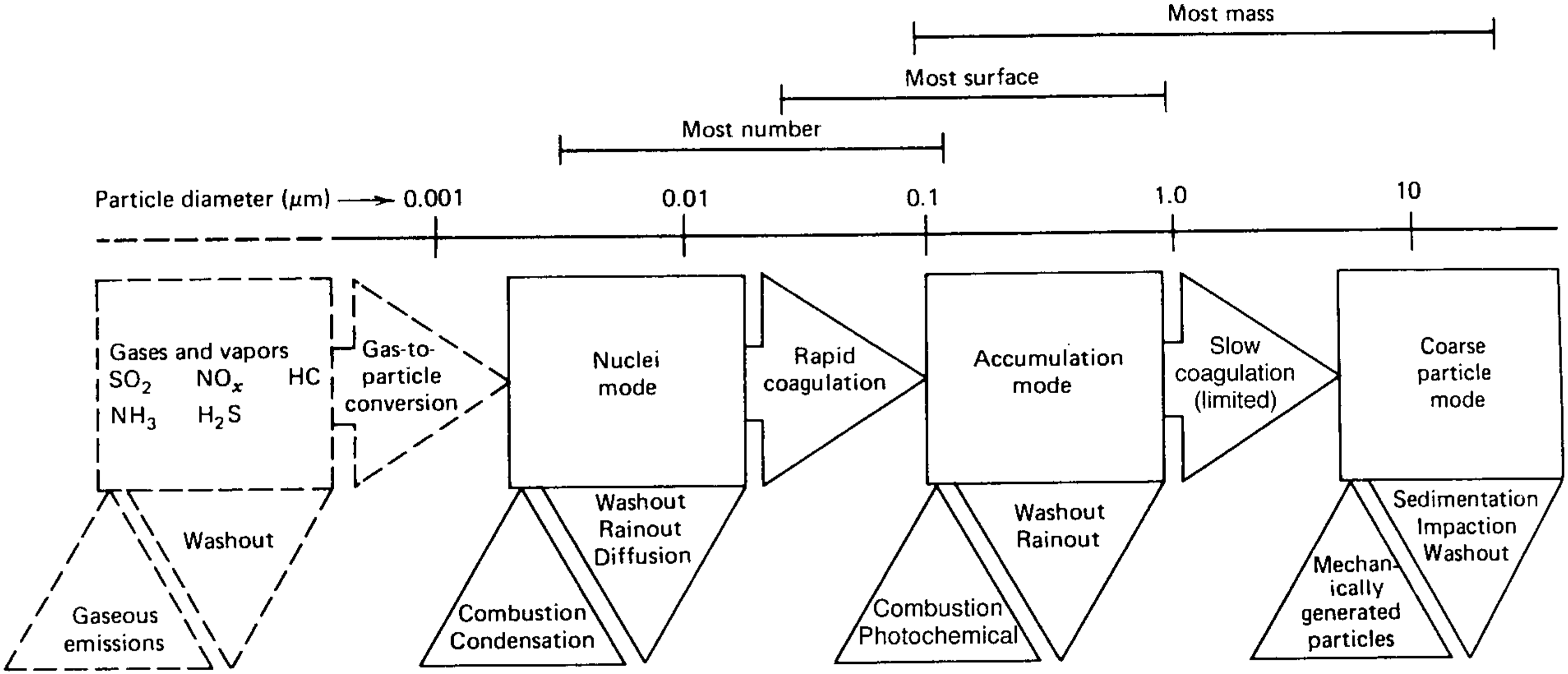
Aerosol Processes in the Atmosphere

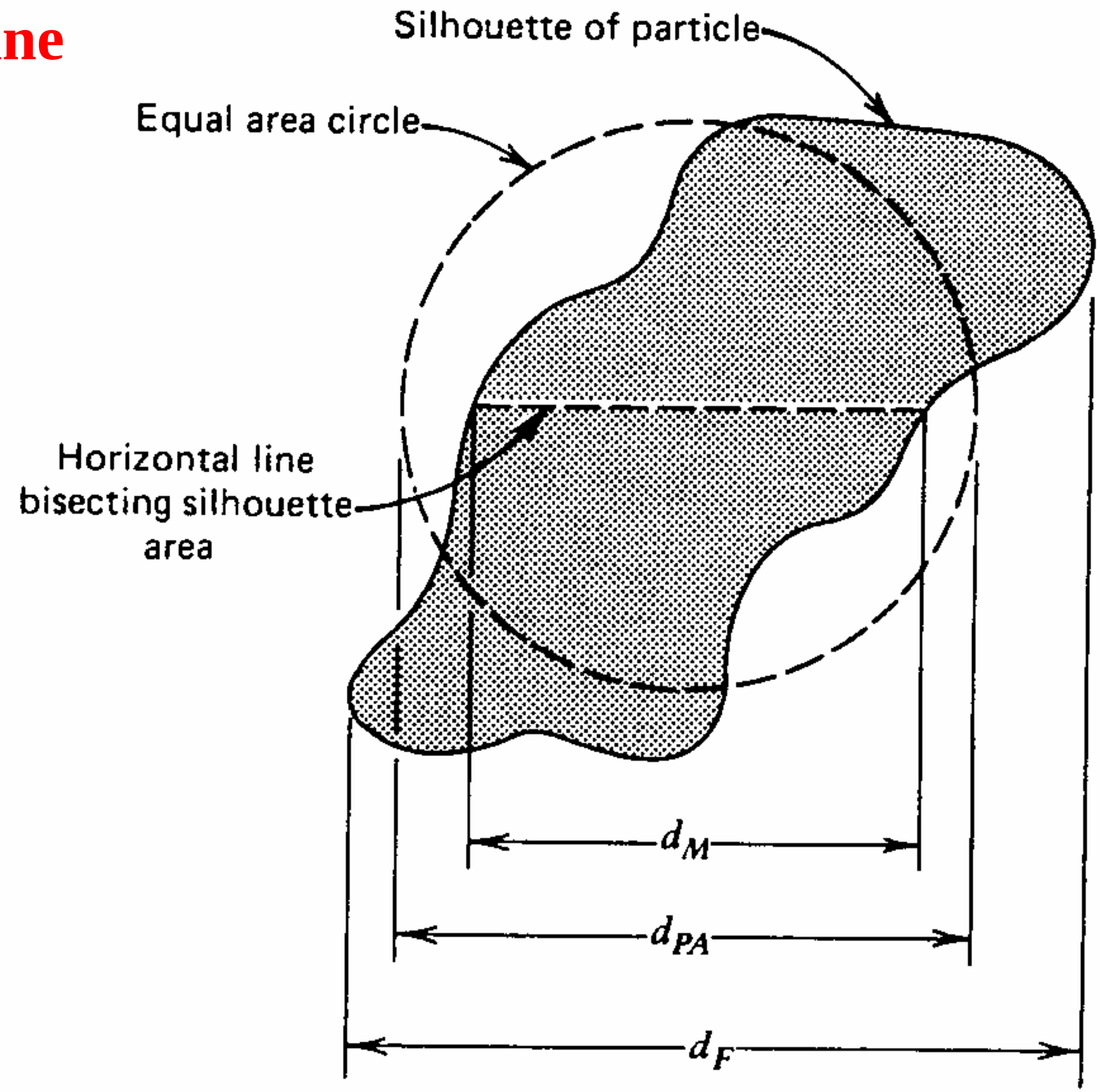


Hinds, Aerosol Technology, 1999

Microscopic Measurement of Particle Size

Q: how do you determine this particle's size?

- Equivalent sizes of Irregular Particles
  - Martin's diameter:
  - Feret's diameter:
  - Projected area diameter:



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Relaxation time τ for a unit density particle in the air(p=1 atm, T=20°C)

Diameter (µm)	$v_{TS}=\tau g$	τ (sec)	Stop Distance (v_o=1m/s)	Stop Distance (v_o=10m/s)
0.05	0.39 µm/s	$4x10^{-8}$	0.04 µm	$4x10^{-4}$ mm
0.1	0.93 µm/s	9.15^{-8}	0.092 µm	$9.15x10^{-4}$ mm
0.5	10.1 µm/s	$1.03x10^{-6}$	1.03 µm	0.0103 mm
1	35 µm/s	$3.57x10^{-6}$	3.6 4µm	0.0357 mm
5	0.77 mm/s	$7.86x10^{-5}$	78.6 µm	0.786 mm
10	3.03 mm/s	$3.09x10^{-4}$	309 µm	3.09 mm
50	7.47 cm/s	$7.62x10^{-3}$	7.62 mm	76.2 mm

Note: 1m/s = 3.6km/h = 2.2mi/h

Aerodynamic Diameter

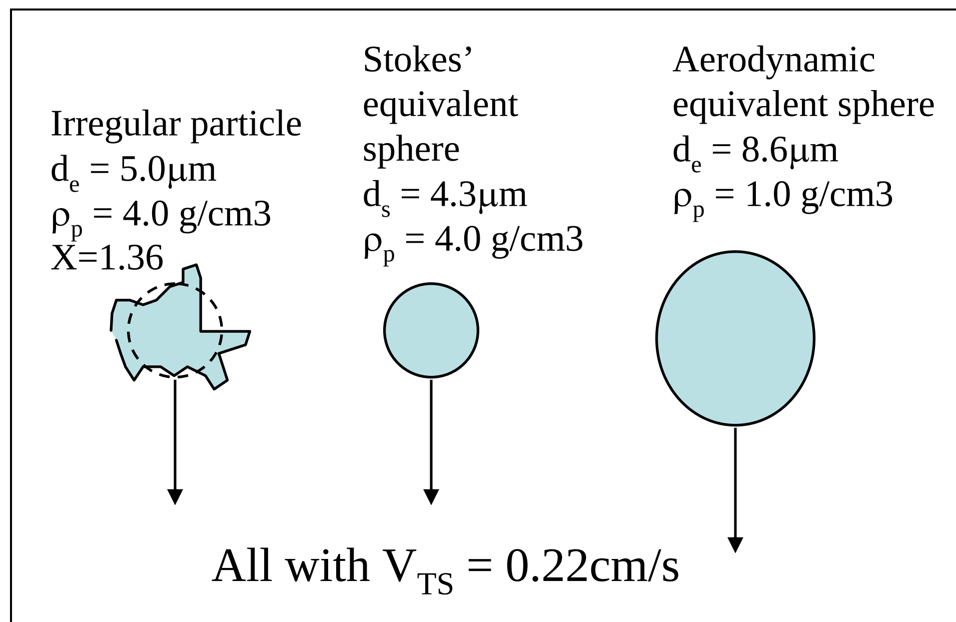
- The **Stokes diameter**, d_s, is the diameter of the sphere that has the same density and settling velocity as the particle.
- The **aerodynamic diameter**, d_a, is the diameter of the unit density ($\rho_0 = 1$ g/cm^3) sphere that has the same settling velocity as the particle.

$$V_{TS} = \frac{\rho_p d_e^2 g}{18\eta X} = \frac{\rho_s d_s^2 g}{18\eta} = \frac{\rho_0 d_a^2 g}{18\eta}$$

Cunningham factor should be included if $d_p < 1$ μm

$$X = \frac{\rho_p}{\rho_0}\left(\frac{d_e}{d_a}\right)^2 = \frac{\rho_p}{\rho_s}\left(\frac{d_e}{d_s}\right)^2$$

$$d_a = d_e\sqrt{\frac{\rho_p}{\rho_0 X}} = d_s\sqrt{\frac{\rho_s}{\rho_0}}$$



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Inertial Impaction

- **Stokes number**: the ratio of the stopping distance of a particle to a characteristic dimension of the obstacle

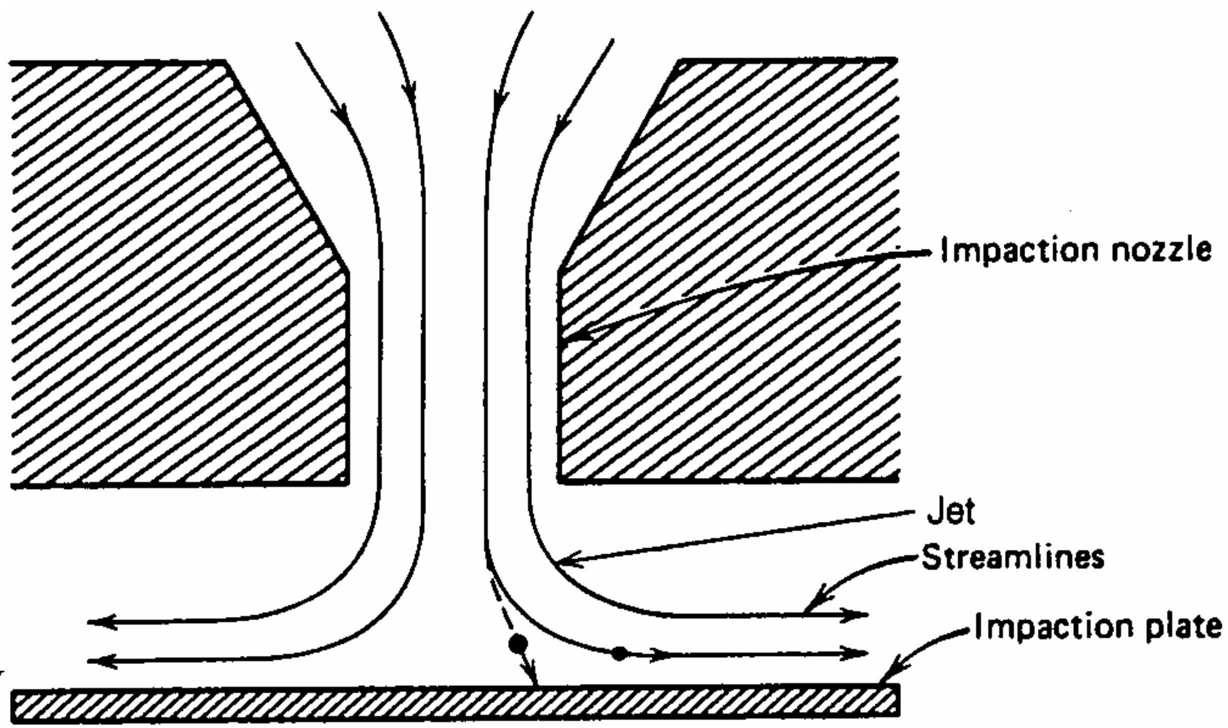
$$Stk = \frac{S}{d_c} = \frac{\tau U_0}{d_c}$$

Q: Stk << 1? Stk >> 1?

- For an impactor

$$Stk = \frac{\tau U}{D_j / 2} = \frac{\rho_p d_p^2 U C_c}{9 \mu D_j}$$

Impaction efficiency $= f(Stk)$



http://plaza.ufl.edu/alallen/cyclone/

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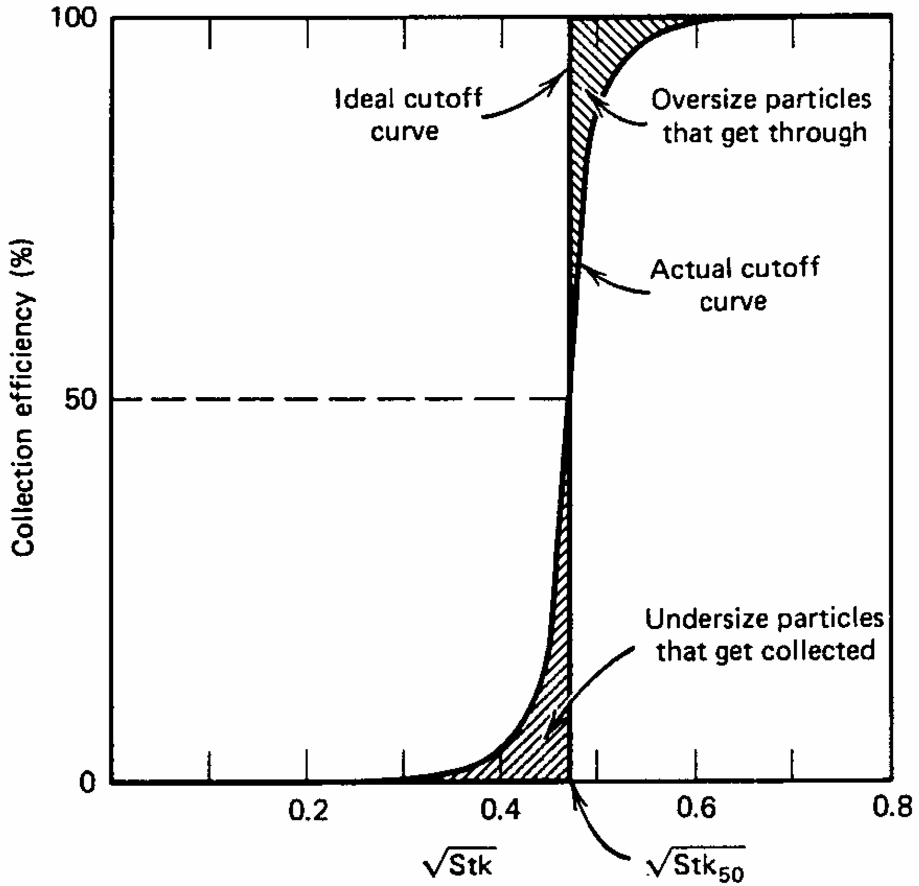


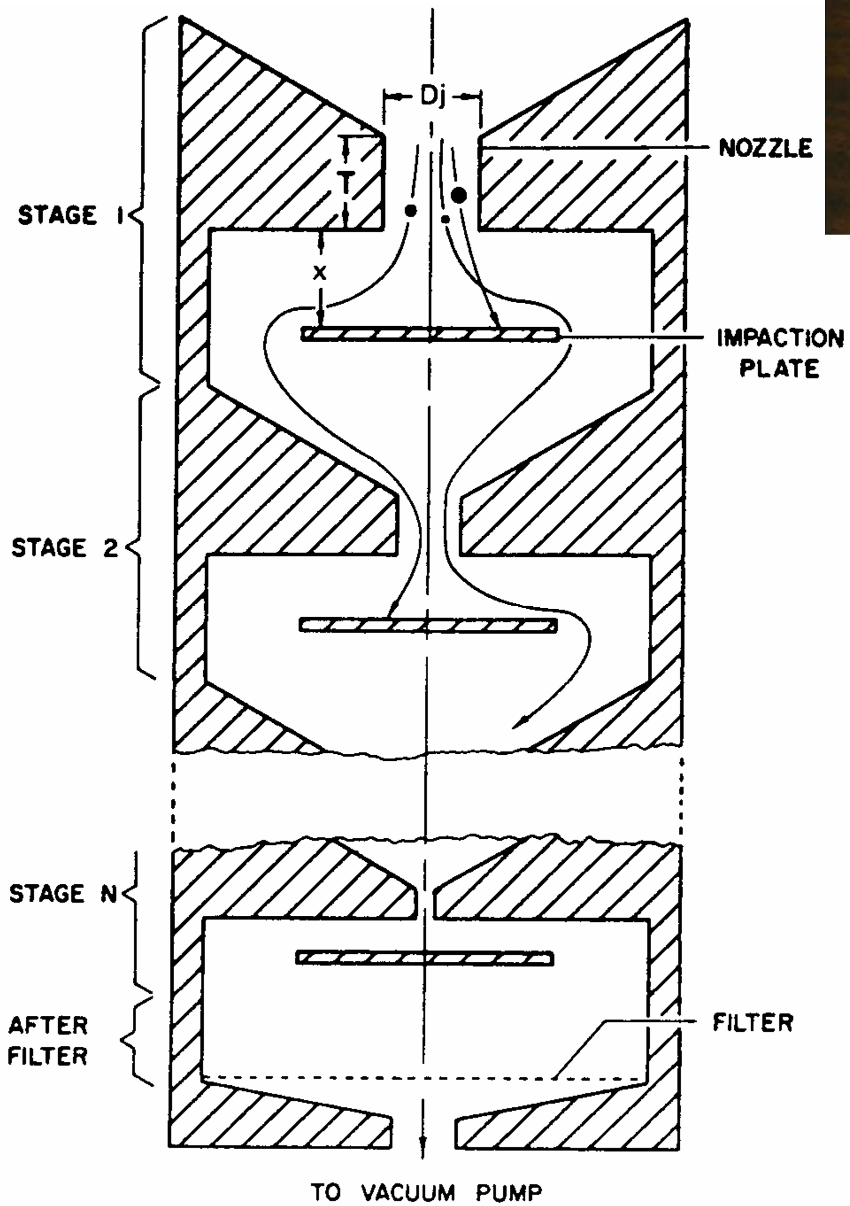
FIGURE 5.8 Actual and ideal impactor cutoff curves.

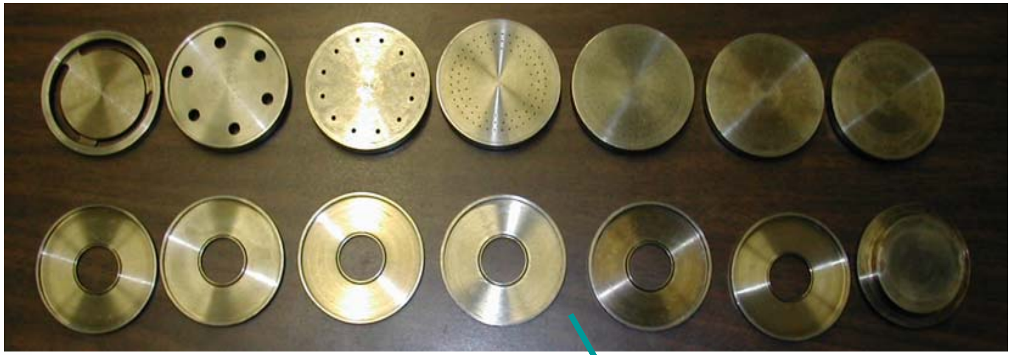
Stk_{50} for 2 impactors

Impactor type	Stk_{50}	$\sqrt{Stk_{50}}$
Circular nozzle	0.24	0.49
Rectangular nozzle	0.59	0.77

$500 < Re_{\text{(nozzle throat)}} < 3000$ and $h'/D_j > 1.5$

Cascade Impactor





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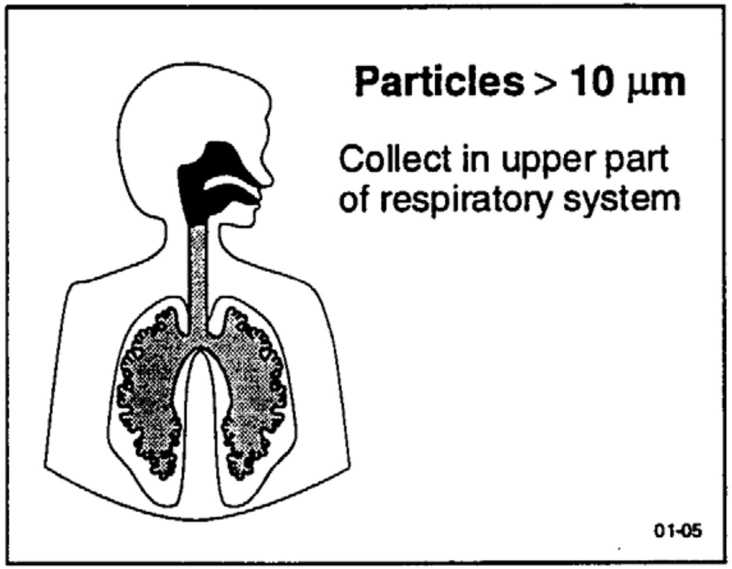
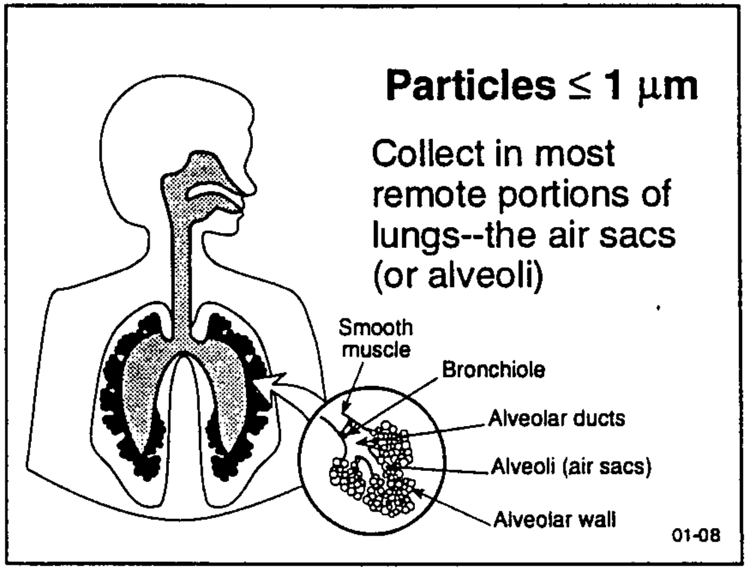
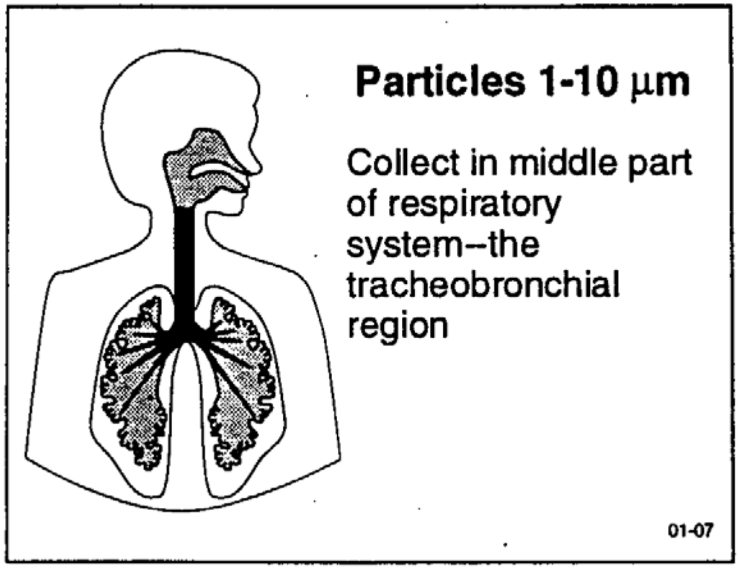
- Health:
  - Deposition in inhalation system
  - Drug delivery
  - Work place, papermill, mining, pesticide, welding







Respiratory Deposition

- Health hazards caused by inhaled aerosols depend on their chemical composition and on the site at which they deposit within the respiratory system
- Effective medicine delivery by the aerosol route also relies on knowledge of aerosol deposition in our respiratory system

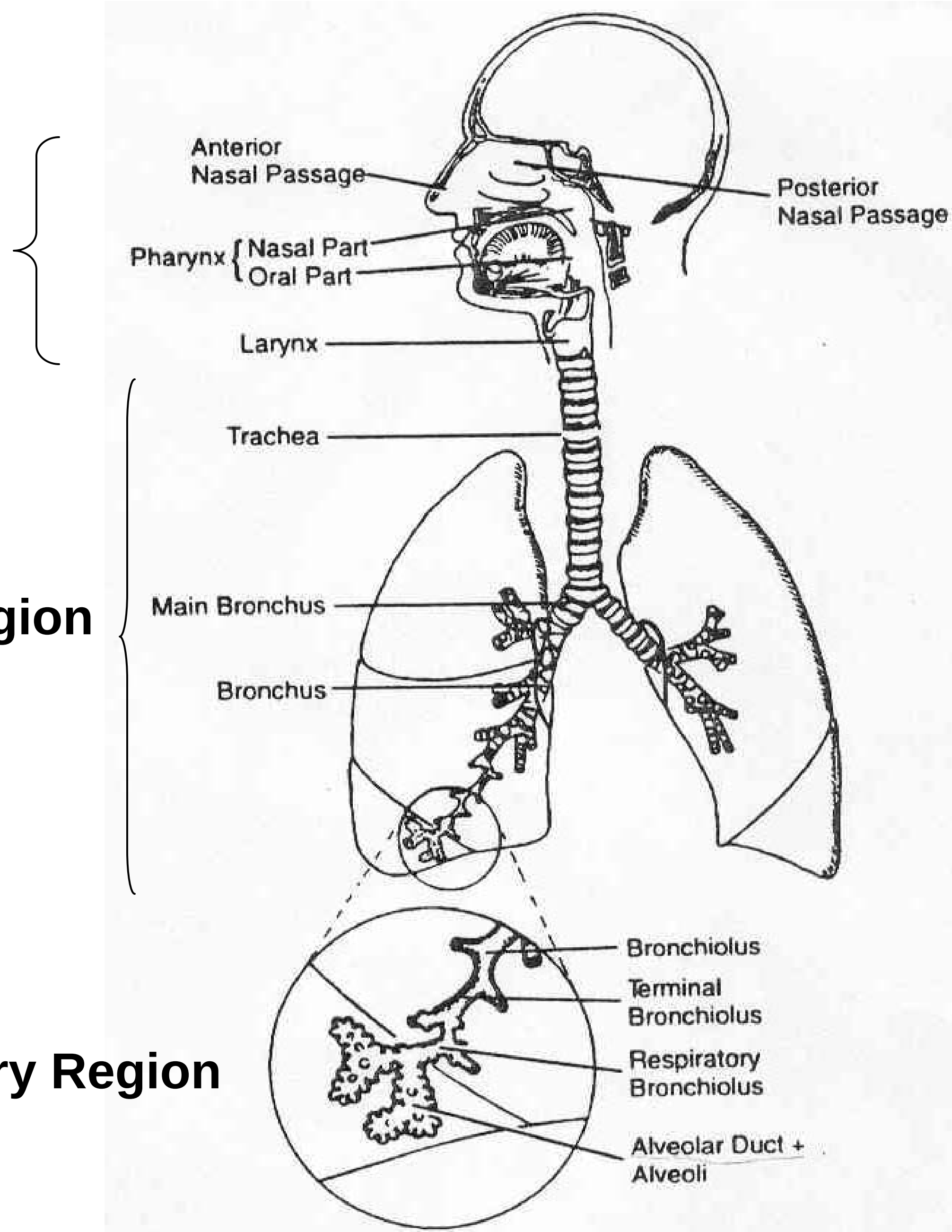
Respiratory System

- **Head airways region** – includes nose, mouth, pharynx and larynx
- **Lung airways or tracheobronchial region** – includes the airways from the trachea to the terminal bronchioles
- **Alveolar region** – gas exchange takes place

Head Airways

Lung Airways/ Tracheobronchial region

Alveolar/Pulmonary Region



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Regional Deposition

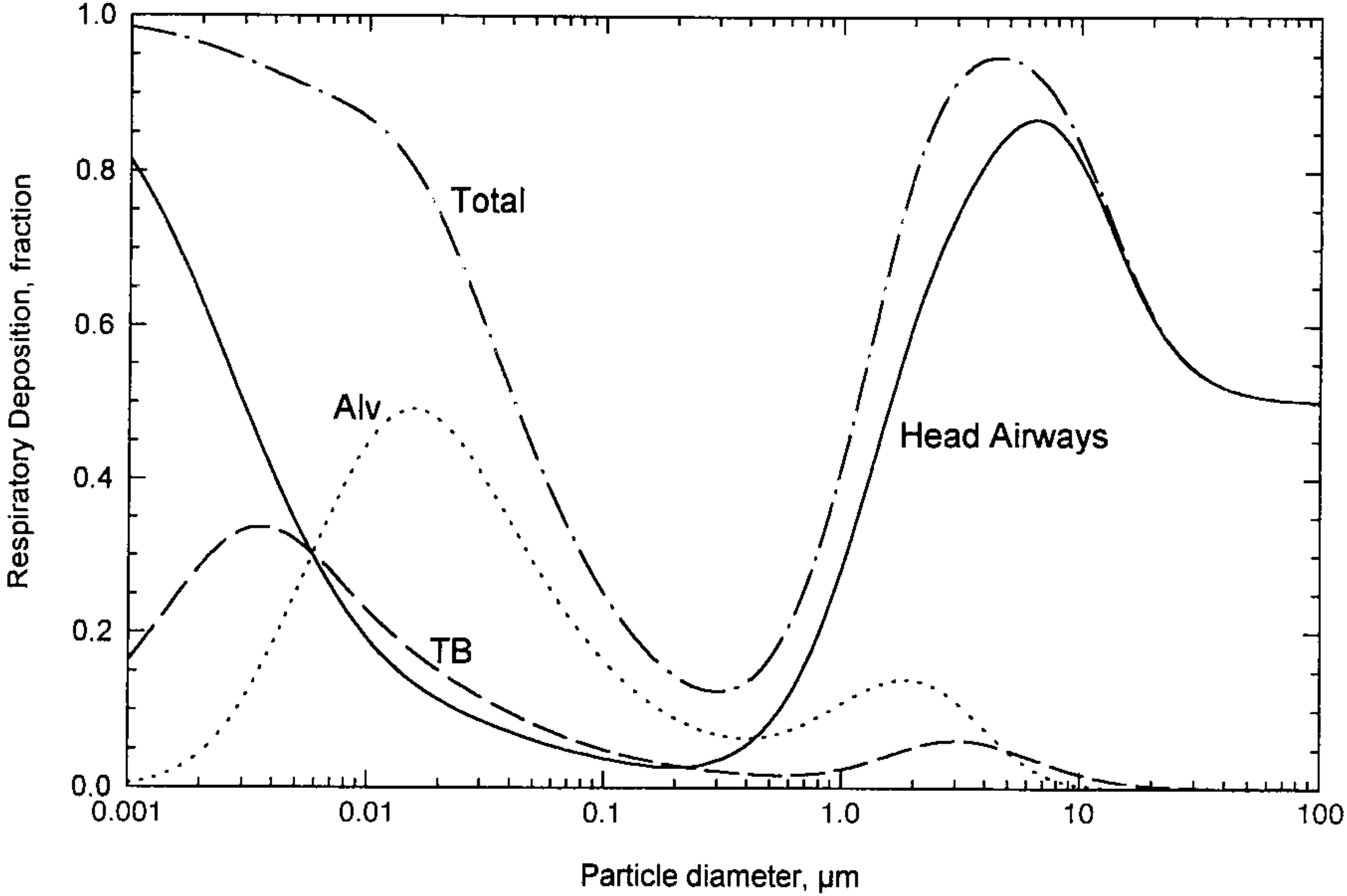


FIGURE 11.3 Predicted total and regional deposition for light exercise (nose breathing) based on ICRP deposition model. Average data for males and females.

Alveolar Region

- Particles in the 2 – 10μm range reach the Alveolar region in attenuated numbers
- Alveolar deposition is reduced whenever tracheobronchial and head airway deposition is high

Size of Particle	Area of Deposition	Method of Deposition
5-30μm	Nose and throat	Impaction
1-5μm	Trachea and bronchial region	Settling
1μm or less	Alveolar Region	Diffusion

EPA Air Quality Standard for Particulate matter:

http://www.epa.gov/particles/actions.html

EPA classifies particulate matter as two types based on size.

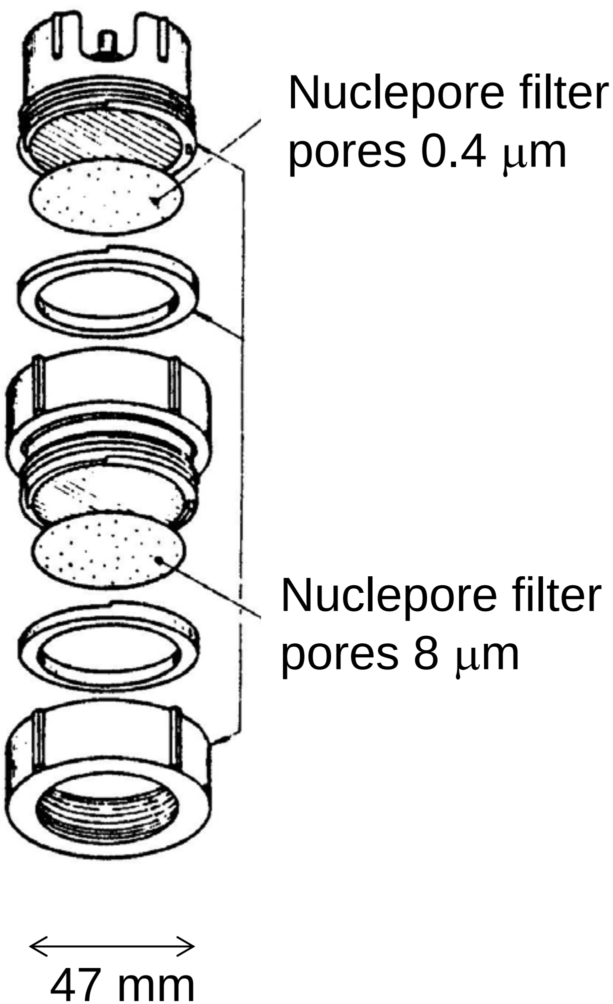
•**Coarse Particulate Matter (PM10)** is less than 10 micrometers in diameter. It primarily comes from road dust, agriculture dust, river beds, construction sites, mining operations, and similar activities.

•**Fine Particulate Matter (PM2.5)** is less than 2.5 micrometers in diameter. PM2.5 is a product of combustion, primarily caused by burning fuels. Examples of PM2.5 sources include power plants, vehicles, wood burning stoves, and wildland fires.

NEW PARTICULATE MATTER REGULATIONS

The EPA recently updated the national standards for Particulate Matter. For PM10, the EPA retained the current 24 hour PM10 standard of 150 µg/m3 and eliminated the annual PM10 standard. The EPA increased the stringency of the PM2.5 standard by lowering the previous 24 hour standard of 65 µg/m3 to 35 µg/m3. EPA left the annual PM2.5 standard of 15 µg/m3 in place.

Stacked Filter Unit



- Very low cost
- PM10 and PM2.5
- Trace element analysis
- SEM analysis
- Mass (microbalance)
- Absorption via Reflectance

Basic Sampling Apparatus