JOHNS HOPKINS
BLOOMBERG
SCHOOL of PUBLIC HEALTH

Particulate Matter

Patrick N. Breysse, PhD, CIH
Peter S.J. Lees, PhD, CIH

Johns Hopkins University

JOHNS HOPKINS
BLOOMBERG
SCHOOL of PUBLIC HEALTH

Section A

Introduction and Definitions

Aerosols: Definition

- Stable suspensions of solid or liquid particles in air
- Examples:
  - Cigarette smoke
  - Welding fume
  - Sea mist

Types of Particulate Aerosols: *Dusts*

- Solid aerosols generated by the handling, grinding, abrasion, or cutting of a bulk material
- Dust particle size is related to the amount of energy involved in creation; the higher the energy—the smaller the particle created; the lower the energy—the larger the particle created
- Examples: Saw dust, coal dust

Types of Particulate Aerosols: *Mists*

- Liquid aerosols generated by condensation from a gaseous state or by the breaking up of a bulk liquid into a dispersed state
- Droplet size related to energy input as in dusts and fibers
- Examples: Metal working fluid from lathe, paint spray, liquid mixing operations

Types of Particulate Aerosols: *Smoke*

- Solid aerosols resulting from the incomplete combustion of carbonaceous materials
- Wide range of particle sizes
- Size related to combustion efficiency
  - High efficiency = smaller particles
  - Low efficiency = larger particles
- Examples: Wood smoke, diesel exhaust

Types of Particulate Aerosols: *Fumes*

- Solid aerosols generated by the condensation of vapors or gases from combustion or other high temperature processes
- Usually very small and spherical
  - Sources: Welding, foundry and smelting operations, hot cutting or burning operations

Types of Particulate Aerosols: *Bioaerosols*

- Solid or liquid aerosols from biological sources
- May be infectious, allergenic, and/or irritating
- Wide range of particle sizes
  - Virus (0.002–0.03 um)
  - Tree pollen (10–100um)
- Examples: Mold spores, animal allergens, anthrax

Types of Particulate Aerosols: *Fibers*

- A special (based on toxicological properties) kind of dust that is fibrous in nature (i.e., longer than it is wide)
- Aspect ratio (L:W) defined as 3:1 or 5:1
- Toxicity a function of composition, size, and number of fibers
- Examples: Asbestos, fiberglass, refractory ceramic fibers

Quantification of Aerosols

$$\text{Concentration} = \frac{\text{mass of contaminant}}{\text{volume of air}}$$

- Typical Units: mg/m3, ug/m3
- Special Units: f/cm3, cfu/m3, mppcf

JOHNS HOPKINS
BLOOMBERG
SCHOOL of PUBLIC HEALTH

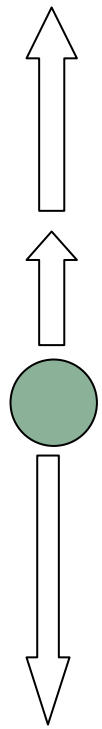
Section B

Particle Size

Behavior of Aerosols

Airborne behavior, such as settling velocity, is a function of:

- Size
- Specific gravity
- Shape
- Surface properties
- Slip factor



Fluid drag forces

Buoyant forces

Particle

Gravity

Aerodynamic Equivalent Diameter

- The *Aerodynamic Equivalent Diameter (AED)* of a particle is the diameter of a unit density sphere that would have the identical settling velocity as the particle

Continued

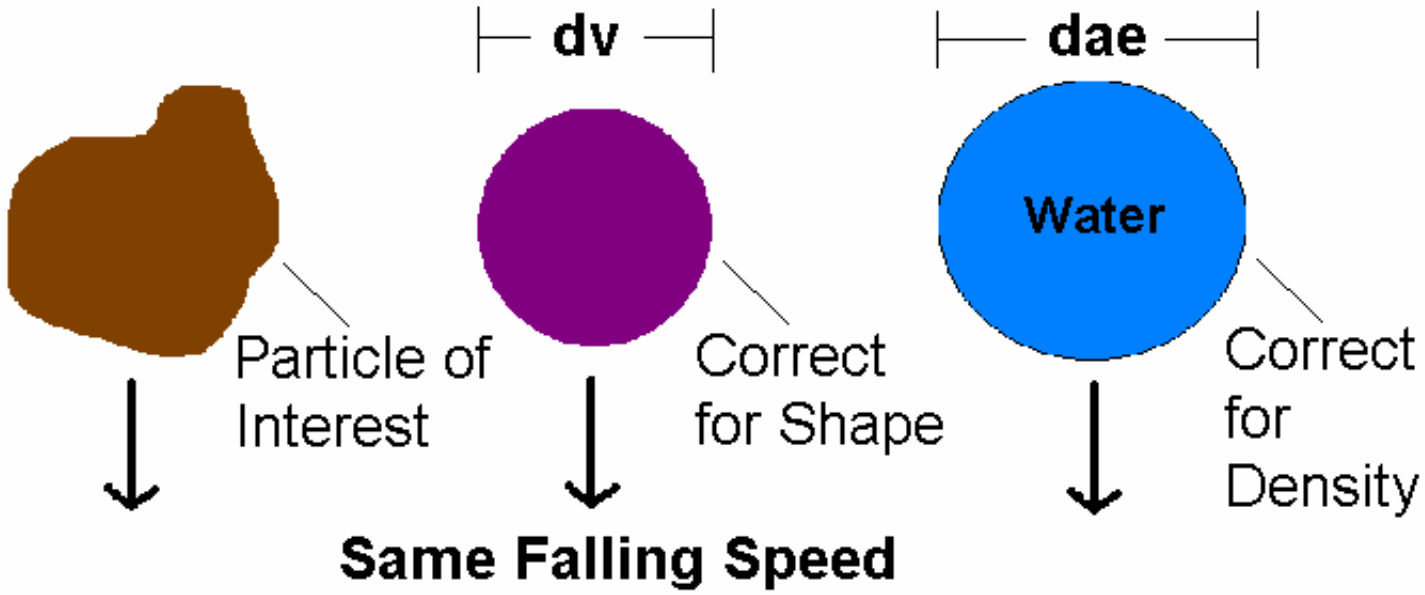
Aerodynamic Equivalent Diameter

- Measure of behavior of particle in air
- Function of particle diameter, density, shape, and surface characteristics
- Determines site of deposition in lung
- Effects air sampling characteristics
- Referenced to spherical drop of water with identical settling velocity

Continued

Aerodynamic Equivalent Diameter

Settling velocity of test particle measured and compared to reference particle ("unit density sphere"):

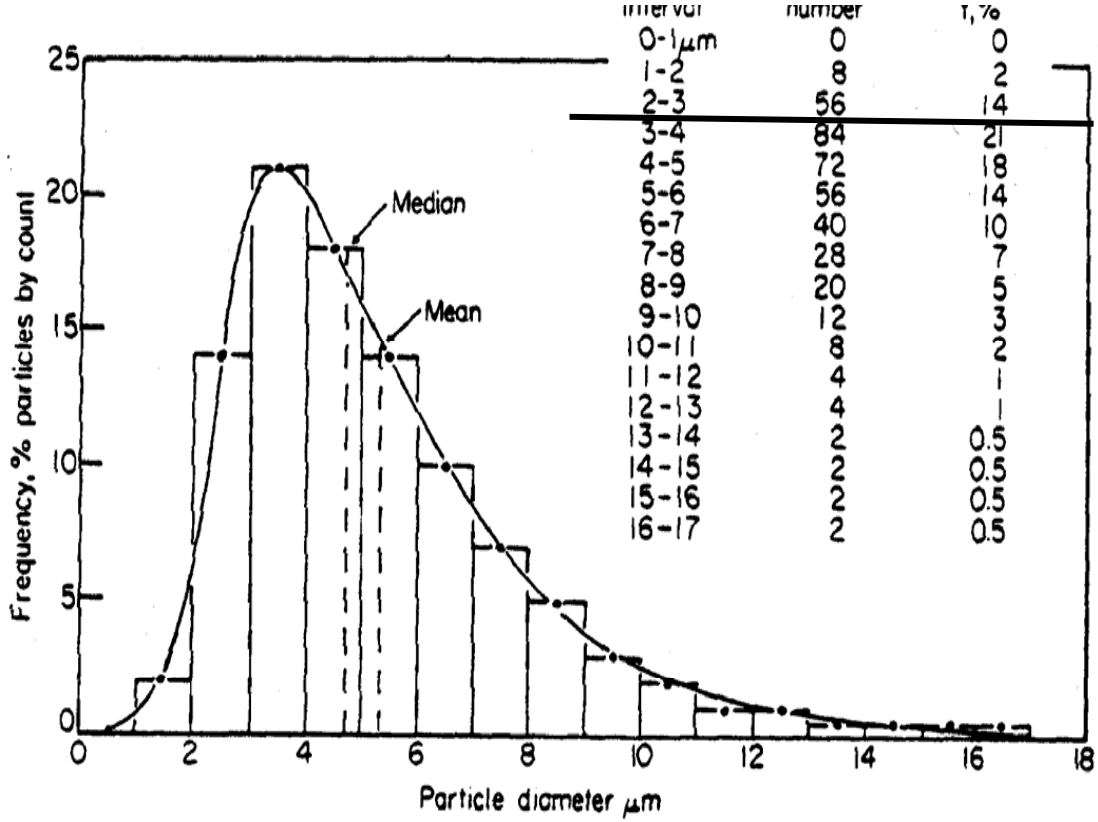


JOHNS HOPKINS
BLOOMBERG
SCHOOL of PUBLIC HEALTH

Section C

Particle Size Distributions

Particle Size Distributions



Interval	number	f, %
0-1 μm	0	0
1-2	8	2
2-3	56	14
3-4	84	21
4-5	72	18
5-6	56	14
6-7	40	10
7-8	28	7
8-9	20	5
9-10	12	3
10-11	8	2
11-12	4	1
12-13	4	1
13-14	2	0.5
14-15	2	0.5
15-16	2	0.5
16-17	2	0.5

FIG. 6.2. Histogram of a skewed particle size distribution.

Particle sizes of an aerosol are typically ***log-normally*** *distributed*

Source: U.S. Government

Continued

Particle Size Distributions

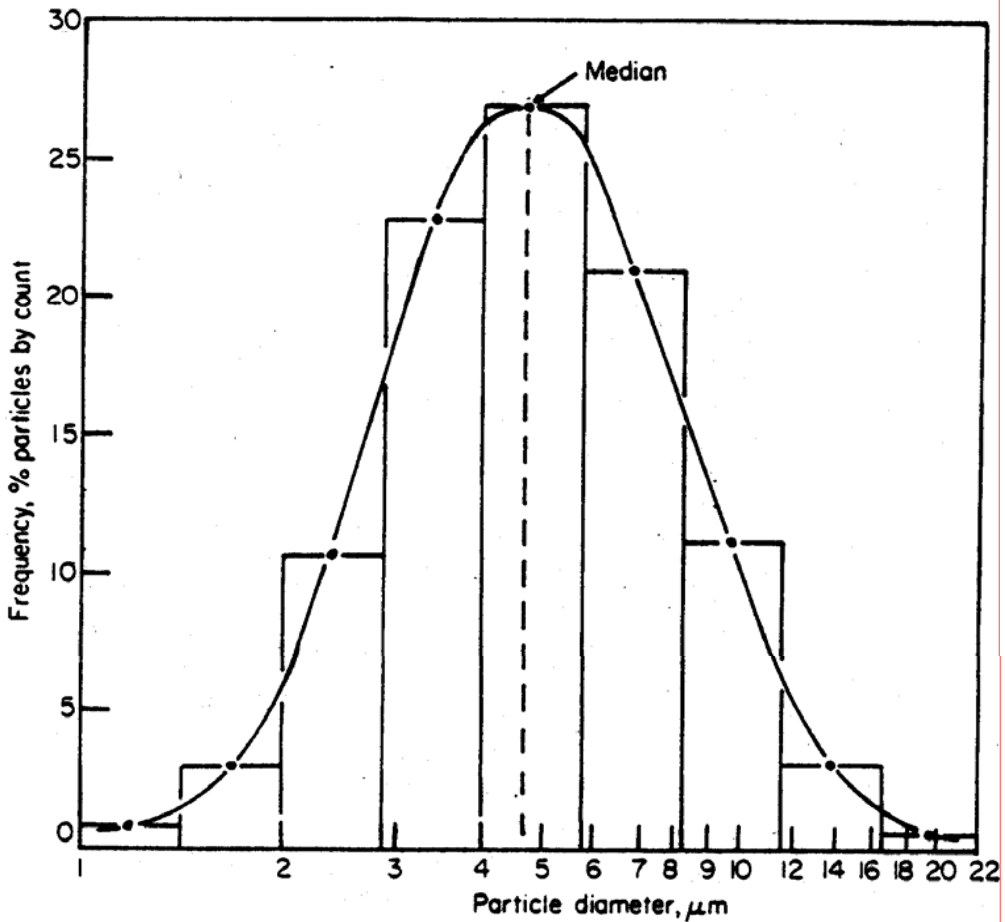


FIG. 6.3. Histogram of a log-normal size distributio

Log transformation of particle size distribution is ***normally*** *distributed*

Source: U.S. Government

Continued

Particle Size Distributions

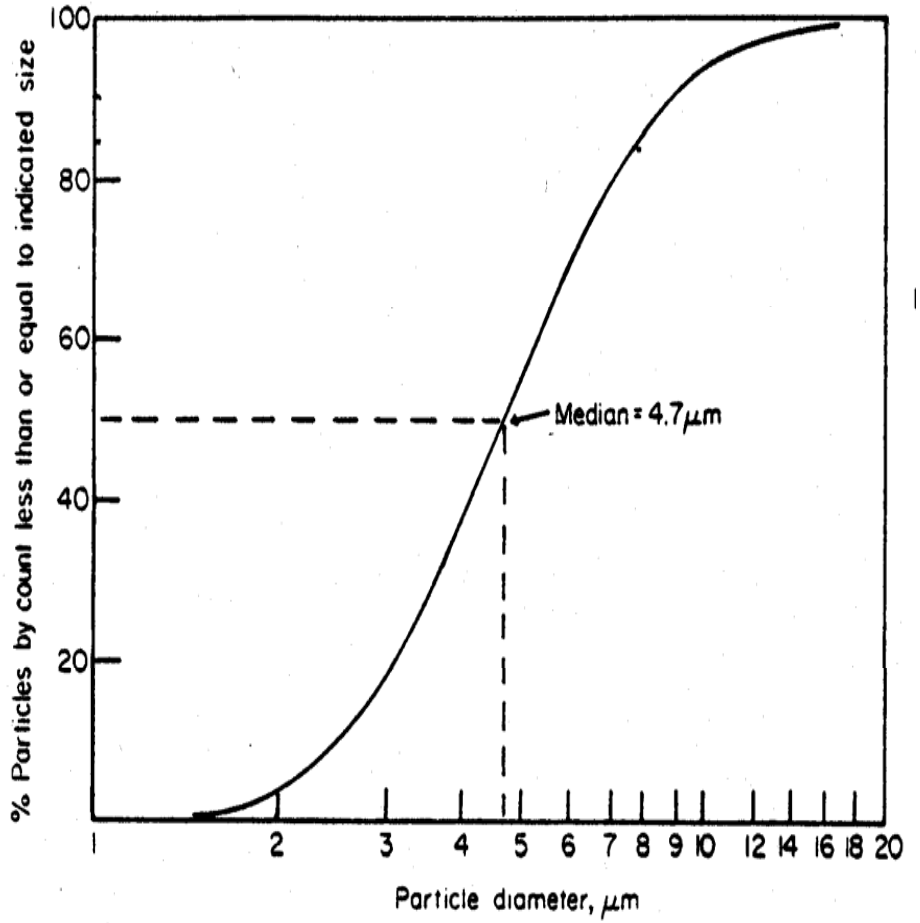


FIG. 6.4. Cumulative log-normal size distribution

*Normalized size distribution plotted as **cumulative** size distribution*

Source: U.S. Government

Continued

JOHNS HOPKINS
BLOOMBERG
SCHOOL of PUBLIC HEALTH

Section D

Particles and Disease

Cytotoxic Dusts

- Direct effect on the lungs
- Examples
  - Silica—Silicosis
  - Asbestos—Asbestosis
  - Coal Dust—Coal workers pneumoconiosis
  - Beryllium—Berylliosis and chronic beryllium disease

Continued

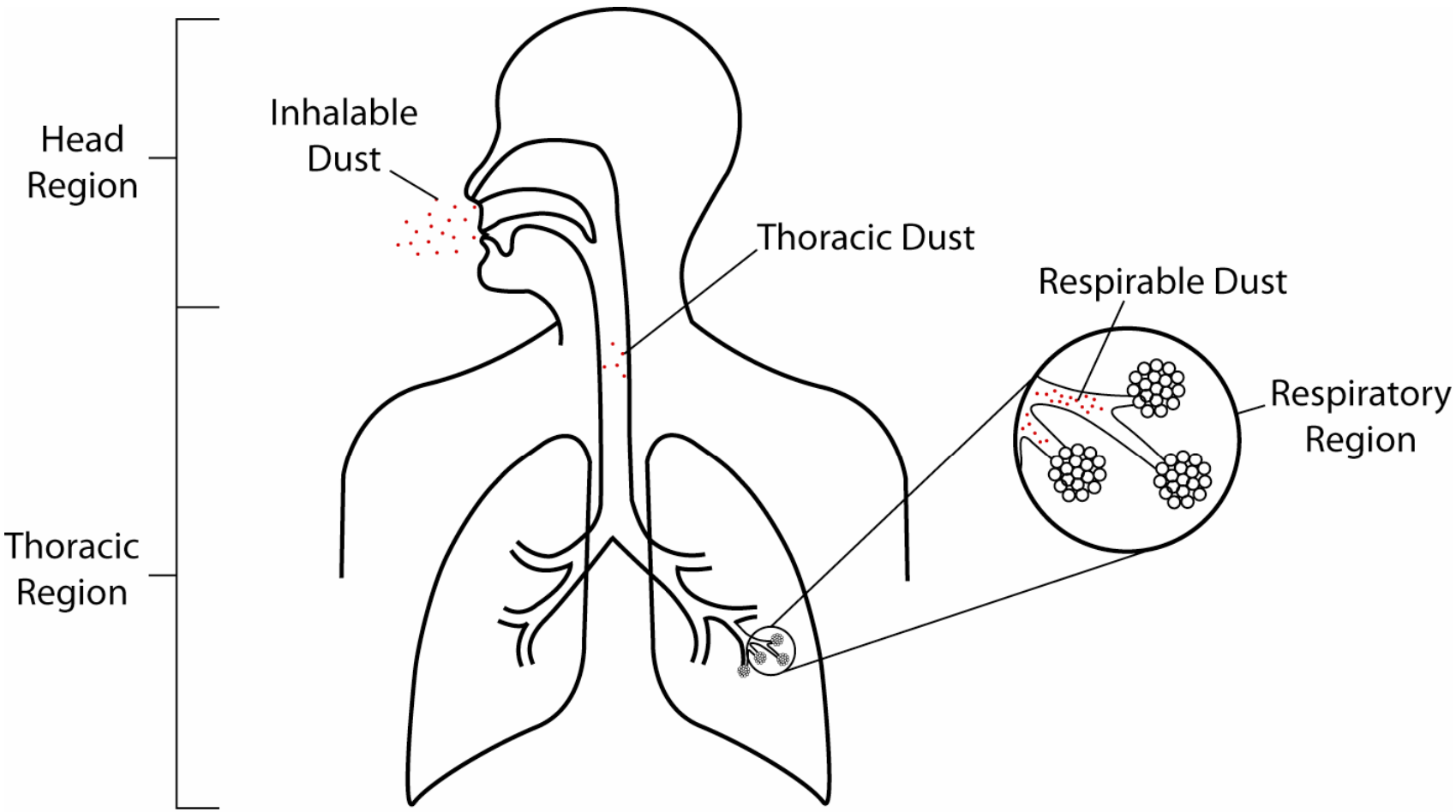
Cytotoxic Dusts

- Knowing how much and where a dust will deposit in the lungs is important for risk determination

Aerosols and Disease

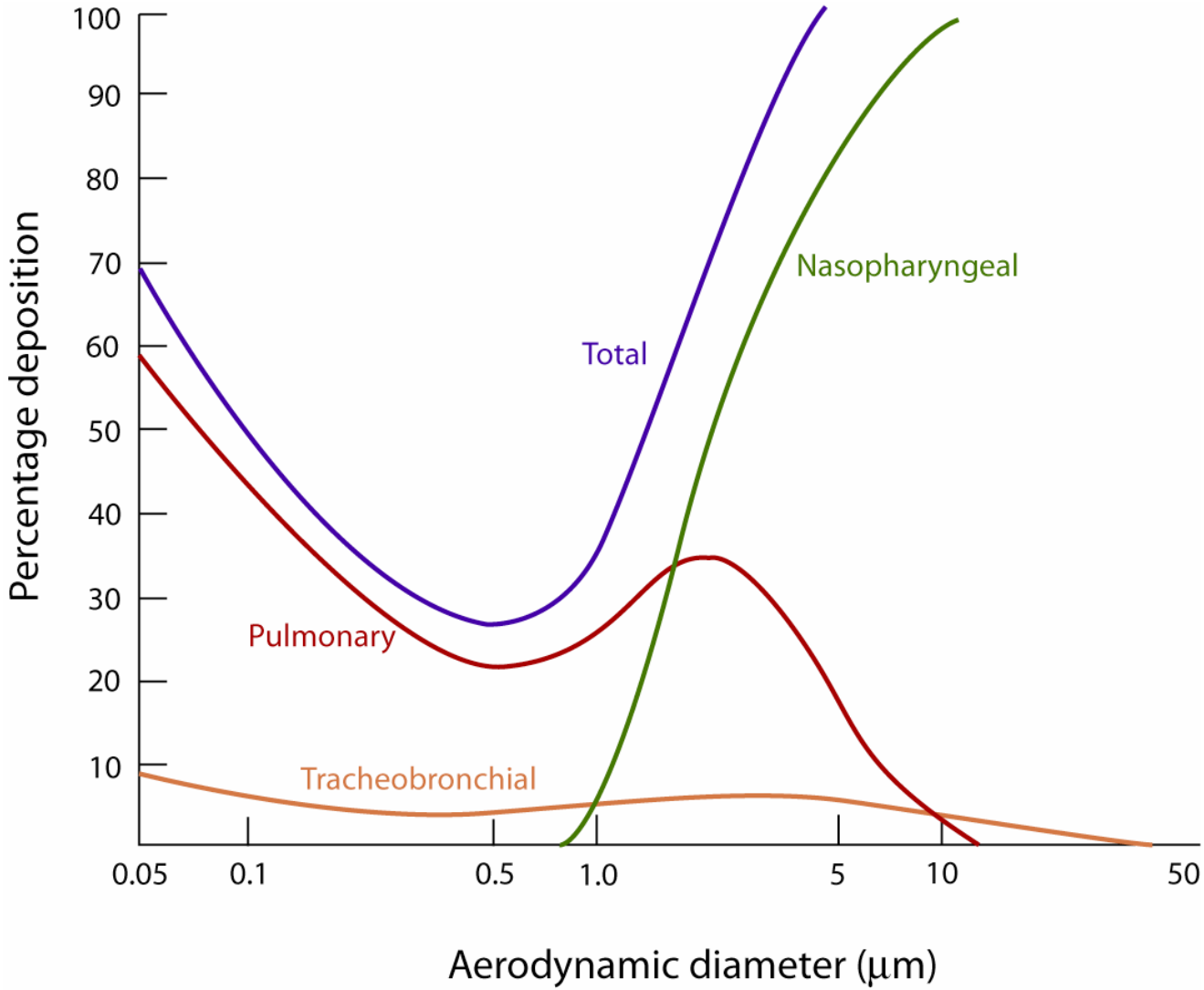
- Disease potential is a function of:
  - Chemical properties of particle
  - Site of particle deposition in respiratory system
    - Head region
    - Thoracic region
    - Respiratory region
  - Particle clearance path/destination

Regional Particle Deposition



Adapted from Annals of American Conference of Governmental Hygienists, Vol. 11

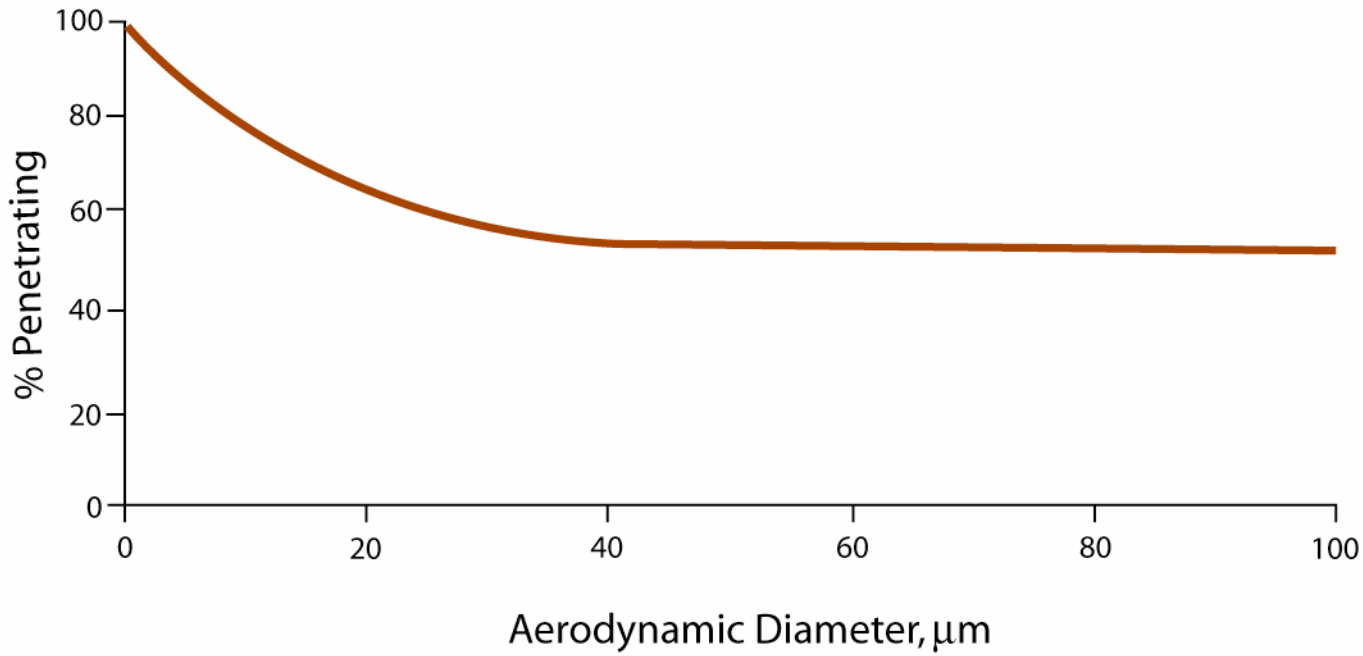
Site of Particle Deposition



Adapted from Annals of American Conference of Governmental Hygienists, Vol. 11

Inspirable/Inhalable Dust Definition

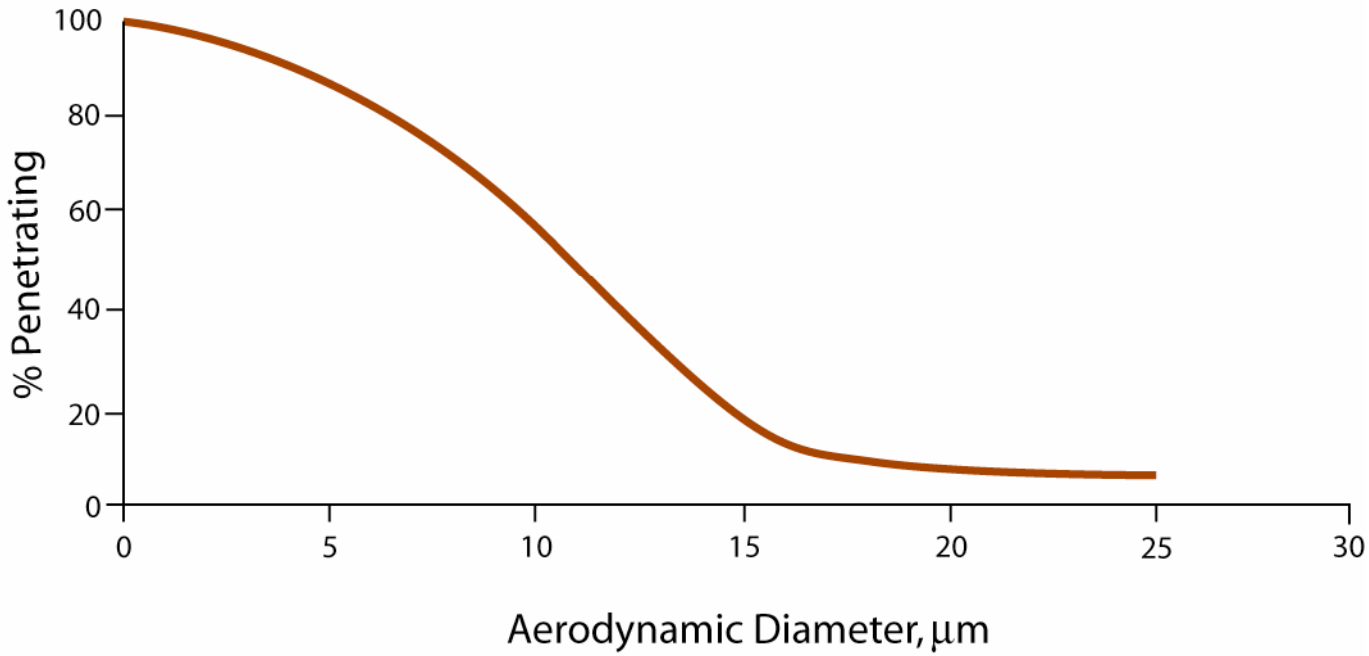
AED, µm	% Penetrating
0	100
5	87
10	77
40	54.5
100	50



Adapted from Annals of American Conference of Governmental Hygienists, Vol. 11

Thoracic Dust Definition

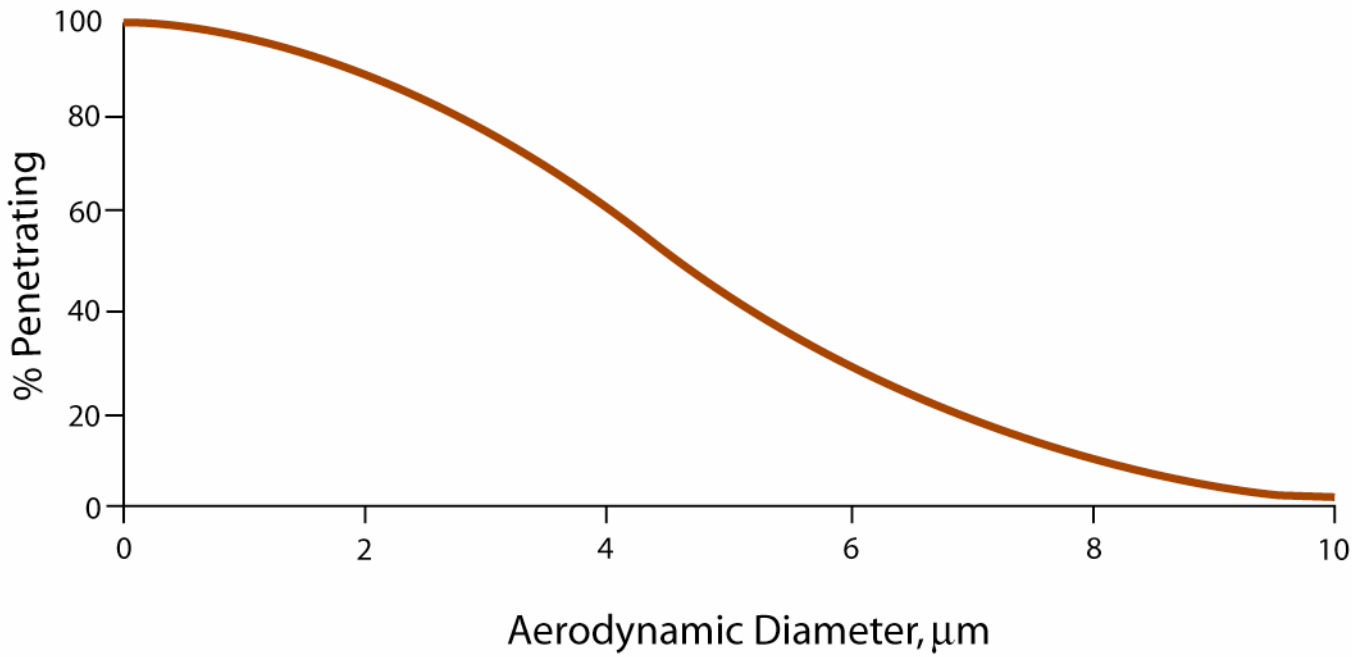
AED, µm	% Penetrating
0	100
2	94
4	89
10	50
14	23
18	9.5
25	2



Adapted from Annals of American Conference of Governmental Hygienists, Vol. 11

Respirable Dust Definition

AED, µm	% Penetrating
0	100
2	91
4	50
6	17
8	5
10	1



Adapted from Annals of American Conference of Governmental Hygienists, Vol. 11

Old Particle-Size Conventions

- **Non-respirable fraction (>10 μm AED)**
  - Can be breathed into nose or mouth, penetrate head airways, and enter lung airways
- **Respirable fraction (<10 μm AED)**
  - Can penetrate beyond terminal bronchioles to gas exchange region

New Particle-Size Conventions

- **Inhalable fraction (<100 μm AED)**
  - Can be breathed into nose or mouth
- **Thoracic fraction (<25 μm AED)**
  - Can penetrate head airways and enter lung airways
- **Respirable fraction (<10 μm AED)**
  - Can penetrate beyond terminal bronchioles to gas exchange region

Continued

New Particle-Size Conventions

- Outdoor or Ambient Air Pollution
- Recommended by EPA
  - Particulate matter <10 um (PM 10)
  - Particulate matter <2.5 um (PM 2.5)
- Not deposition-based
- Roughly correspond to inhalable and respirable dust

JOHNS HOPKINS
BLOOMBERG
SCHOOL of PUBLIC HEALTH

Section E

Mechanisms of Particle Deposition

Mechanisms of Particle Deposition in the Lung

- Inertial impactions
  - Function of particle velocity and mass
- Interception
  - Function of particle diameter

Continued

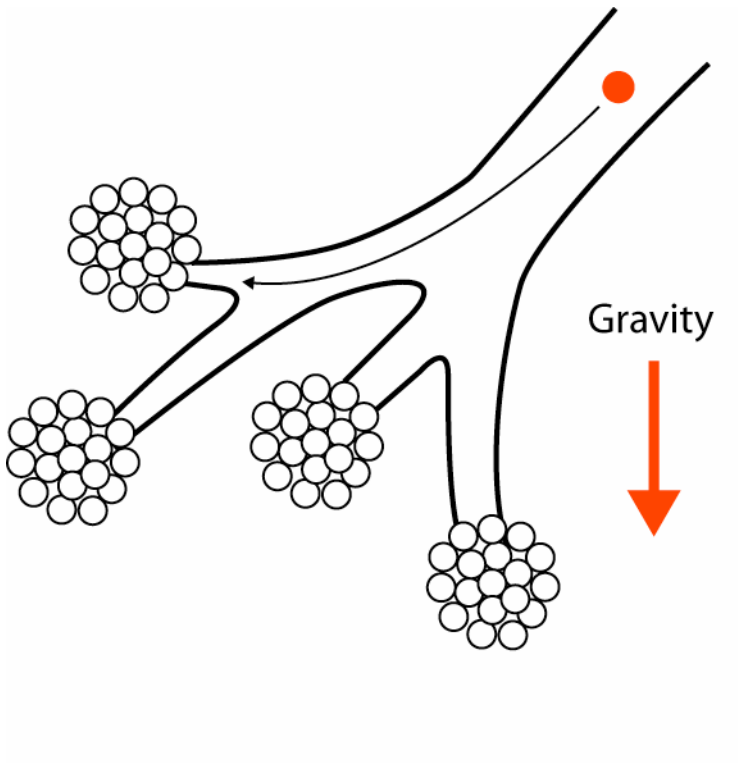
Mechanisms of Particle Deposition in the Lung

- Sedimentation (gravitational settling)
  - Function of particle velocity (residence time) and mass
- Diffusion
  - Function of particle diameter, concentration, velocity (time), and distance

Continued

Mechanisms of Particle Deposition in Lung

Inertial impaction:



Adapted from http://www.mfg.mtu.edu/cyberman/environment/air/depos.html

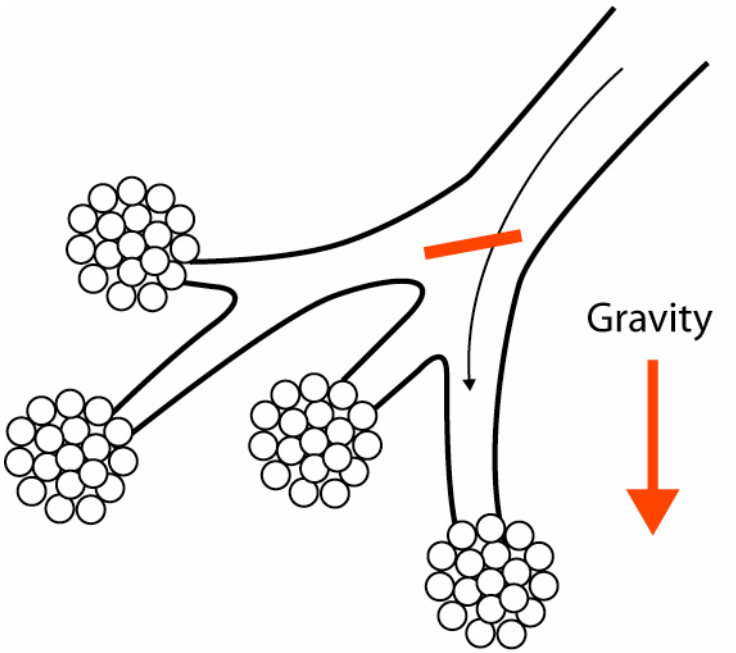
The process whereby a particle moving in a gas stream is unable to remain in the streamline when the gas changes direction (turns). As a result, the particle strikes a stationary obstacle (e.g., surface in respiratory system) directly in its path and is removed from the air.

Animated version at http://www.mfg.mtu.edu/cyberman/environment/air/depos.html

Continued

Mechanisms of Particle Deposition in Lung

Interception:



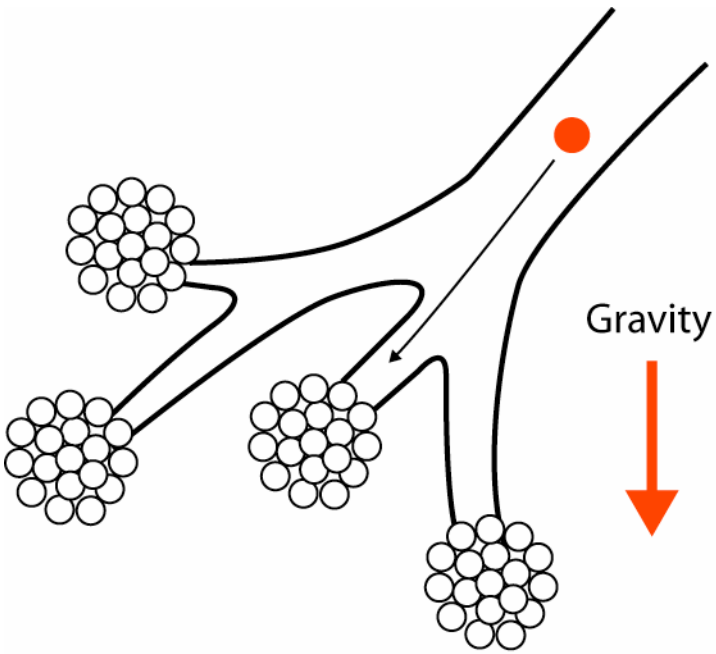
Adapted from http://www.mfg.mtu.edu/cyberman/environment/air/depos.html

The process whereby a particle moving in a gas stream remains in that airstream but, because of its dimensions, strikes a stationary obstacle (e.g., surface in respiratory system) and is removed from the air.

Animated version at http://www.mfg.mtu.edu/cyberman/environment/air/depos.html

Mechanisms of Particle Deposition in Lung

Sedimentation (gravitational settling):



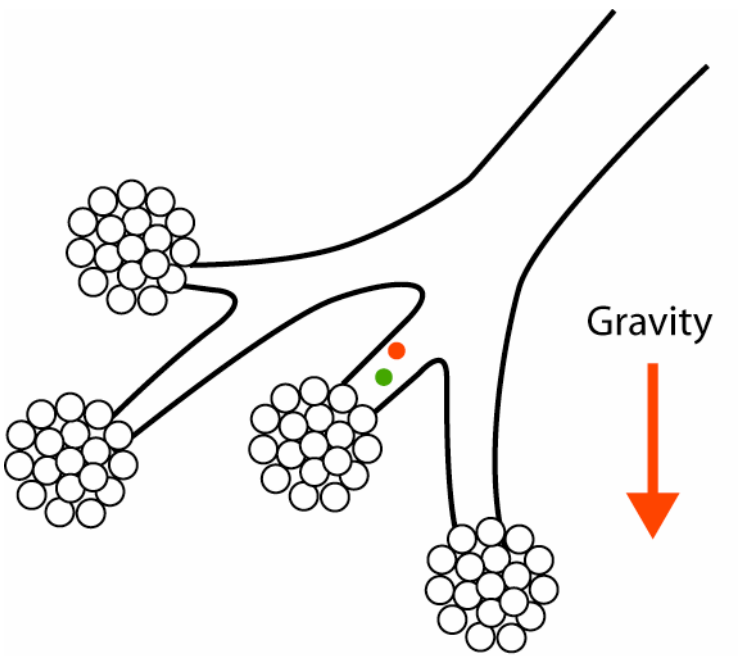
Adapted from http://www.mfg.mtu.edu/cyberman/environment/air/depos.html

The process by which a particle in an airstream is pulled downward by gravity until it strikes a stationary obstacle (e.g. surface in respiratory system) and is removed from the air.

Animated version at http://www.mfg.mtu.edu/cyberman/environment/air/depos.html

Mechanisms of Particle Deposition in Lung

Diffusion:



Adapted from http://www.mfg.mtu.edu/cyberman/environment/air/depos.html

The process by which the molecules of two or more substances (very small particles having some molecular characteristics) gradually mix as a result of random thermal motion, will strike a stationary obstacle (e.g., surface in respiratory system) and be removed from the air.

Animated version at http://www.mfg.mtu.edu/cyberman/environment/air/depos.html