Generation and Behavior of Airborne Particles (Aerosols)

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Overview

I. Particle size range

II. Inhalation & lung deposition

III. Particle behavior

- Settling, impaction, electrostatic effects

IV. Particle generation

- Energy input, size, charge, humidity

Scenarios

- Letter release
- Carpet release

VI. Particle collection and measurement

What is an AEROSOL?

- Simply defined- tiny particles or droplets suspended in air.

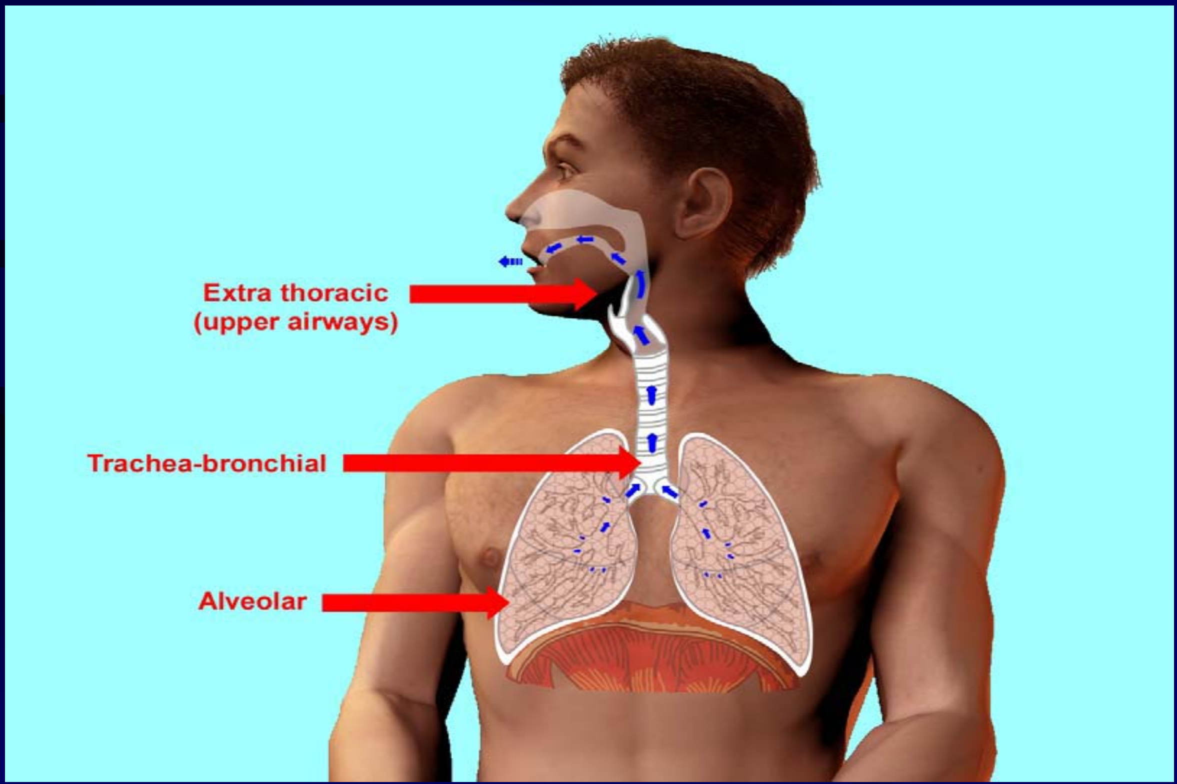
- The haze in the picture on the right is caused by light scattering from numerous water/oil droplets and mineral particles released into the air from the drilling of rock.

Are Aerosols dangerous?

- The air we breathe always contains solid particles or droplets and is therefore an aerosol.
- These aerosol particles can be from natural sources or man-made sources
- Sometimes the particles are of type that, at sufficient concentration, are toxic to our body.
- The organ in our body most sensitive to particle exposure is the respiratory system

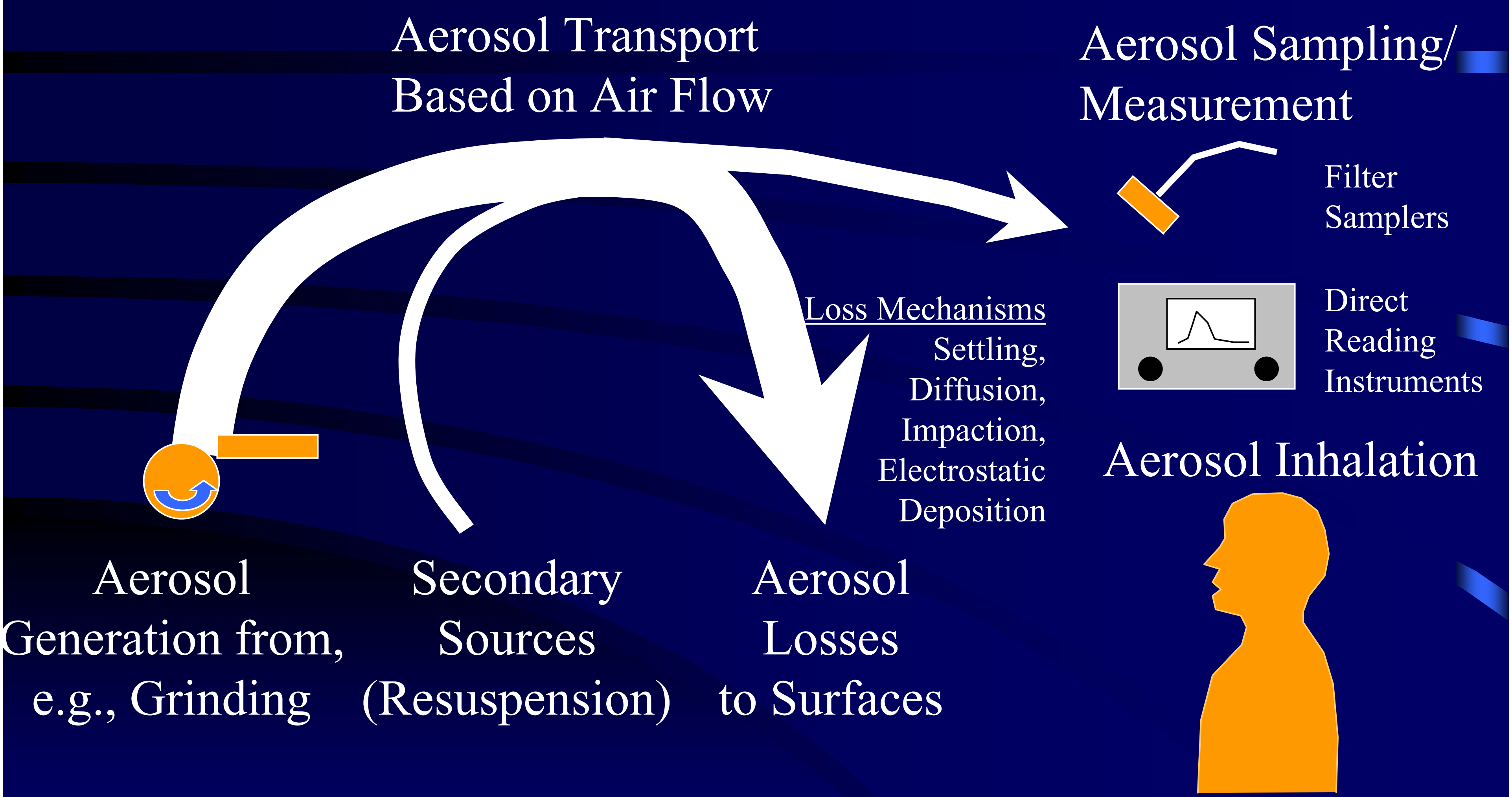
Toxic Aerosols!?

Our respiratory system is efficient at removing aerosols, but if they fall within particular size ranges, are highly concentrated, or toxic, they may cause adverse health effects. They may also deposit on skin or eyes, generally only causing irritation, though more toxic effects may occur. Very small particles may pass through the skin and enter the body that way. Soluble particles may dissolve and pass through the skin.



Read on for more details on aerosol generation and behavior

Overall Scenario:
Evaluation of Exposure in Workplaces



Aerosol Assessment in the Workplace: Types of Measurements

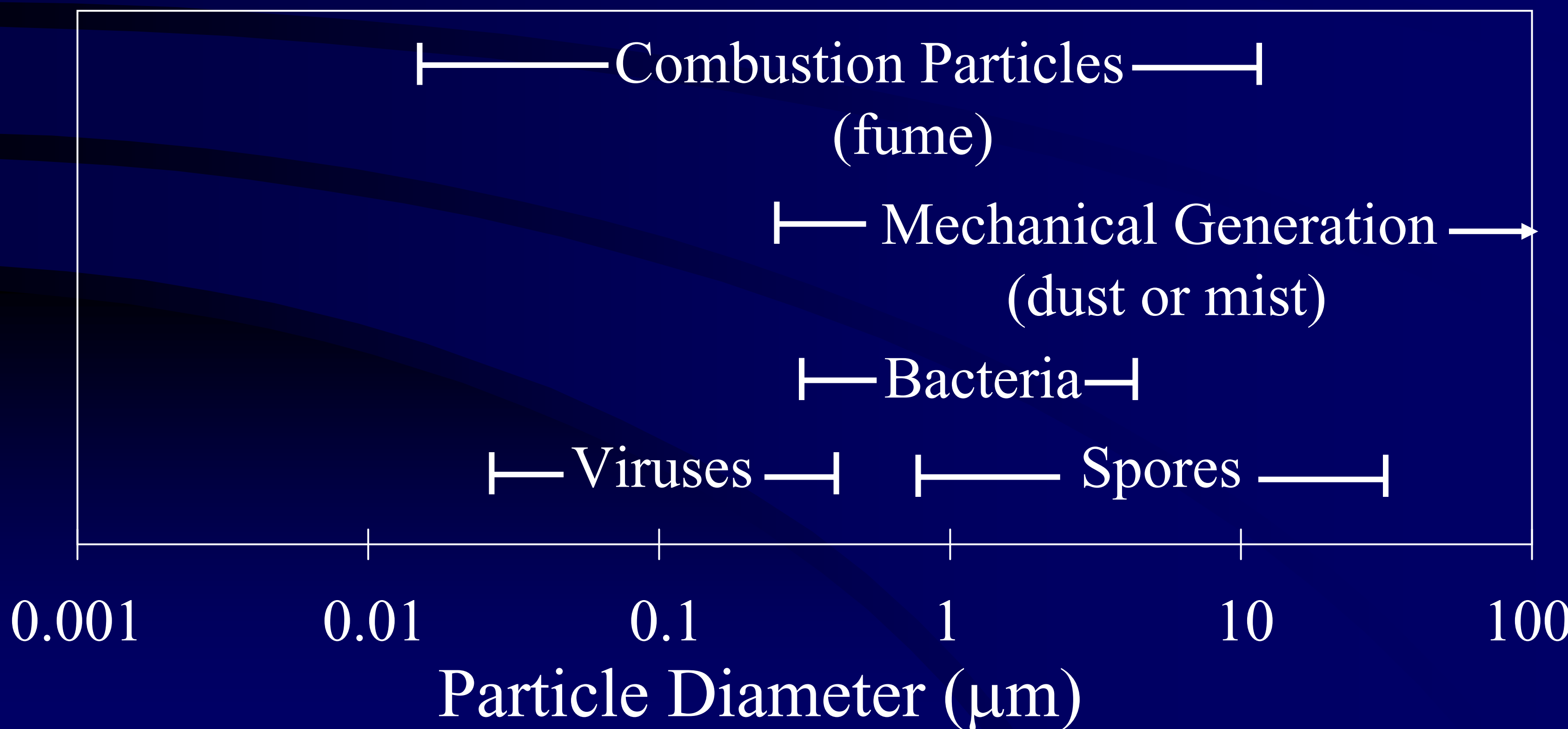
- Sampling, usually with a filter and pump, provides a sample that can be analyzed in the lab for specific chemicals, quantity of dust, particle shape (fibers), etc.
- Direct reading instruments allow continuous observation of dust concentrations, e.g., mass or concentration or size distribution, but do not usually provide specifics of the aerosol type.

Aerosol Assessment in the Workplace: Types of Measurements

- The most accurate assessment of worker's exposure is measurement with a personal sampler, i.e, a collection or measurement device placed on the worker's chest.
- Techniques for control of exposures can use either personal samplers or (fixed) area measurement devices. Direct reading devices allow rapid assessment of the effectiveness of dust control devices or strategies.

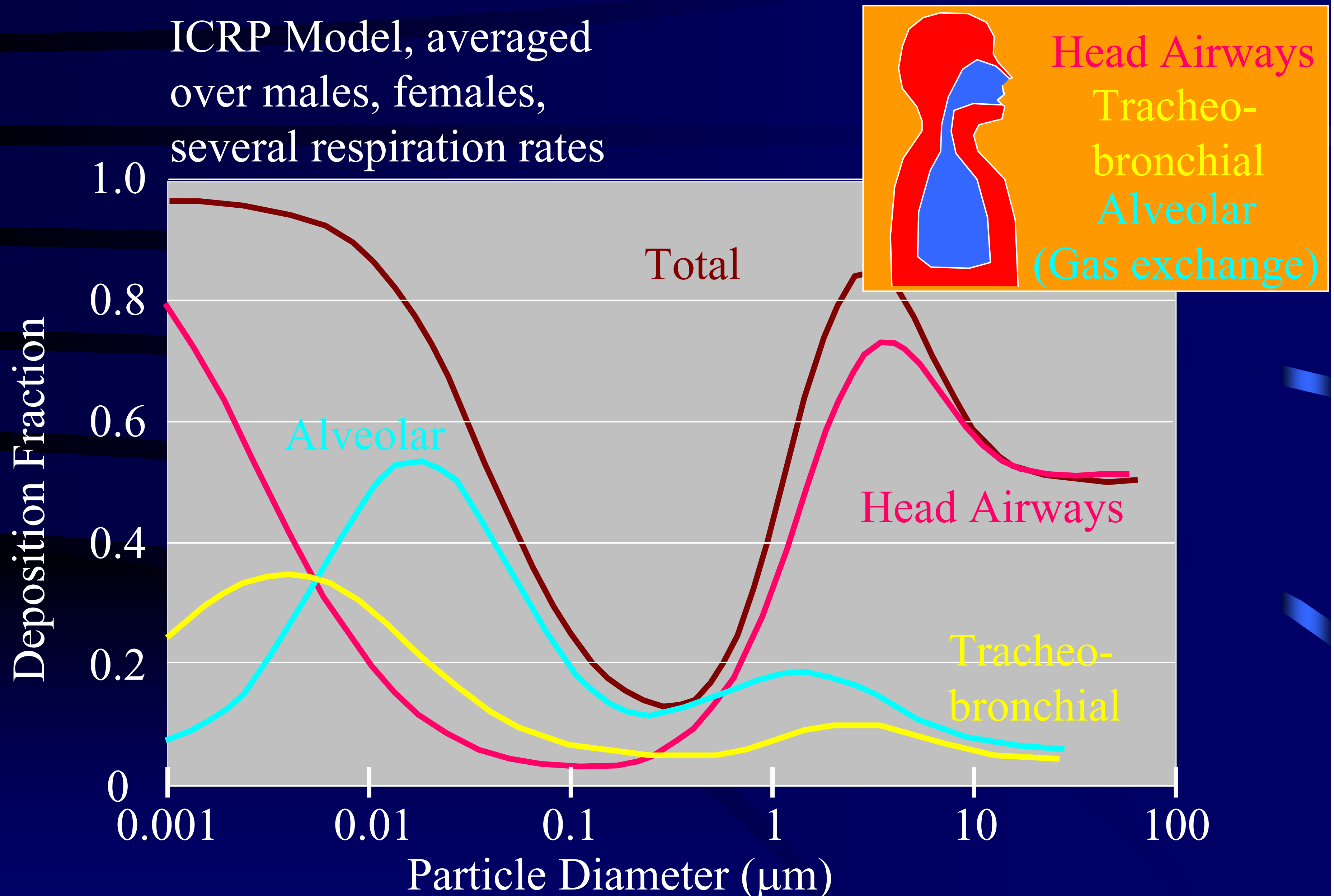
I. Aerosol Size Range

Particle size is often determined by the process that generated the particle. Combustion particles usually start out in the 0.01-0.05 µm size range, but combine with each other (agglomerate) to form larger particles. Powder is broken down into smaller particles and released into the air; it is difficult to break down such particles smaller than ~0.5 µm. Biological particles usually become airborne from liquid or powder forms, so these particles are usually larger than ~0.5 µm.



II. Respiratory System Deposition

ICRP Model, averaged over males, females, several respiration rates



III. Aerosol Particle Behavior

- Settling
- Impaction
- Charge effects
- Release from surfaces
- Agglomeration/ Deagglomeration

Particle Settling in Still Air

Time to settle 5 feet by unit density spheres

0.5 µm — 41 hours

1 µm — 12 hours

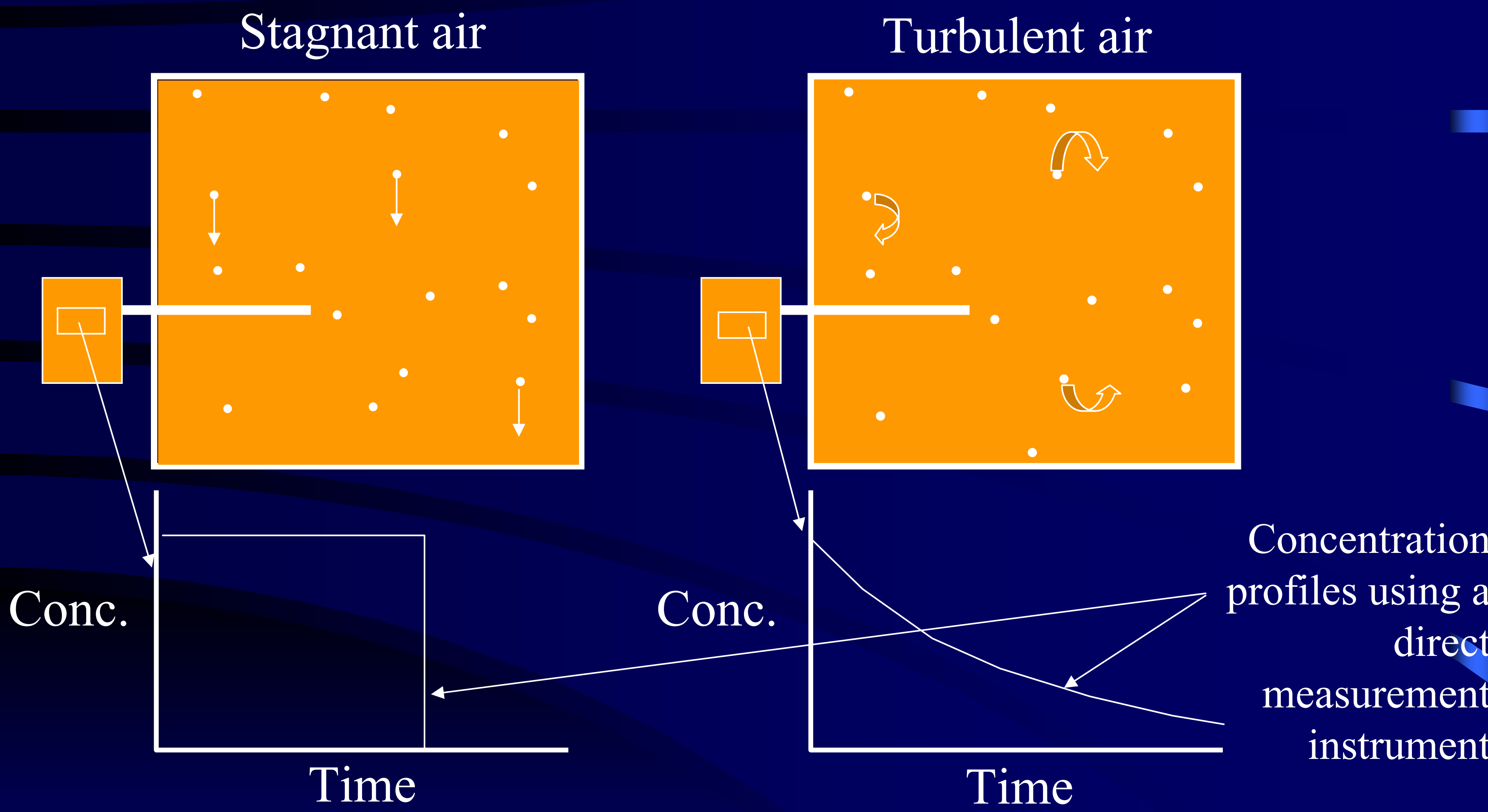
3 µm — 1.5 hours

10 µm — 8.2 minutes

100 µm — 5.8 seconds

Aerodynamic diameter definition: diameter of a unit density sphere that settles at the same velocity as the particle in question

Particle Settling in a Closed Room



Particles of the same size will settle at the same speed in still or stagnant air

Particles passing close to a horizontal surface can settle, but the rest will continue to be stirred.

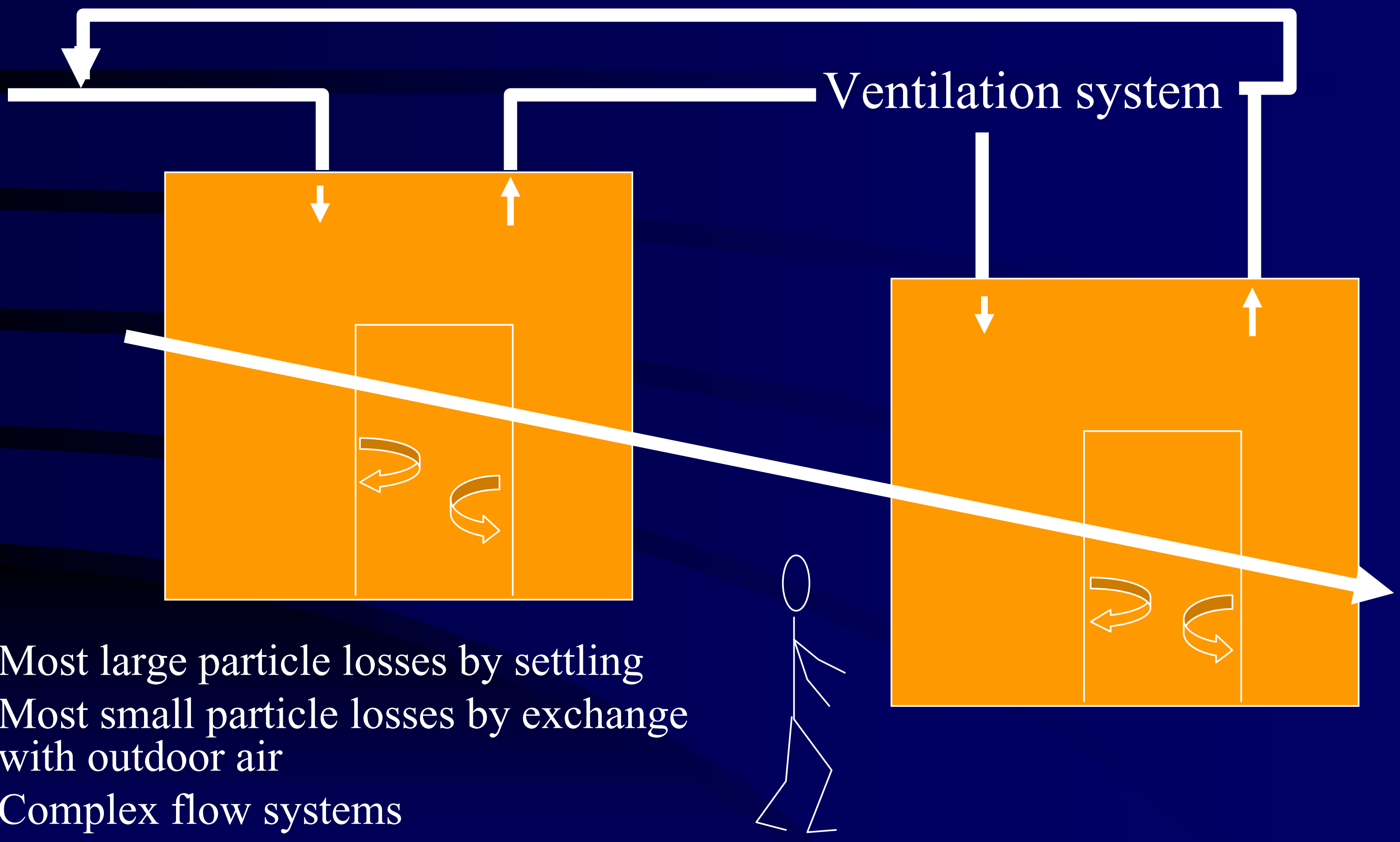
Particle Settling in Turbulent Air

Half-life of particles in 8 foot high room

0.5 µm	1 µm	3 µm	10 µm	100 µm
41 hours	12 hours	1.5 hours	8.2 minutes	5.8 seconds

Particles settling in turbulent air will have an exponential decay rate as indicated in the previous slide

Particle Transport in Buildings



- Most large particle losses by settling
- Most small particle losses by exchange with outdoor air
- Complex flow systems
- Turbulence production

  Doors, people, fans. ventilation

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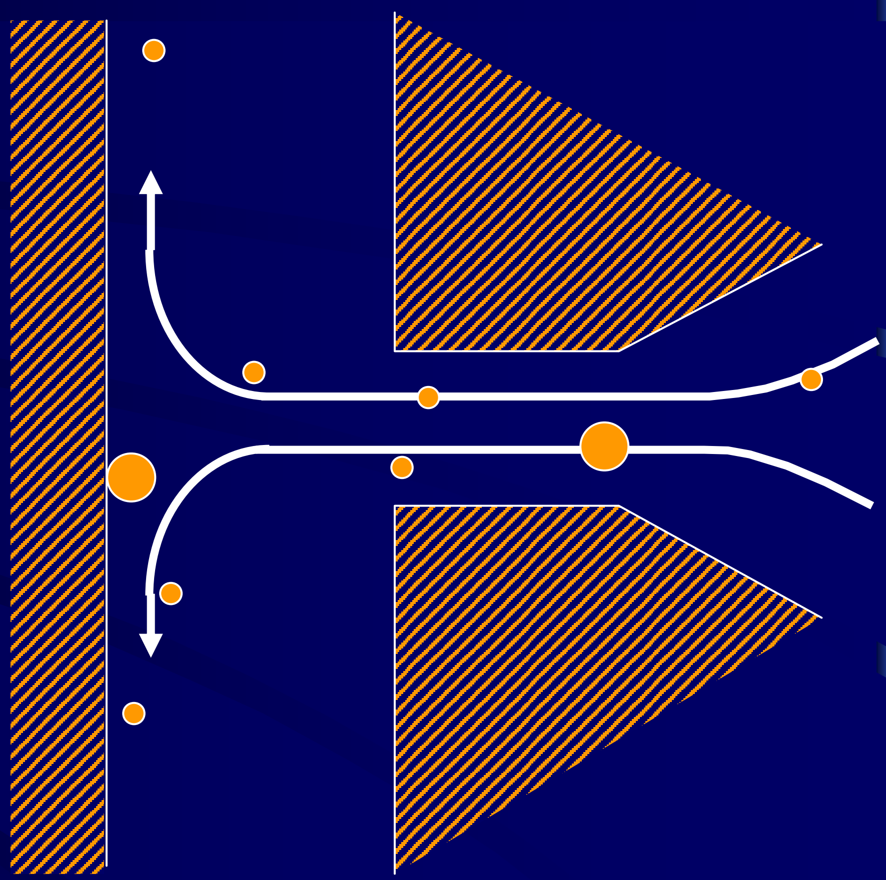
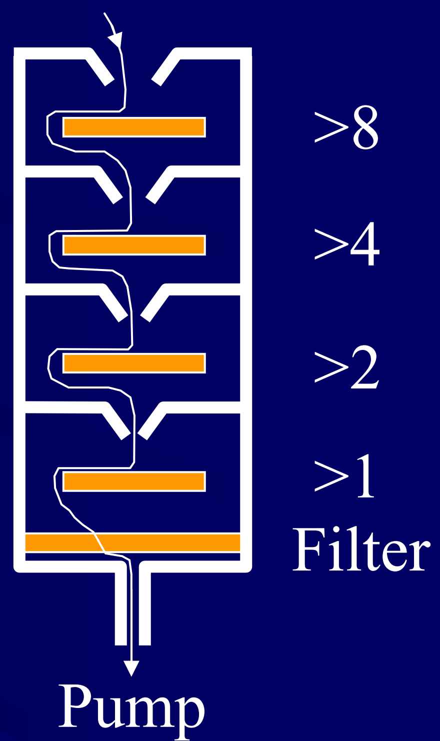
Particle Impaction

- Impaction depends on particle size, air velocity, jet diameter
- Large particles deposit more easily
- Even larger particles can bounce from surface
- Impaction surface can be modified to improve collection, e.g., add oil



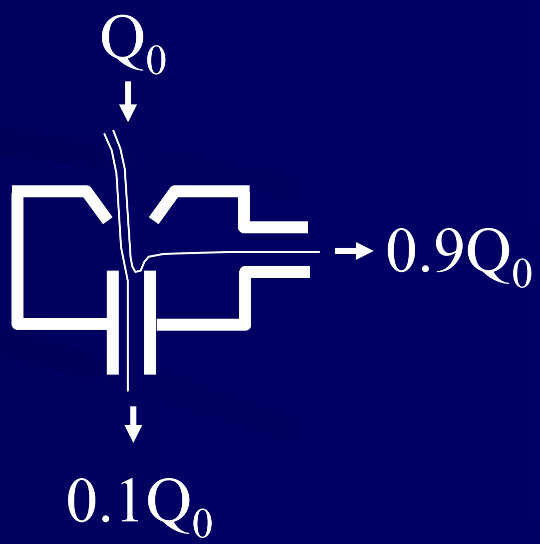
Cascade Impactors

- Used for size distribution measurement
- Commercial impactors
  - Andersen
  - MOUDI



Virtual Impactors

- Used to reduce particle bounce
- Used to concentrate larger particles
  - Commercial virtual impactor up to 100:1
  - Contains smaller particles in minor flow



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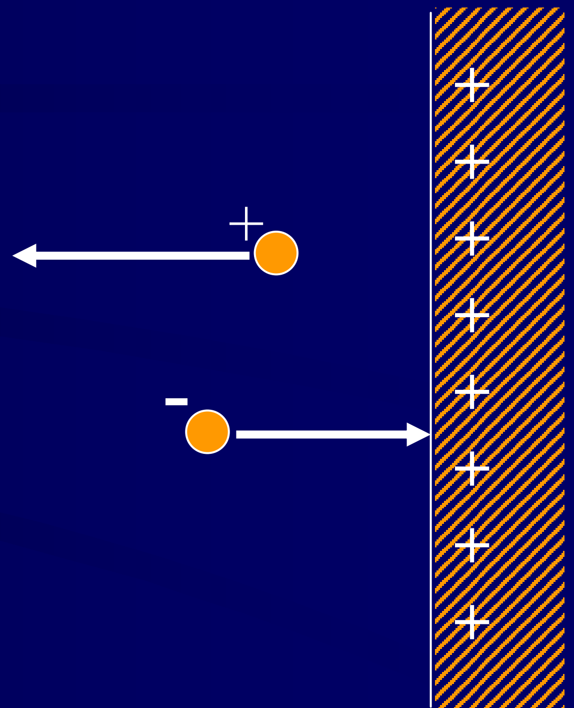
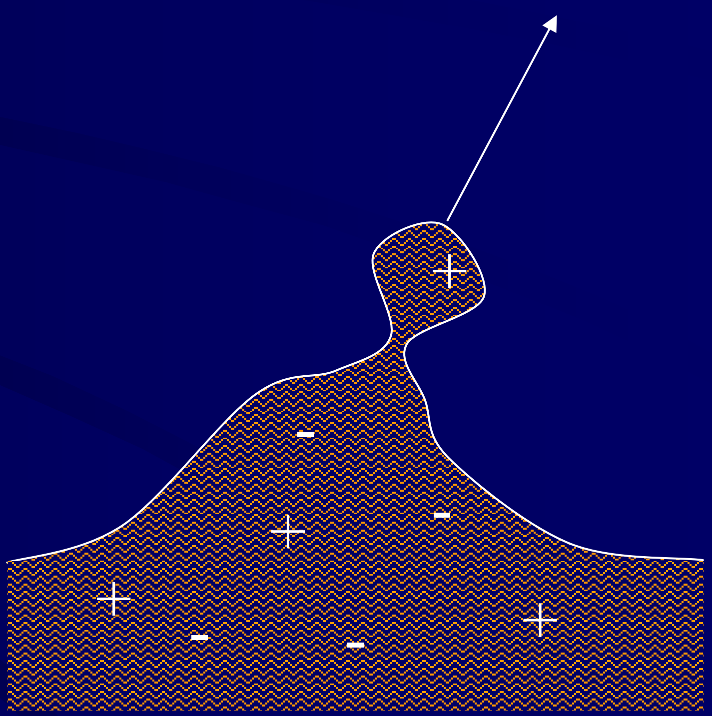
Electrostatic Effects

- Particle-particle interaction small
- Particle-surface interaction large
- Particle charge depends mostly on generation process, surface energy, humidity, time in the air
- Airborne particle charge gradually decreases due to ions in air (particles are nearly neutral after about 30 min)



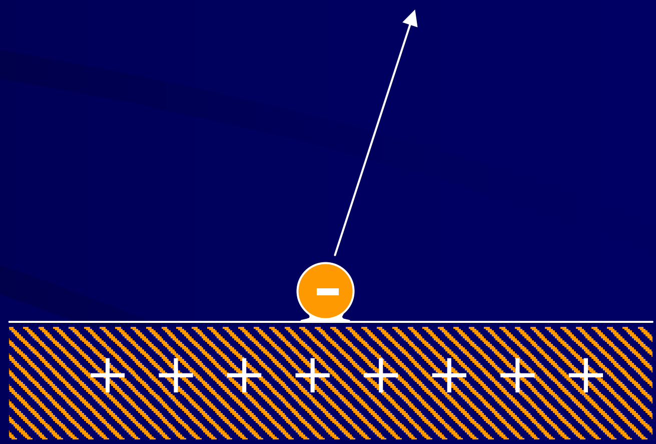
Particle Charge Imparted During Generation—Liquid Droplets

- In conductive solution, ions equally distributed
- In nonconductive solution, fewer ions
- Droplet charge generally low
- When liquid evaporates, the final particle may have relatively high charge



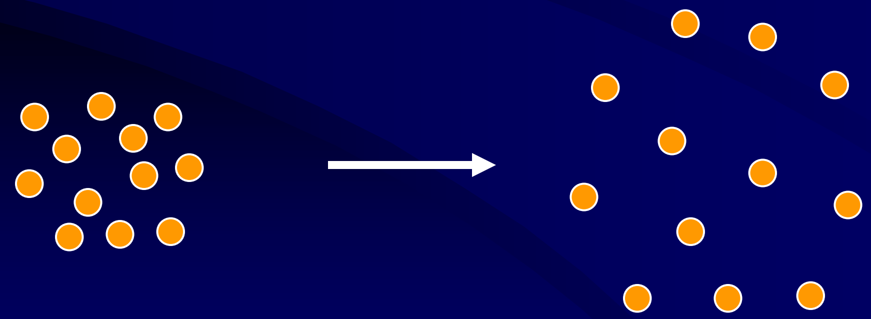
Particle Charge Imparted During Generation—Solid Particles

- Difference in surface energy levels
- Separation energy
- Humidity creates bridge between particle and surface



Space Charge
Expansion of Aerosol

- High aerosol concentration
- Particles are highly charged
- All particles have same polarity
- Aerosol will expand because of particle-particle repulsion



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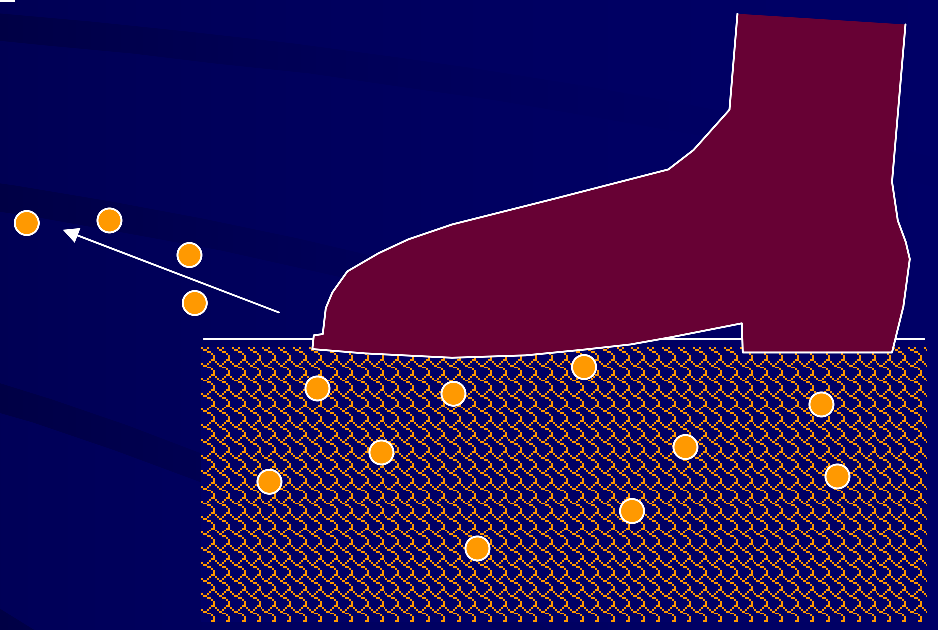
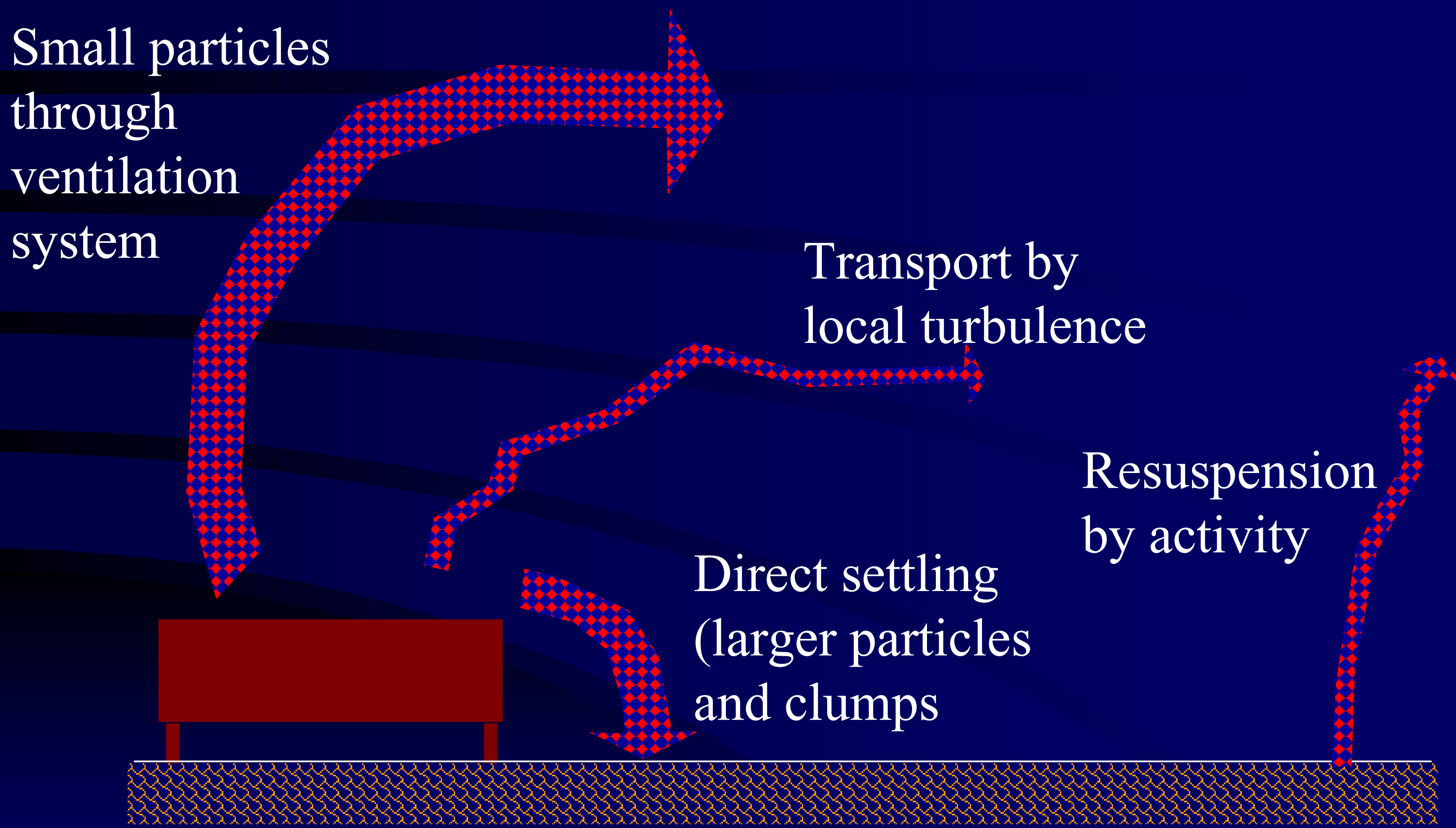
Generation from Carpet

- Particles deposited in carpet; acts as a sink
- Footstep crushes fibers against each other
- Footstep compresses carpet, creating high velocity air flow

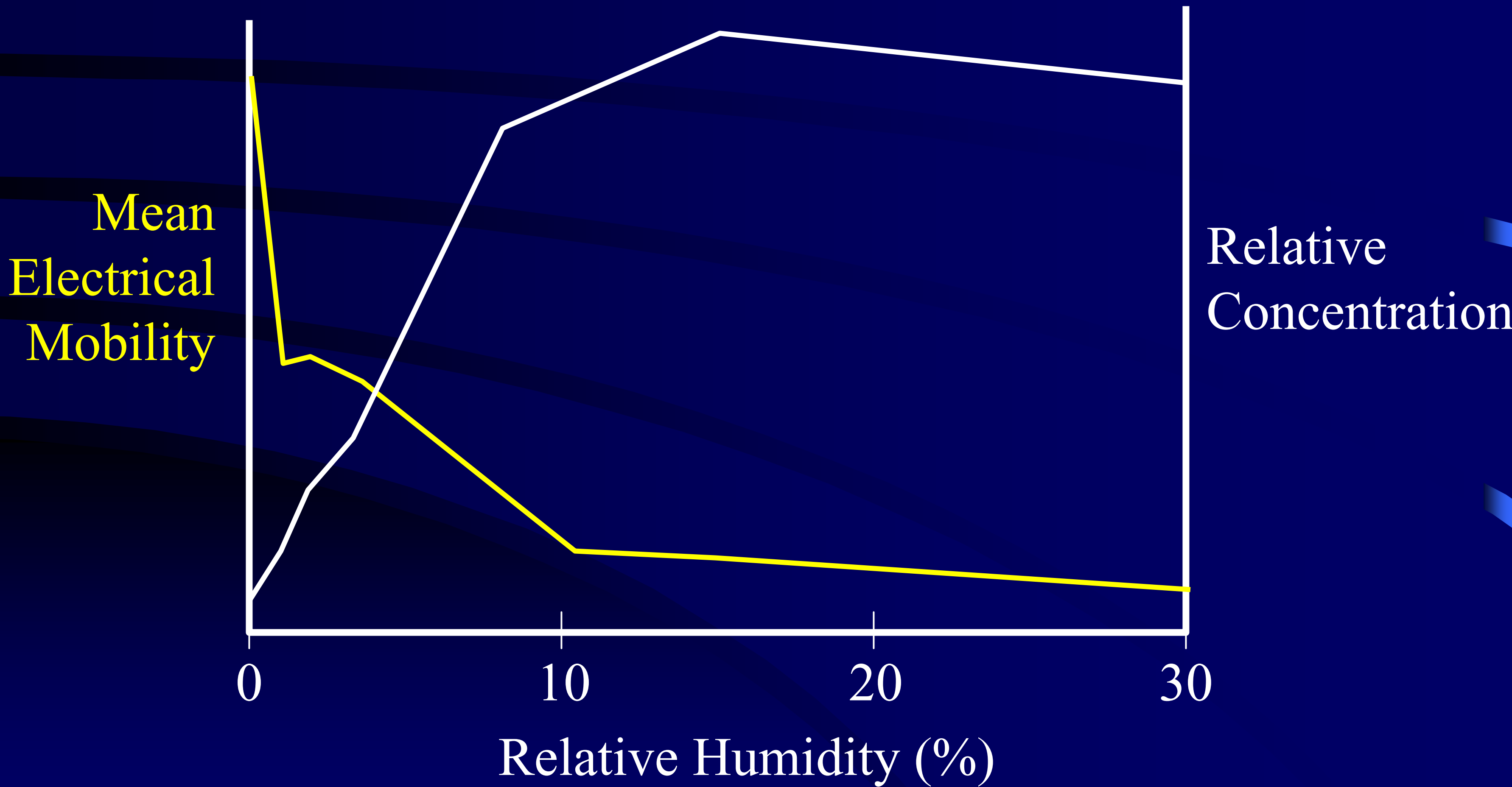


Particle Transport from Sources



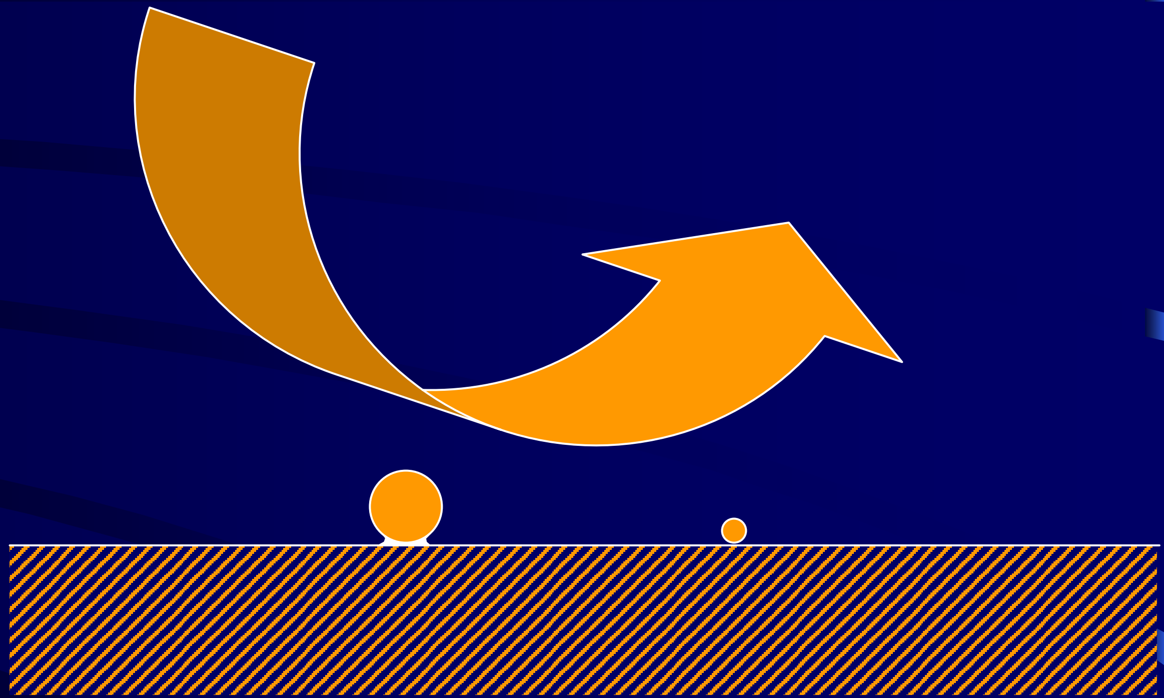
Asbestos Fiber Generation

Effect of humidity on particle charge
and particle generation efficiency



Particle Removal from Surfaces by Air Flow

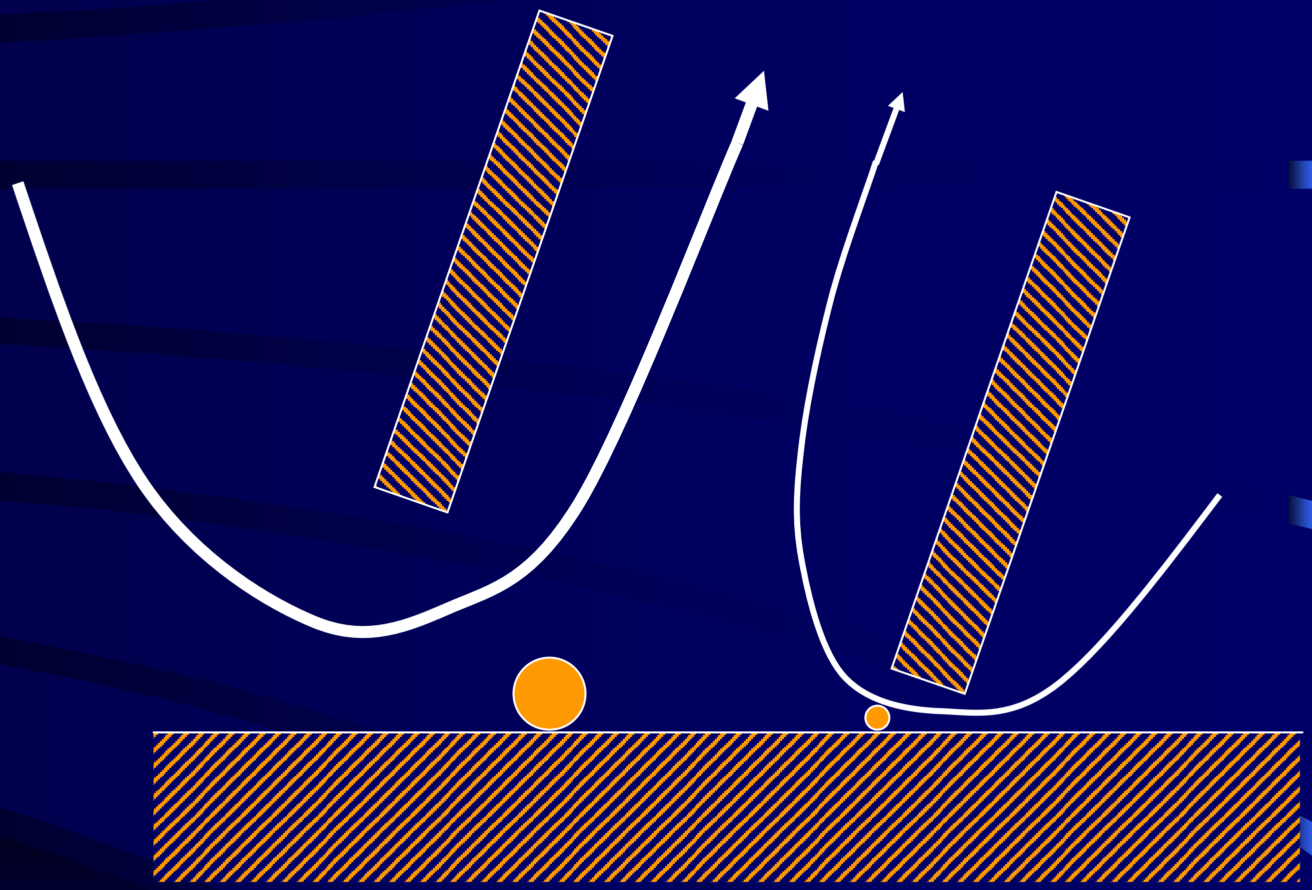
- Boundary layer near surface—produced by motionless surface
- Factors affecting release: Air velocity, particle attraction to surface versus particle cross section
- Water (humidity) can increase adhesion



< 0.1 µm virtually impossible
> 20 µm relatively easy

Vacuum Removal

- Suction forces air near surface to remove particles
- Variable removal efficiency



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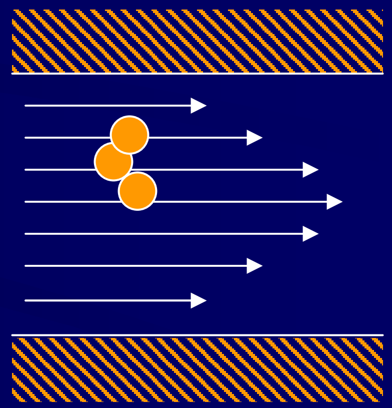
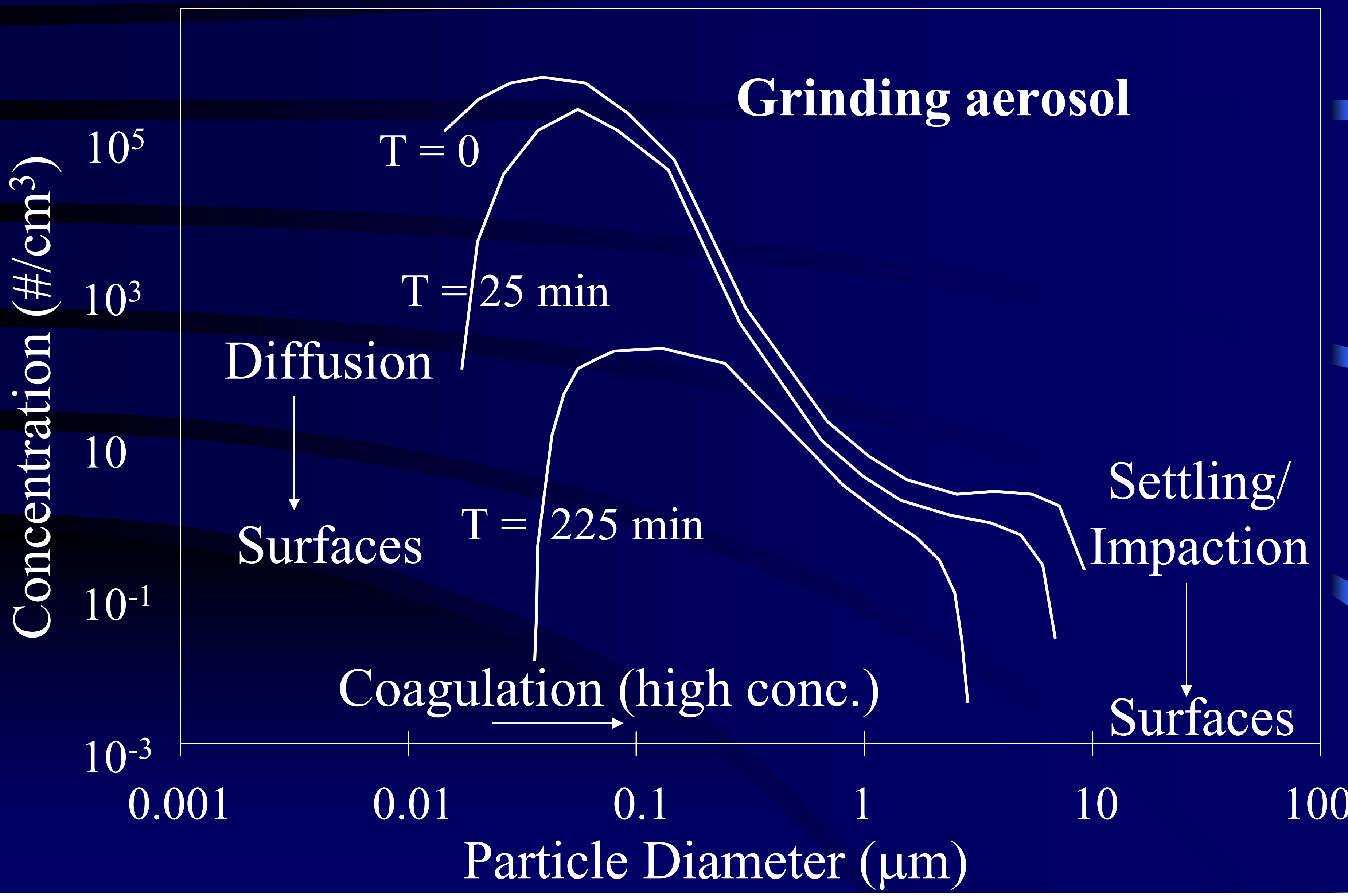
Agglomeration/ Deagglomeration

- Particles in a powder are in close contact, primarily agglomerates
- Shaken powder releases clumps (agglomerates) and single particles
- Shear forces, caused by difference in air velocity across the particle, can break apart clumps
- Shear forces increase with increasing energy (air velocity)



Particle Size Evolution

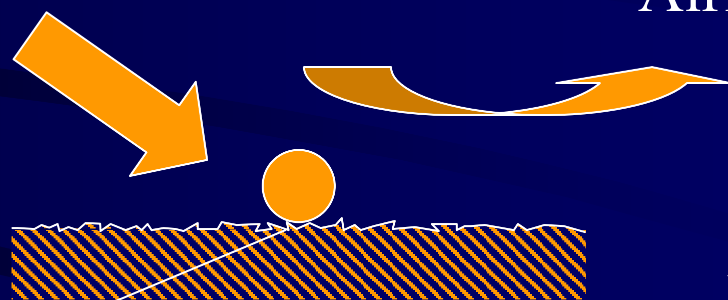


IV. Aerosol Generation

Energy Input
Air flow
Mechanical energy

< 0.1 µm virtually impossible
> 20 µm relatively easy

Airflow to entrain particles



Adhesion depends mostly on micro-roughness of surface, also on relative surface energies

Overcome adhesion between particle and surface

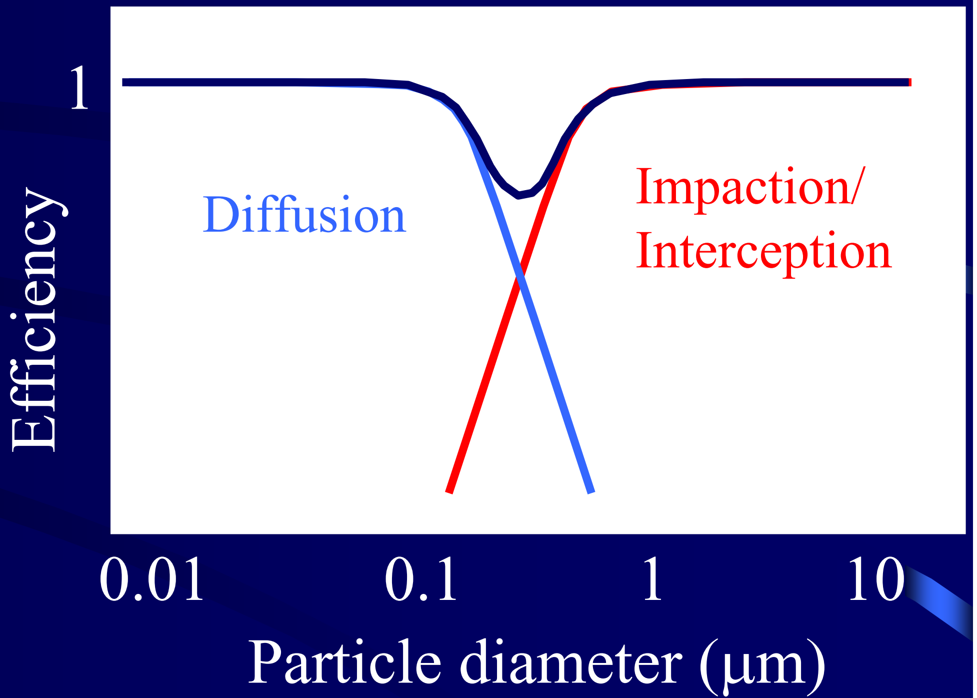
Release happens in microseconds

V. Particle Collection and Measurement

- Filter sampling
  - Filter efficiency, pore size, filter type
  - Sufficient volume for analysis
  - Dries particles because of continuous air flow
  - Removal from filter can be an issue
- Impactor sampling
  - Cascade impactor: 3 to 8 stages, size resolution
  - Sufficient volume for analysis
  - Dries particles, though less than filter
  - Inert (oiled?) surface or direct to growth medium

Filtration

- Air filtration different from liquid filtration
- Pore size in air filters generally meaningless as indicator of efficiency
- Small particles collected by diffusion, large ones by impaction/interception
- Maximum penetration at about 0.3 µm
- Efficiency increases with increasing air velocity



Direct Reading Aerosol Measurement

Optical particle counter

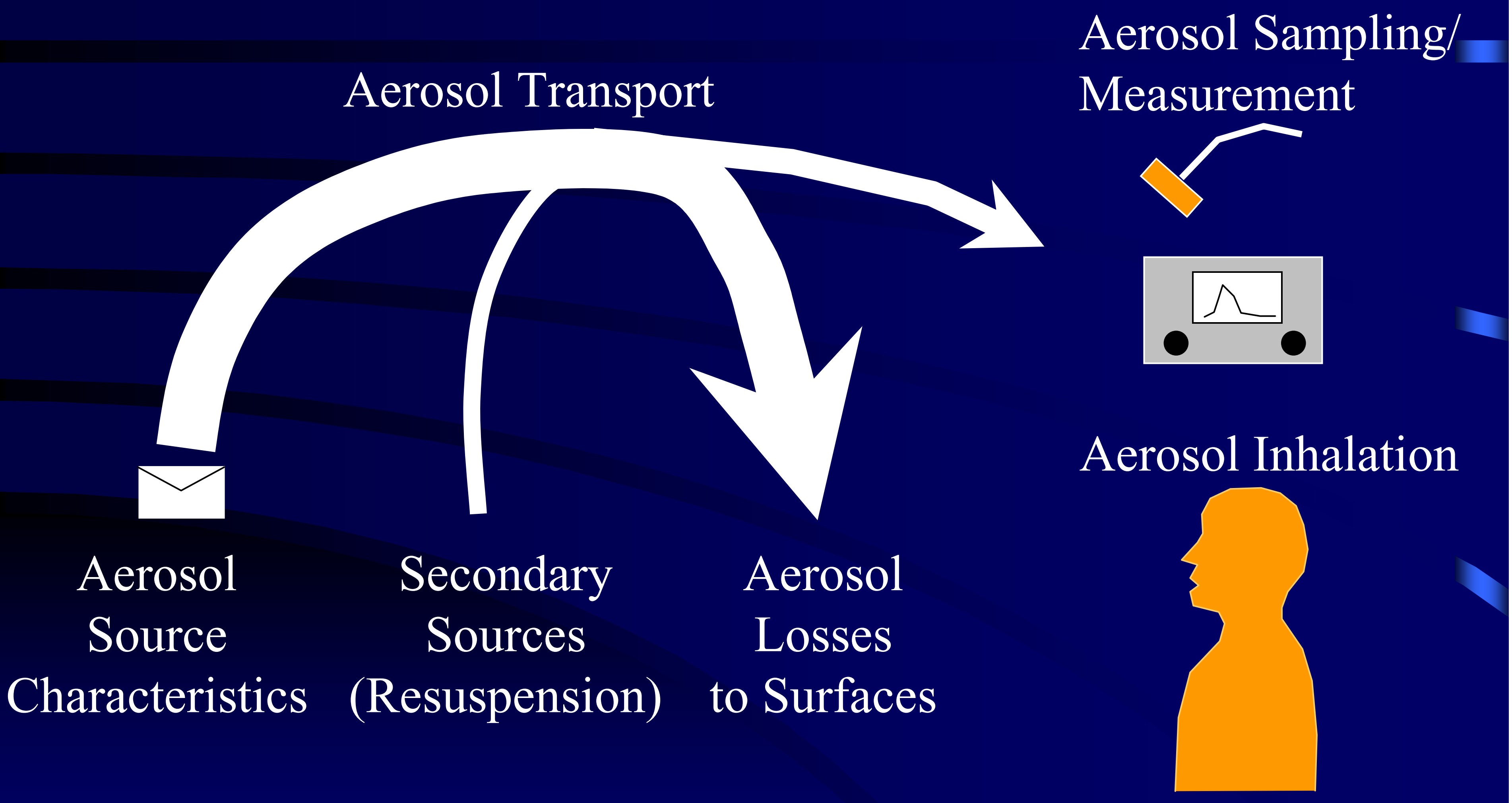
- Relatively inexpensive (~2K – $10K)
- Portable, battery operated
- Rapid detection
- Nonspecific for bacteria
- Toxic concentrations near or below ambient particle concentrations
- Can be used for tracer studies

Direct Reading
Aerosol Measurement

Aerodynamic Particle Sizer

- Relatively expensive (~$40K)
- Movable, line operated
- Higher size resolution, possibly improved size distribution signature
- Fluorescent detection version
- Can be used for tracer studies

Overall Scenario



Resources for Aerosol Information

- Hinds, 1999, Aerosol Technology, Wiley
- Baron and Willeke, 2001, Aerosol Measurement, Wiley
- Hurst, 1997, Manual of Environmental Microbiology, ASM Press
- Spreadsheet: Aerosol Calculator available from www.tsi.com or www.bgiusa.com