
Aerobiology

Aerobiology

- The interdisciplinary science that deals with the movement and dispersal of bioaerosols
- The movement of bioaerosols is generally passive and is greatly influenced by the environment
- The survival of viable bioaerosols is also dependent on the environmental conditions

Bioaerosols

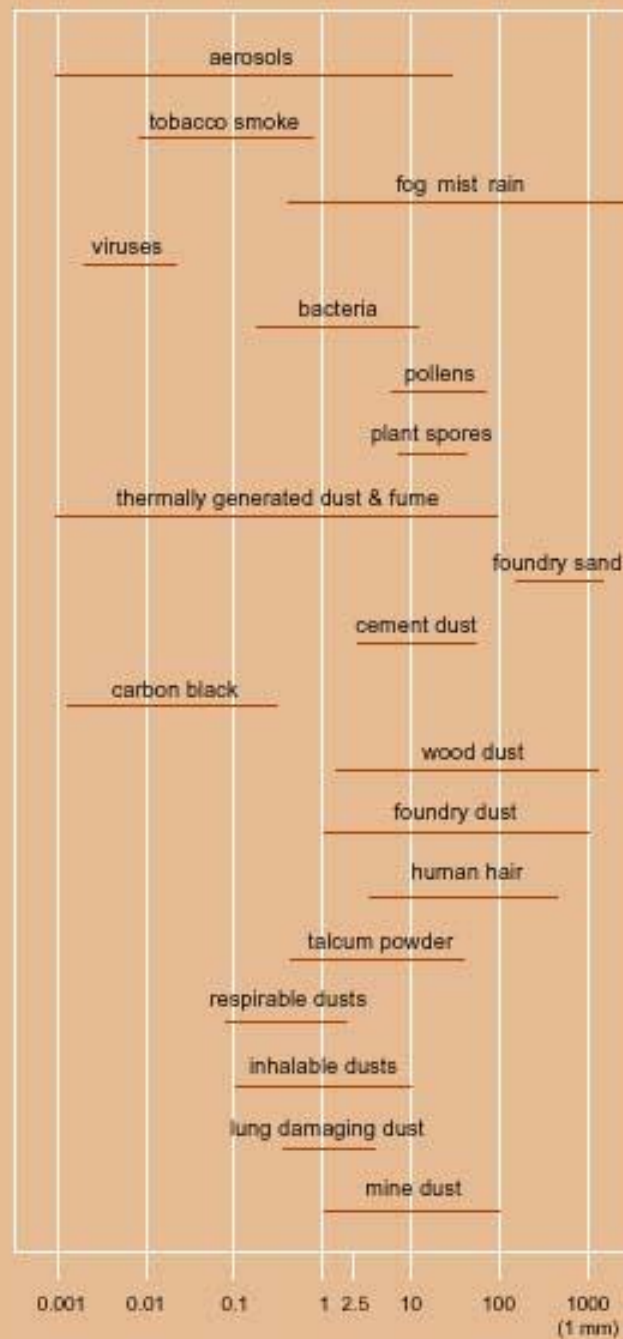
- Biological agents carried in the air as large molecules, volatile compounds, single particles, or clusters of particles that are living or were released from a living organism
- Particles sizes – typically $0.5\mu\text{m}$ to $100\mu\text{m}$
- Capable of eliciting diseases that may be infectious, allergic, or toxigenic with the conditions being acute or chronic

TABLE 3.1 Biological Particles That May Be Present in Indoor Air and Their Sizes

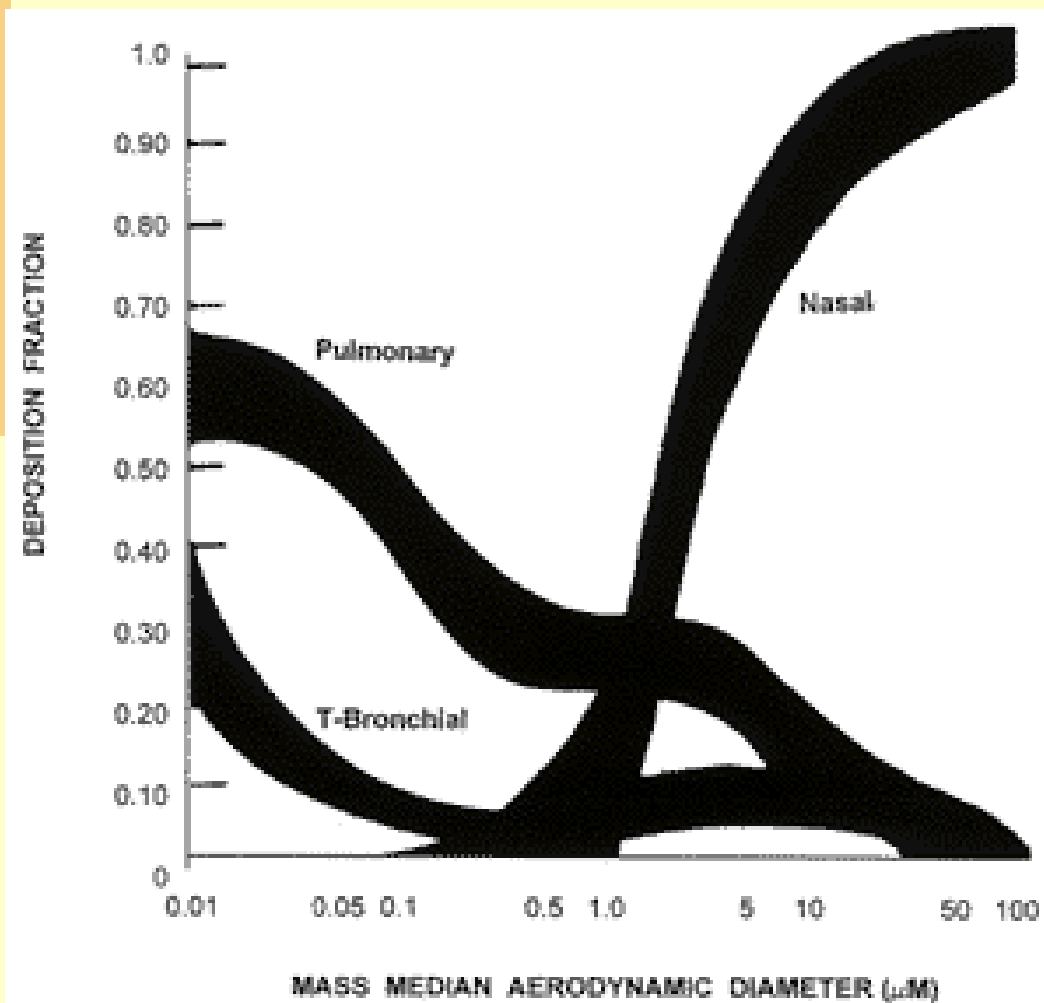
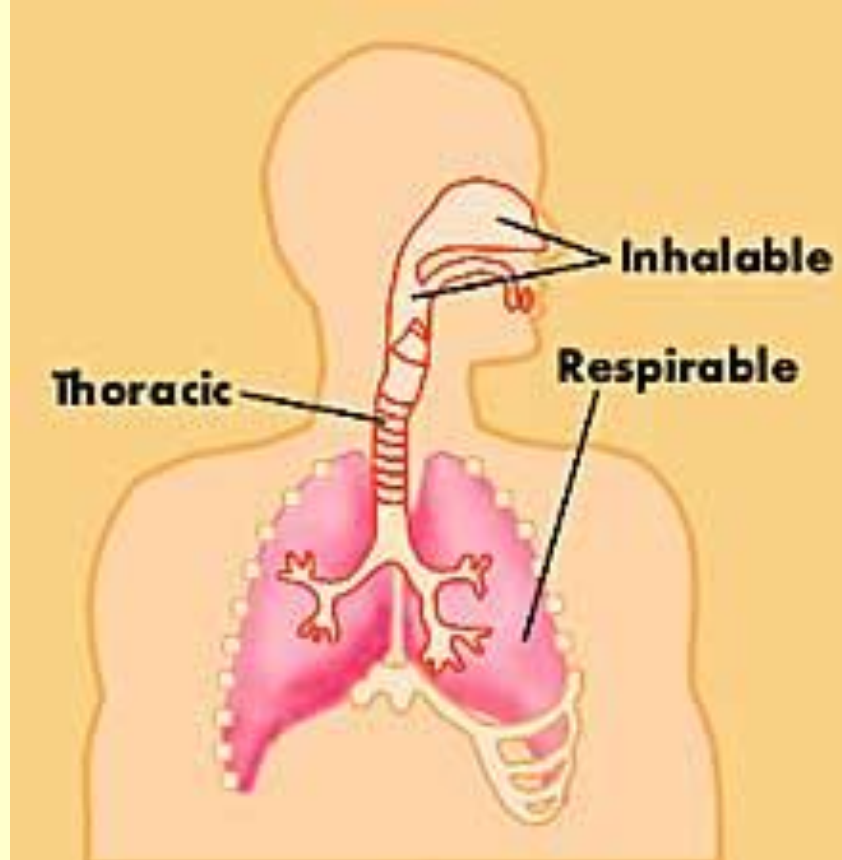
Source Organism	Particle	Size Range (µm)	Common Examples	Unique Characteristics
Virus	One or more virions in droplet nucleus	<0.1-3	Influenza	Particle may be much larger than organism; RNA or DNA, not both
Mycoplasma	One or more organisms in droplet nucleus	1-5	M. pneumoniae	No cell wall
Chlamydia	One or more organisms in droplet nucleus	1-5	Chlamydia psittaci	
Rickettsia	One or more organisms in droplet nucleus	1-5	Coxiella burnetii	Obligate intracellular pathogen
Bacteria	One or more bacteria in droplet nucleus or on a raft	1-5	Micrococcus luteus	Variable in size, shape, cell wall composition
	Single or grouped dry spores	0.5-5 3	Bacillus cereus Thermoactinomyces	Highly resistant endospores
	Cell wall fragments	<0.1		
Algae	One or more cells	5-10	Chlorococcus	Chlorophyll, cellulose
Nonvascular plants	One or more spores	15-30	Mosses	Chlorophyll, cellulose
Vascular plants	Spore	15-30	Lycopodium ferns	
	Pollen	10-50	Trees, grasses, weeds	Sporopollenin
	Pollen allergens	?		
	Hairs	10-100		Cellulose
	Fragments	?	Soy beans	Cellulose
Arthropods	Fragments	?	Cockroach, dust mite	Chitin
	Fecal material	20-30		
Animals	Fragments	?	Cats, dogs, mice	Keratin
	Skin scales	10-50		
Fungi	One or more spores	1.5-100	Mushrooms, aspergillus	Chitin
	One or more hyphae	1.5-100		Ergosterol
	Fragments	?		1-3 β-D-glucan

Table 2. Some types and diameters of airborne particles

Types	Diameters (μm)
Smoke	0.001–0.1
Condensation nuclei	0.1–20.0
Dusts	0.1–cm
Viruses	0.015–0.45
Bacteria	0.3–10
Fungal Spores	1.0–100
Algae	0.5–cm
Lichen Fragments	1.0–cm
Protozoa	2.0–cm
Bryophyta spores	6.0–30.0
Pteridophyta spores	20.0–60.0
Pollen	10.0–100.0
Vegetal and animal fragments, seeds, insects	> 100



Particle size micrometres (log scale)



Aerosols and Respiratory Deposition

- Aerosols $\lesssim$ 5 microns in diameter are removed in the upper respiratory tract, especially the nose.
 - Particles are brought to the pharynx by mucociliary activity of the upper respiratory epithelial mucosa, where they are expectorated or swallowed.
 - Swallowed particles containing enteric microbes can initiate enteric infections.

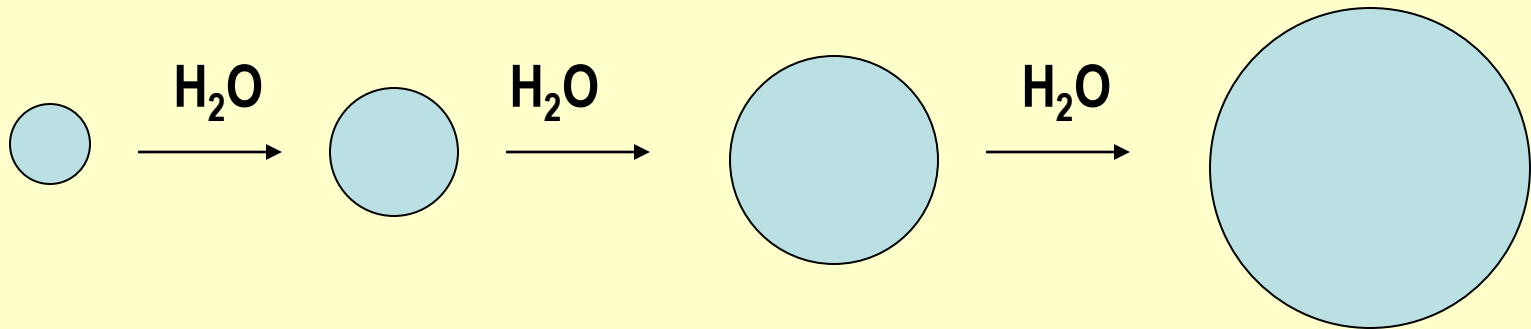
Aerosols and Respiratory Deposition

- **Particles <5 microns in diameter, esp. 1-3 microns diameter, penetrate to the lower respiratory tract**
 - **Can be deposited in the bronchioles, alveolar ducts and alveoli.**
 - **Deposition efficiency in lower respiratory tract is ~50% for particles 1-2 microns diameter.**
 - **Particles <0.5 microns dia. can also be deposited in the lower respiratory tract, especially particles <0.25 microns dia.**
 - **Particles deposited in the lower respiratory tract can be phagocytized by respiratory (alveolar) macrophages**
 - **can be destroyed or**
 - **carried to the ciliary escalator, where they are transported upward to the pharynx.**

Hydroscopicity and Aerosol Deposition in the Respiratory Tract

When inhaled, aerosol particles derived from aqueous fluids pick up moisture (water) while traveling in the respiratory passageways, thereby increasing in size.

- Increased size changes deposition site



Respiratory Deposition - Impaction

- **Each time airflow changes due to a bifurcation in the airways, suspended particles tend to travel along their original path due to inertia and may impact on an airway surface.**
- **This mechanism is highly dependent on aerodynamic diameter, since the stopping distance for very small particles is quite low.**
- **Occurs mostly for larger particles that are very close to airway walls, near the first airway bifurcations.**
- **Therefore, deposition by impaction is greatest in the bronchial region.**
- **Impaction accounts for the majority of particle deposition on a mass basis.**

Respiratory Deposition - Sedimentation

- **Settling out of particles in the smaller airways of the bronchioles and alveoli, where air flow is low and airway dimensions are small.**
- **Rate of sedimentation is dependent on the terminal settling velocity of the particles**
- **Sedimentation plays a greater role in the deposition of particles with larger aerodynamic diameters.**
- **Hygroscopic particles may grow in size as they pass through the warm, humid air passages, thus increasing the probability of deposition by sedimentation.**

Respiratory Deposition - Interception

- **Occurs when a particle contacts an airway surface due to its physical size or shape.**
- **Unlike impaction, particles that are deposited by interception do not deviate from their air streamlines.**
- **Most likely to occur in small airways or when the air streamline is close to an airway wall.**
- **Interception is most significant for fibers, which easily contact airway surfaces due to their length.**
 - **Furthermore, fibers have small aerodynamic diameters relative to their size, so they can often reach the smallest airways.**

Respiratory Deposition - Diffusion

- **Primary mechanism for particles <0.5 microns in diameter**
- **Governed by geometric rather than aerodynamic size**
- **Net transport of particles from a region of higher to lower concentration due to Brownian motion.**
 - **Brownian motion: random wiggling motion of a particle due to the constant bombardment of air molecules.**
- **Occurs mostly when particles have just entered the nasopharynx**
- **Also most likely to occur in the smaller airways of the pulmonary (alveolar) region, where air flow is low.**

Concentrations in Air

- Concentrations of indoor bacteria range from <100-1500 cfu/m³; avg 0-500
 - heated dwellings lower
- Avg concentrations of outdoor bacteria 200-1000
- Avg concentrations of indoor Fungi range from 10-500
- Avg concentrations of Outdoor Fungi range from 100-1000

Microbial IAQ

- Outdoor spores enter readily
- Many fungi can also amplify indoors – anytime moisture is available fungi can grow on many indoor substrates
- *Penicillium*, *Aspergillus*, and *Cladosporium* are most common indoors
- Many can form mycotoxins – *Aspergillus* spp and *Stachybotrys*

per liter), with naturally ventilated building levels lower than levels in mechanically ventilated ones.^{56,57} On the other hand, in areas where agricultural and animal confinement activities are occurring, levels are often much higher (e.g., 490 nanograms per cubic meter for swine confinement).⁵⁸

TABLE 3.8 Reported Concentrations of Bacteria in Indoor Air in Various Circumstances

Analysis Method	Concentration	Type of Building	Location	Authors
Culture	0.9-1.2 cfu/liter	Auditorium with people	Rome	Sessa, Di Pietro, et al. ^a
Culture	0.735 cfu/liter	Day care centers	Taiwan	Li, Hsu et al. ^b
Culture	8-11org/liter ^c	Office buildings	U.S. Midwest	Reynolds, Black et al. ^d
Culture	425 (167-930) cfu/liter	Swine confinement	Canada	Duchaine, Grimard et al. ^e
Culture	57-260 cfu/m ³	Homes	Poland	Lis, Pastuszka et al. ^f
Culture	19-118 cfu/m ³	Offices	Poland	Lis, Pastuszka et al. ^f
Culture	0-0.196 cfu/liter	Offices	Mauritius	Bholah and Subratty ^g
Culture	0.088-16 cfu/liter	Residences	Poland	Gorny, Reponen, et al. ^h
Culture	5 cfu/liter ⁱ	Residences	Poland	Gorny, Reponen et al. ^h

^a R. Sessa, M. Di Pietro, G. Schiavoni, I. Santino, A. Altieri, S. Pinelli, and M. Del Piano. 2002. Microbiological indoor air quality in healthy buildings. *New Microbiol.* 25:51-56.

^b C.S. Li, C.W. Hsu, and M.L. Tai. 1997. Indoor pollution and sick building syndrome symptoms among workers in day-care centers. *Archive of Environmental Health* 52:200-207.

^c Combination of directly counted individual bacterial and fungal cells.

^d S.J. Reynolds, D.W. Black, S.S. Borin, G. Breuer, L.F. Burnmeister, L.F. Guortes, T.F. Smith, M.A. Stein, P. Subramanian, P.S. Thoms, and P. Whitten. 2000. Indoor environmental quality in six commercial office buildings in the Midwest United States. *Appl. Occup. Environ. Hyg.* 16:1065-1077.

^e C. Duchaine, Y. Grimard, and Y. Cormier. 2000. Influence of building maintenance, environmental factors, and seasons on airborne contaminants of swine confinement buildings. *Am. Ind. Hygiene Assn J.* 61:56-63.

^f D.O. Lis, J.S. Pastuszka, and R.L. Gorny. 1997. [The prevalence of bacterial and fungal aerosol in homes, offices and ambient air of Upper Silesia. Preliminary results.] *Rocz. Panstw. Zakl. Hig.* 48:59-68.

^g R. Bholah and A.H. Subratty. 2002. Indoor biological contaminants and symptoms of sick building syndrome in office buildings in Mauritius. *Int. J. Environ. Heal. Res.* 12:93-98.

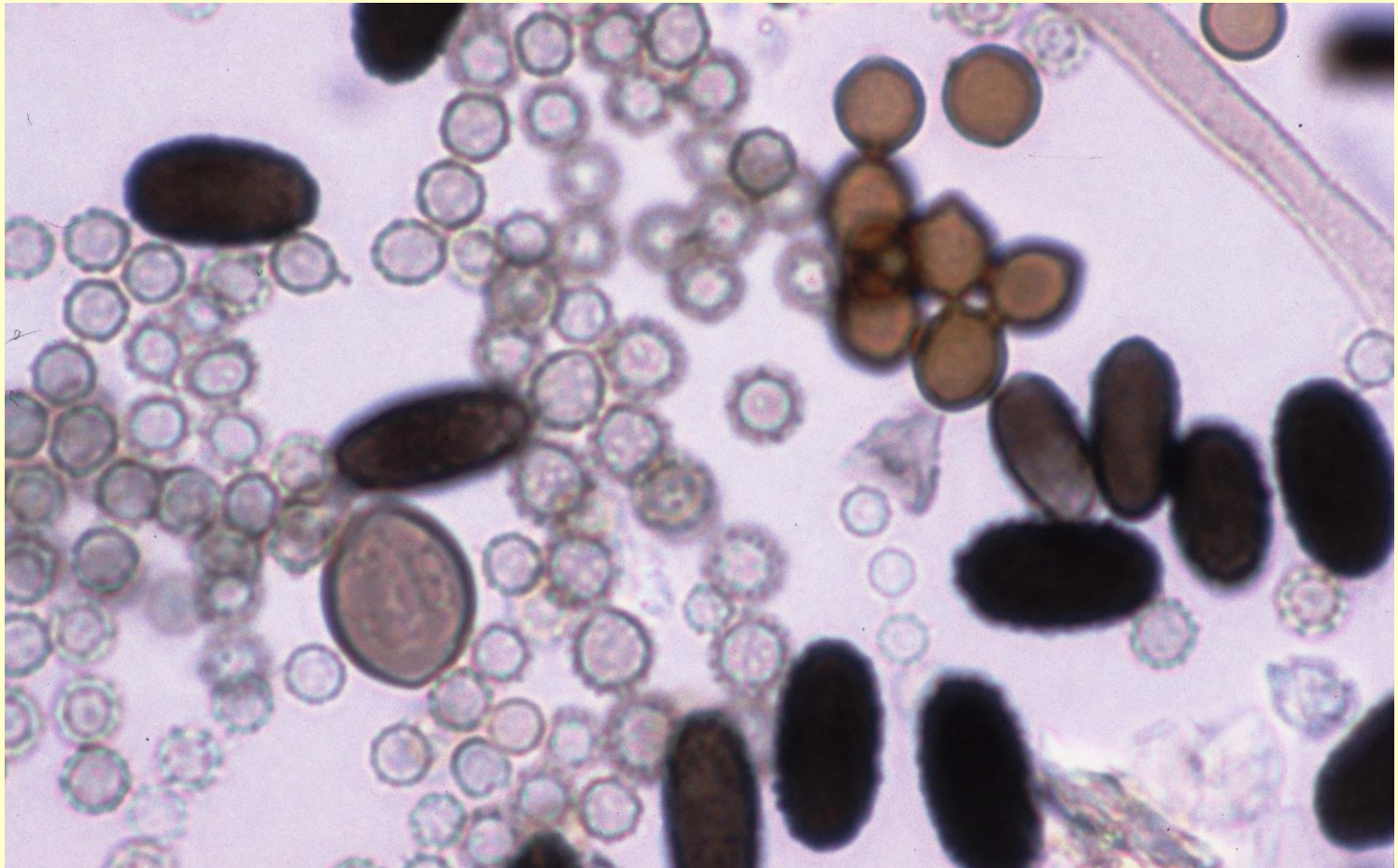
^h R.L. Gorny, T. Reponen, K. Willeke, D. Schmechel, E. Robine, M. Boissier, and S.A. Grinshpun. 2002. Fungal fragments as indoor air biocontaminants. *Appl. Environ. Microb.* 68:3522-3531.

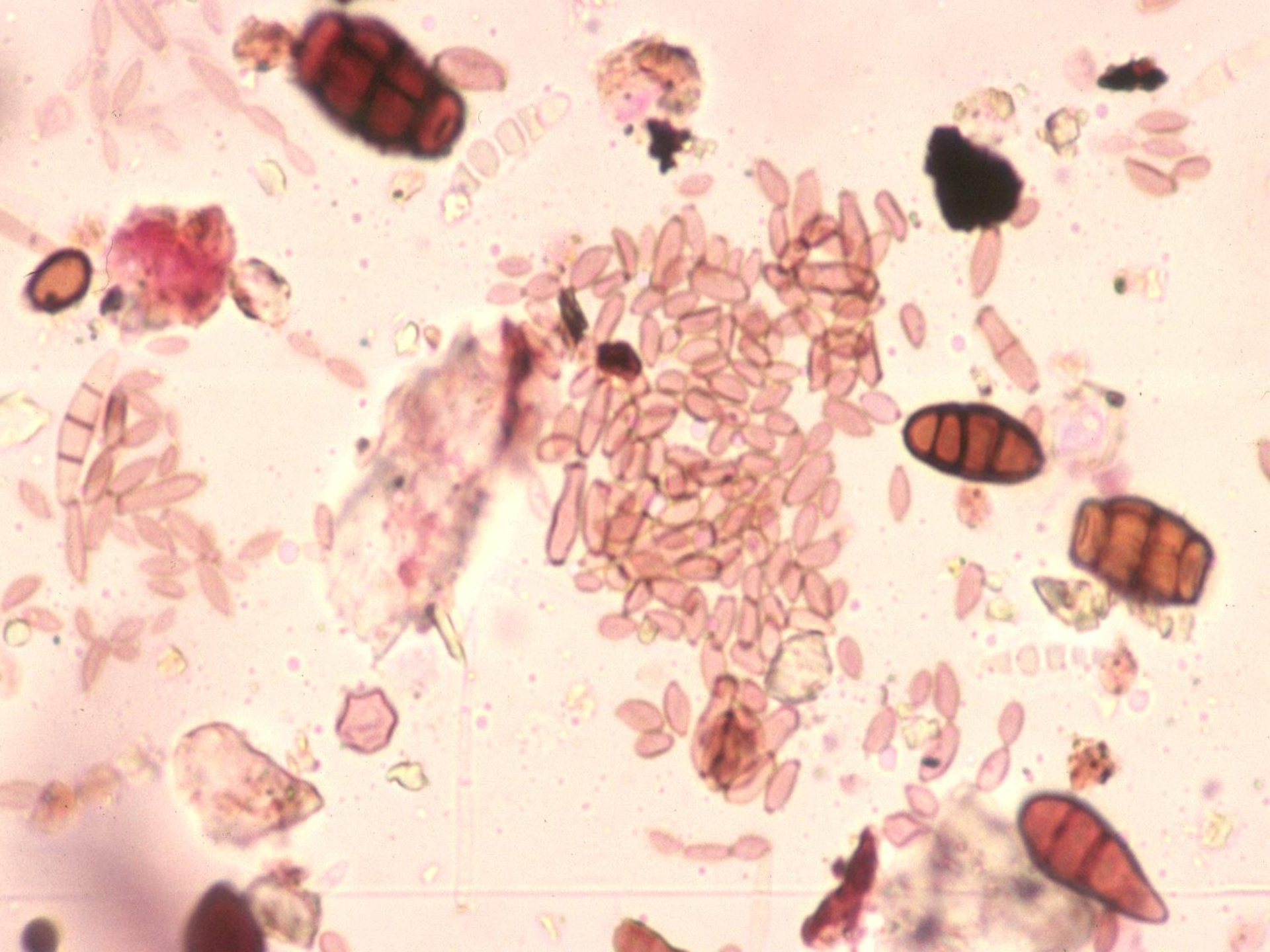
ⁱ exposure limit

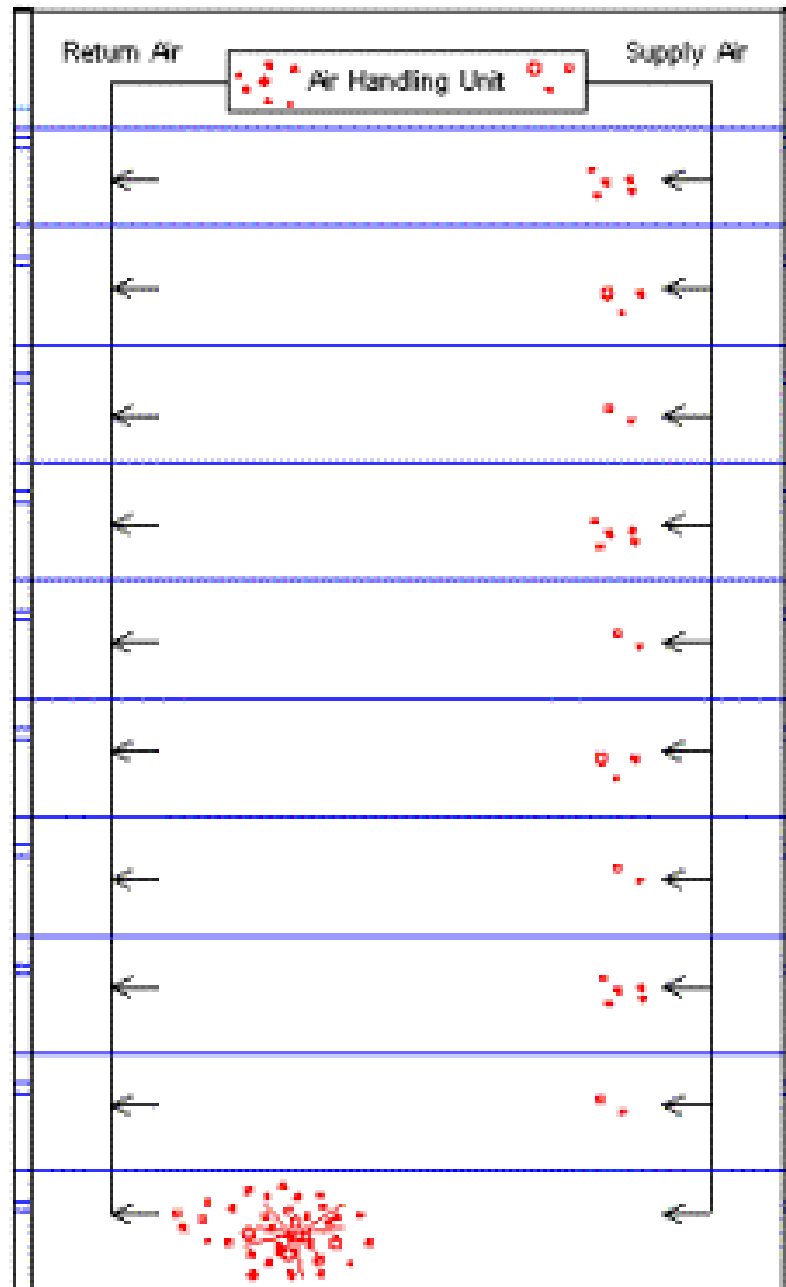
Environmental factors that influence indoor fungal contamination

- Outdoor concentration and type
- Type and rate of ventilation
- Activity levels
- Indoor moisture levels
- Modern building materials

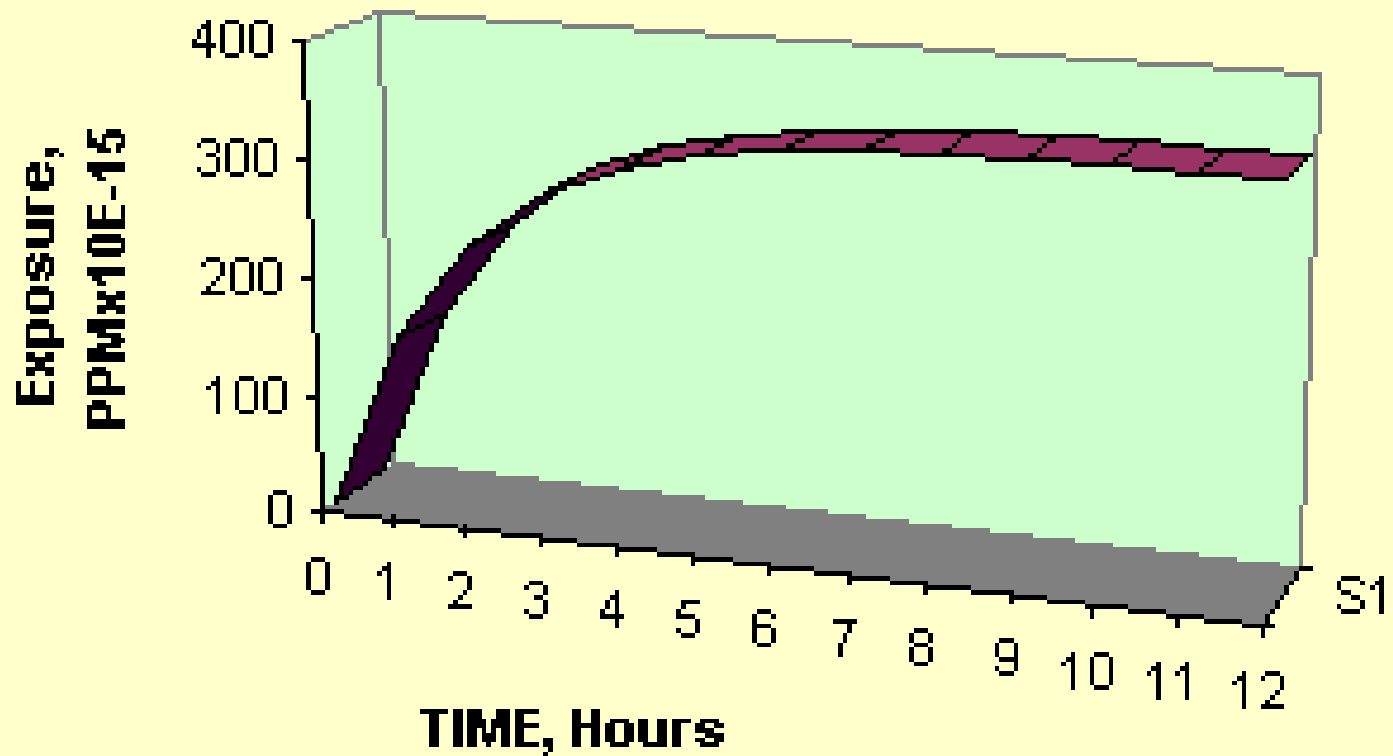
Indoor air sample







TB EXPOSURE ON THE 10th FLOOR FROM A 1st FLOOR SOURCE



Typical 80/20 recirculation/ventilation consistent with ASHRAE 62-89

Dry Air Spora

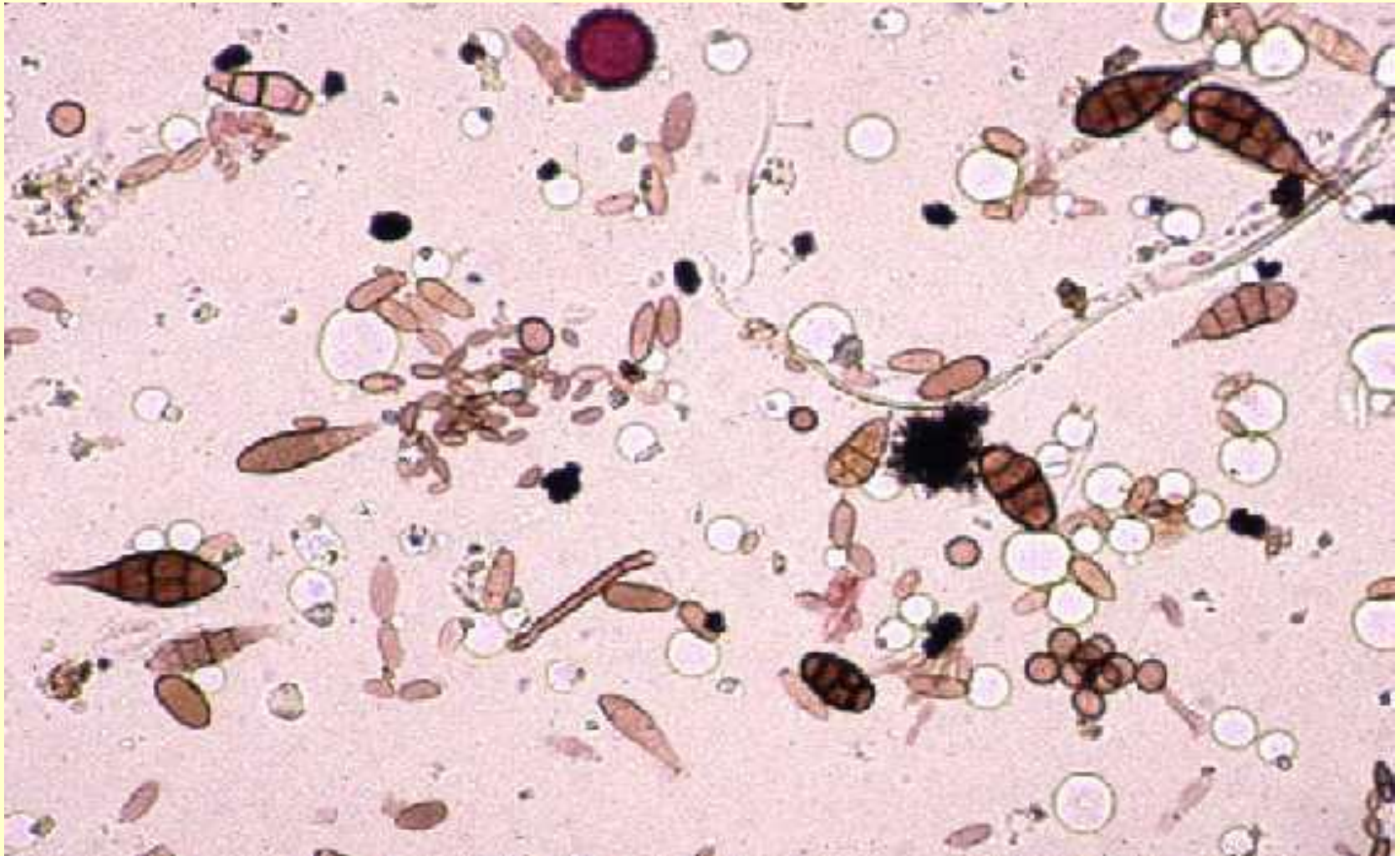


TABLE 3.5 Reported Concentrations of Total Bacteria in Outdoor Air

Assay Method	Concentration	Sample Environment	Location	Authors
Culture	0.1-0.6 cfu/liter (24-hr average) ^a	Urban air	Oregon	Shaffer and Lighthart ^b
Culture	0-4 cfu/liter (3-year averages)	Rural and urban air	Sweden	Bovallius, Bucht et al. ^c
Culture	1.4-2.2 cfu/liter	Above waste treatment plant		Brandi, Sisti et al. ^d
Culture	0.09-4.7/liter		Eastern Europe	Gorny, Reponen et al. ^e
Culture	10-1,000/liter	Wheat harvest	Egypt	Hameed and Khodr ^f
Culture	0.5-78.9 cfu/liter	Yard waste compost site	Illinois	Hryhorczuk, Curtis et al. ^g
Culture	0.004-1.5 cfu/liter	Ambient	Washington, D.C.	Jones and Cookson ^h
Culture	10 cfu/liter	Sewage sludge application	Texas	Pillai, Widmer et al. ⁱ
Culture	0.4 cfu/liter	Ambient	Taiwan	Li, Hsu et al. ^j
RNA probes	>25 organisms/liter	Ambient peaks	England	Biggins, Pomeroy et al. ^k

^a Colony-forming unit, cfu.

^b B.T. Shaffer and B. Lighthart. 1997. Survey of culturable airborne bacteria at four diverse locations in Oregon: urban, rural, forest, and coastal. *Microb. Ecol.* 34:167-177.

^c A. Bovallius, B. Bucht, R. Roffey, and P. Anas. 1978. Three year investigation of the natural airborne bacterial flora at four localities in Sweden. *Appl. Environ. Microb.* 35:847-852.

^d G. Brandi, M. Sisti, and G. Amagliani. 2001. Evaluation of the environmental impact of microbial aerosols generated by wastewater treatment plants utilizing different aeration systems. *J. Appl. Microb.* 88:845-852.

^e R.L. Gorny, T. Reponen, K. Willeke, D. Schmechel, E. Robine, M. Boissier, and S.A. Grinshpun. 2002. Fungal fragments as indoor air biocontaminants. *Appl. Environ. Microb.* 68:3522-3531.

^f A.A. Hameed and M.I. Khodr. 2001. Suspended particulates and bioaerosols emitted from an agricultural nonpoint source. *J. Environ. Monit.* 3:206-209.

^g D. Hryhorczuk, L. Curtis, P. Scheff, J. Chung, M. Rizzo, C. Lewis, N. Keys, and M. Moomey. 2001. Bioaerosol emissions from a suburban yard waste composting facility. *Ann. Agr. Environ. Med.* 8:177-185.

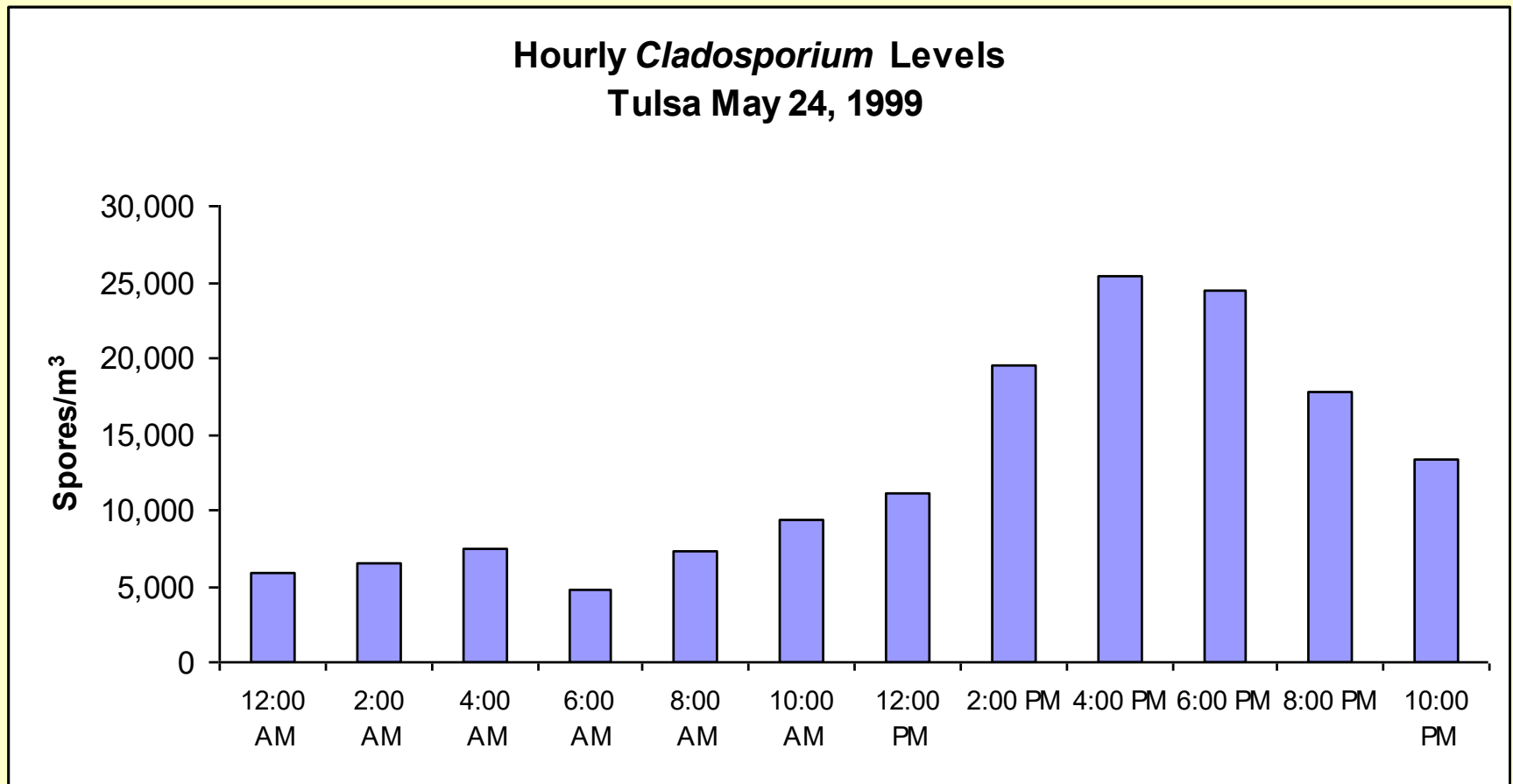
^h B.L. Jones and J.T. Cookson. 1983. Natural atmospheric microbial conditions in a typical suburban area. *Appl. Environ. Microb.* 45:919-934.

ⁱ S.D. Pillai, K.W. Widmer, S.E. Dowd, and S.C. Ricke. 1996. Occurrence of airborne bacteria and pathogen indicators during land application of sewage sludge. *Appl. Environ. Microb.* 61:296-299.

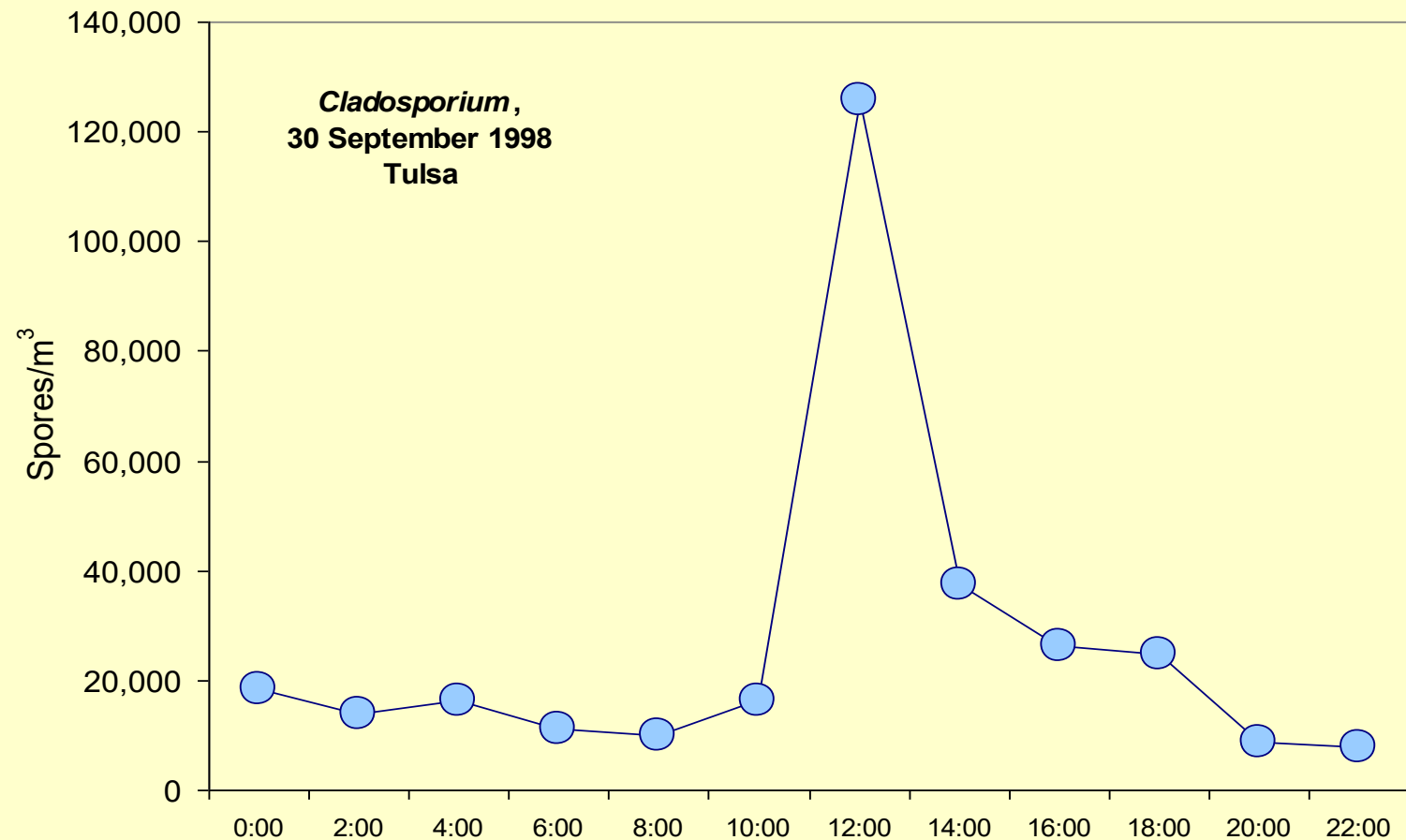
^j C.S. Li, C.W. Hsu, and M.L. Tai. 1997. Indoor pollution and sick building syndrome symptoms among workers in day-care centers. *Arch. Envir. Heal.* 52:200-207.

^k P. Biggins, N. Pomeroy, M. Pearce, C. Stone, N. Brown, R.M. Harrison, J. Hobman, and A. Jones. 2002. Characterisation of the ambient respirable biological aerosol. In *Proceedings of the Sixth Annual UK Review Meeting on Outdoor and Indoor Air Pollution Research*. Available at <http://www.le.ac.uk/leh/pdf/w12.pdf>. Accessed November 2003. pp. 75-77.

Diurnal Rhythm of *Cladosporium*

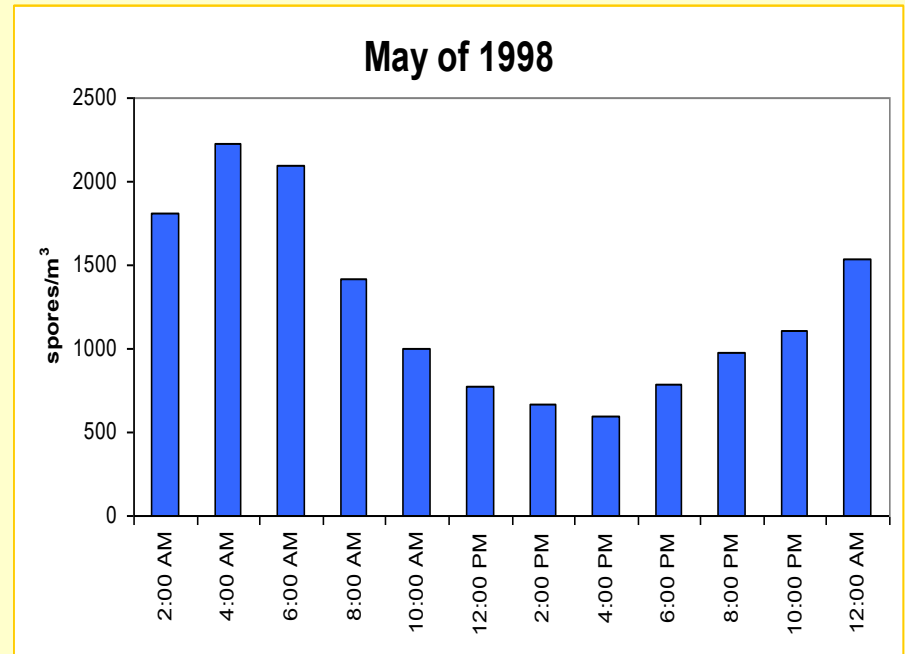


Cladosporium spores peak hourly concentration of >120,000 spores/m³ during a spore plume

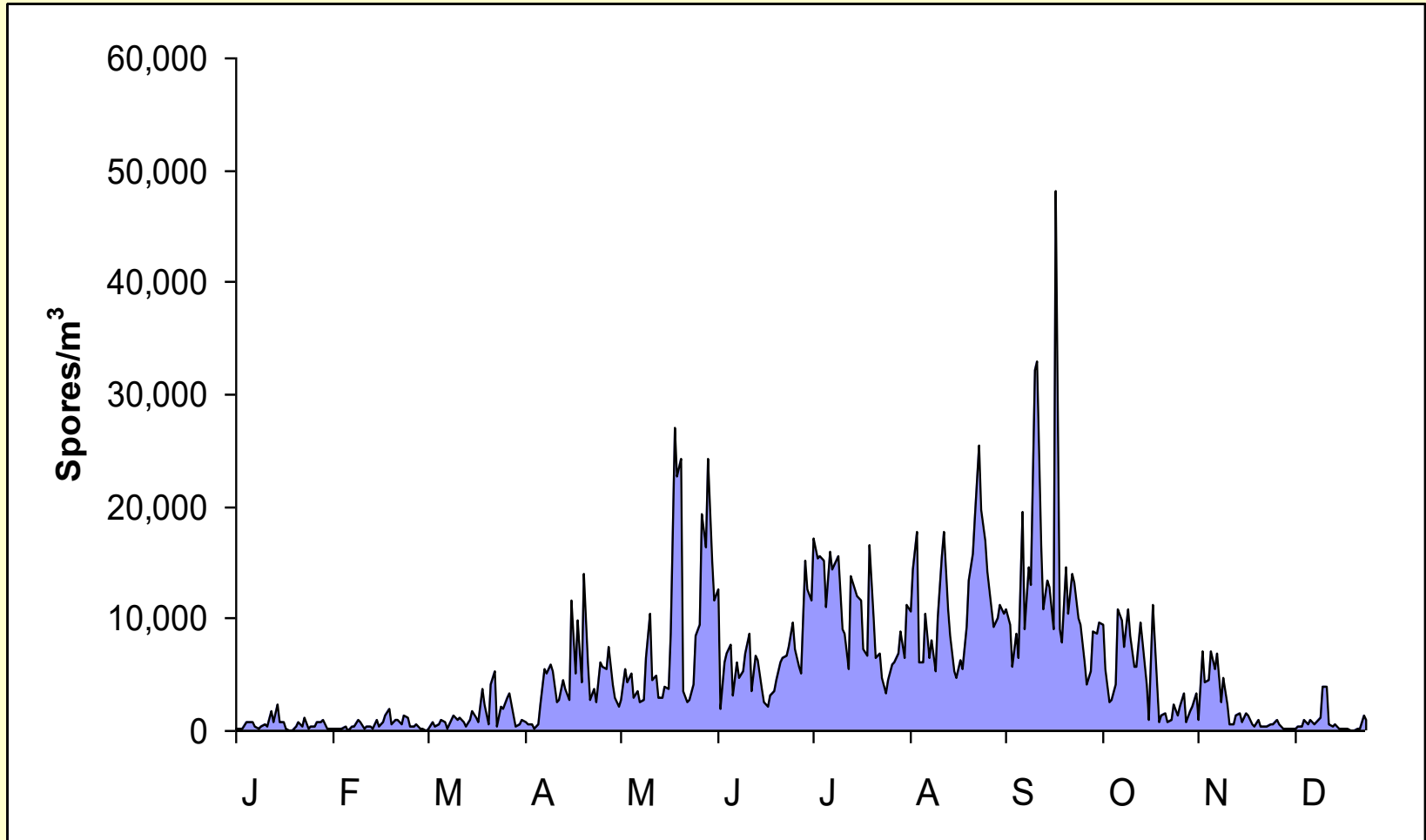


Basidiospore Rhythm

- Need for moisture confines spore release to periods of high humidity
- Typically peak levels in pre-dawn hours and low levels in afternoon

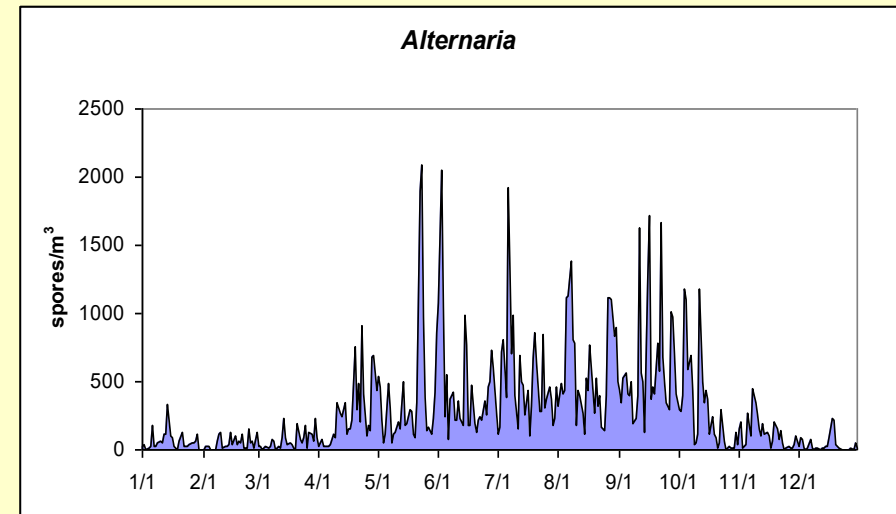
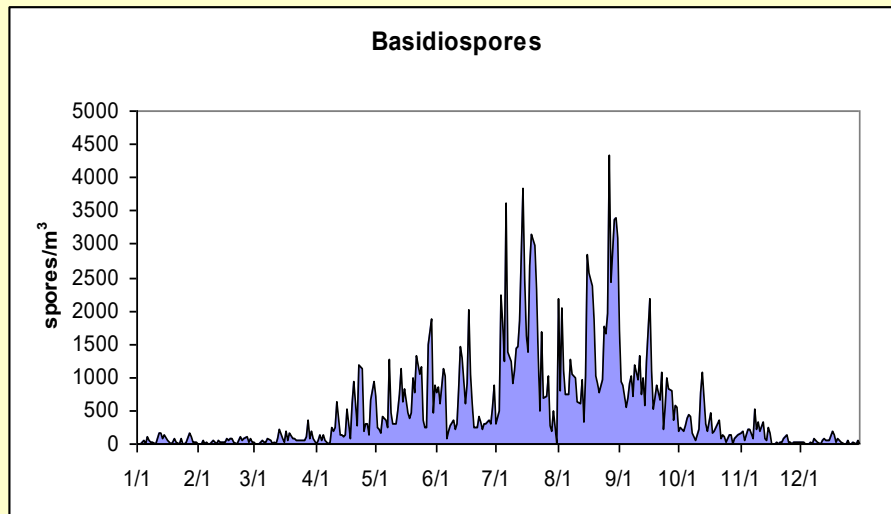
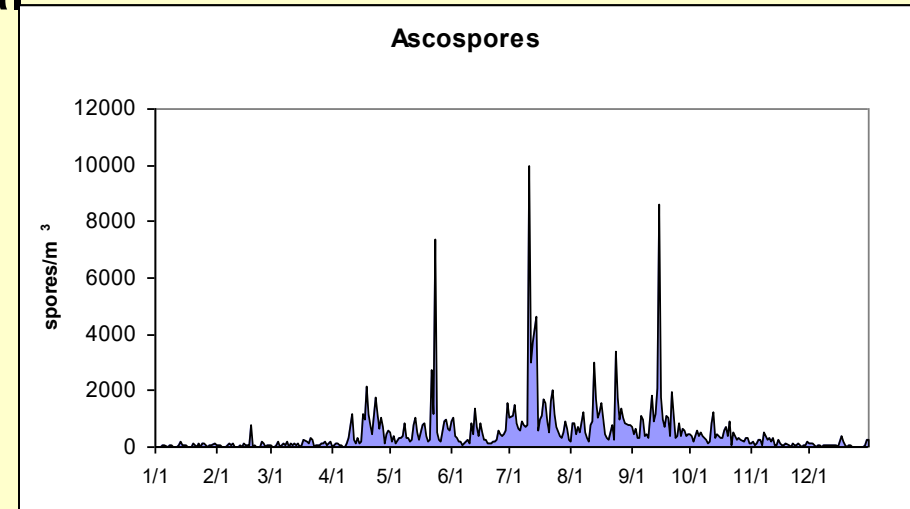
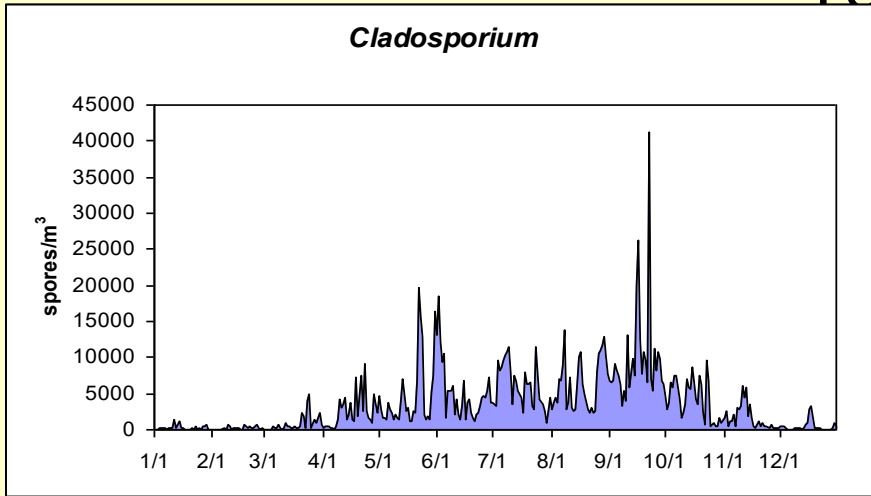


Airborne Fungal Spore Concentrations in Tulsa 2002

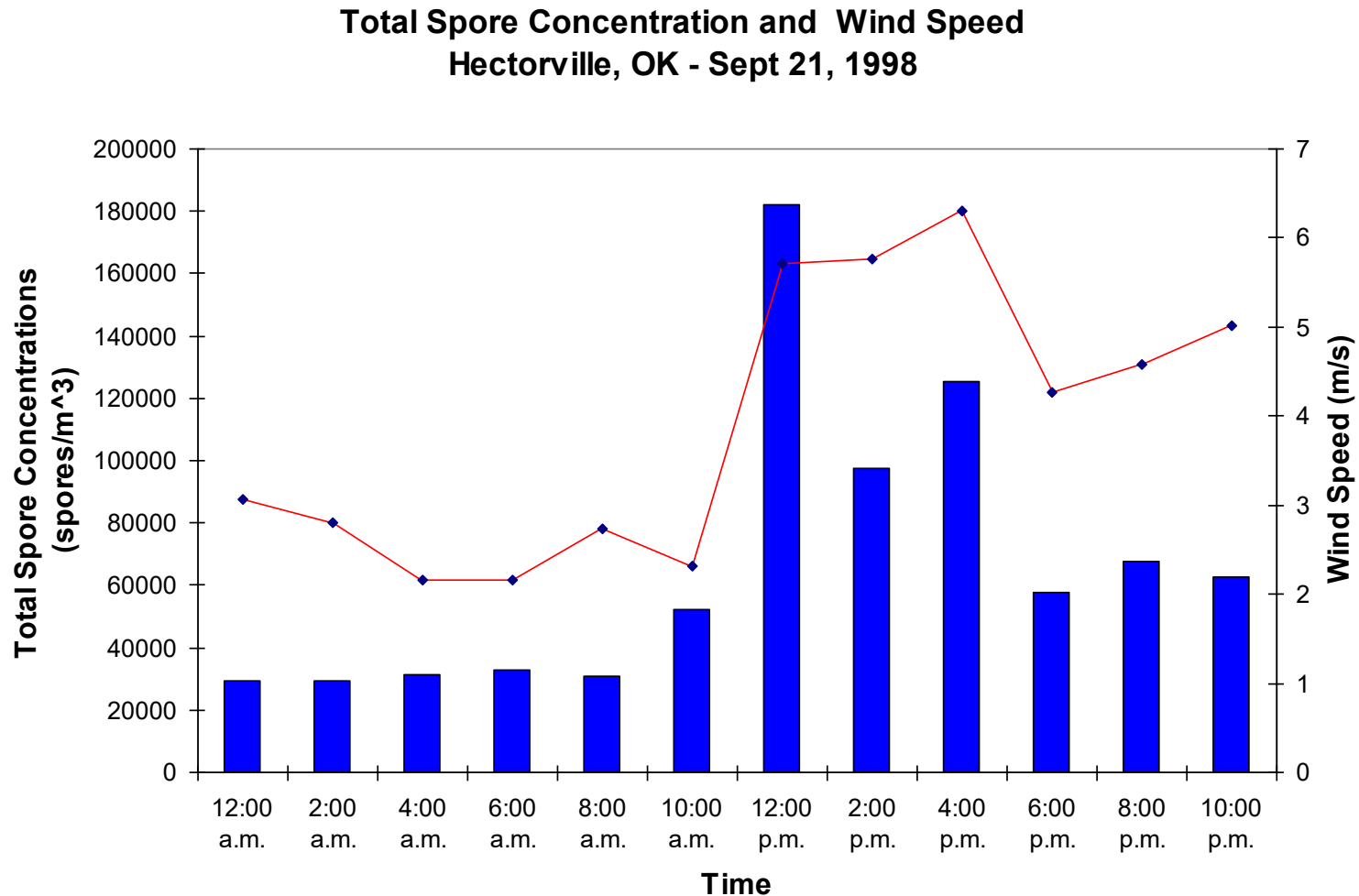


23 Taxa identified: *Cladosporium*, Ascospores, Basidiospores, and *Alternaria* Comprised 90% of

Total



Spore plumes show the influence of environmental conditions



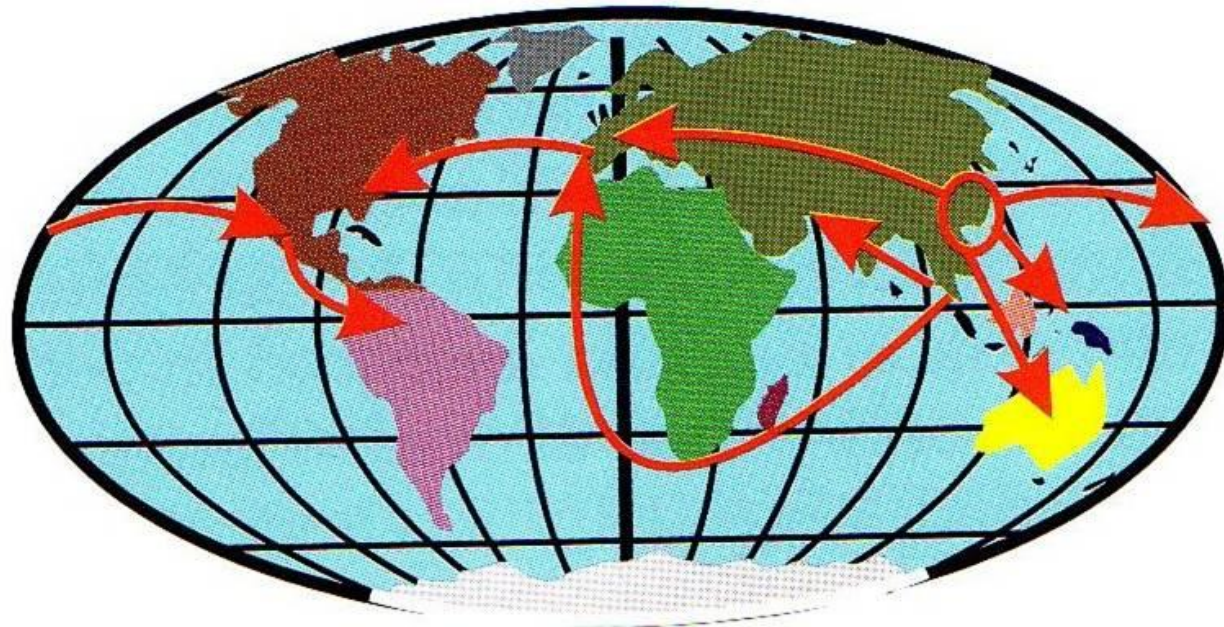


FIGURE 5.8 This figure shows the estimated path of the 1957 Asian flu as it migrated around the globe. This indicates the ability of microorganisms (in this case virus) to spread worldwide. The Asian flu of 1957 was believed to have started in central China as indicated by the black circle. In early 1998, a new influenza virus strain known as the Avian flu made a cross-species jump from chickens to humans. There was considerable concern that this new human pathogen would follow a similar path as the Asian flu causing another pandemic.



FIGURE 5.17 This photo shows a field of wheat, which is highly infected by phytopathogenic wheat rust. The field is being harvested by a hay machine, which is releasing a cloud of rust spores into the aeromicrobiological pathway. These spores can spread thousands of miles and infect other crops downwind causing catastrophic losses to wheat crops. (From McIntosh *et al.*, 1995, with kind permission from Kluwer Academic Publishers.)

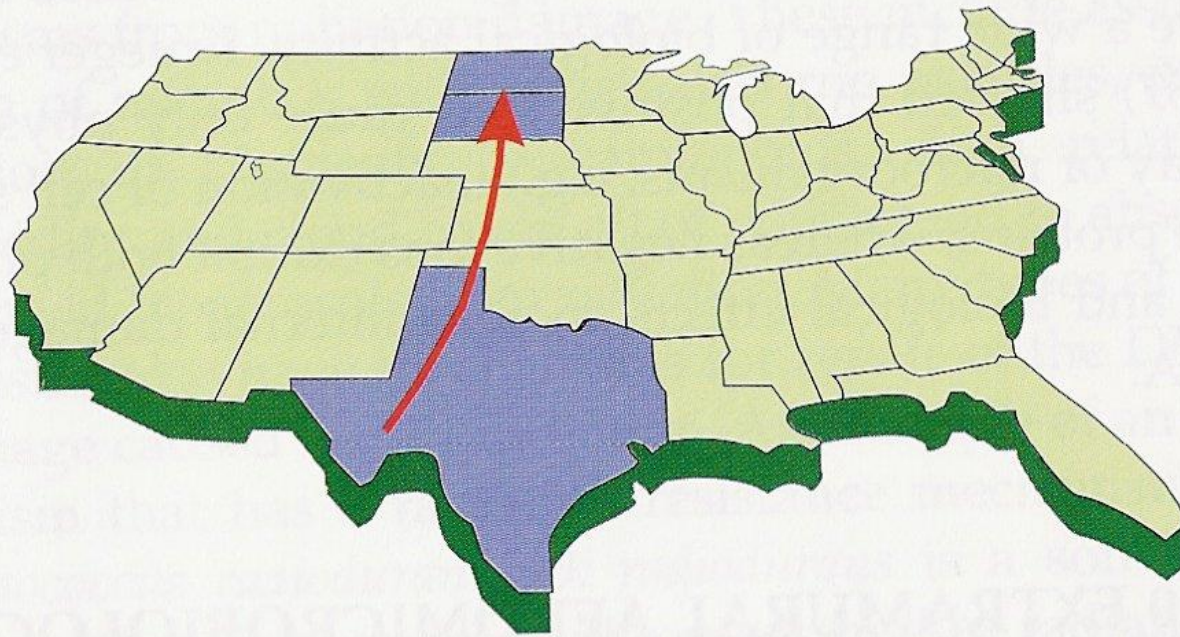


FIGURE 5.18 In this map of the United States, the arrow indicates the northern path of wheat rust infections as spread by the aeromicrobiological pathway. As depicted here, the wheat rust infection begins in the winter harvest in Texas and spreads northward with the prevailing wind currents. The epidemic spread of these phytopathogens infects maturing crops in Kansas and then moves up into the young crops in the Dakotas.

Sources of Aerosols

Point Sources

- Personal (i.e. sneezes, vomitus, etc)
- Natural
- Anthropogenic
 - Agricultural
 - Intentional
 - Industrial

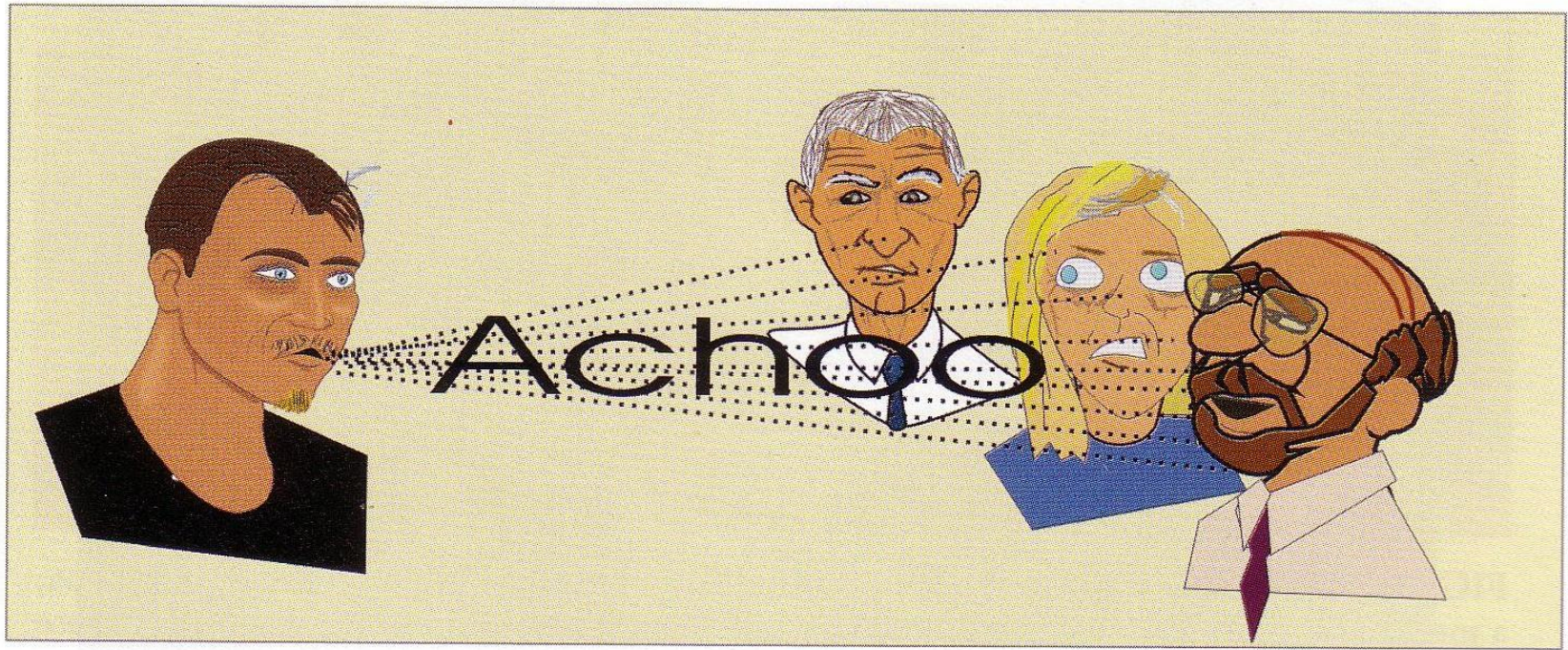
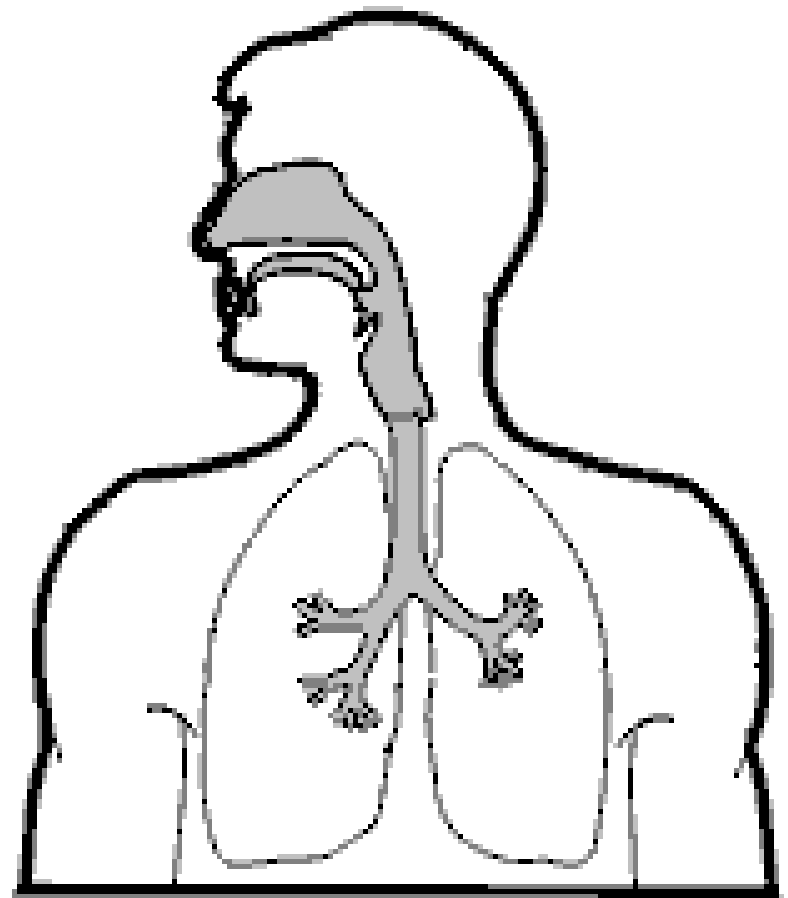
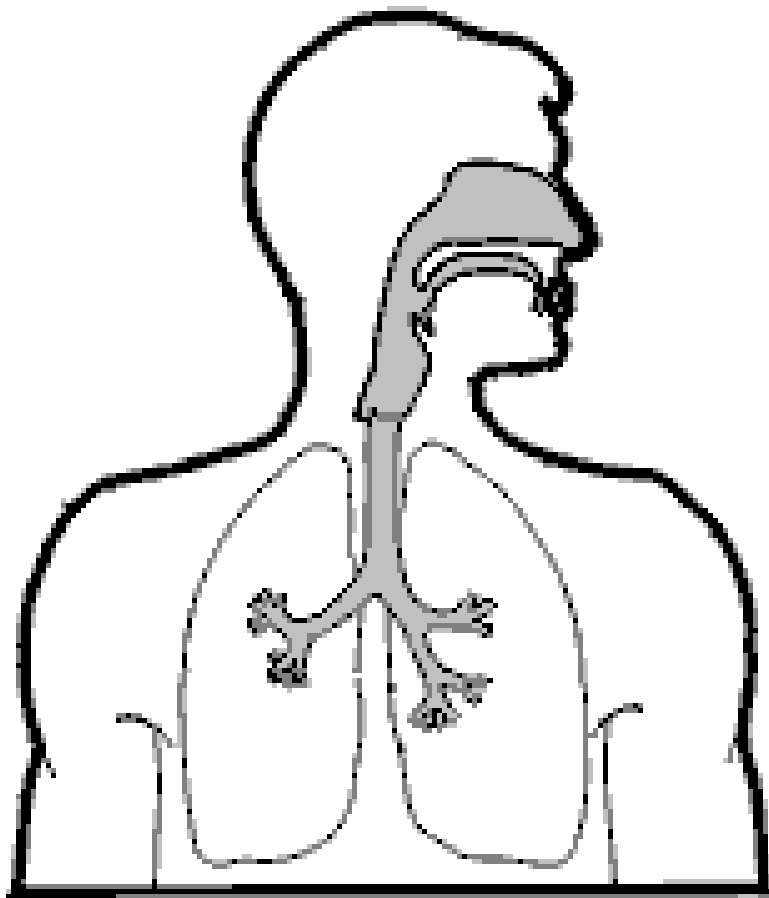


FIGURE 5.4 As shown in this figure, a cough or sneeze launches infectious microbes into the air. Anyone in the vicinity may inhale the microbes resulting in a potential infection.



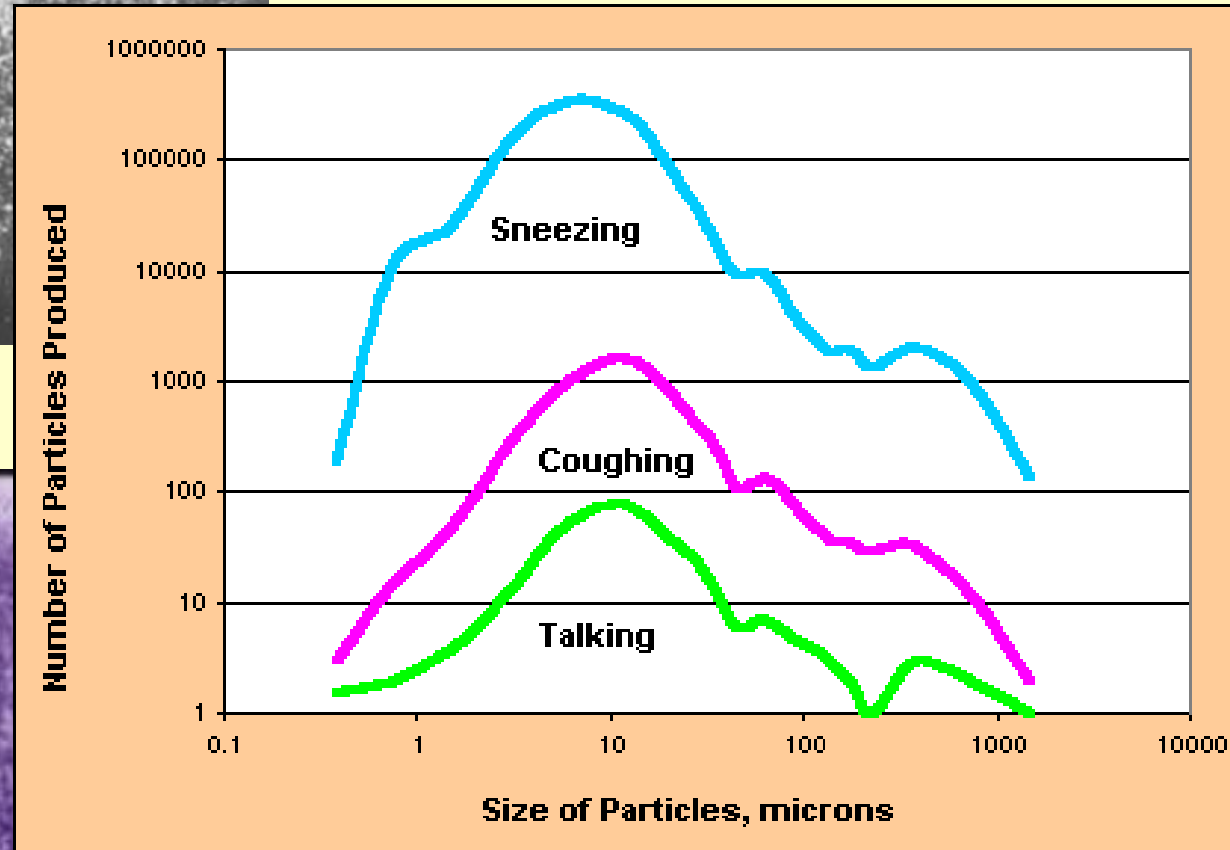
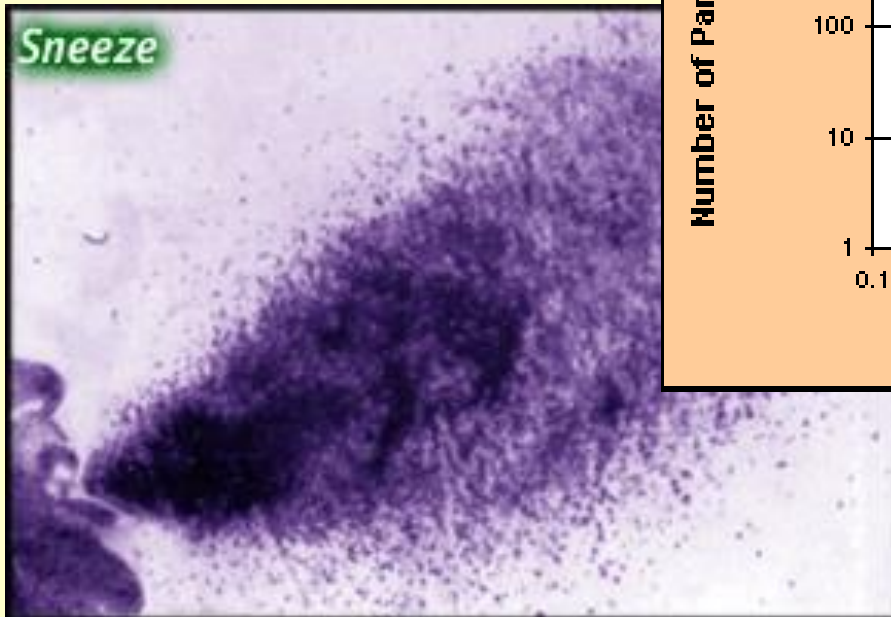










FIGURE 5.20 These photos show an agricultural field in Tucson, Arizona, with the effects of

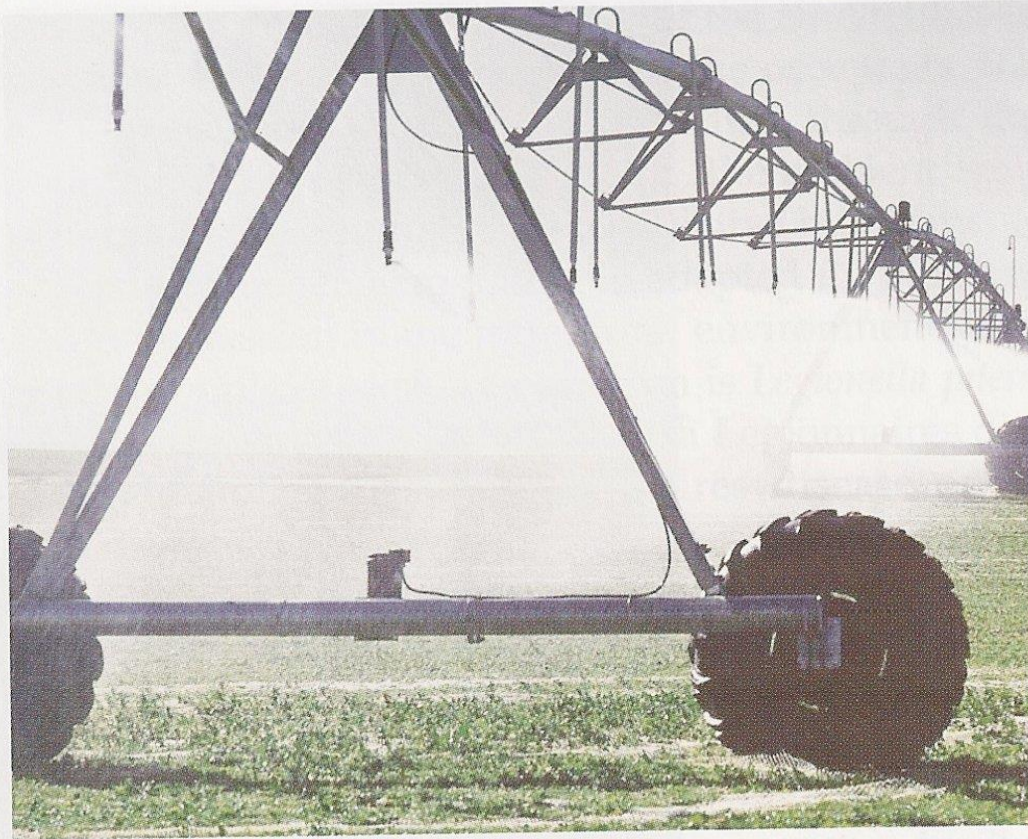


FIGURE 5.19 This is a photo depicting the application of secondary treated wastewater onto agricultural lands. This method is highly efficient at conserving water and has been shown to improve the fertility of soils. Due to the presence of pathogens in wastewater, and the nature of these land application systems, there are high concentrations of bioaerosols generated. Currently, however, there is little epidemiological and microbial risk assessment information available to determine if there may be health concerns for populations living in the vicinity of such operations, though there is a growing base of information on the concentrations and types of pathogens found in these bioaerosols. (Reprinted with permission from Corel Gallery www.corel.com)



FIGURE 5.7 This photo shows a linear bioaerosol source using the example of the release of biological warfare agents. This is an illustration of an instantaneous linear bioaerosol release. (Corel Gallery www.corel.com)



FIGURE 5.5 This is a photo of a large pile of biosolid material, which is being loaded onto a mechanical spreader. This biosolid material will then be placed upon a nearby field. These areas, because of the physical disturbance caused by the machinery, are associated with large bioaerosol loading rates. The biosolid pile is an example of a continuous point source because bioaerosols can be generated over a long period of time and the source is relatively small and well defined. (Photo courtesy of S. D. Pillai.)

What are other sources?

- Home IAQ
- Occupational Sources
 - Healthcare setting
 - Food processing
 - Other
- Outdoor Sources

Factors Affecting Survival of Pathogens in Bioaerosols

Factors Affecting Bioaerosol Stability

- Temperature
- Humidity
- Composition (moisture, salts, protein, etc.)
- (Sunlight)
- (Wind)

Stability of Airborne Microbes

- Relative Humidity
- Temperature
- Oxygen
- Open Air Factors (e.g. Ozone, olefins..)
- Radiation (e.g. UV, γ -rays, X-rays)
- Suspending media (salts, proteins, sugars)
- (Air Movement- e.g. wind shear)

Table 6.1. Summary of Most Probable Target Molecules

Stress	Most Probable Target
RH and temperature	Membranes phospholipids, proteins
Oxygen	Phospholipids, proteins
Ozone	Phospholipids, proteins
Open Air Factor (Ozone+olefins)	Phospholipids, proteins, nucleic acids
γ -rays, X-rays, UV	Phospholipids, proteins, nucleic acids

Major Losses of Viability

- Maillard Reactions (dessication)
- Membrane phase Changes
- Cross linking
- Free radical damage (hydroperoxide and hydroxyl)
- Resulting in
 - Phospholipid crystalization
 - Change in permeability barrier function
 - Energy production capability
 - Temp. associated death mechanism

Mobility of Aerosols

Movement in Air

- Advection
- Mechanical Diffusion
- Molecular Diffusion

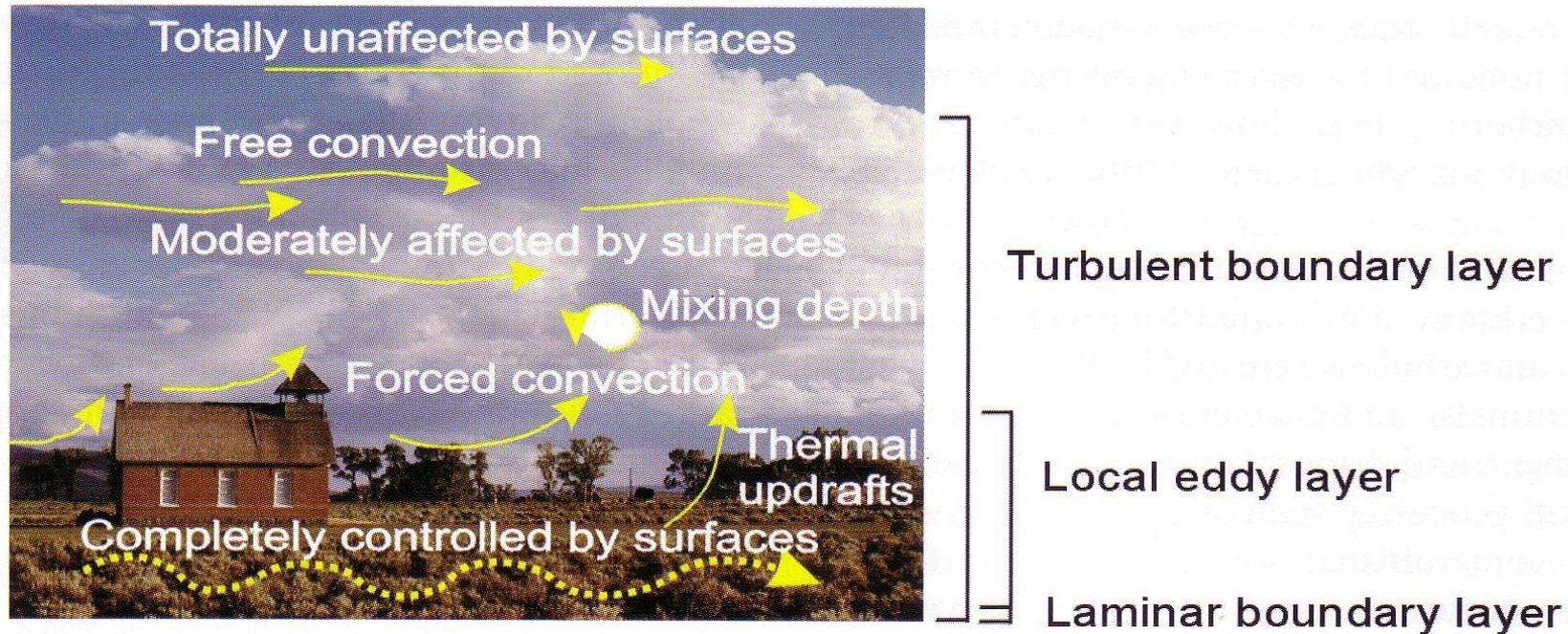


FIGURE 5.3 Atmospheric layers and airflow patterns. The figure shows the airflow patterns associated with the boundary layer. Upper air layers are relatively unaffected by objects such as buildings and airflow is unhindered. The middle layers are only moderately affected, and lower layers known as the local eddy layers are increasingly controlled by the presence of surface objects. The laminar boundary layer is a thin layer of still air associated with all surfaces. This laminar layer is still even under extremely windy conditions though the thickness decreases with increasing turbulence.

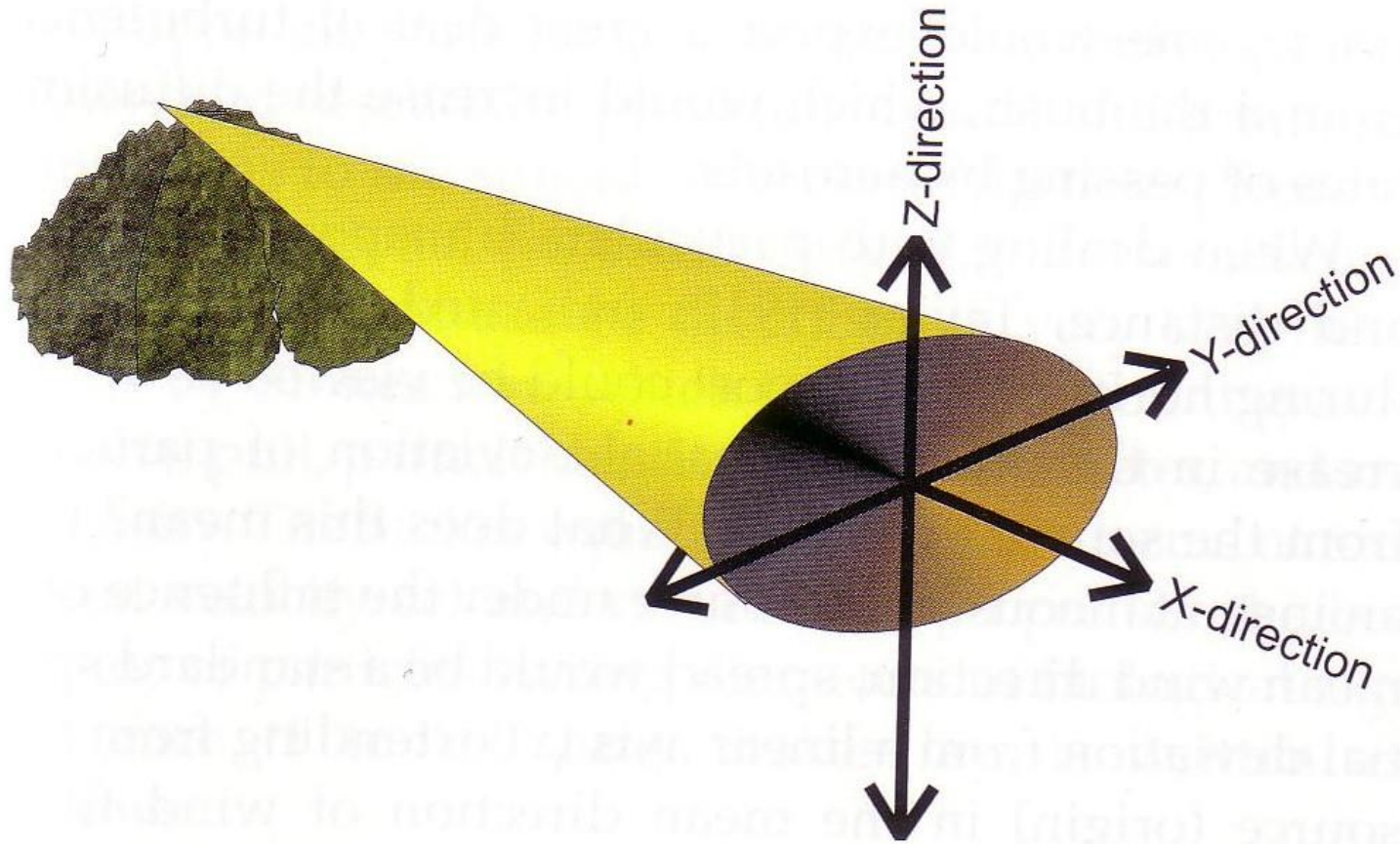


FIGURE 5.6 Schematic representation of the type of bioaerosol distribution expected from a point source. This figure shows the three plains of diffusion: 1) x-direction is the mean direction in which the wind is blowing; 2) y-direction is the lateral diffusion; and 3) z-direction is the vertical diffusion.

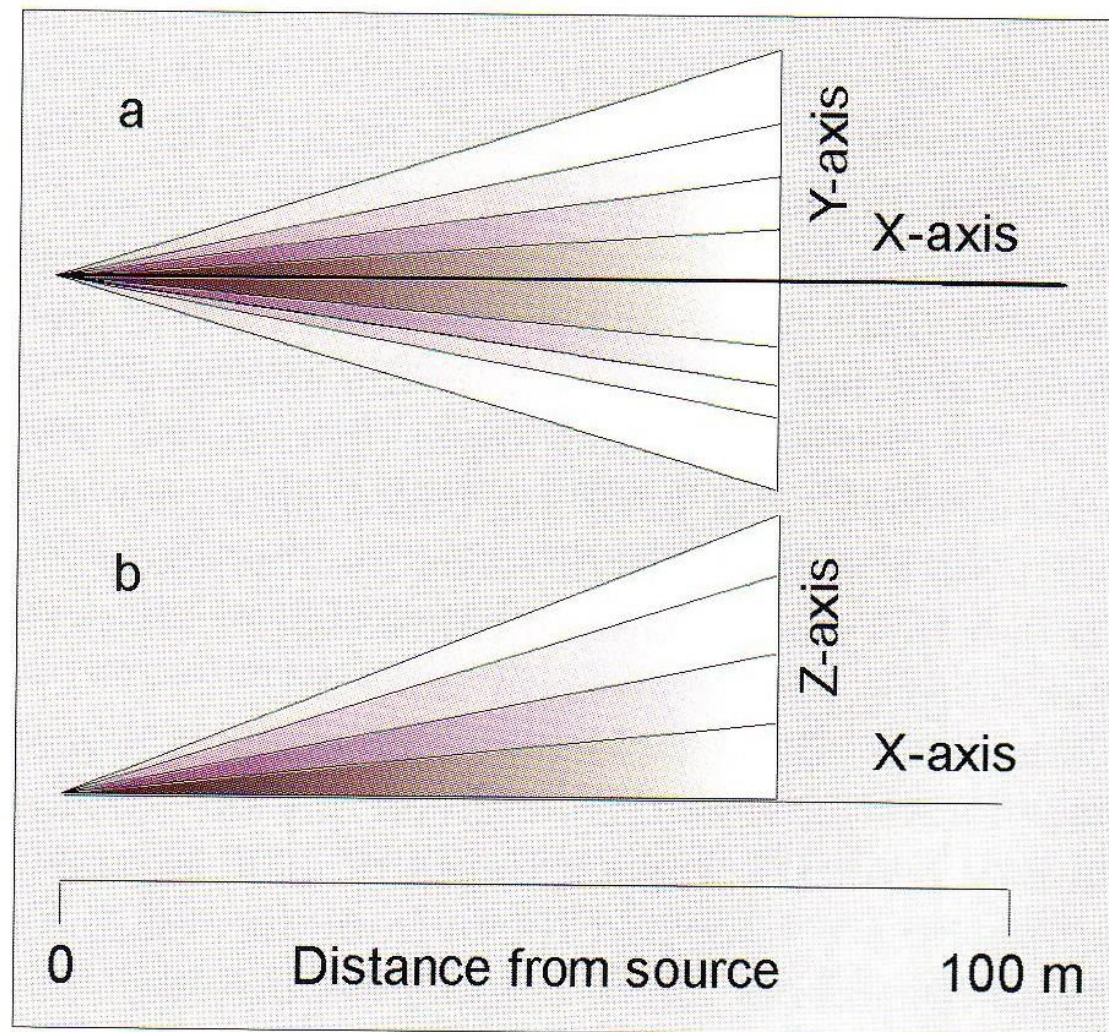


FIGURE 5.12 This is a schematic illustration of the effects of lateral (a) and vertical (b) diffusion on the downwind concentration of a microbe. As shown in this figure, as the distance from the source increases, the microbe concentration on the x-axis decreases due to lateral and vertical spreading. Note that darker shades of color represent higher concentrations of microbes.

Deposition

- Surface impaction
 - Essentially a collision between particles and surfaces
 - Not necessarily permanent
- Rainfall
- Electrostatic
- Turbulent Diffusion
- Thermal gradients
- Electromagnetic radiation

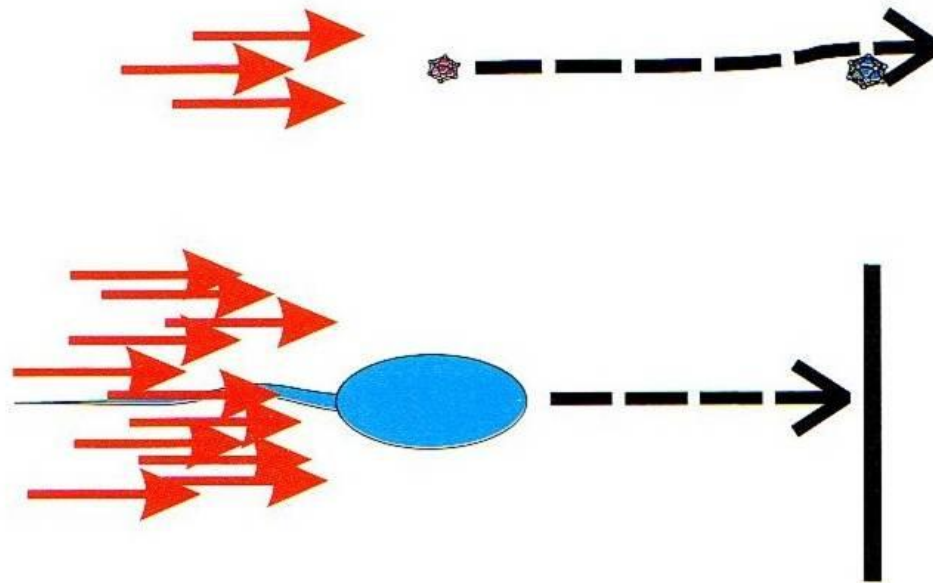


FIGURE 5.11 Schematic representation of forces that influence impactation potential. In the top figure a small particle represented by an icosahedral virus is traveling slowly toward another small particle (target) also represented by an icosahedral virus. The small size and slow velocity of the red virus and the small size and round shape of the target result in a low impactation potential. On the other hand a large object with greater mass, represented as a bacterium, traveling at a high velocity toward a large flat surface has a very high impactation potential.

Deposition

- Gravitational Settling

- Stokes Law: $v = \frac{pd^2g}{18n}$ (cm/sec)

- v = velocity, p = particle density, d = particle diameter, g = acceleration due to gravity, n = viscosity of air

- Assumes spherical shape

- For particles > 1 micron diffusion due to gravitational settling is dominant
- For particles < 0.5 micron, $V \rightarrow 0$

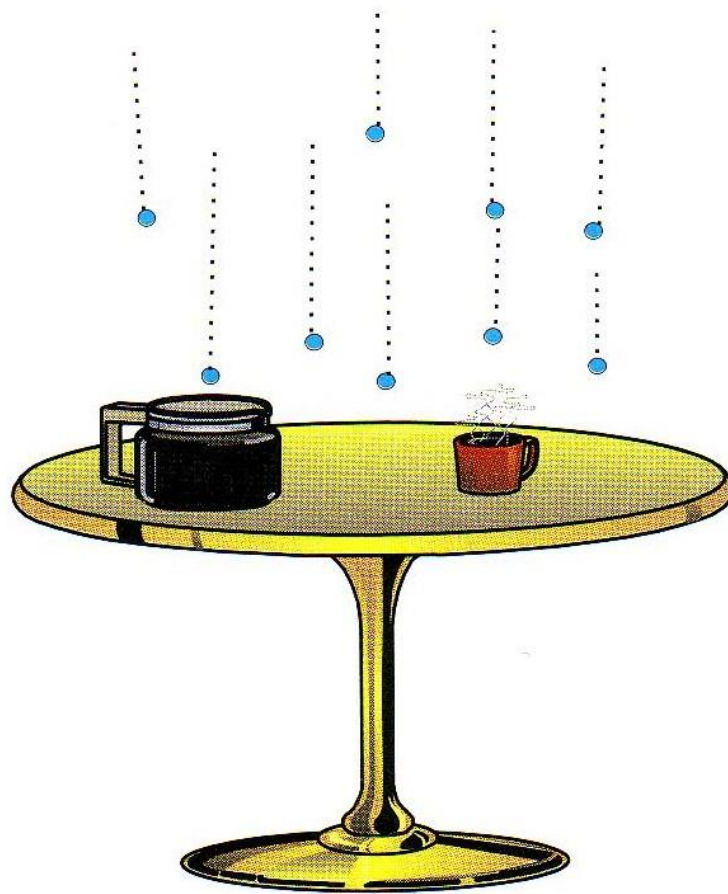


FIGURE 5.9 Schematic representation of gravitational settling, which is a function of the earth's gravitational pull, particle density, particle diameter, and the viscosity of air. This figure does not take into account random air movement. Stokes equation was developed to give an estimate of the terminal velocity achieved by particles as a function of gravitational settling.

Deposition

- Molecular Diffusion
 - Tend to be downwardly directed by gravity
 - Random movements
 - Highly influenced by wind
 - Increases with wind strength

Brownian Motion

- Bioaerosols are subject to Brownian motion as described by Einstein's equation
- X =root mean square particle displacement, cm
- t = time, s
- r =particle radius

$$X = 5 \cdot 10^{-6} \sqrt{\frac{t}{r}}$$

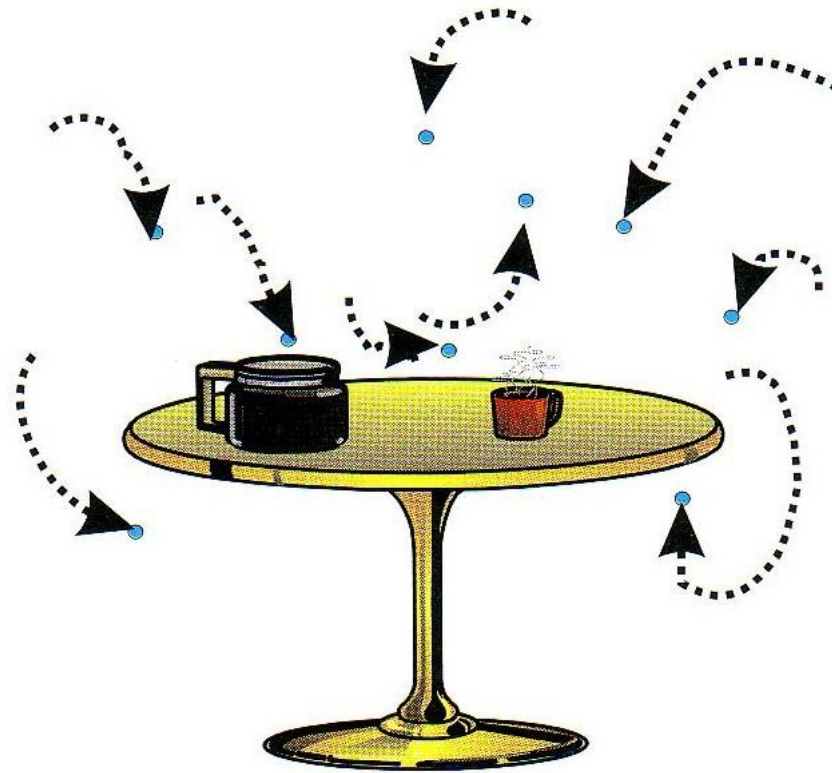


FIGURE 5.10 Schematic representation of downward molecular diffusion, a naturally occurring process caused by the air currents and eddies that promote and enhance gravitational settling of airborne particles. Although molecular diffusion can occur in any direction, due to the effects of gravity, the overall trend of the process results in net downward movement and deposition.