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Introduction to Bioaerosols Assessment and Control, 2nd Edition

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Introduction to Bioaerosols Assessment and Control, 2nd Edition

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- Thank you to the many authors and contributors to the ACGIH *Bioaerosols: Assessment and Controls* 2nd edition, as well as to the ACGIH Bioaerosol Committee members.

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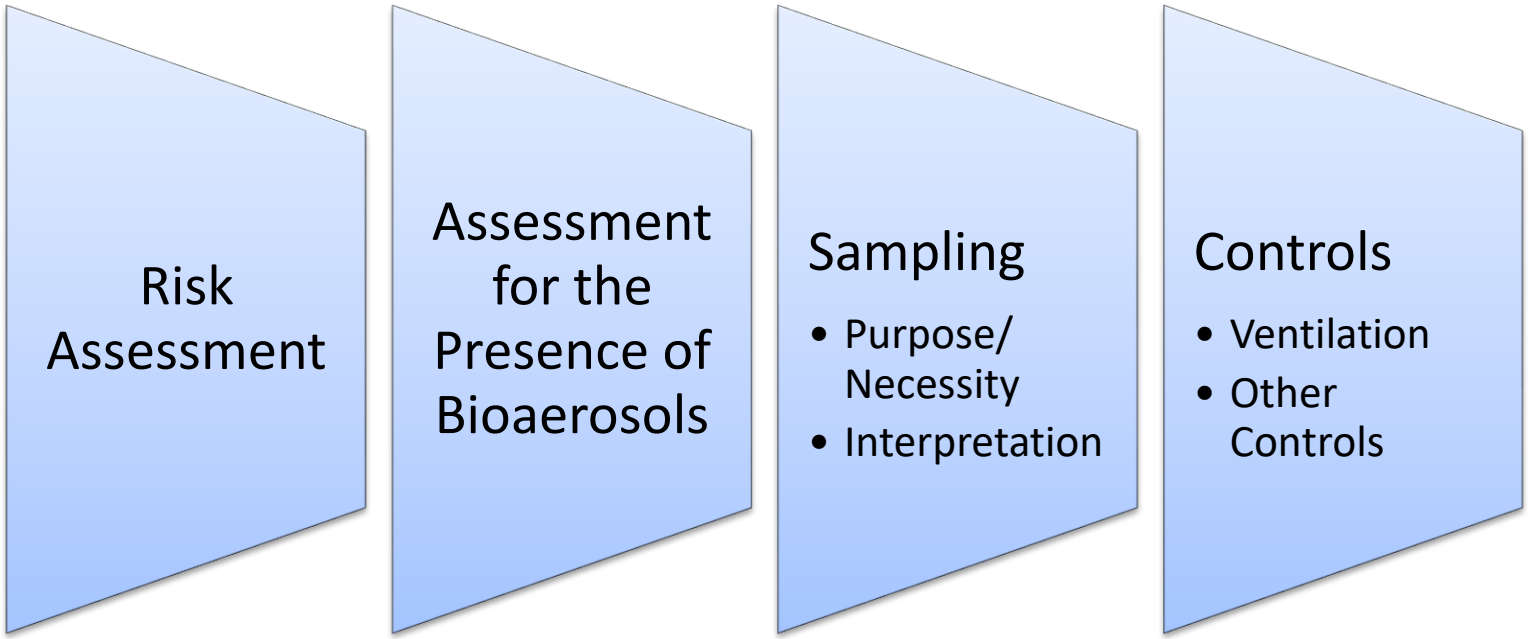
Presentation Outline



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ACGIH Definitions

- ***Bioaerosols:*** Airborne compounds and fragments from plants, animals, and insects that can consist of fungi, bacteria, spores, pollen, mites, viruses, cell membrane components, metabolites, and by-products of cells, that may be viable or nonviable, and can include:
    - Body parts and feces from dust mites, cockroaches, and other insects.
    - Proteins in saliva, urine, and dander from cats, dogs, and other furred animals.
    - Endotoxins (from gram-negative bacteria).
    - β-glucans (from cell walls of bacteria, fungi, yeasts, algae, and some plants).
    - Low molecular weight secondary metabolites (e.g., mycotoxins).
    - Antigens and allergens.
    - Microbial volatile organic compounds (mVOCs).

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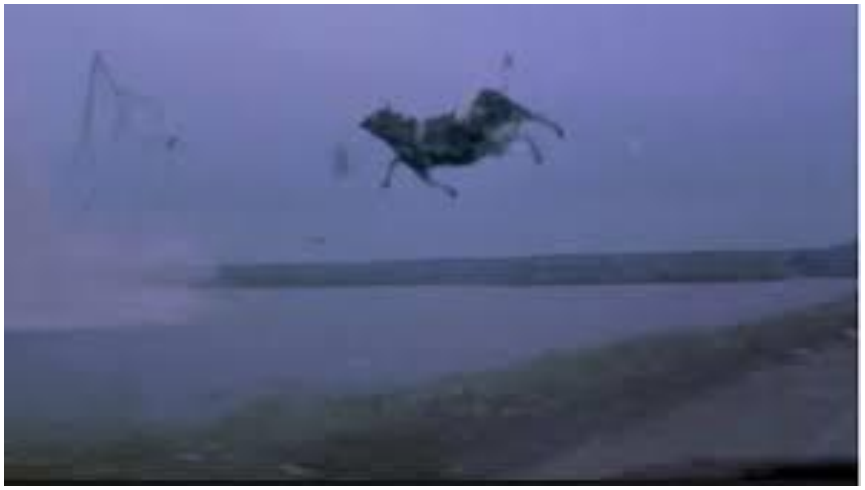
Bioaerosols

- Are these bioaerosols?*



*a question to contemplate later at the bar ☺

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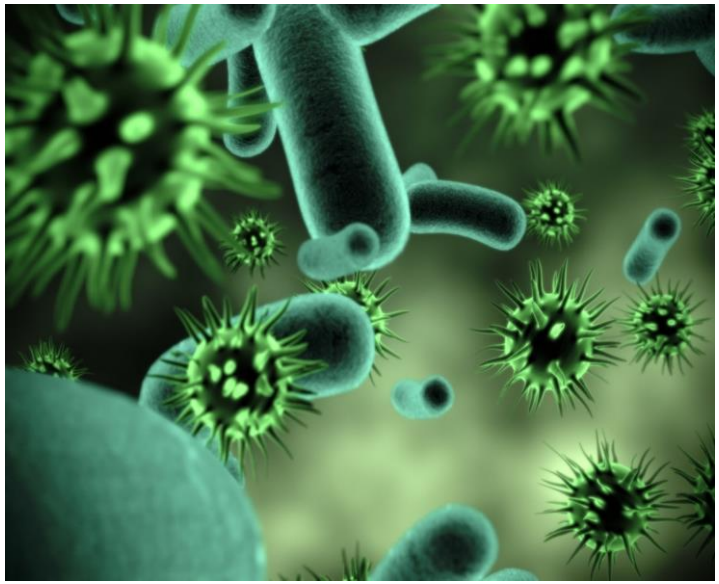
ACGIH Definitions

- ***Biological agent:*** A substance of biological origin that is capable of producing an adverse health effect (e.g., an infection or a hypersensitivity, irritant, inflammatory, or other adverse response).
  - Are ubiquitous in nature.
  - May be amplified in man-made environments and materials.



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Risk Assessment

- Humans are frequently exposed, day after day, to a wide variety of bioaerosols/biological agents at varying concentrations, usually at very low levels that do not necessarily elicit a response, pose a health risk, or otherwise result in harm.
- So how does one assess the risk?

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Risk Assessment

- Bioaerosol characterization and/or assessment involves:
  - identifying the presence of a source and the hazardous characteristics of a known or potentially infectious or non-infectious bioaerosol agent or material (***the hazard/source***);
  - the activities that can result in a person's exposure to such an agent (***the pathway***);
  - the susceptibility of the exposed individual (***the receptor***), and
  - the likelihood or probability that such exposure will cause a particular adverse health response (***the risk***).

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Risk Assessment

- Determining whether a bioaerosol exposure is hazardous, or may result in an adverse health effect, is typically not a simple problem.
  - Bioaerosols cause a wide array of potential health effects.
  - Limited to no information available on dose/response.
  - May have concomitant exposures with other agents and/or bioaerosols.
  - Receptor response to bioaerosols can be different, depending on receptor health status, sensitivity, immune system, and other factors.
  - Significant sampling and analysis limitations.
    - Components and concentrations vary widely over time, space, and environmental conditions.

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Risk Assessment

- Because of the variables in the potential health effect(s) of individual or collective bioaerosols, and the differences in receptor response(s), it is more likely that the practitioner will determine that there is a *potential* hazard associated with a particular bioaerosol exposure and default to a control strategy using a ***precautionary principle*** concept.

Precautionary Principle:

Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

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Risk Assessment

- How to define “acceptable risk”?
  - Hazard + Exposure = Risk
- But also:
  - Risk = Hazard + Outrage (Sandman)

Responding to Community Outrage: Strategies for Effective Risk Communication

https://www.psandman.com/media/RespondingtoCommunityOutrage.pdf

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Health Effects

- Potential health effects from bioaerosols are clearly dependent on the type(s) of bioaerosols present.
  - Viruses can cause diseases such as severe acute respiratory syndrome (SARS), COVID-19, and influenza.
  - Bacteria that can cause infectious disease include:
    - *Streptococcus pneumoniae* (pneumonia)
    - *Mycobactera tuberculosis* (TB)
    - *Coxiella burnetii* (Q fever)
    - *Legionella* bacteria (Legionnaires' disease and Pontiac fever)

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Health Effects

- The occupants of buildings introduce gram-positive bacteria (e.g., *Staphylococcus*), skin scales, and viruses.
  - The primary food for house dust mites is skin scales.
  - Dust mites can cause rhinitis, allergic asthma, atopic dermatitis, conjunctivitis, and hypersensitivity diseases.
  - Dust mite allergen exposure is associated with development of asthma in childhood.[1]
- Gram-negative bacteria (often found in humidifiers in HVAC systems) contain endotoxin which can cause humidifier fever (fever, chills, muscle aches, malaise, chest symptoms).

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Health Effects

- Cockroaches can cause asthma and rhinitis.
- Fungal infections from potential occupational exposures to contaminated soils and bird droppings include *Coccidioides* (Valley fever) and *Histoplasma capsulatum.*
- Dampness and the growth of fungi on building surfaces, in HVAC systems, or in dusts on porous surfaces, such as carpets, can lead to asthma and allergic rhinitis.[2,3]

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Assessment for the Presence of Bioaerosols

- Bioaerosol assessments should be designed to answer one or more questions, not just to collect samples.
  - Some assessments are limited in nature, such as inspecting dampness in a single location from a known moisture problem, such as a pipe leak.
  - Other assessments are more open-ended, which may involve a more thorough evaluation.
- The purpose of the assessment is to find answers to questions about the affected ***people***, the ***contaminants*** that may impact their health, and the ***environments*** they occupy.

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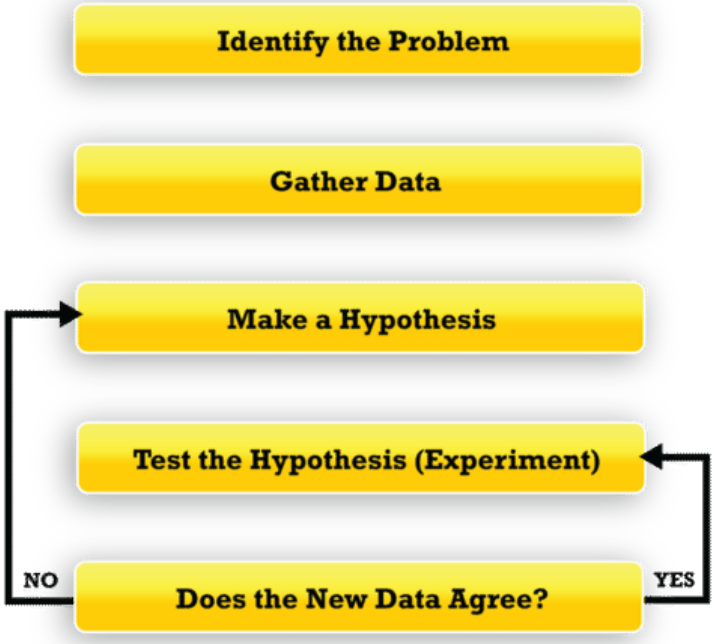
Assessment for the Presence of Bioaerosols

- The steps of a bioaerosol assessment should generally follow the scientific method:
    1. identifying the problem;
    2. gathering information;
    3. formulating a hypothesis;
    4. testing the hypothesis, and
    5. drawing conclusions.



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Assessment for the Presence of Bioaerosols

- In developing a hypothesis and assessing the conditions and environment, it is important to remember that the mere presence of biological agents may or may not constitute the presence of a health hazard.

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Assessment for the Presence of Bioaerosols

- Assessment should include:
  - age and history of the building;
  - the structure;
  - surrounding outdoor environment;
  - the HVAC system;
  - building occupant activities;
  - operations & maintenance;
  - known problem areas;
  - recent renovations, and
  - water systems.

- Assessment may also include:
  - humidity levels;
  - moisture measurements;
  - air pressure relationships, and
  - other potential sources (IAQ).

For mold:
ASTM D7338, *Standard Guide for Assessment of Fungal Growth in Buildings*

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Sampling

- After completion of the visual inspection, if microbial or other biological contamination is identified, **no sampling may be even needed.**
  - "When investigating and evaluating bioaerosols in a building or space, or microbial growth present on building materials and/or contents, environmental sampling for bioaerosols is generally unnecessary and not recommended in most cases. This is particularly true when bioaerosol sampling will not add any additional information to that already documented by a thorough assessment based on visual inspection…" (ACGIH)

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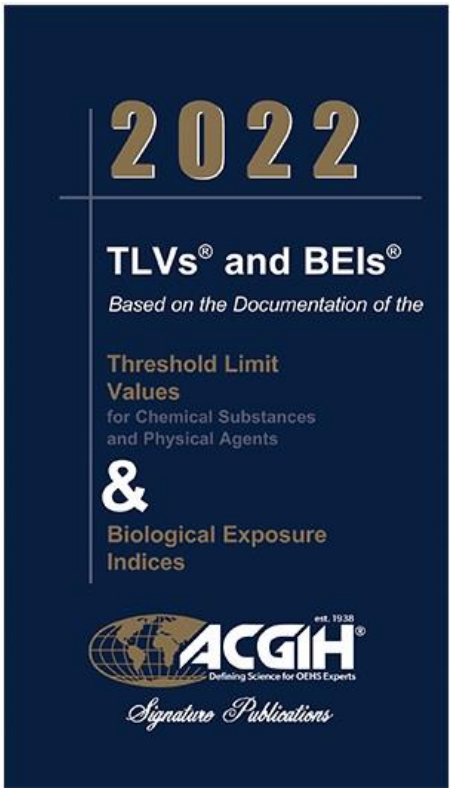
Sampling Purpose

- Samples should only be planned and collected if the sample results can answer an unanswered question or supply data to support a hypothesis.
- Unlike chemical or physical hazards, there are no numerical health-based OELs or TLVs for interpreting exposure measurements for most bioaerosols.



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Sampling Purpose

- Personal sampling is not often achievable (duration of sampling limitations).
- Area air sampling used as surrogate to:
  - test suspected sources of biological agents;
  - identify and quantify the agents present, and/or
  - evaluate bioaerosol release from environmental and organism sources.

Sample results cannot correlate airborne exposures with health effects.

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Sampling Purpose

- The mere presence of a biological agent does **not** mean the presence of a health risk!

Evidence of exposure = Evidence of a potential for a health response

Evidence of exposure ≠ Evidence of causation of a health response

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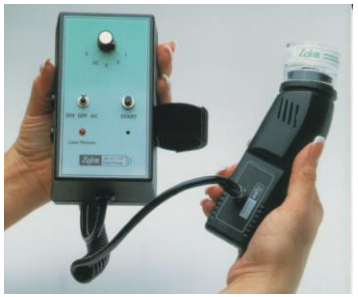
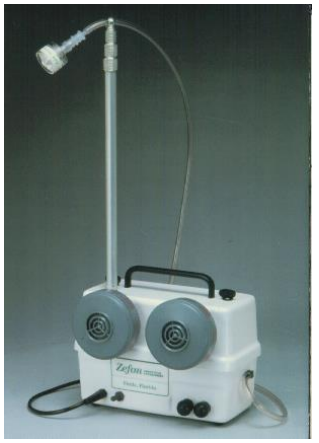
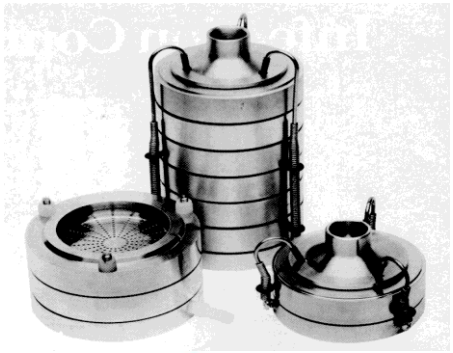
Sampling

- Widely-used bioaerosol samplers:
  - Multiple-hole impactors (impaction onto agar).
  - Centrifugal samplers (impaction onto agar).
  - Slit impactors (impaction onto agar, sticky tape, or greased slide).
  - Liquid impingers (impingement into liquid).
  - Wetted cyclones (impingement into liquid).
  - Filters.
  - Real-time bioaerosol detection:
    - Fluorescence spectroscopy
    - Elastic scattering







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Sampling

- Before ever taking a sample:
  - The type of sampler to be used needs to be selected based on the suspected bioaerosol present, the hypothesis about the bioaerosol, and the laboratory capability to distinguish and identify the bioaerosol of concern.
  - Criteria as to how the data will be interpreted should be established.
- Interpretation depends on:
  - the hypothesis/question being asked;
  - the type(s) of sample collected and method of analysis, and
  - the number and location of samples collected.

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Spatial and Temporal Variabilities

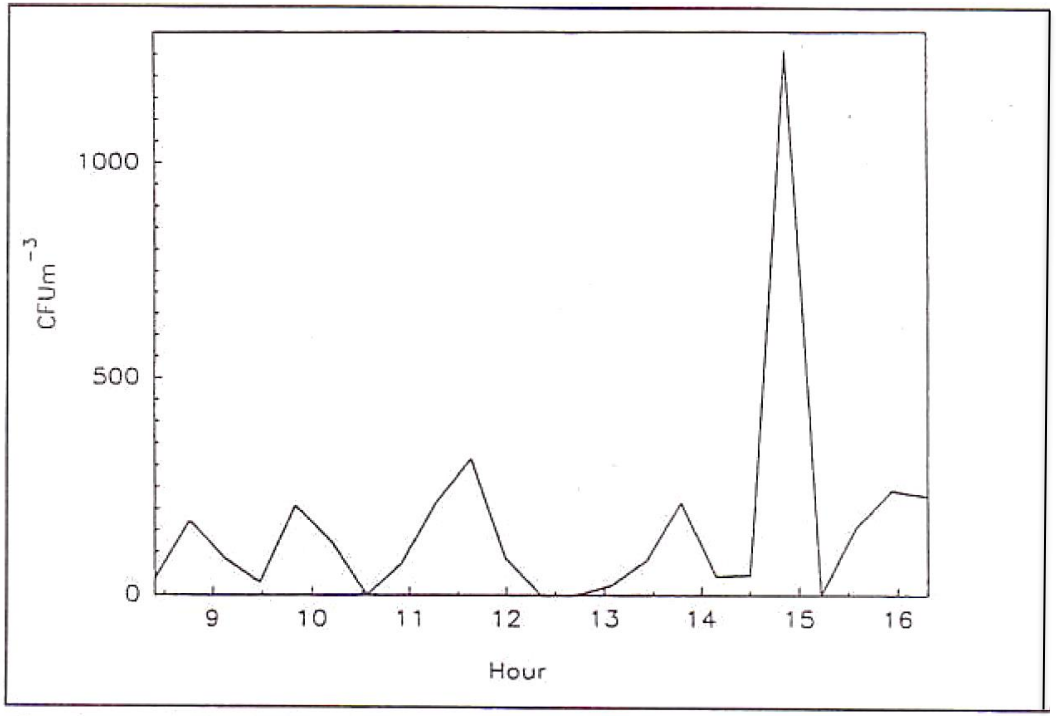

Figure 6 *A study of fungi in a classroom*

Airborne concentrations of many bioaerosols, particularly fungi, are highly variable with respect to place and time.

Miller, J.D.: Fungi and the Building Engineer. Presented at IAQ 92: Environments for People, San Francisco, Calif., Oct. 19–21, 1992

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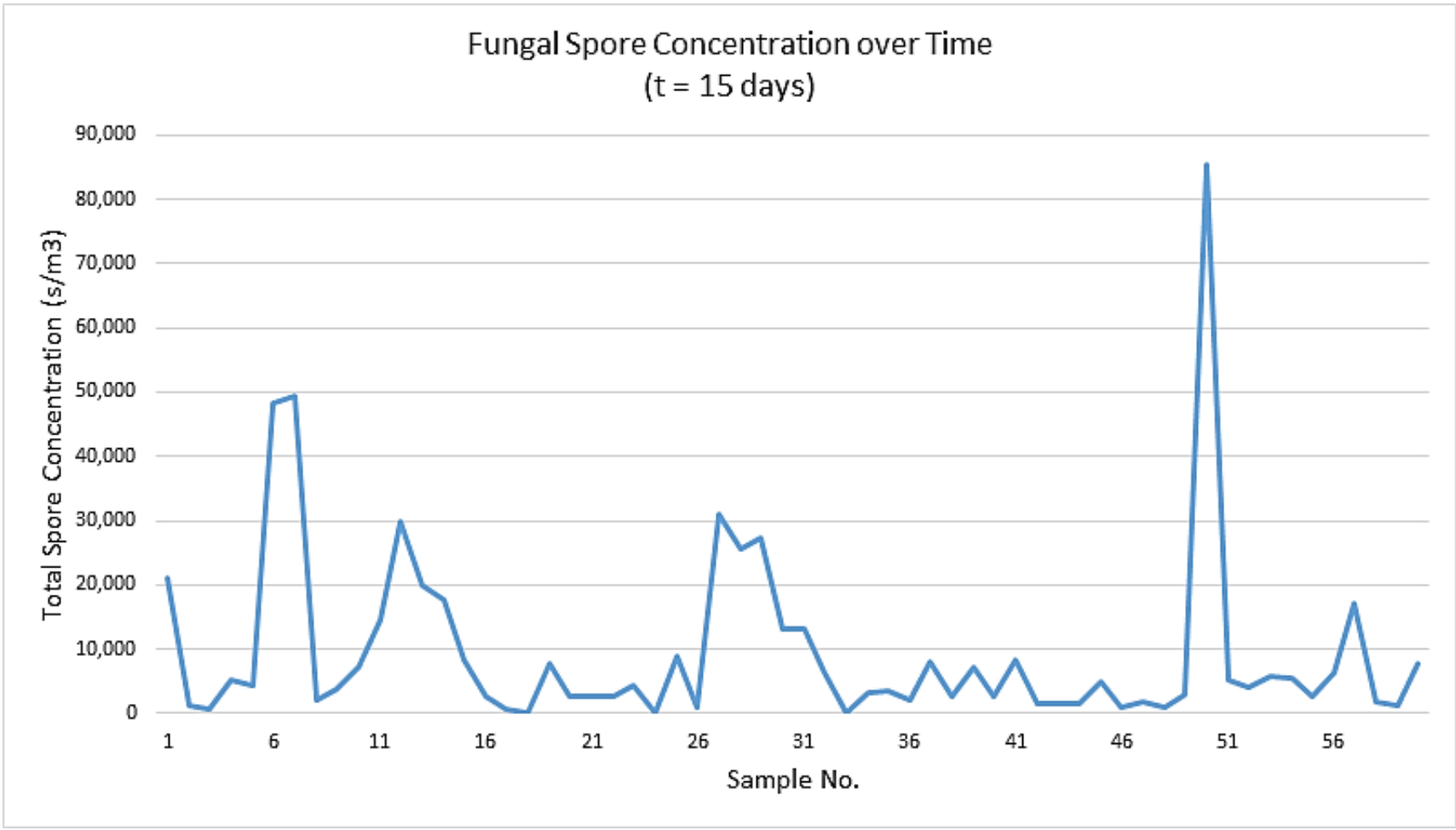

Unpublished data collected at a building next to Ground Zero in 2002 (Courtesy of Jack Springston)

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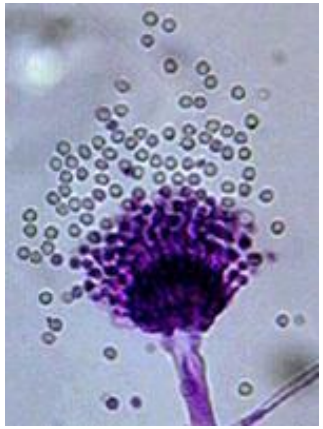
Data Interpretation

- Observational data:
  - Visible microbial growth.
  - Musty/moldy odors.
- Descriptive data:
  - Observation of fruiting bodies (e.g., conidiophores) on surface samples is indicative of fungal growth (as opposed to the presence of just settled spores, which are expected on surfaces of all indoor spaces).



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Data Interpretation

- Qualitative database comparisons:
  - Species or types indoors that are typically only found outdoors (e.g, basidiospores, rusts/smuts/mildews).
- Quantitative database comparisons:
  - National Allergy Bureau section of American Academy of Allergy, Asthma and Immunology's (AAAAI) Aeroallergen Network data on outdoor ambient mold spore levels at numerous locations in North America.
    - Helps with historical ranges and diversity of mold spores within a given region
  - Environmental Relative Moldiness Index (ERMI).
    - Scale of "relative moldiness."
    - Even though developed by EPA, EPA states that ERMI is a research tool only and "does not recommend the routine public use of ERMI in homes, schools, or other buildings"

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EPA: “The ERMI has not been validated for routine public use in homes, schools, or other buildings.”

U.S. Environmental Protection Agency
Office of Inspector General

13-P-0356
August 22, 2013

At a Glance

Why We Did This Review

An Office of Inspector General hotline complaint alleged that firms were using the U.S. Environmental Protection Agency-developed Environmental Relative Moldiness Index tool to evaluate homes for indoor mold even though the EPA had not validated the tool for public use. The EPA developed ERMI as a way to objectively describe the mold burden present in a home. The index is based on a national sample of indoor mold values. These mold values were determined using an EPA-patented technology called mold specific quantitative polymerase chain reaction. MSQPCR is a way to identify and quantify indoor mold

Public May Be Making Indoor Mold Cleanup Decisions Based on EPA Tool Developed Only for Research Applications

What We Found

We substantiated the allegation that firms were using the mold index tool although the EPA had not validated the tool for public use. The EPA readily acknowledged that it had not validated or peer reviewed MSQPCR or ERMI for public use. The agency said it considers MSQPCR and ERMI to be research tools not intended for public use. Although the EPA has licensed MSQPCR to companies for introduction into the marketplace under the Federal Technology Transfer Act of 1986, neither federal law nor the EPA's procedures address the level of validation needed before or after transferring federally developed technologies to the private sector. In addition, there are no EPA regulatory requirements for developing or validating indoor mold test methods or assessing indoor mold levels.

Licensees were marketing MSQPCR to the public as part of the ERMI tool. In our view, one current and one past licensee's advertising could mislead the public into thinking that these research tools are EPA-approved methods for evaluating indoor mold. The license agreements stipulate that the licensee should not state or imply in any medium that the EPA endorses MSQPCR. In addition, information that appeared on an EPA webpage suggested that the EPA validated and endorsed MSQPCR for public use. Consequently, there is a risk that the public

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Data Interpretation

- Comparison Studies:
  - Indoor/outdoor comparisons.
    - Comparing indoor/outdoor fungal sample results.
    - Comparing indoor/outdoor bacterial air concentrations.
      - Different criteria than for mold.
  - Activity/non-activity comparisons.
  - Complaint/non-complaint environment comparisons.
- Can be qualitative or quantitative, and several methods are identified in the updated *Bioaerosols* book.

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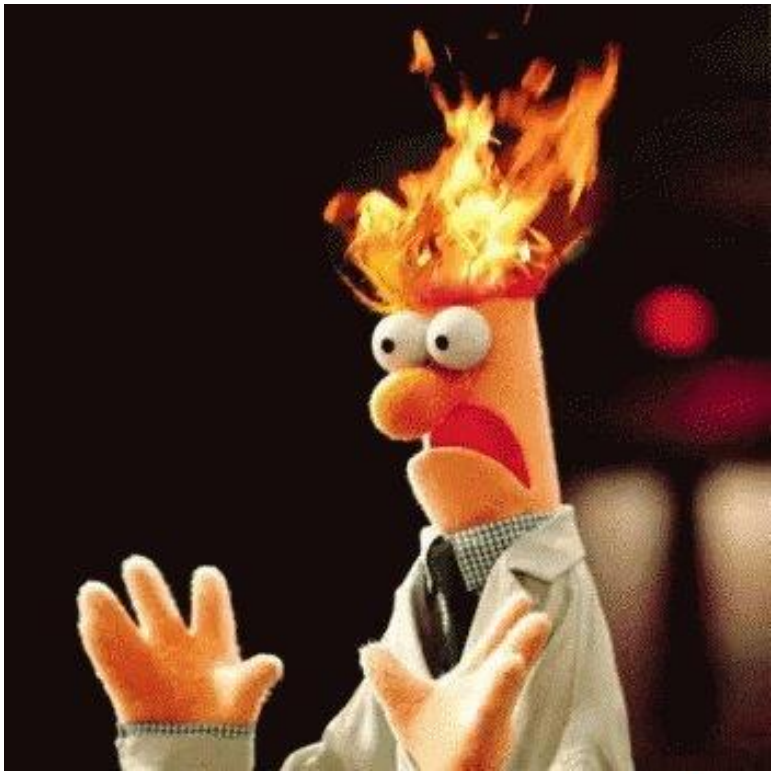
Statistical Tests

- Wilcoxon Sign Rank
- Two-sample Wilcoxon Test
- Kruskal-Wallis Test
- Spearman Rank Correlation Coefficient
- Mann-Whitney Test
- Agreement Ratios
- Cluster Analysis
- Friedman Procedure
- Bootstrapping
- Monte Carlo
- Bayesian Model



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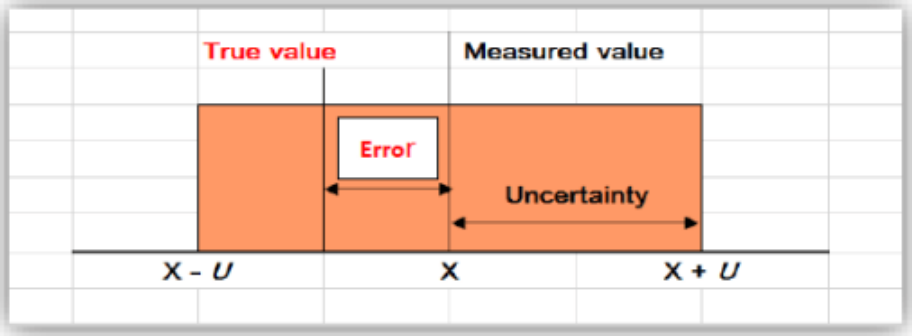
Data Interpretation

- Points to note:
  - Because of spatial and temporal variability, along with measurement uncertainty, each measured value has a range in which the actual value lies.
  - To overcome these ranges and variabilities, multiple samples are needed if statistical analysis is to be performed.
  - Will statistical analysis really answer the question you are asking?



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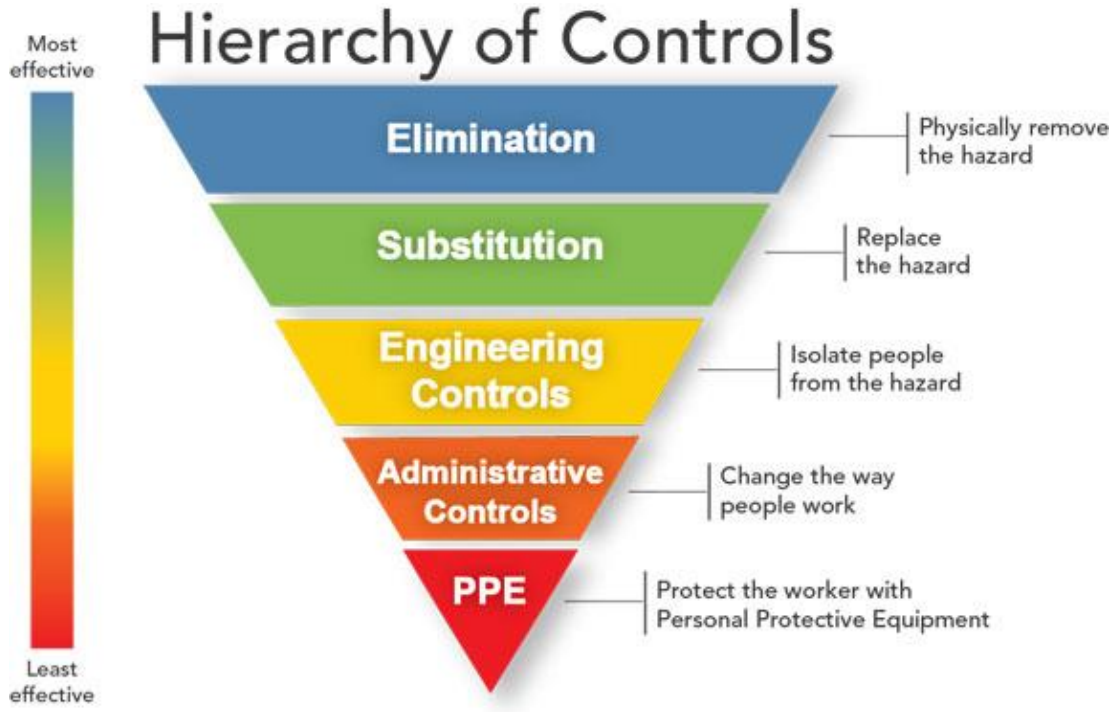
Controls

- Elimination:
  - Remediation
  - Source Removal
    - People
    - Processes
- Engineering:
  - Ventilation
- Administrative:
  - Minimize aerosols
  - Distance
- PPE



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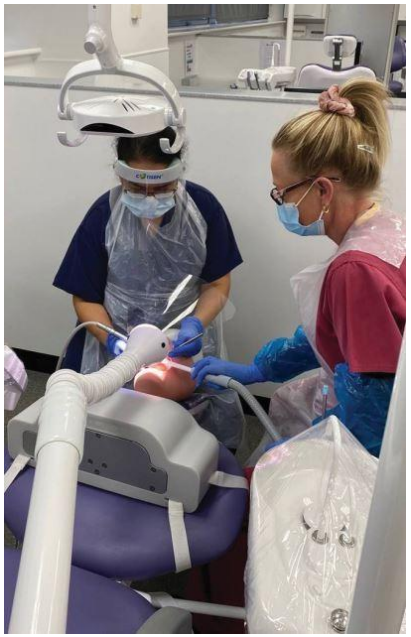
Controls - Ventilation

Local Exhaust Ventilation (LEV):

Removal of contaminants at the source.



General Ventilation (GV)/General Exhaust Ventilation (GEV):

- Dilution ventilation
- Displacement ventilation

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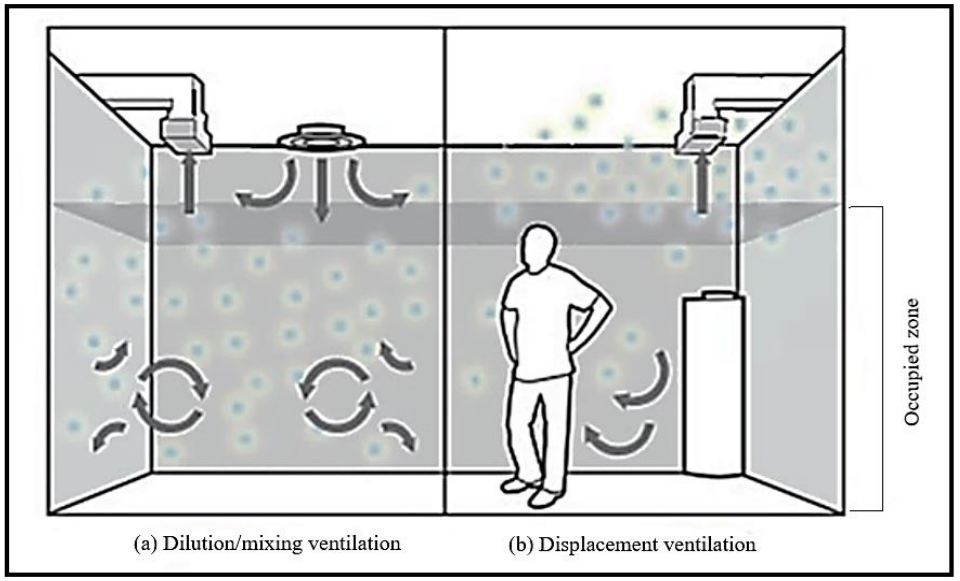
Controls - Ventilation

- Dilution (Mixing) Ventilation
  - The intent is to mix (thus, dilute) contaminated air with clean air to lower the concentration of the contaminant to below some recommended or accepted safe level to avoid adverse health effects.
- Displacement Ventilation
  - The intent is to keep overall room air mixing to a minimum and to push the contaminated air away from the breathing zone in as close to a laminar, directed flow as is possible.



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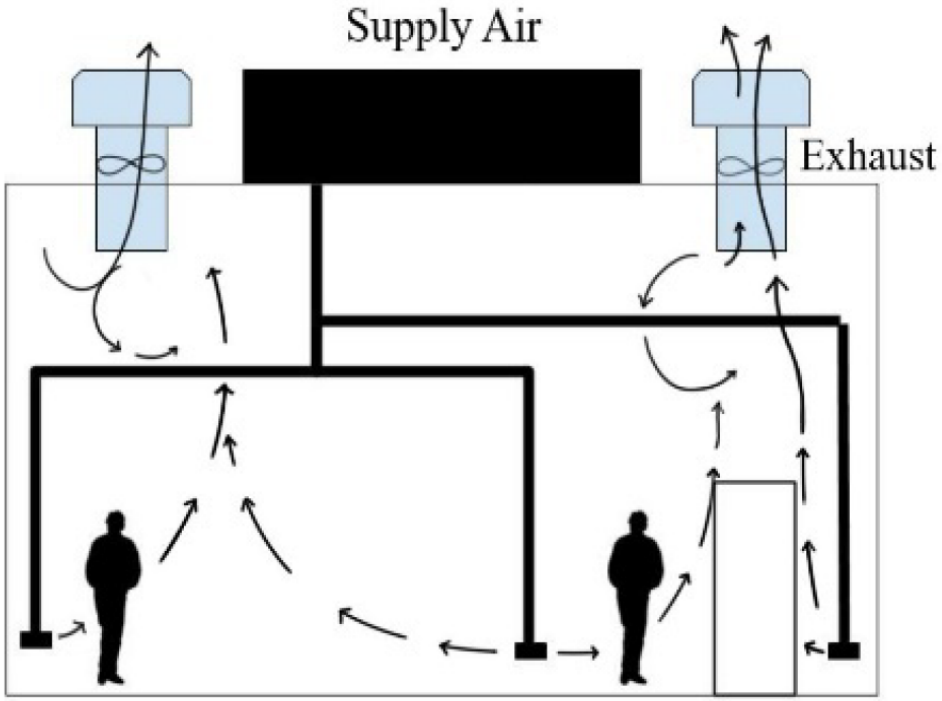
Controls - Ventilation



- Displacement Ventilation

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Controls - Ultraviolet Germicidal Irradiation

- UVC wavelength range of 200 to 280 nm.
- It is widely known that viruses (including SARS-CoV-2) are highly susceptible to germicidal UV light.
  - A classic study by William Firth Wells (et al., 1942) used germicidal UV lamps in schools to prevent the epidemic spread of measles.
- Accidental overexposure to UV light in the 254 to 275 nm range can cause acute eye or skin irritation/damage, so UV in this range is not recommended for occupied rooms unless occupants can be isolated from the UV light.
- UV lights can be installed inside occupied rooms on the upper section of walls (upper room) and inside HVAC systems.
  - The time the agent is exposed to the UV source and the agents distance from the UV source together determine in situ effectiveness.

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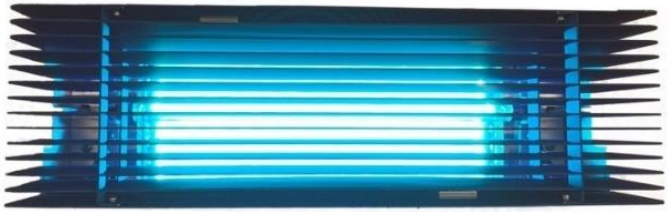
Controls - Ultraviolet Germicidal Irradiation

- Upper room UVGI is designed to incorporate sufficient shielding to protect room occupants from excessive exposure to UVC light, while relying on air movement from the lower (human occupancy and agent source height) to the upper portion of the room, where the air is in the path of the UV, allowing inactivation of some bioaerosols.
- Typically, upper air germicidal UV consist of low pressure Hg lamps equipped with baffles and a reflector to prevent light from spreading.



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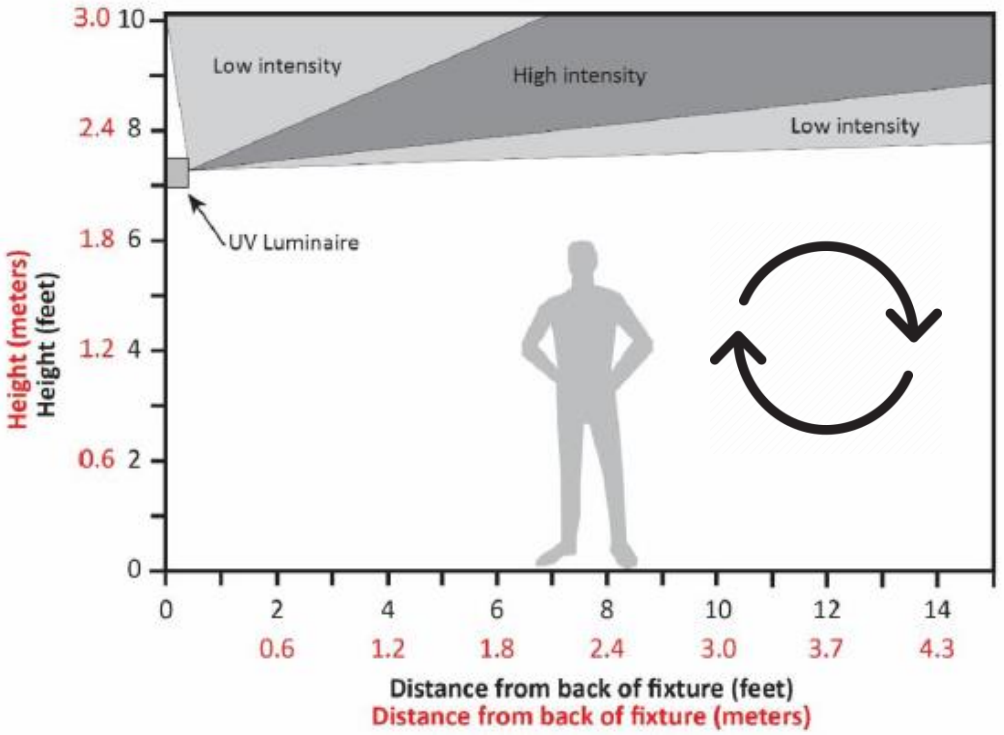
Controls - Ultraviolet Germicidal Irradiation

- Good vertical air mixing is required for upper room UVGI to work with any efficacy.
- For upper-room systems, the following must be considered to ensure proper operation and protect occupants and maintenance personnel from UV light exposure:
  - ceiling height;
  - light placement;
  - directionality;
  - penetration of the UV light;
  - stability of materials irradiated, and
  - remote shutoff/motion sensors/ safety interlocks.



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Controls - Ultraviolet Germicidal Irradiation

- In-duct UV systems:
  - Effectiveness varies on the biological agent and the system design.
    - Some biological agents are more resistant than others (effectiveness on viruses > vegetative bacteria > spore forming bacteria > fungal spores).
  - For in-duct applications, a balance between duct size, ventilation flow rate, and residence time in the UV light zone must be achieved to allow the UV light sufficient time for inactivation, while also allowing sufficient supply volume for meeting ventilation/ACH requirements.
  - System must be sealed to prevent any UV light leakage.
  - May be cost-prohibitive for retrofitting existing systems.

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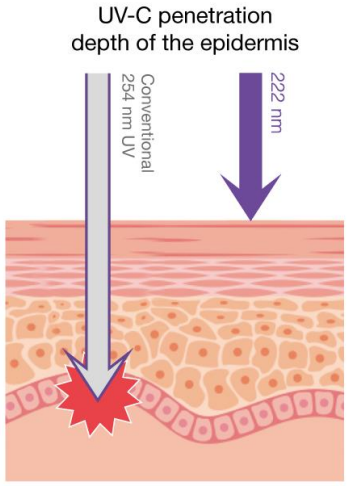
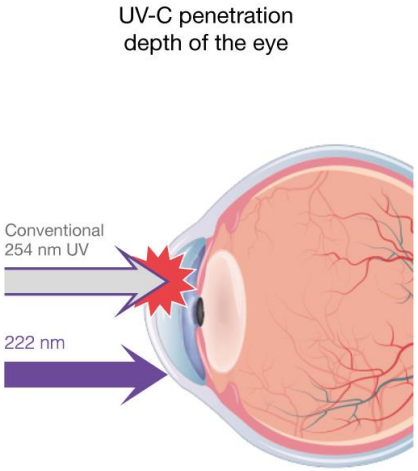
Controls - Ultraviolet Germicidal Irradiation

- Far-UVC wavelength <222 nm might be a safer alternative.
- Far-UVC has minimal, if any, effect on mammalian cells, but can inactivate viruses and prokaryotic cells (e.g., bacteria).
  - Could be used in public spaces with no special protection from UV irradiation to the skin.
- However, the residence time for inactivation is much longer.





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Controls - Ultraviolet Germicidal Irradiation

- Points to note:
  - Lamps have a distinct warmup period and need at least 10-30 minutes to stabilize.
  - Lamps last between 1-2 years.
  - Keeping lamps clean is important.
  - Can damage plants placed in the UV zone.
  - Can cause fading and blemishes to wood and wallpaper surfaces in the UV zone.
  - Make sure the device is registered with the EPA.

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Portable Air Cleaners

- ASHRAE, AIHA, and the CDC recommend that portable in-room HEPA air cleaners be used to increase the capture of airborne virions in the local environment, as well as increase the number of air changes per hour (ACH).

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Portable Air Cleaners

- Many portable HEPA filtration units are assigned a Clean Air Delivery Rate (CADR) in cubic feet per minute (cfm).
  - The CADR is an established standard defined by the Association of Home Appliance Manufacturers (AHAM).
- In a given room, the larger the CADR, the faster it will ‘clean’ the room air.
- Three CADR numbers are given on the AHAM label, one each for smoke, dust, and pollen.
  - Smoke particles are the smallest, so that CADR number applies best to viral particles.
- The label also shows the largest room size (ft^2) that the unit is appropriate for, assuming a standard ceiling height of up to 8 feet.

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Portable Air Cleaners

- Guidance for determining the appropriate number and size of air cleaning devices, based on room size and CADR ratings, are available at:
  - ASHRAE: In-Room Air Cleaner Guidance for Reducing COVID19 in Air in Your Space/Room. https://www.ashrae.org/file%20library/technical%20resources/covid-19/in-room-air-cleaner-guidance-for-reducing-covid-19-in-air-in-your-space-or-room.pdf
  - CDC: Ventilation in Buildings. https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html
  - AIHA: The Role of the Industrial Hygienist in a Pandemic. https://aiha-assets.sfo2.digitaloceanspaces.com/AIHA/resources/Role-of-the-Industrial-Hygienist-in-a-Pandemic-2nd-edition.pdf
  - ACGIH: *Bioaerosols Assessment and Control,* 2nd edition.

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Controls – Control Banding/ Respiratory Protection

- **Control Banding** - a strategy that groups workplace risks into control categories, or bands, based on combinations of hazard and exposure information.
  - Canadian Standards Association standard CAN/CSA-Z94.4-02 has a control banding approach to respiratory protection selection.
  - Ranking agents and selecting appropriate respirator APFs was proposed by McCullough and Brosseau in 1999.[4]
  - ACGIH's *Bioaerosols: Assessment and Control* (2nd ed.) and White Paper on *Engineering Controls for Bioaerosols in Non-Industrial/Non-Healthcare Settings*[5] have a decision matrix for control measures.

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Decision Matrix for Controls

- The first step in the decision matrix process is to categorize the hazard level of the specific agent, based upon the severity of possible adverse health outcomes and the type of adverse health effects caused by the biological agent.

	Hazard Categorization				
	Catastrophic	Critical	Treatable	Marginal	Negligible
Toxic Response	4	4	4	2	2
Infection	4	4	3	2	2
Irritation	4	3	2	2	1
Sensitization	4	3	2	1	1
Allergy/Asthma	3	2	2	1	1

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Decision Matrix for Controls

- The second step is to categorize the potential for exposure, based upon the anticipated intensity or magnitude of exposure, and the duration and/or frequency of exposures, to the specific agent.

	Exposure Categorization				
	Aggressive Disturbance	Active Disturbance	Moderate Activity	Light Activity	No Activity
Constant	4	4	4	3	2
Chronic/Interrupted	4	4	3	2	2
Chronic/Episodic	4	3	3	2	1
Occasional	3	3	2	1	1
Acute/Short Term	3	2	1	1	1

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Decision Matrix for Controls

	Risk Level = Hazard + Exposure			
	Hazard Category 4	**Hazard Category 3**	**Hazard Category 2**	**Hazard Category 1**
Exposure Category 4	**8**	**7**	**6**	**5**
Exposure Category 3	**7**	**6**	**5**	**4**
Exposure Category 2	**6**	**5**	**4**	**3**
Exposure Category 1	**5**	**4**	**3**	**2**

Risk Level	Action
2	Minimize duration and frequency of exposure for immunocompetent persons.
3, 4	PPE for brief exposure periods. Minimizing duration of exposure. Source elimination for chronic or long-term exposures.
5, 6	Respirators with APF of 10 or more. Add administrative and engineering controls or source elimination.
7, 8	**Respirators with APF of 100 or more.** **Administrative and engineering controls until or while mitigation/source elimination is occurring.**

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Conclusions

- Bioaerosols are a complex mixture comprised of fungi, bacteria, mites, etc. and their metabolites and byproducts, and airborne concentrations vary widely both temporally and spatially.
- Assessing and controlling bioaerosols is more complex and difficult than for other chemical and physical hazards faced by health and safety professionals.

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Questions?

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