
Mitigating Pathogen Dispersion in Public Transit

Meghan Ramsey

June 21, 2022



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Speaker Introduction

- **Meghan Ramsey is a member of the Counter-WMD Systems Group at MIT Lincoln Laboratory**
 - Federally-Funded Research and Development Center
 - Lexington, MA
- **The Counter-WMD Systems Group provides mission-driven solutions to the nation's highest priority WMD defense needs**
 - Core competencies: threat characterization, systems analysis, rapid prototyping, development test and evaluation
- **Significant expertise characterizing how biological and chemical threats propagate in realistic environments (including urban areas and transit) and evaluating effective response strategies**
 - Variety of sponsors including the Department of Homeland Security Science & Technology Directorate





Domestic Bioaerosol Threats

- Traditional biodefense efforts have focused on **Category A Bioterrorism agents**
 - Small, unobservable quantities can cause major impacts
 - Symptoms may be delayed by days after exposure
 - Disease may spread between infected individuals
- Naturally occurring diseases also pose a threat, with significant potential health and economic impacts
- Biothreats are of increasing concern
 - Reduced barriers to access for traditional threats
 - Environmental disruption and climate change contributing to increased “pathogen spillover”

CDC Category A Bioterrorism Agents

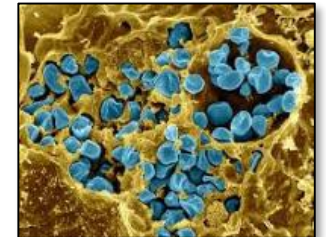
Bacillus anthracis
(Anthrax)



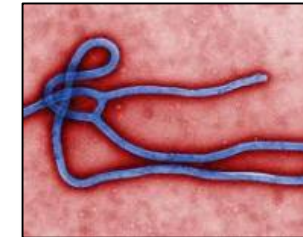
Yersinia pestis
(Plague)



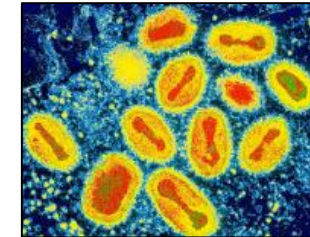
Francisella tularensis
(Tularemia)



Viral hemorrhagic fevers
(e.g. Ebola)

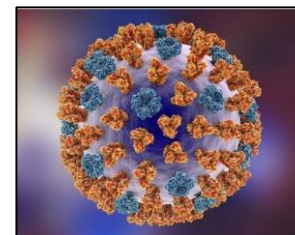


Variola major
(Smallpox)

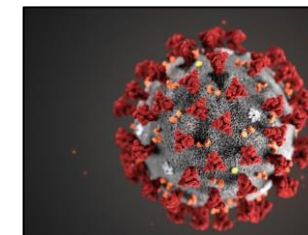


Naturally-Occurring Airborne Diseases

Influenza Virus



SARS-CoV-2 Virus



...Others



Dispersion of Biothreats in Urban Areas and Transit Systems

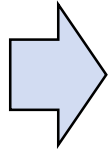
- Urban areas have high population density & are interconnected by transit networks
- Transit systems can contribute to the dispersal of air and airborne particles on a macro-scale
- Passenger proximity and density inside transit vehicles can provide opportunity for disease transmission



Today’s talk will focus on biothreat dispersion within transit vehicles, and factors that can reduce dispersion



Outline

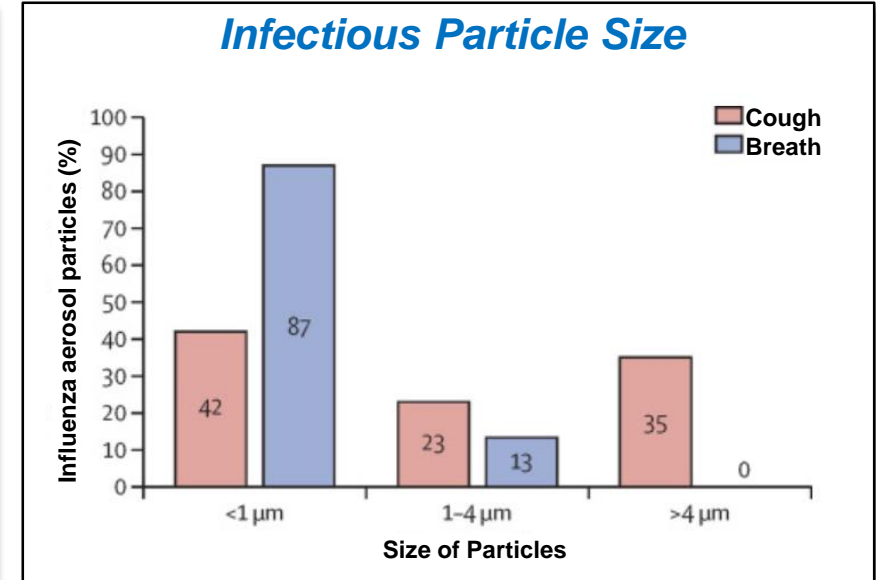
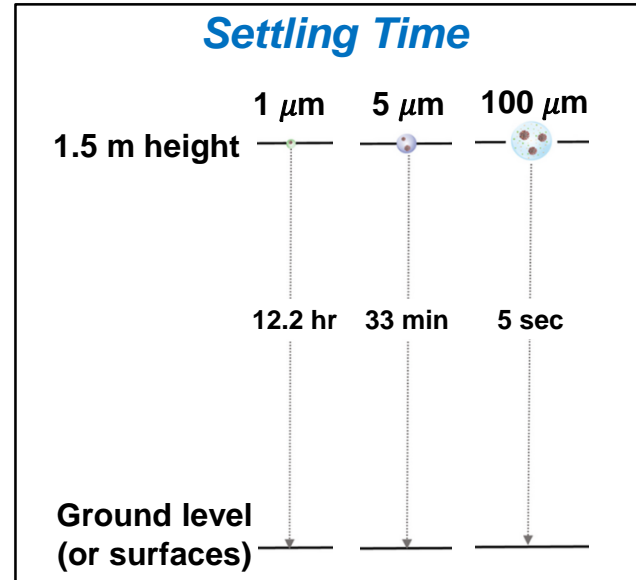
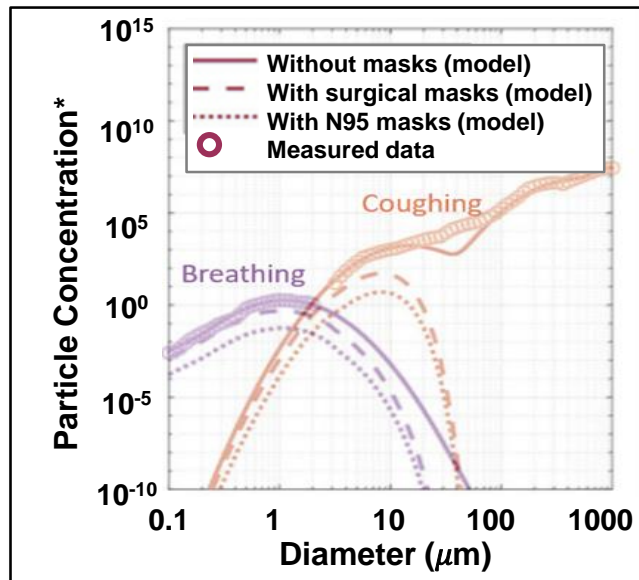


- **Properties of respiratory aerosols**
- **Factors that impact air quality and pathogen dispersion**
 - **Characteristics of transit environments**
- **Use of tracer materials to characterize dispersion and mitigation**
- **Summary**



Respiratory Aerosol Production

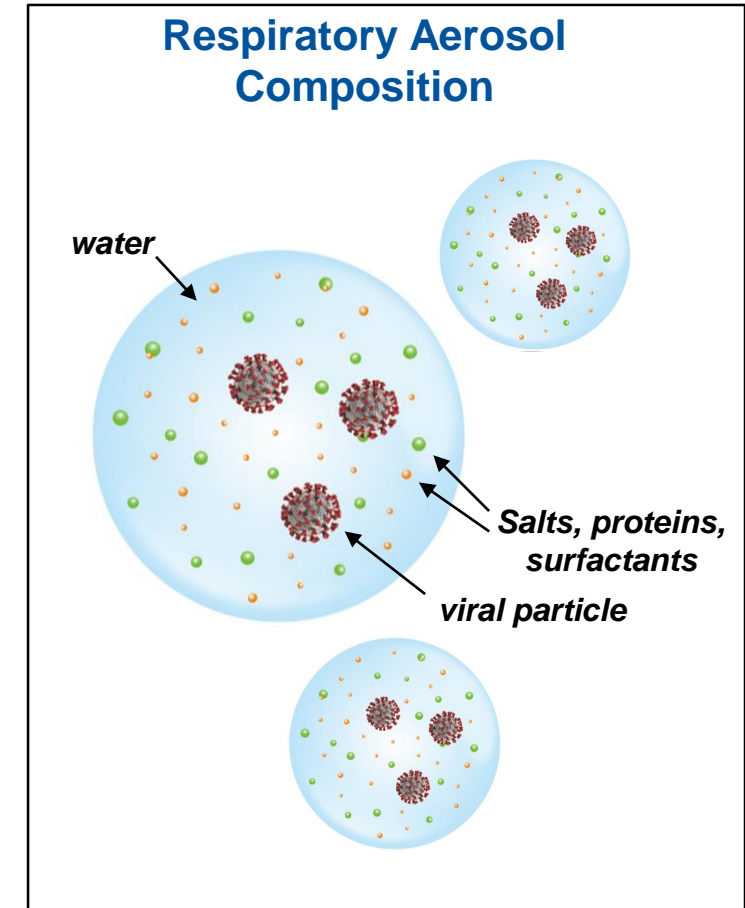
- Normal respiratory activities generate liquid particles in a range of sizes
 - Particle size is a key determiner of dispersion properties
 - Small particles remain airborne longer than larger particles
- For a respiratory disease like COVID-19, respiratory aerosols may contain virus
 - Studies across multiple diseases show that pathogens are present in small aerosol particles
- Our understanding of SARS-CoV-2 transmission has evolved
 - Early emphasis on larger particles and surface contamination
 - Shift to recognition of aerosol transmission





Respiratory Aerosol Risk Factors

- **Many different factors affect infection risk**
 - How prevalent is pathogen transmission in the community at large?
 - How many pathogen-containing particles are shed by infected individuals?
 - What size are the pathogen-containing particles?
 - Dispersion distance
 - Deposition in different parts of the lung
 - How long does the pathogen retain infectivity in aerosols?
 - Dependent on aerosol composition, environmental conditions, specific pathogen
 - What is the health status and proximity of other individuals in the environment?
 - Are mitigations like mask usage in effect?
- **In general, reducing the number of pathogen-containing particles in the environment will reduce risk**





COVID-19 Transmission on Transit Vehicles

JAMA Internal Medicine | Original Investigation

Community Outbreak Investigation of SARS-CoV-2 Transmission Among Bus Riders in Eastern China

Ye Shen, PhD; Changwei Li, PhD; Hongjun Dong, MD; Zhen Wang, MD; Leonardo Martinez, PhD; Zhou Sun, MD; Andreas Handel, PhD; Zhiping Chen, MD; Enfu Chen, MD; Mark H. Ebell, MD, MS; Fan Wang, MA; Bo Yi, MD; Haibin Wang, MD; Xiaoxiao Wang, MD; Aihong Wang, MD; Bingbing Chen, MD; Yanling Qi, PhD; Lirong Liang, MD, PhD; Yang Li, PhD; Feng Ling, MD; Junfang Chen, MD; Guozhang Xu, MD

PUBLIC HEALTH

Evaluating COVID Risk on Planes, Trains and Automobiles

Stay safer on different forms of transportation

By Sophie Bushwick, Tanya Lewis, Amanda Montañez on November 19, 2020

Transmission of SARS-CoV-2 in Public Transportation Vehicles: A Case Study in Hunan Province, China

Kaiwei Luo,^{1,a} Zhao Lei,^{2,a} Zheng Hai,^{3,a} Shanliang Xiao,^{4,a} Jia Rui,² Hao Yang,¹ Xiping Jing,³ Hui Wang,⁴ Zhengshen Xie,³ Ping Luo,⁴ Wanying Li,³ Qiao Li,³ Huilu Tan,³ Zicheng Xu,³ Yang Yang,^{5,b} Shixiong Hu,^{1,b} and Tianmu Chen^{2,k}

Public transportation and transmission of viral respiratory disease: Evidence from influenza deaths in 121 cities in the United States

Renata E. Howland^{1,c,*}, Nicholas R. Cowan^{1,2,c}, Scarlett S. Wang^{1,c}, Mitchell L. Moss^{1,2,c}, Sherry Glied^{1,c}

RESEARCH ARTICLE

Aerosol tracer testing in Boeing 767 and 777 aircraft to simulate exposure potential of infectious aerosol such as SARS-CoV-2

Sean M. Kinahan^{1,2,c,*}, David B. Silcott^{3,c}, Blake E. Silcott^{3,f}, Ryan M. Silcott^{3,f}, Peter J. Silcott^{3,f}, Braden J. Silcott^{3,f}, Steven L. Distelhorst^{2,f}, Vicki L. Herrera^{1,f}, Danielle N. Rivera^{2,f}, Kevin K. Crown^{2,f}, Gabriel A. Lucero^{2,f}, Joshua L. Santarpia^{1,2}

Reducing COVID-19 airborne transmission risks on public transportation buses: an empirical study on aerosol dispersion and control

Nathan J. Edwards^{https://orcid.org/0000-0002-7636-3073^a}, Rebecca Widrick^{https://orcid.org/0000-0002-2812-3411^b}, Justin Wilmes^{https://orcid.org/0000-0001-8095-9040^c}, Ben Breisch^{https://orcid.org/0000-0003-0687-8378^a}, Mike Gerschefske^{https://orcid.org/0000-0002-4586-6436^d}, Jon Sullivan^e, Richard Potember^{https://orcid.org/0000-0002-2683-0219^f}, and Angelica Espinoza-Calvio^f

Risk of Coronavirus Disease 2019 Transmission in Train Passengers: an Epidemiological and Modeling Study

Maogui Hu,^{1,a} Hui Lin,^{2,a} Jinfeng Wang,¹ Chengdong Xu,¹ Andrew J. Tatem,³ Bin Meng,⁴ Xin Zhang,⁵ Yifeng Liu,² Pengda Wang,² Guizhen Wu,⁶ Haiyong Xie,^{2,7,a} and Shengjie Lai^{3,8,a}

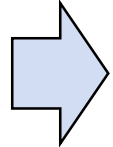
Air and surface measurements of SARS-CoV-2 inside a bus during normal operation

Piero Di Carlo^{1,2,x}, Piero Chiacchiaretta³, Bruna Sinjari⁴, Eleonora Aruffo^{1,2}, Liborio Stupia^{1,2}, Vincenzo De Laurenzi^{2,4}, Pamela Di Tomo², Letizia Pelusi², Francesca Potenza², Angelo Veronese², Jacopo Vecchiet^{5,6}, Katia Falasca^{5,6}, Claudio Ucciferri^{5,6}

- COVID-19 disease transmission has been reported in transit environments
- Limited evidence overall for transit as a key driver of infections in urban areas



Outline

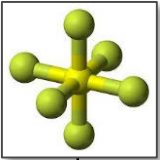


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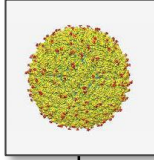


Properties of Air Contaminants

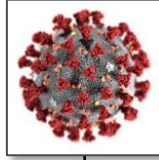
Gas Molecule



Zika Virus



SARS-CoV-2



Wildfire Smoke



Bacteria



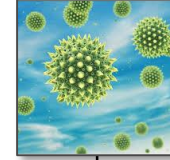
Blood Cell



Dust (PM₁₀)



Pollen



Fine Beach Sand



Human-generated respiratory aerosols

<0.0005 μm

0.045 μm

0.1-0.5 μm

0.4-0.7 μm

1-3 μm

7-8 μm

10 μm

15 μm

90 μm

Gases

- Examples: odors, exhaled CO₂
- Do not settle onto surfaces
- Not removed from environment by filtration
- Only removed by dilution with fresh air

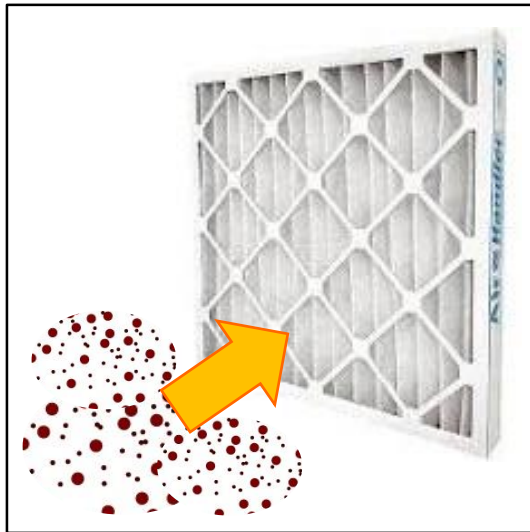
Particles

- Examples: Pollen, dust, bacteria, viruses, respiratory aerosols
- Settle onto surfaces based on size
- Removed from the environment by filtration
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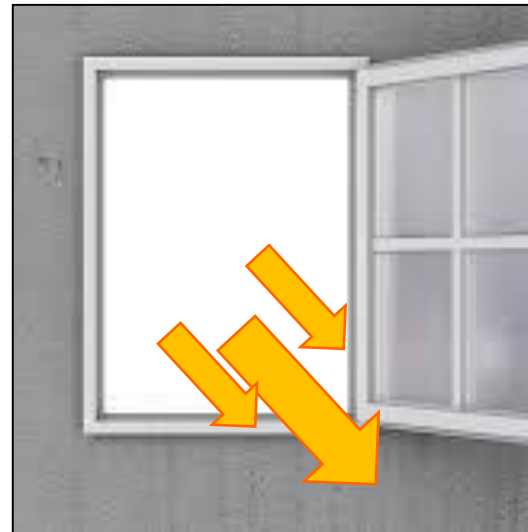


Mechanisms to Reduce Pathogen Exposure

**Filter air
to remove particles**



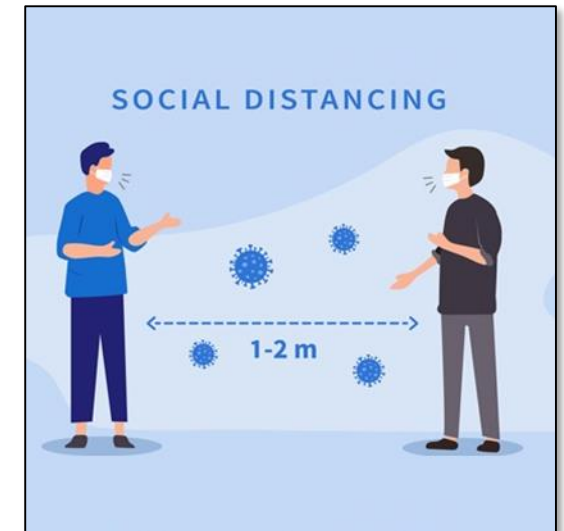
**Introduce fresh air
to dilute particles**



**Decontamination
to inactivate pathogen**



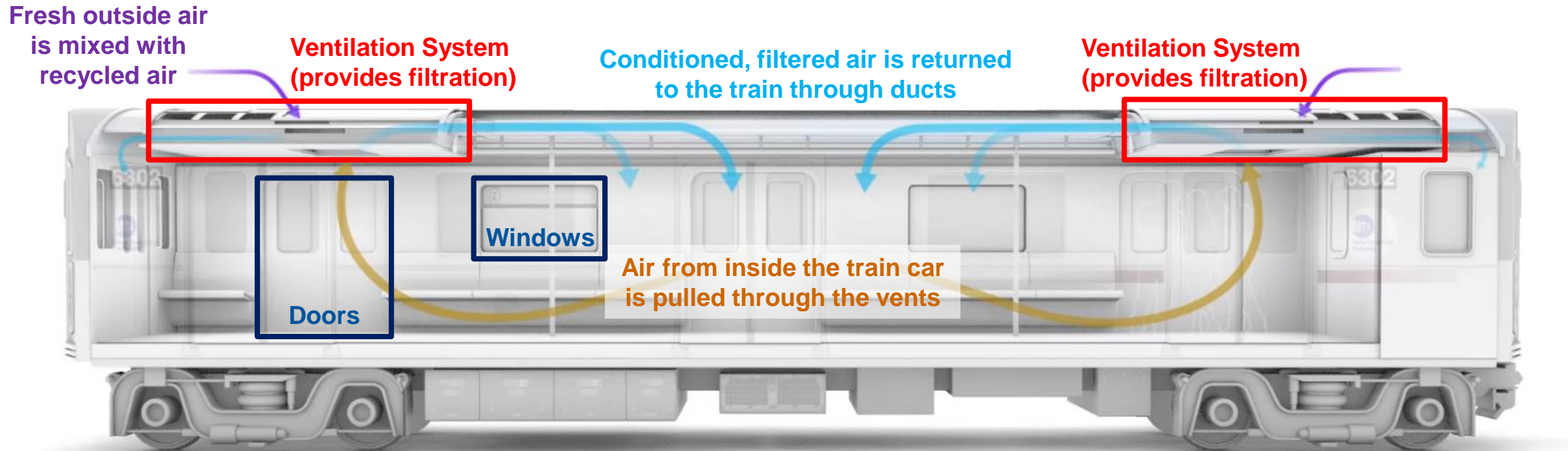
**Individual actions to
reduce shedding & exposure**





Air Exchange in a Transit Vehicle

Example Subway Train Car



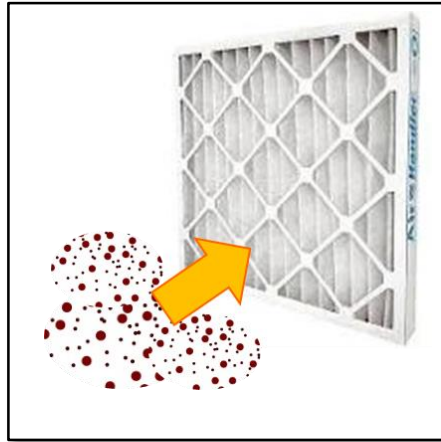
- Specifics of air filtration and air exchange systems vary significantly across vehicle type and model
- Available options for improving air quality and reducing pathogen transmission risk will vary



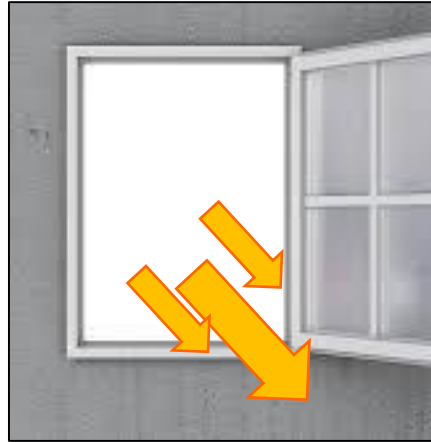
Mechanisms to Reduce Viral Exposure

Focus

Filter air to remove particles



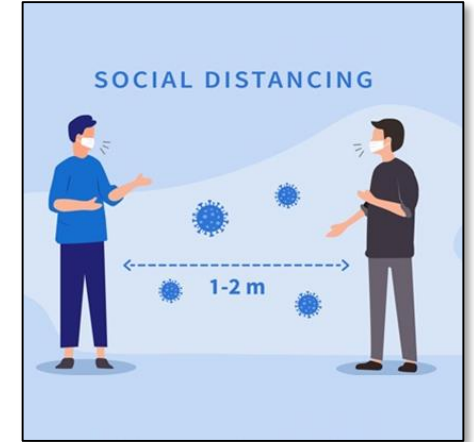
Introduce fresh air to dilute particles



Decontamination to inactivate pathogens



Reduce shedding & exposure



Actions

- Increase efficiency of filtration in HVAC system

- Increase fresh air intake through HVAC system
- Open windows
- Alter door operations

- Spray or wipe surfaces
- Treat the air

- Wear masks
- Surveillance testing
- Maintain distance from others

Challenges

- More efficient filters burden HVAC systems

- HVAC system may not enable fresh air intake
- Reduced ability for climate control

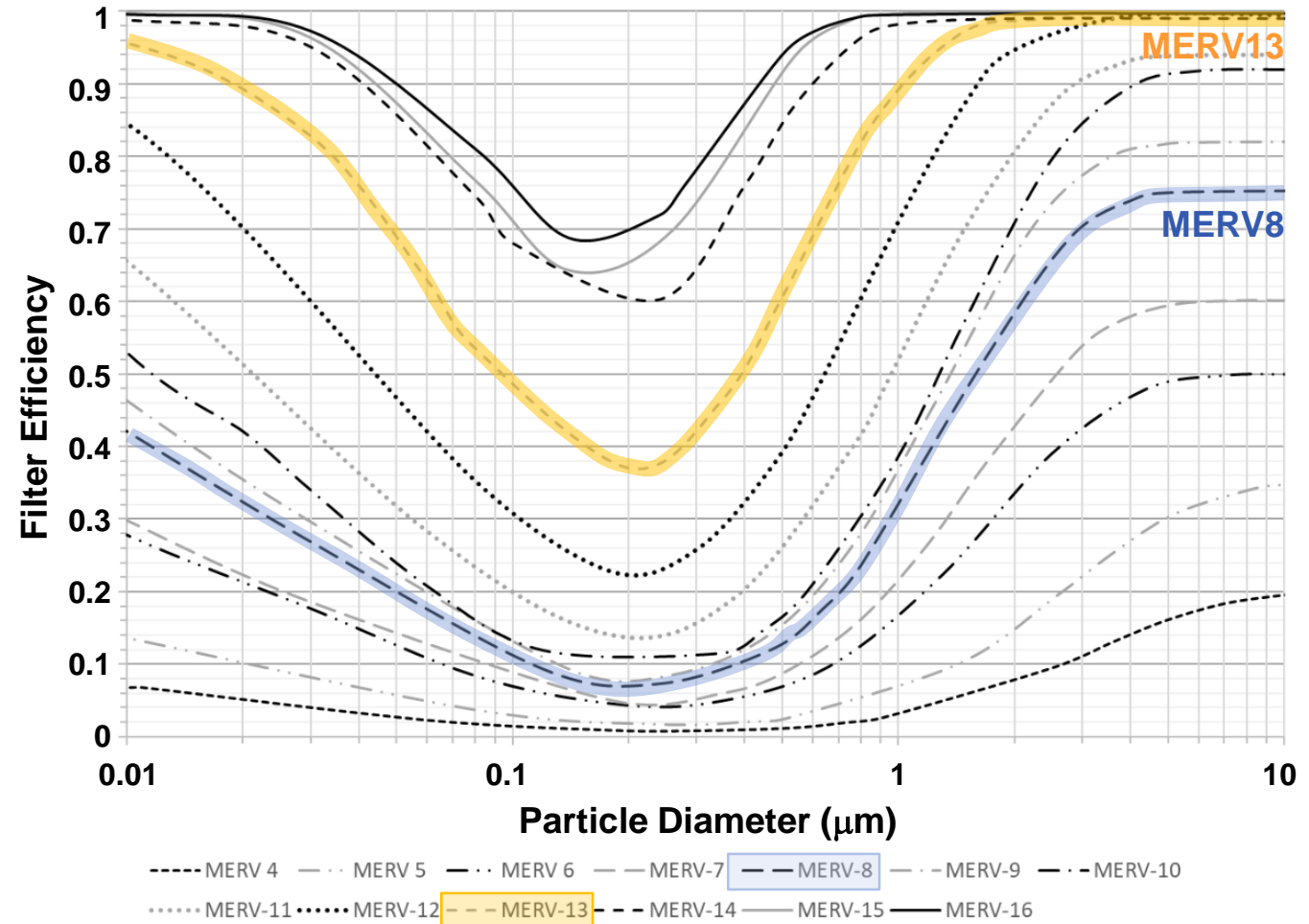
- Dwell time, logistics

- Policy challenges, compliance



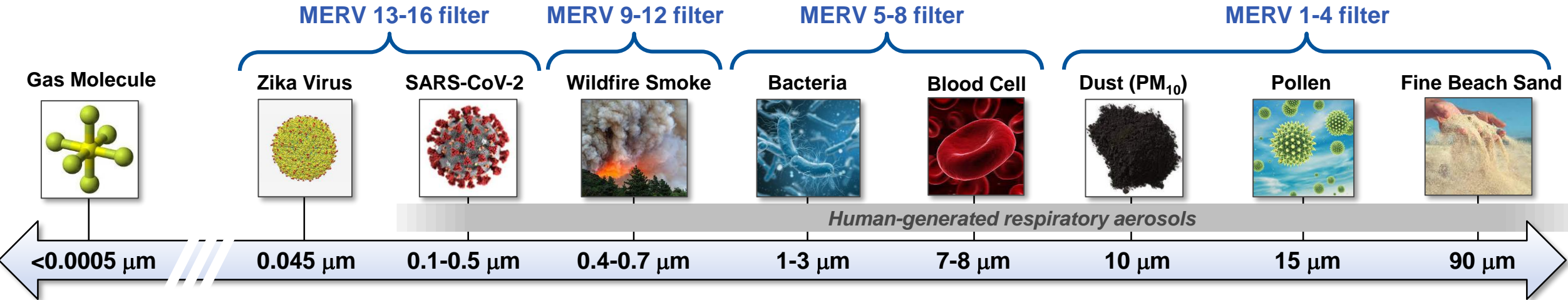
Filtration Efficiency

- Filter efficacy is rated based on a **Minimum Efficiency Reporting Value (MERV)**
- Filters with higher MERV ratings are more efficient at removing smaller particles
- Why not just install MERV-16 filters everywhere?
 - Higher MERV = higher pressure drop
 - Reduced airflow through the HVAC system
- Different mechanisms for achieving MERV rating:
 - Physical pore size
 - Surface treatments (electrostatic coatings)





MERV Ratings Mapped to Air Contaminants



Gases

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Particles

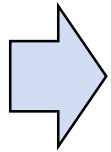
- Examples: Pollen, dust, bacteria, viruses, respiratory aerosols
- Settle onto surfaces based on size
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The required MERV rating for effective filtration of an air contaminant depends on the particle size



Outline

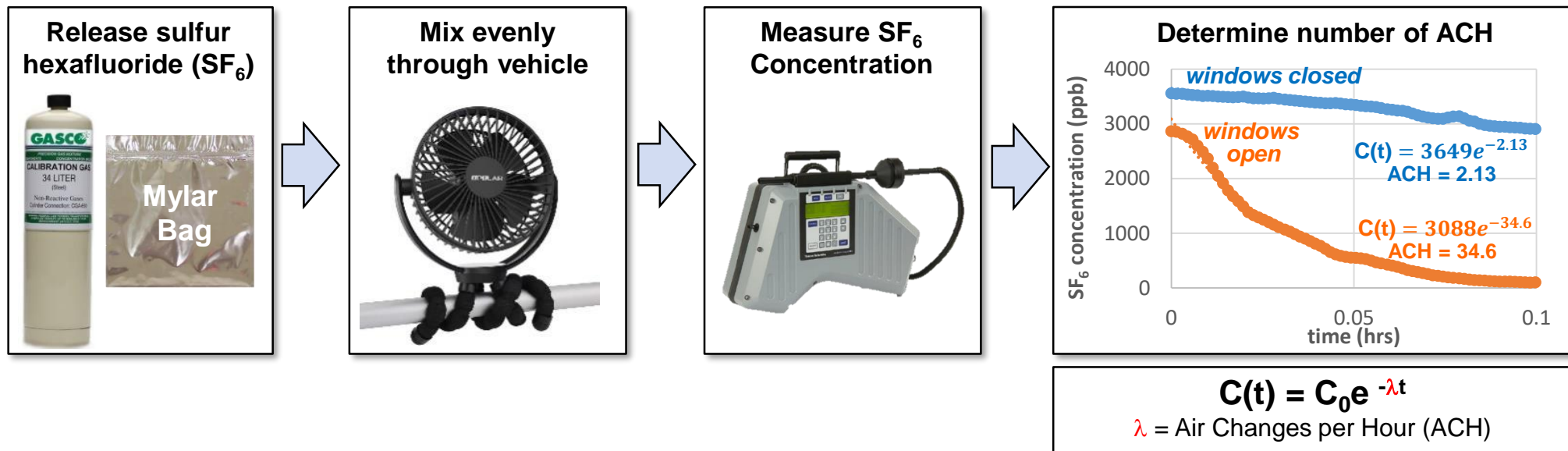
- **Properties of respiratory aerosols**
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Gas Tracer Testing

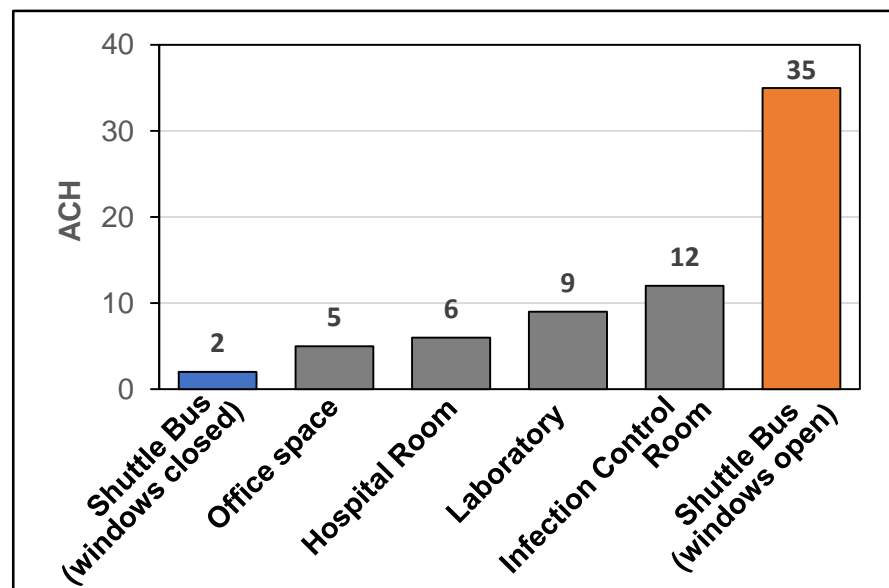
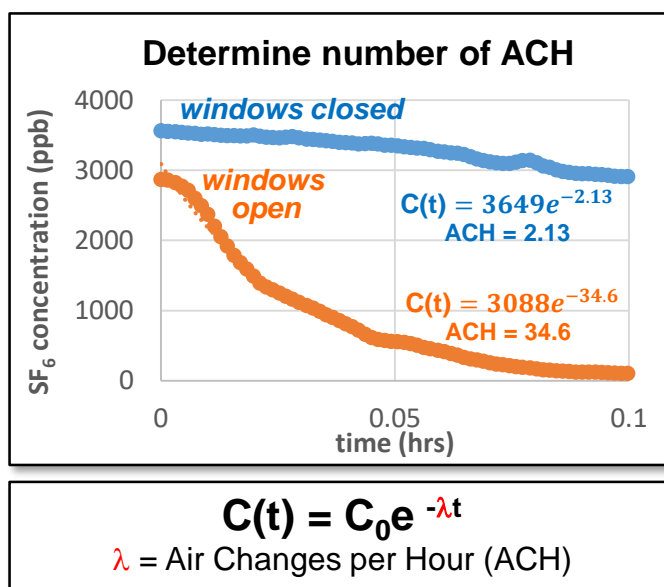
- The number of Air Changes per Hour (ACH) is a quantitative measure of air exchange
 - ACH: the number of times per hour air in a space is replaced with outdoor air
 - Higher ACH = more air exchange = lower risk
- ACH can be measured using a tracer gas like sulfur hexafluoride (SF_6)
 - Example provided for MIT LL shuttle bus, with vehicle in motion
 - Provides quantitative measure of impact of changing operating conditions





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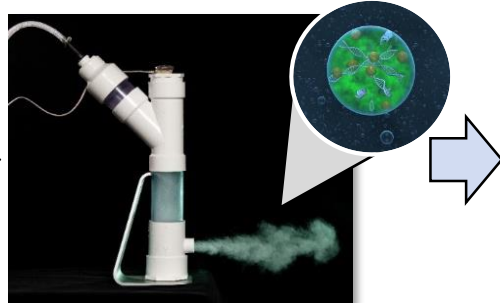
Particle Simulant Testing

- **Tracer gases like SF₆ do not capture all of the complexity of respiratory aerosols**
 - Do not settle onto surfaces
 - Cannot be removed by filtration
- **More complex simulant materials can be designed to mimic respiratory aerosols**
 - Customize size, release characteristics
 - Add specific constituents to enable detection (fluorescence, molecular barcodes)
- **Measurement of simulant concentration decay over time can be used to determine “Equivalent ACH” under different operating conditions**

Define important parameters of respiratory aerosols



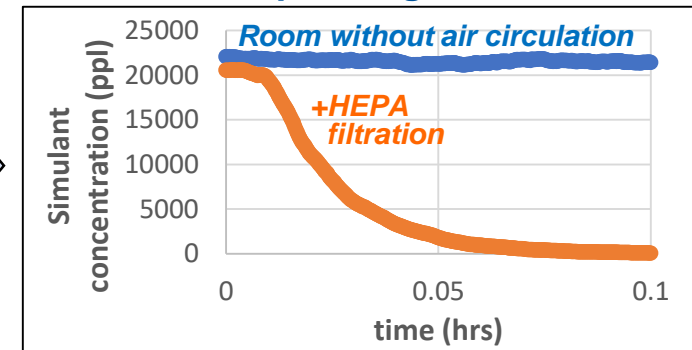
Design safe simulant to mimic aerosol production



Collect measurements of simulant concentration



Quantify Equivalent ACH under different operating conditions



Safe simulants can be used to mimic pathogens of interest and generate quantitative, actionable information



Summary

- **Traditional biothreats, naturally-occurring diseases, and new emerging pathogens are all of concern from a national security perspective**
 - **Because of their high population density and interconnectedness, urban areas and transit systems pose unique challenges**
- **A variety of mitigation actions exist that can reduce risk of pathogen transmission**
 - **Some easier to implement than others**
 - **Trade-offs must be balanced with overall risk climate**
- **Gas tracers and particle simulants can be used to provide quantitative information regarding threat dispersion and the efficacy of interventions**
 - **Widely adaptable approach across scenarios and environments**