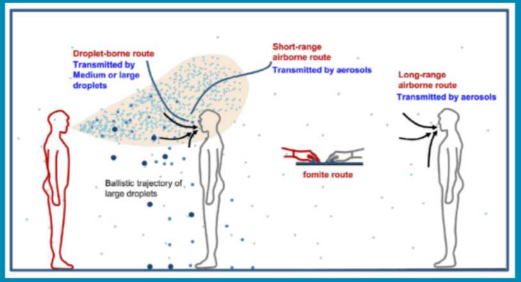
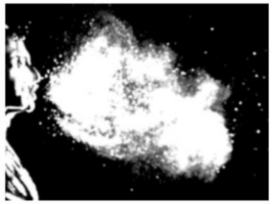
SAND2020-8643PE

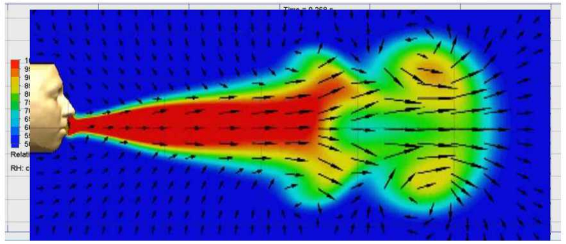
Near-Field Exposure Modeling
Sandia National Labs

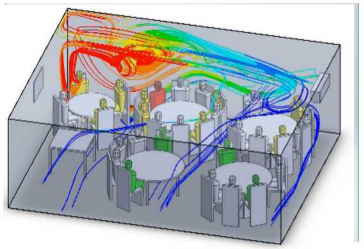


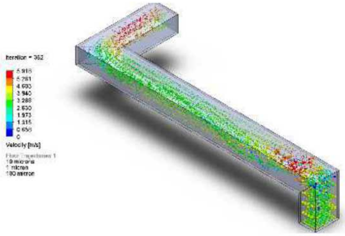
Wei and Li (2016)



Bourouiba et al. (2014)







PRESENTED BY

Clifford K. Ho, ckho@sandia.gov

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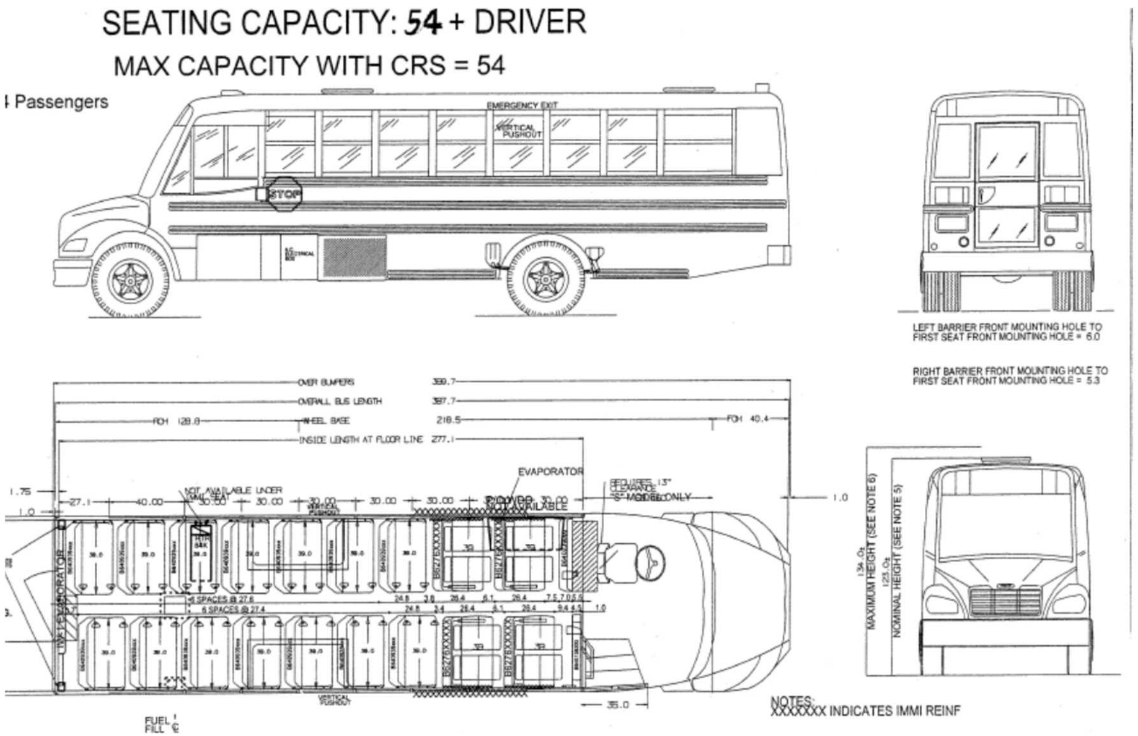
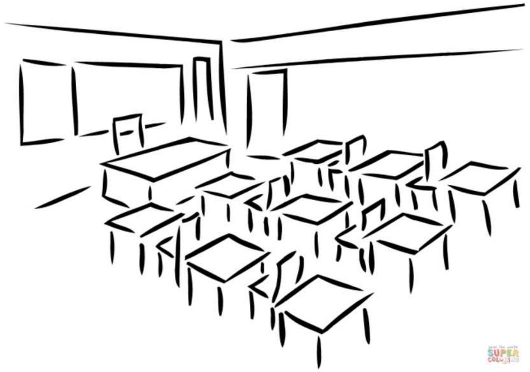
Sandia Work Scope

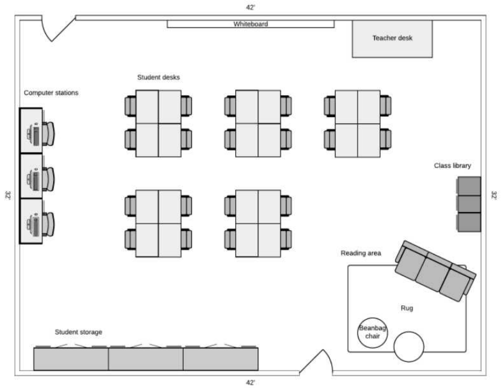
- Near-Field Modeling
  1. Simulation of droplet dynamics (evaporation, transport) and persistence resulting from coughs, talking (Stefan Domino)
     - Understand relation between initial droplet spray and final droplet nuclei distributions
  2. Near-field simulations to better understand exposure risks and mitigations for multi-person (restaurant, classroom, bus) configurations (Cliff Ho)
- Near-Field Testing
  - Testing of aerosol plume dynamics under various ventilation and barrier configurations (Andy Glen/Andres Sanchez)

Sandia Near-Field Modeling – Scope (Ho)

- Environments/Case Studies
  - Buses
  - Classroom
- Hypotheses
  - Exposure to teachers can be minimized via proper ventilation and classroom configuration
  - Exposure to students can be minimized via acrylic barriers

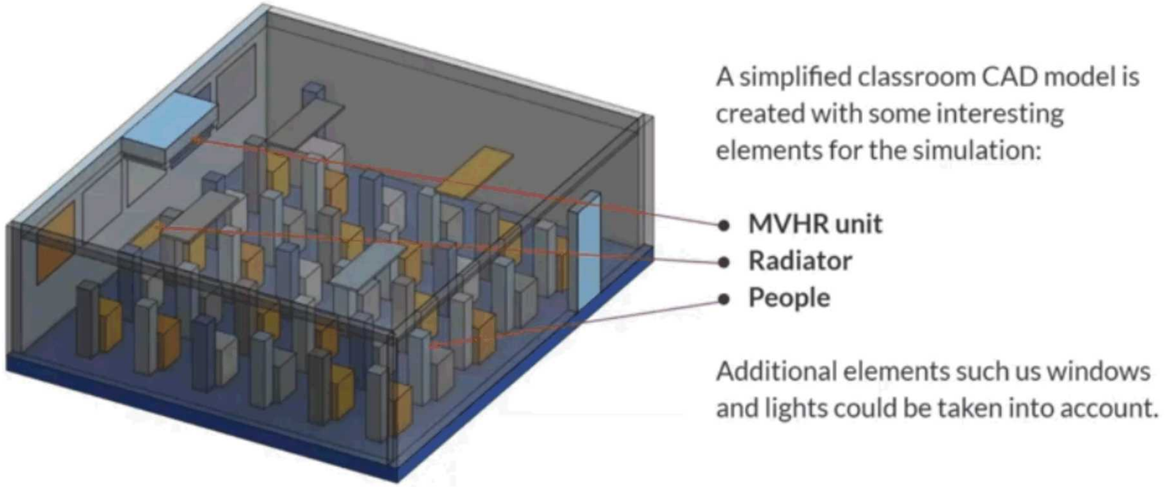




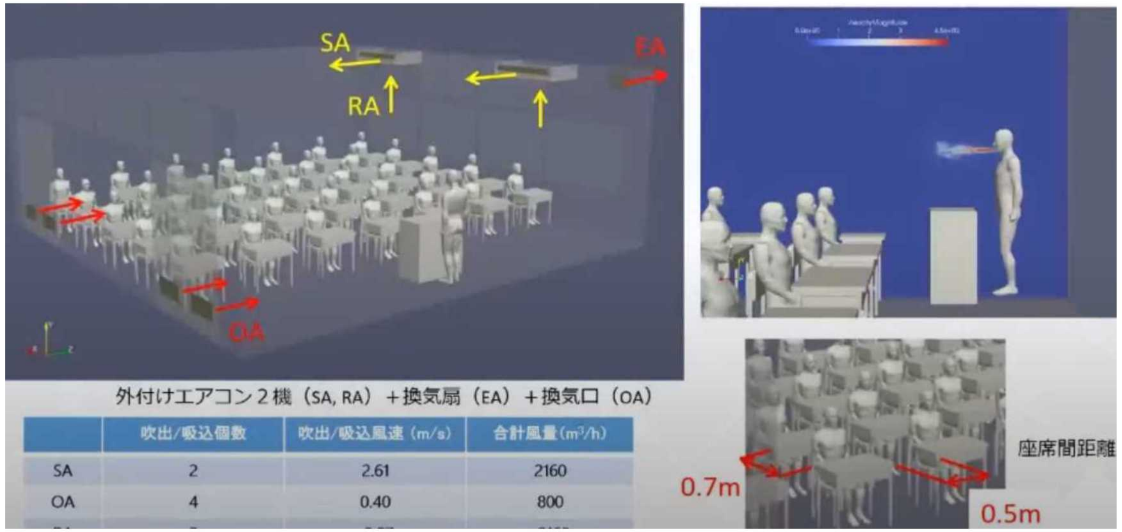


Sandia Near-Field Modeling – Scope (Ho)

- **Baseline Conditions**
  - Select classroom configuration
    - Dimensions of classroom
    - Number and location of students/desks
    - Location of teacher/podium/desk
    - Ventilation intake and exhaust locations (including open/closed windows)
      - Assume baseline ventilation condition
  - Determine required fidelity of features and people for CFD models



SimScale (https://www.youtube.com/watch?v=4CIXpo3zPh8)

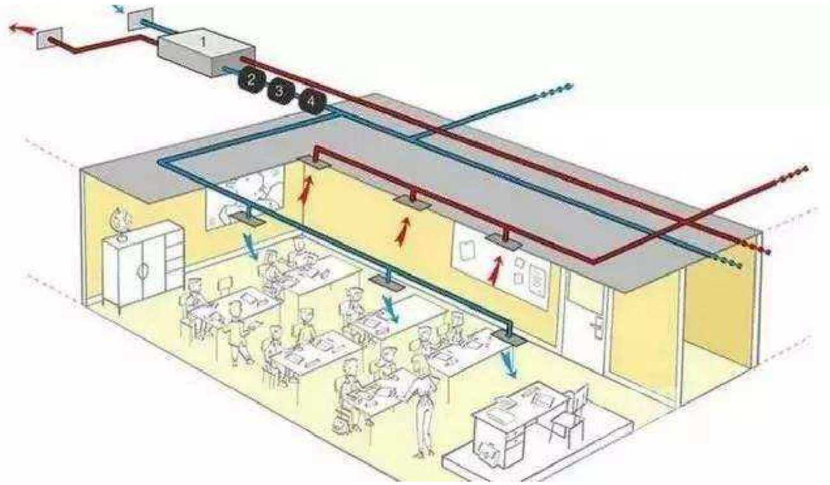


M. Tsubokura (https://www.youtube.com/watch?time_continue=23&v=Z6EbAO3nLy8&feature=emb_logo)

Sandia Near-Field Modeling – Scope (Ho)

- **Boundary Conditions and Scenarios**
  - Source
    - Students breathing and teacher talking
    - One or more students coughing/sneezing
  - Ventilation
    - Direction (arrange teacher and student seating)
      - Teacher located upwind of students
      - Teacher located downwind of students
      - Teacher located crosswind relative to students
    - Flow rate
      - None (quiescent)
      - Low
      - High
  - Barrier on desks
    - None
    - Acrylic barriers (3 sides) around each desk
      - Height variation (low, high?)
  - Masks?
    - None
    - Everyone wears masks

108 Simulations!

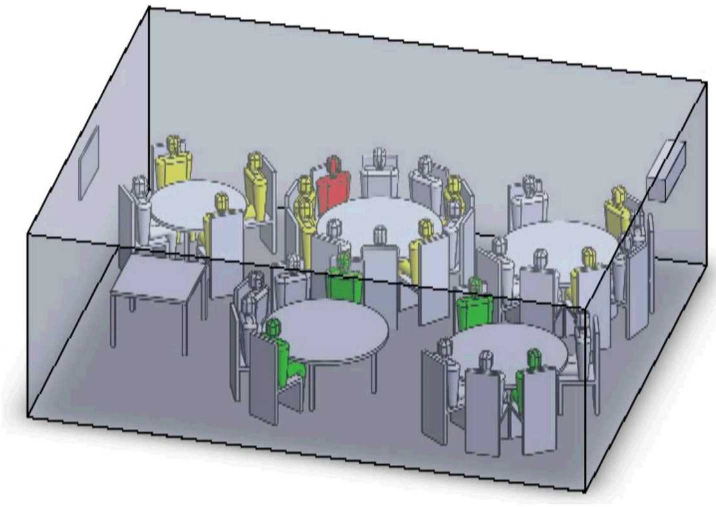


http://en.meishischool.com/a/IB/2017/0228/47.html

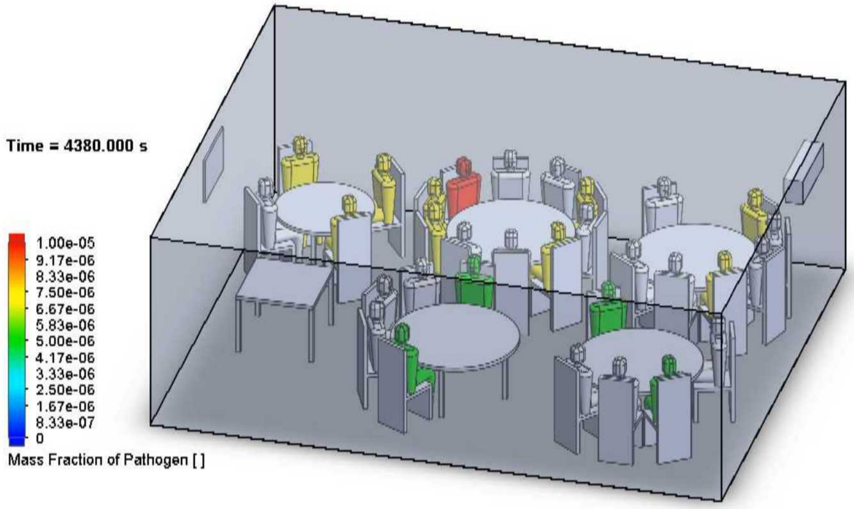
Students at a primary school in Bangkok returned on July 1, a delayed start to their academic year. Credit: Adam Dean for The New York Times (https://www.nytimes.com/2020/07/11/health/coronavirus-schools-reopen.html)

Sandia Near-Field Modeling – Calibration/Controls (Ho)

- Guangzhou restaurant
  - Inverse modeling – use observed infection rates to calibrate uncertain parameters
    - Viral load, infectious dose
- Remaining tasks
  - Parametric analyses
    - Ventilation flow rate/direction
  - Grid convergence

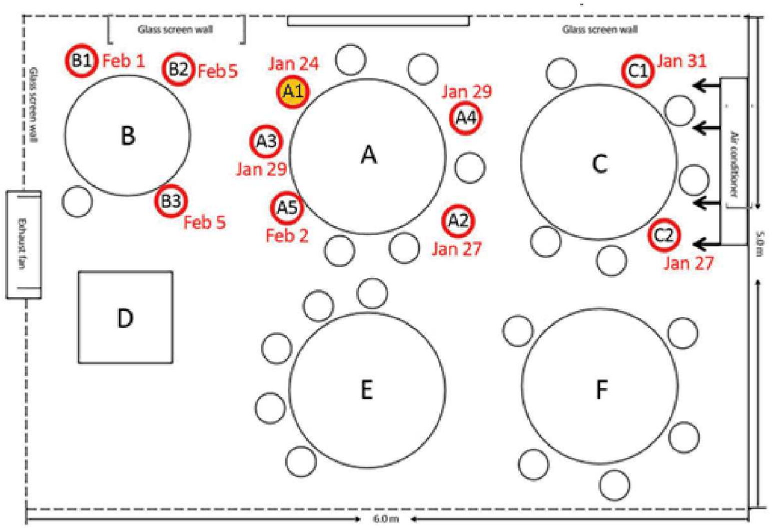


Flow lines colored by velocity



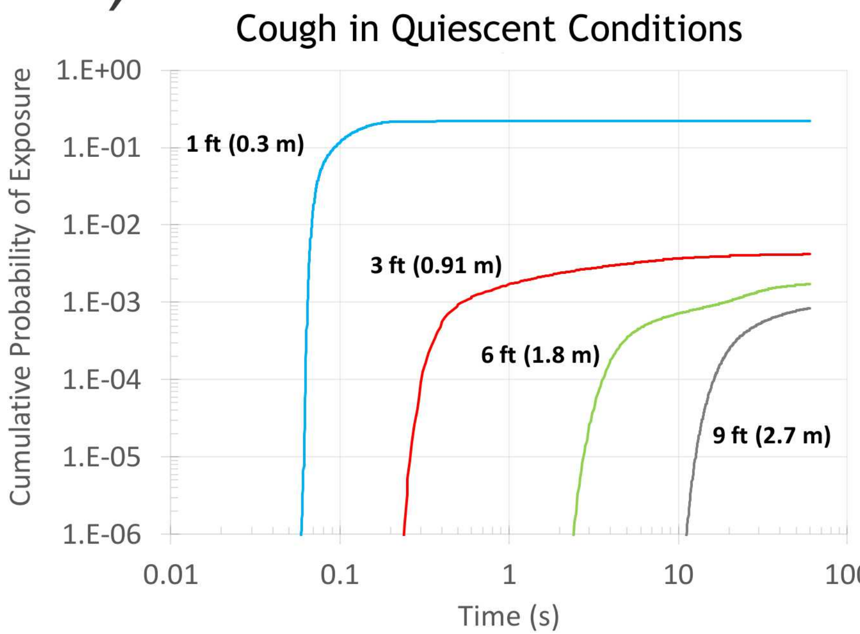
Mass fraction of pathogen

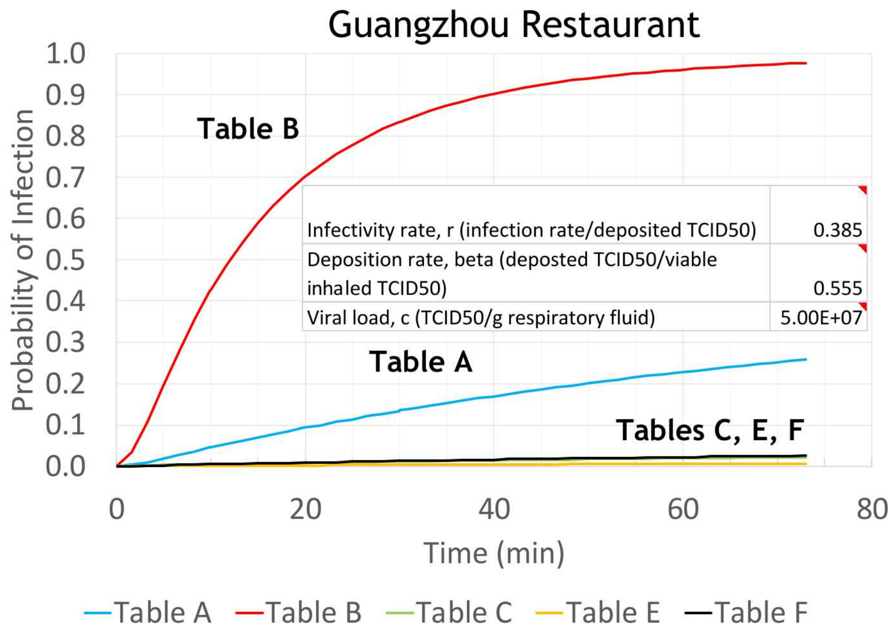
Red = Index patient
Yellow = Infected receptors
Green = Uninfected receptor



Sandia Near-Field Modeling – Scope (Ho)

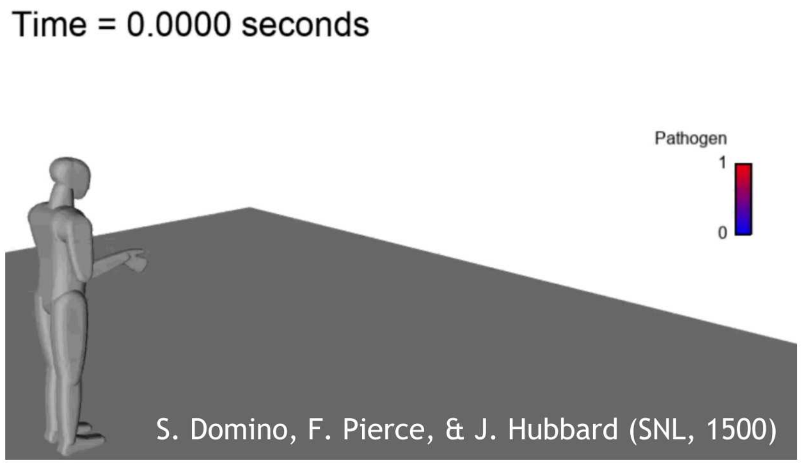
- **Metrics**
  - Exposure Assessment
    - Ratio of time-integrated concentration at various locations to the time-integrated concentration at the source (infected person's mouth) as a function of time
  - Probability of Infection
    - **Viral load** ($TCID_{50}$ per mL respiratory fluid)
      - Data for SARS-CoV-2 vary by 4 – 5 orders of magnitude depending on patient, swab location, and stage of illness
    - **Infectivity** (infection rate per deposited pathogen)
      - Use ID_{50} from other viruses and assume exponential distribution
    - **Deposition fraction** (pathogen deposited in lungs/pathogen inhaled)
    - **Viability/decay**
      - Data exist for SARS-CoV-2

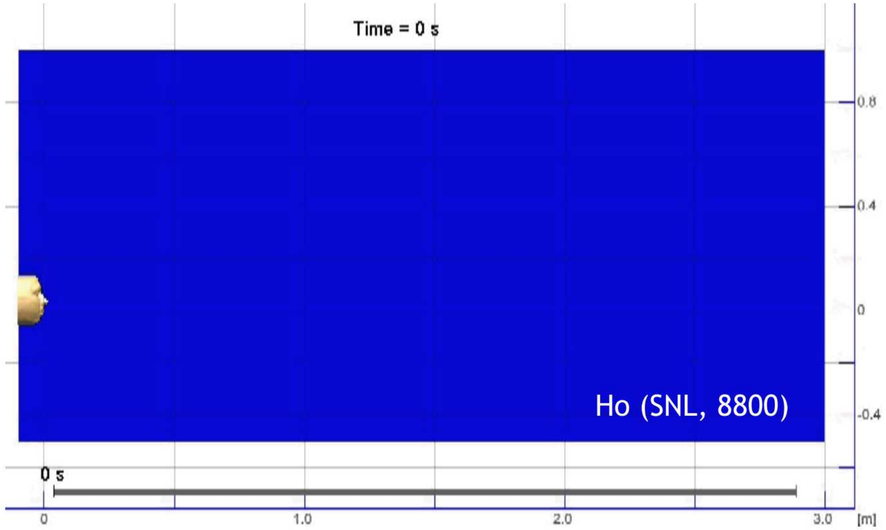




Sandia Near-Field Modeling – Scope (Ho)

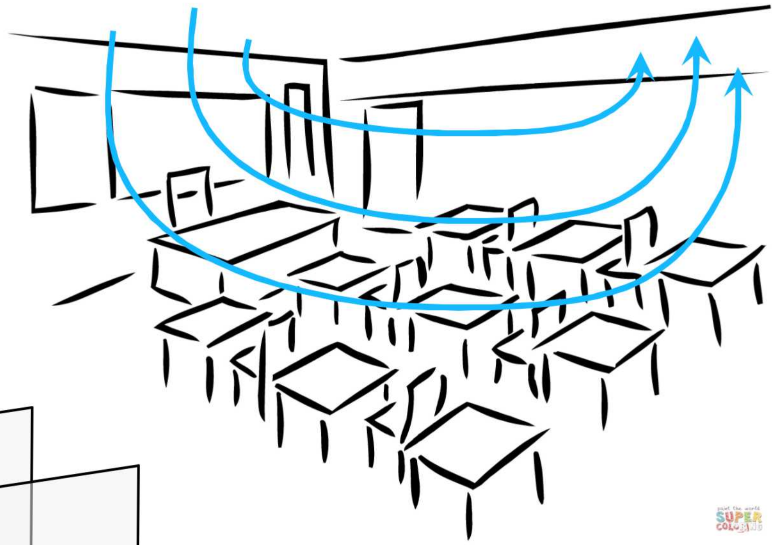
- **Key Physical Dynamics**
  - Simulate spatial/temporal dispersion of droplets and aerosol plume under different scenarios
  - Evaluate different fidelity CFD models to bound results
    - Large Eddy Simulation of droplets (S. Domino)
    - Transient RANS-based turbulent plume models (C. Ho)
    - Others? (ANL, BNL, LANL, LBNL, PNNL)

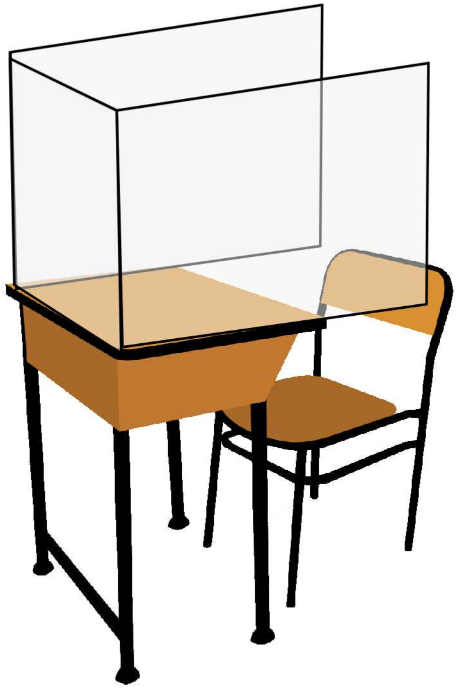




Sandia Near-Field Modeling – Scope (Ho)

- **Key Questions**
  - Can classrooms with prescribed ventilation systems be configured to minimize exposure to teachers that may be more at risk than younger kids?
  - Can exposure to students be minimized by using acrylic barriers on each desk (3 sides)?
    - What are optimal dimensions?





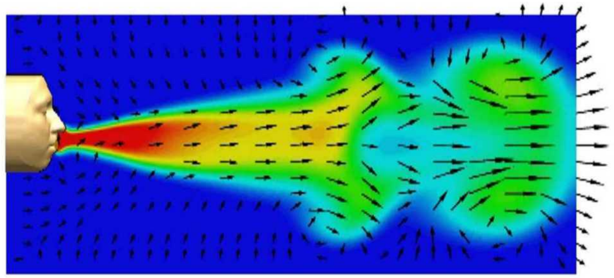
Sandia Near-Field Modeling – Scope (Ho)

- **Milestones**
  - Develop initial CAD models of classroom scenarios and share models/meshes with others (July 31)
    - **Can develop CAD models of scenarios for partners based on collective needs and priorities**
  - Develop mesh and perform grid convergence studies using baseline scenario (Aug 31)
  - Perform CFD simulations of various scenarios (Sep – Oct)
  - **Model tests performed at Sandia's Aerosol Complex** (Oct. 31)
    - "Validation"/confidence building
  - Document results (Nov. 30)

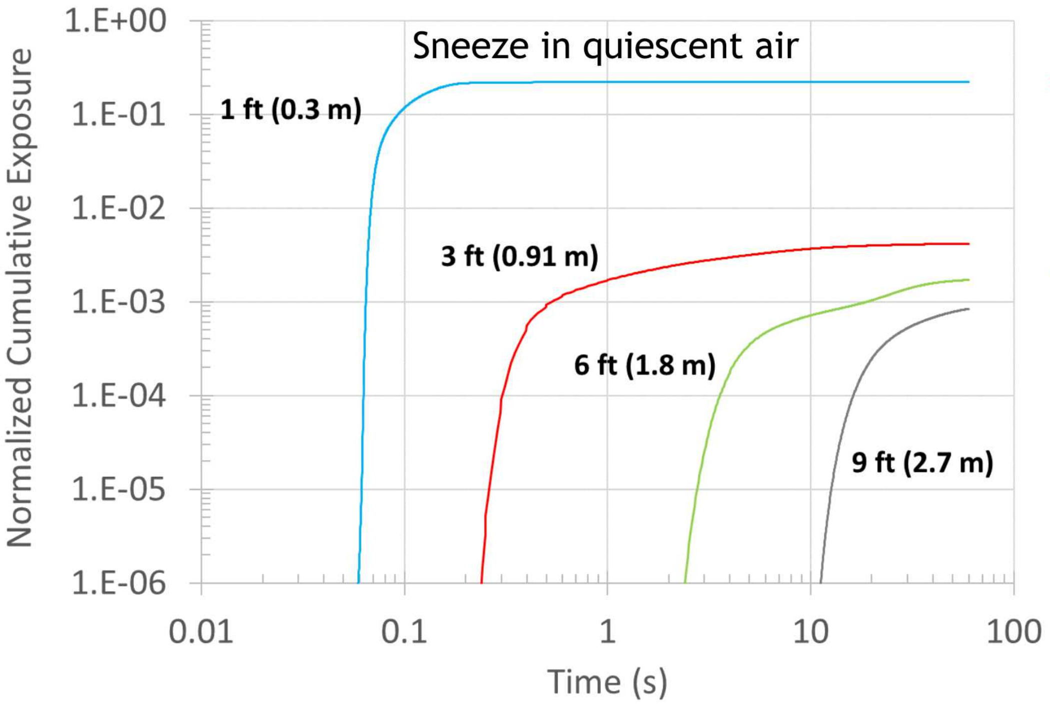
Backup Slides

CFD ⇒ Exposure Assessment ⇒ Infection Risk

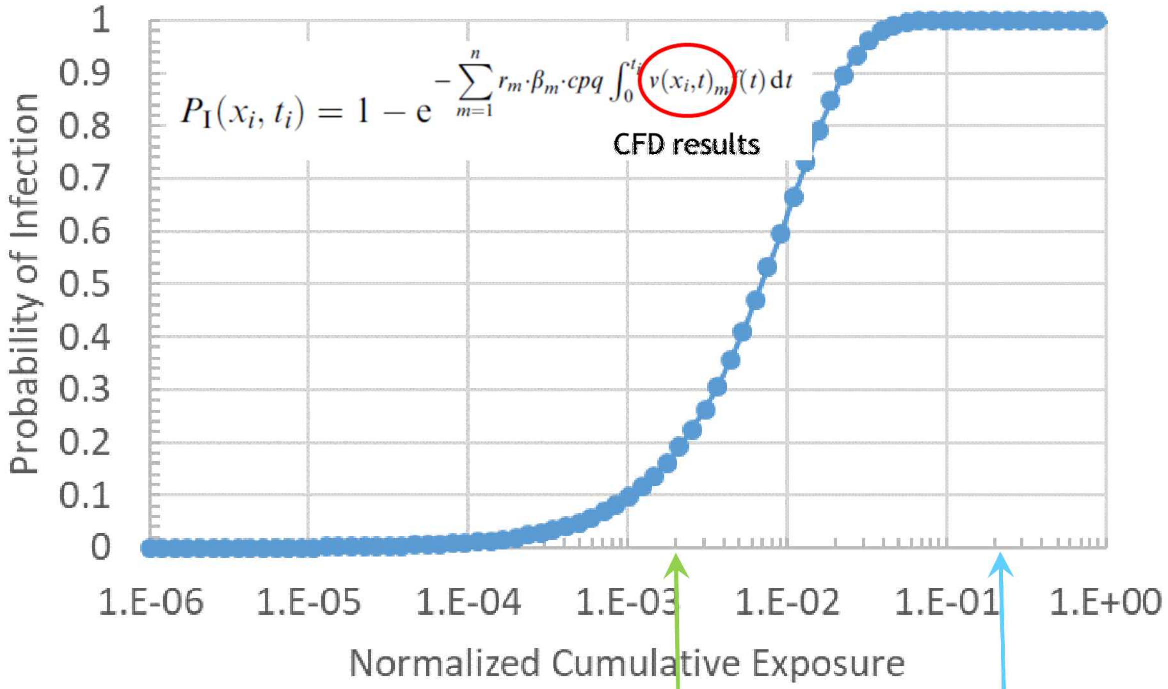
(1) CFD simulations of exhaled vapor concentrations



(2) Cumulative exposure (function of time and space)



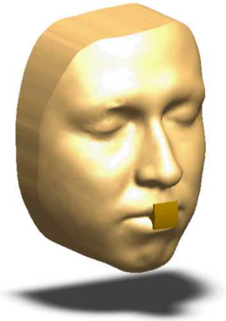
(3) Cumulative probability of infection

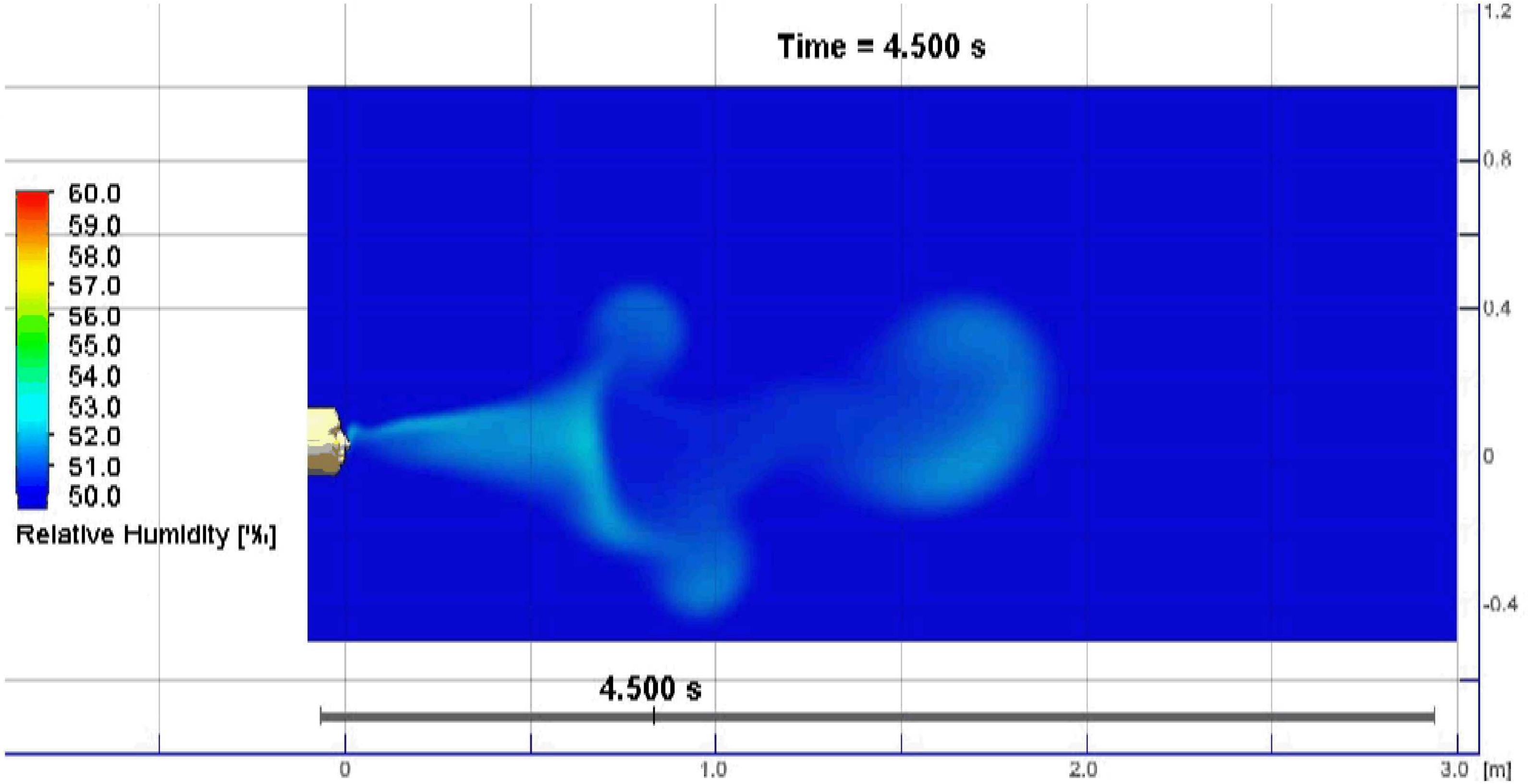


Impact of Face Coverings

Impact of Face Mask

Cough/Sneeze with No Mask

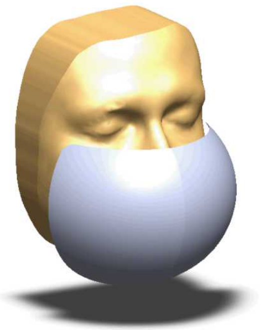


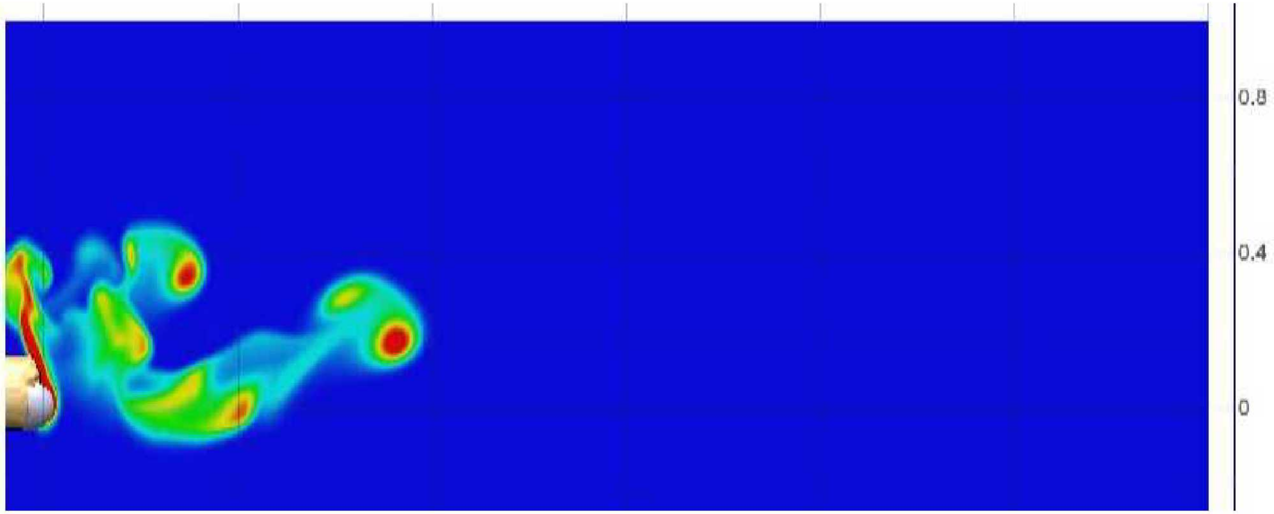


Cough/Sneeze With Mask

Mask material equivalent to MERV* 11 filter (1-inch)

Neglects pathogen filtering effects

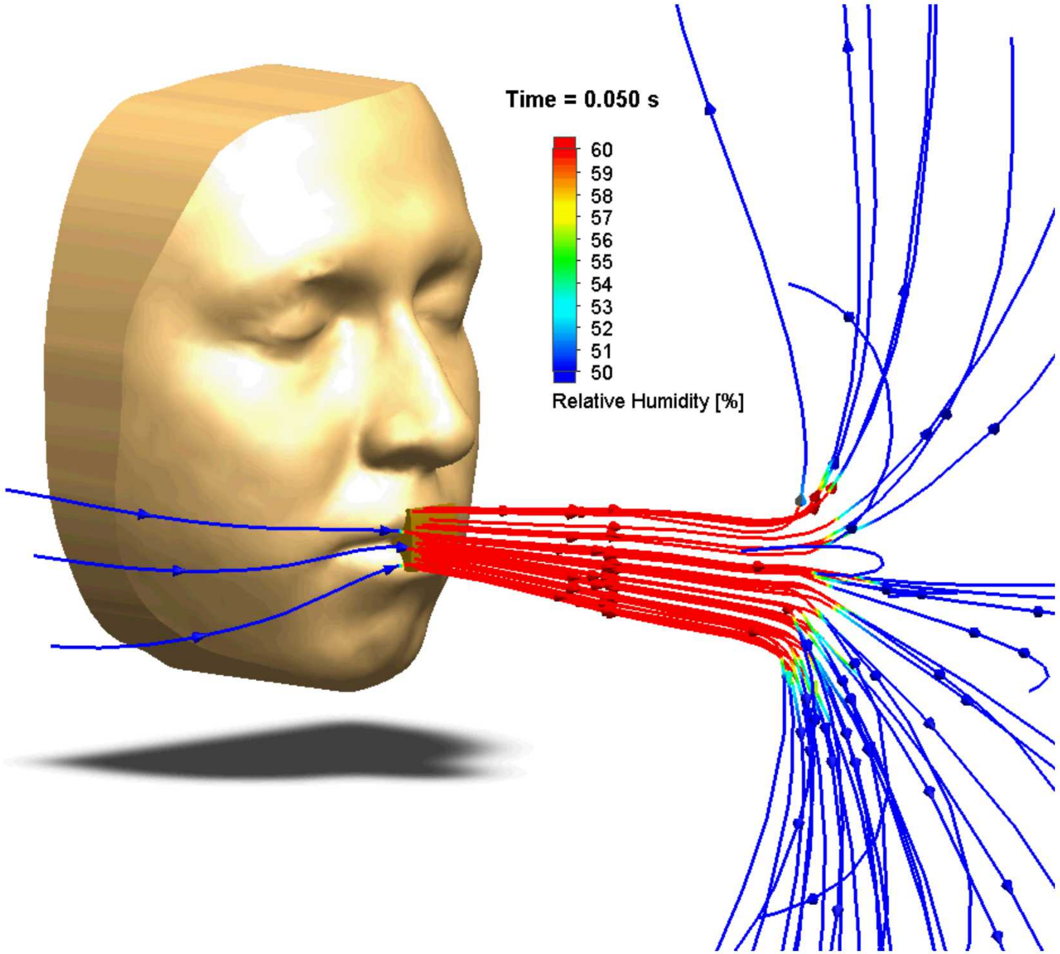




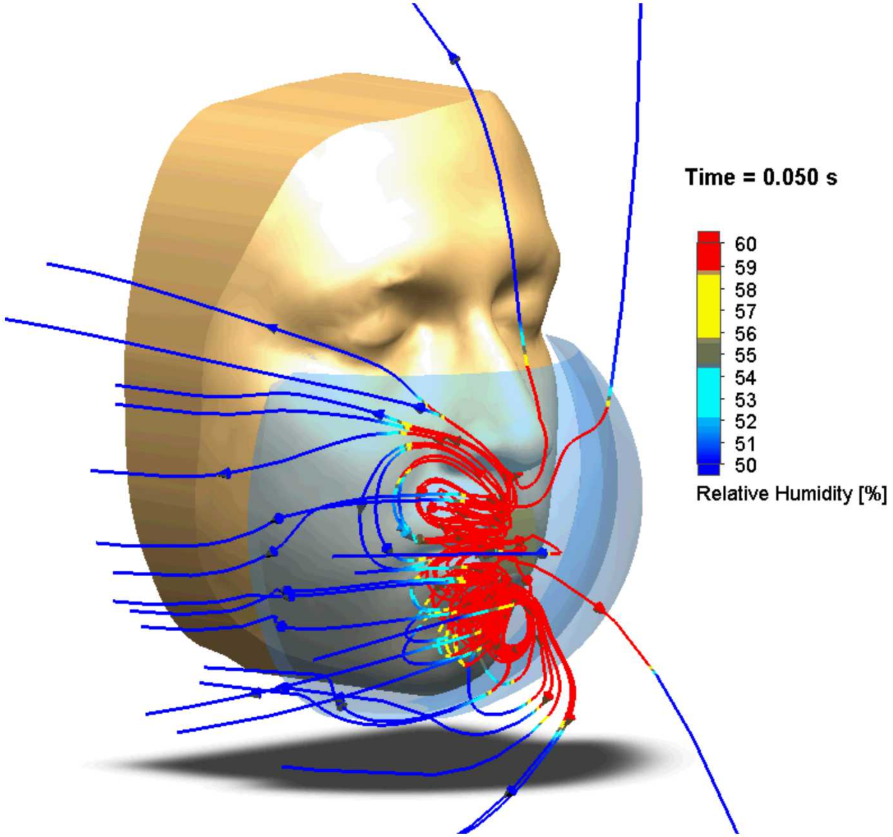
*Minimum Efficiency Reporting Value

Impact of Face Mask – Flow Trajectories

Flow trajectories without mask at 0.05 s

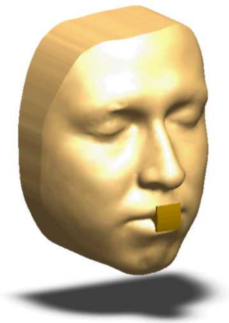


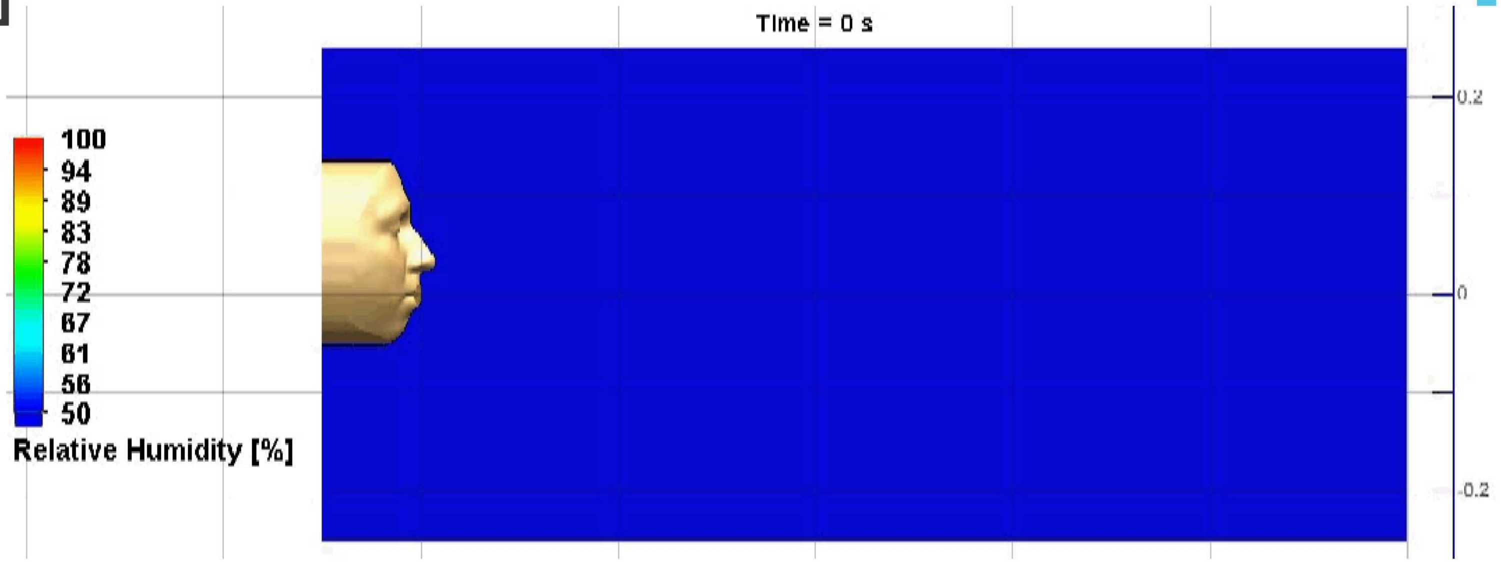
Flow trajectories with mask at 0.05 s



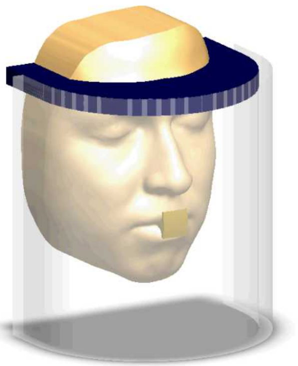
Impact of Face Shield

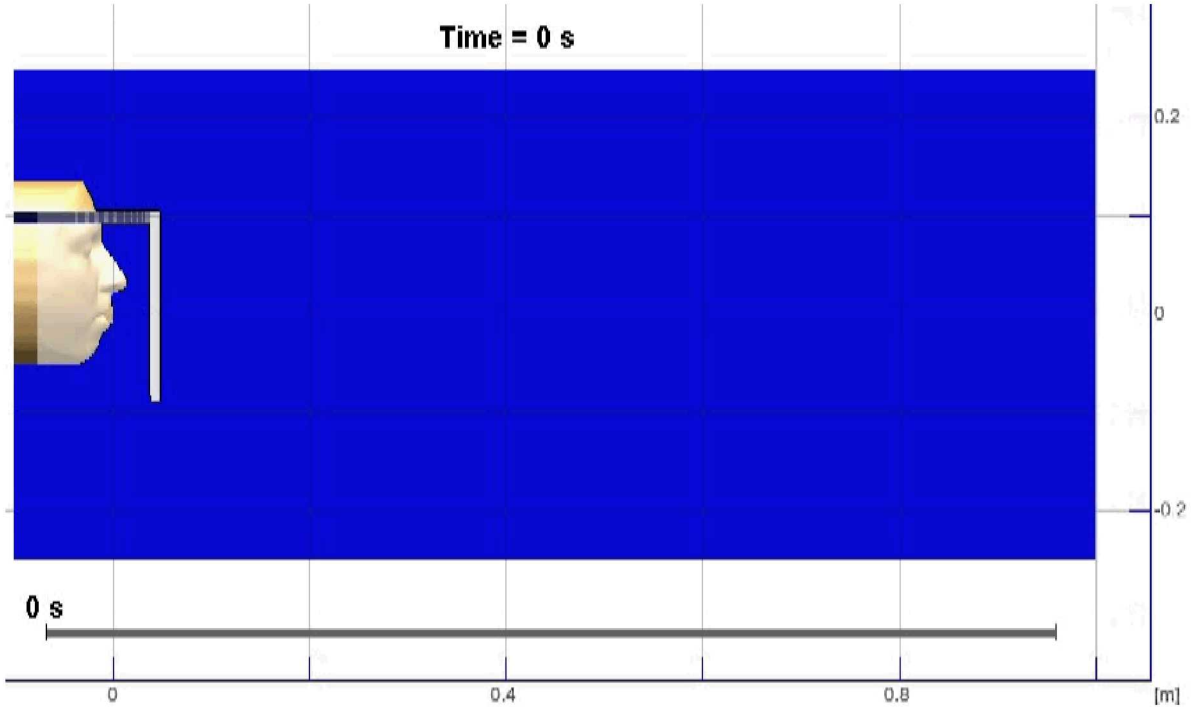
Cough/Sneeze with No Mask





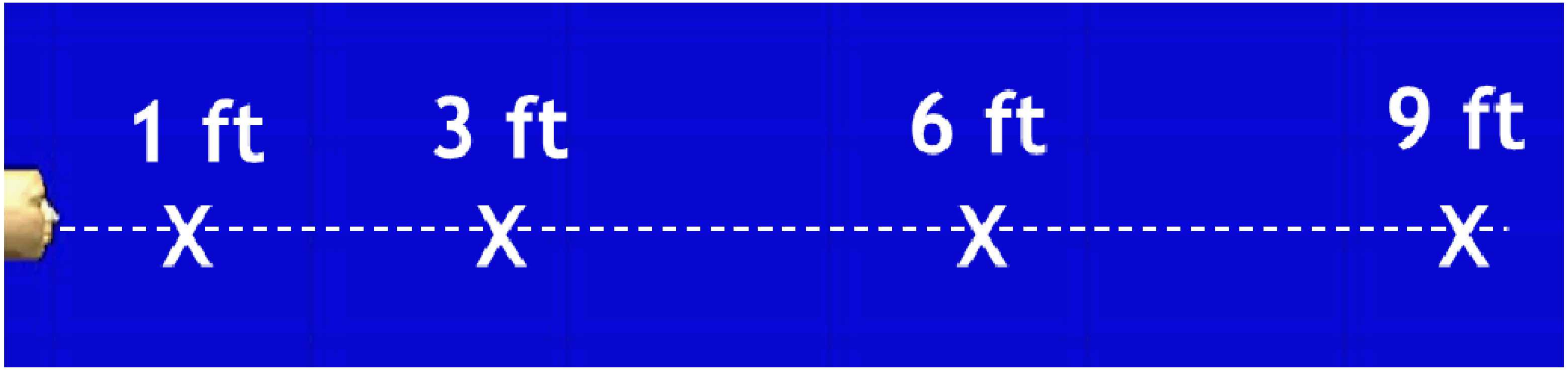
Cough/Sneeze With Face Shield





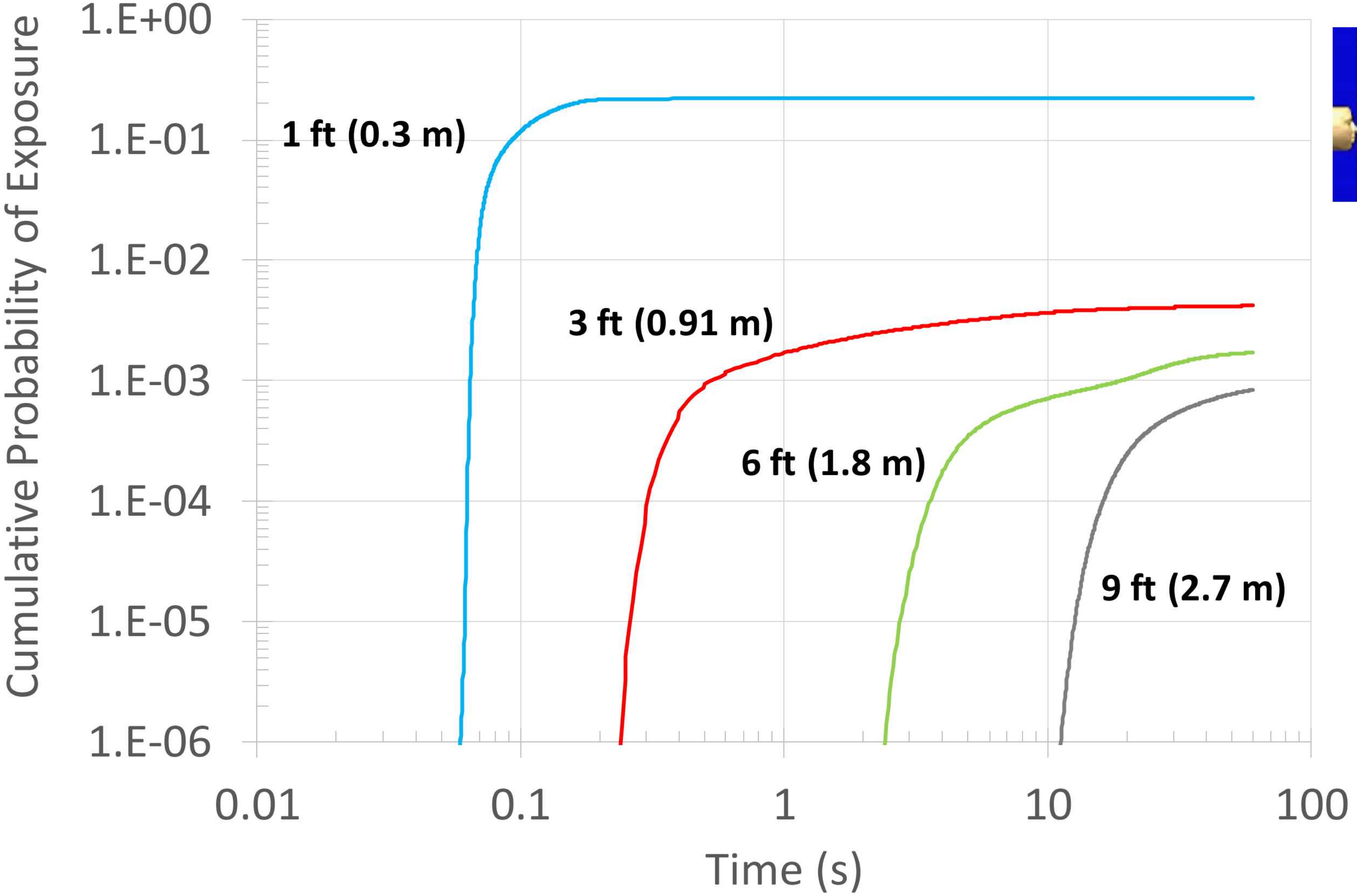
Impact of Airflow on Exposure Risk and Transmission

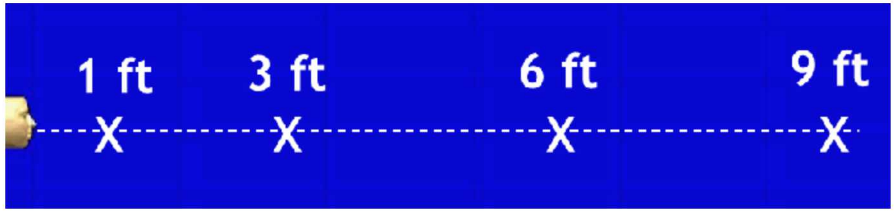
Comparison of Exposure Probabilities for a Cough/Sneeze

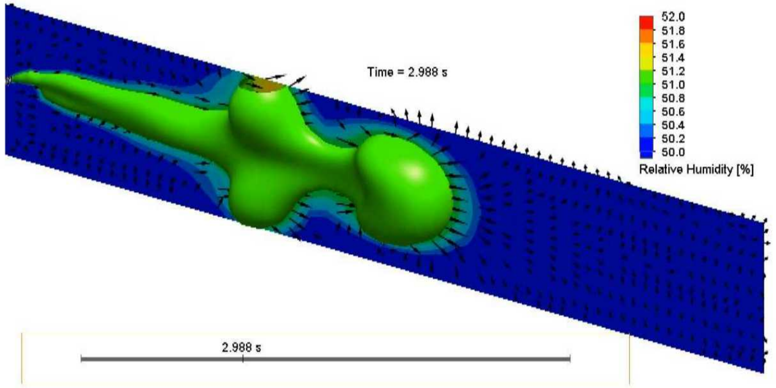


Comparison of Exposure Probabilities for a Cough/Sneeze

Quiescent

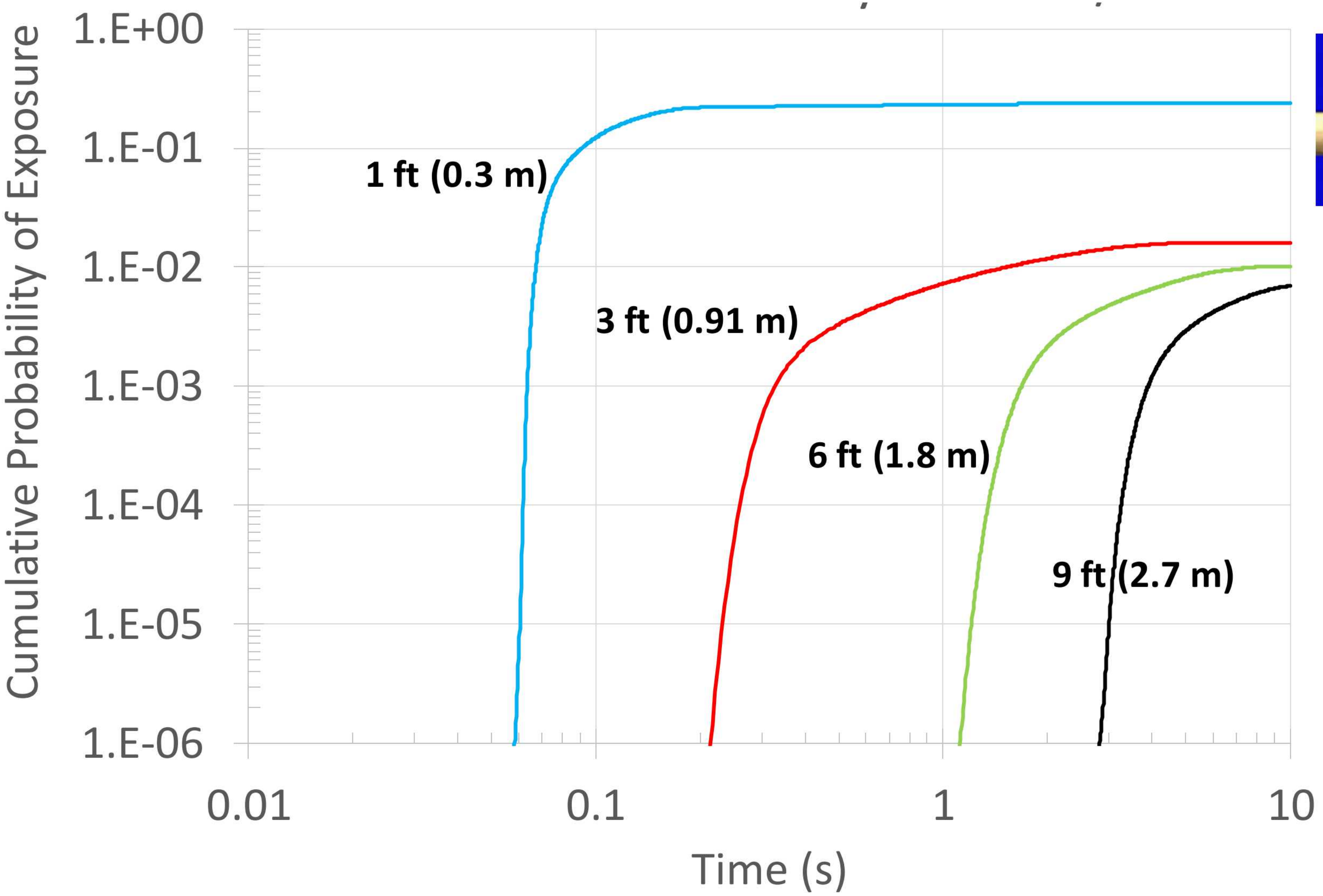


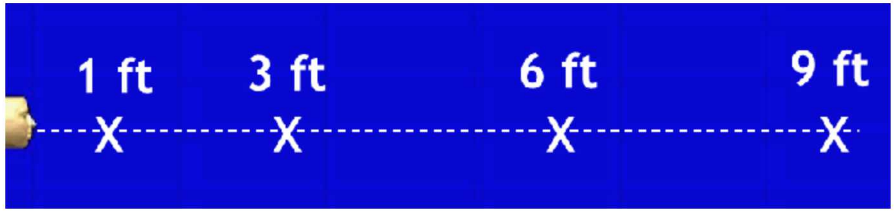




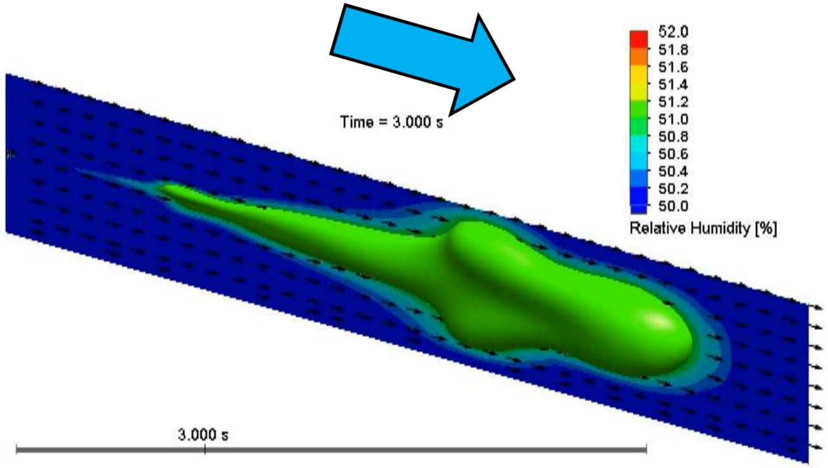
Comparison of Exposure Probabilities for a Cough/Sneeze

Downwind





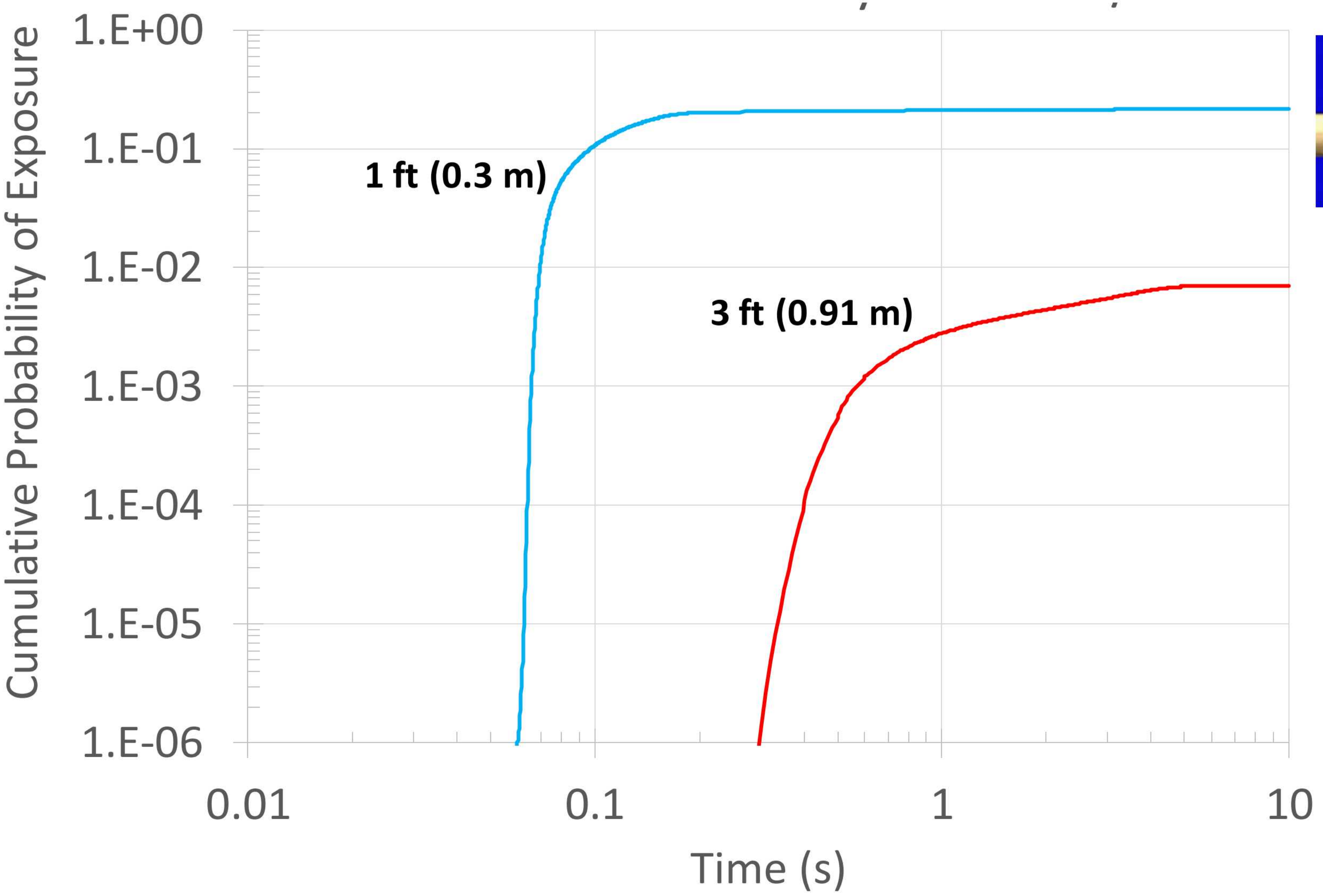
0.25 m/s* downwind

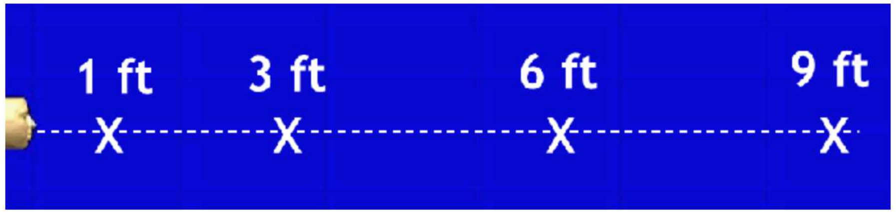


*0.25 m/s is maximum indoor air velocity for thermal comfort (ASHRAE)

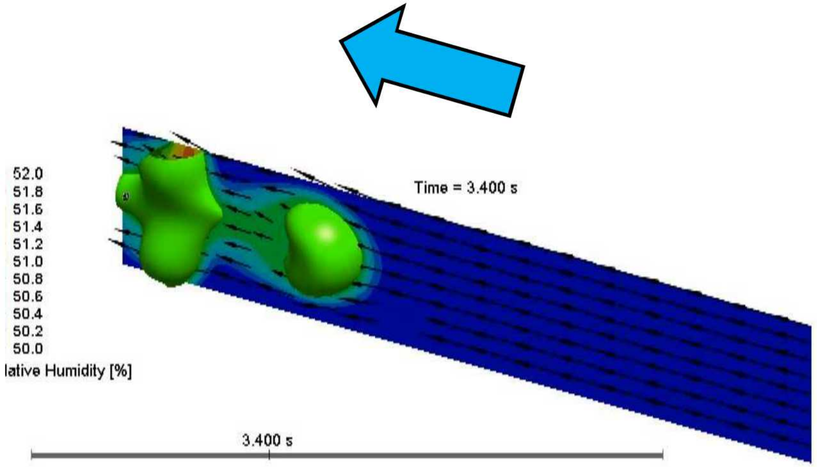
Comparison of Exposure Probabilities for a Cough/Sneeze

Upwind





0.25 m/s* upwind



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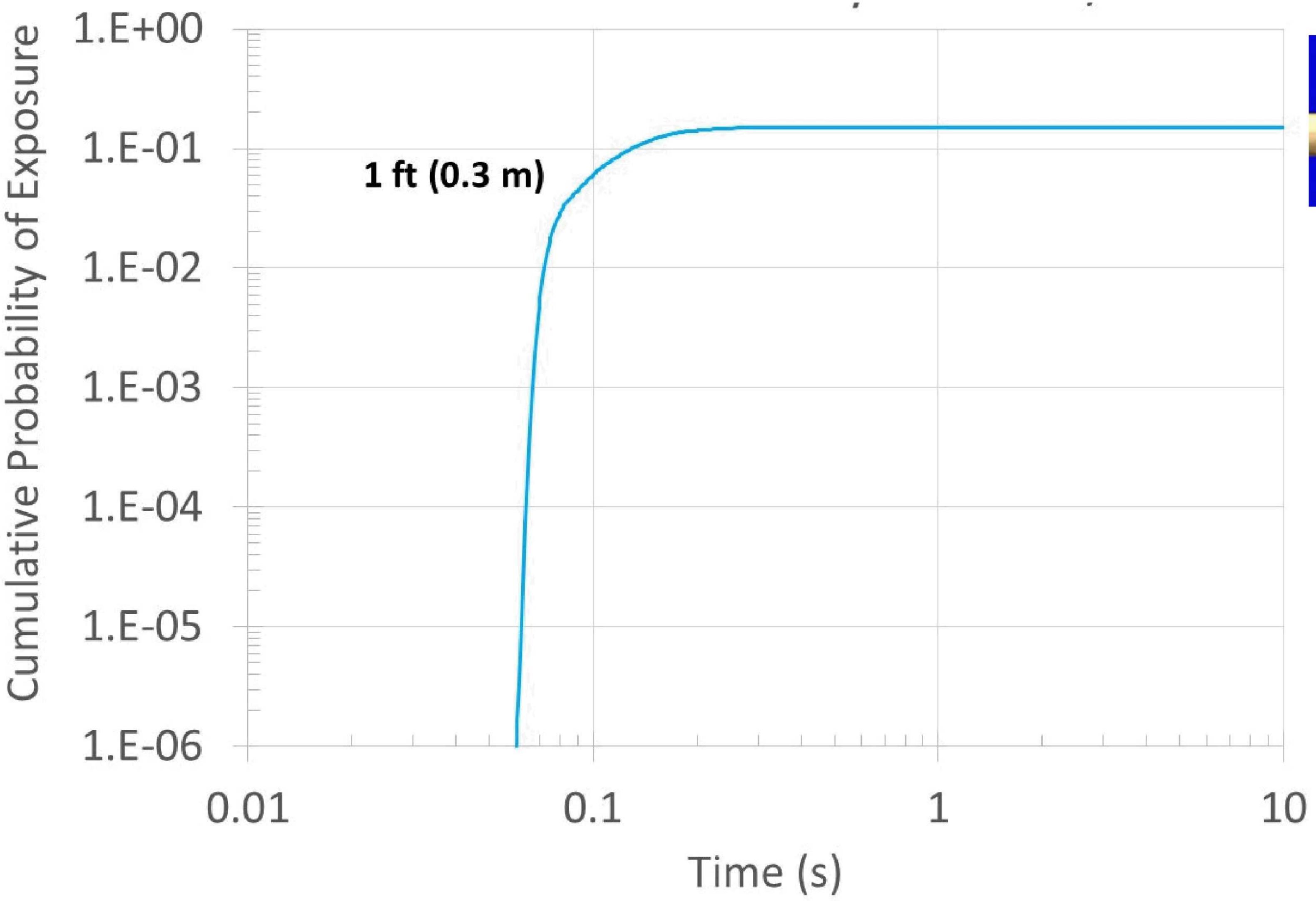
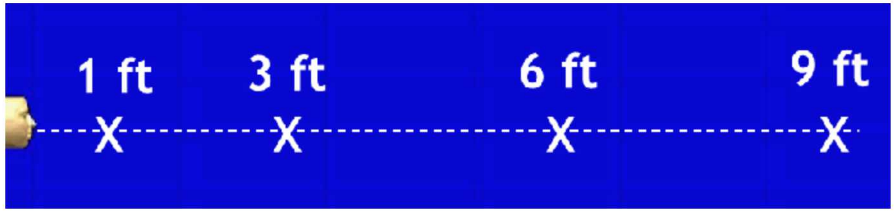
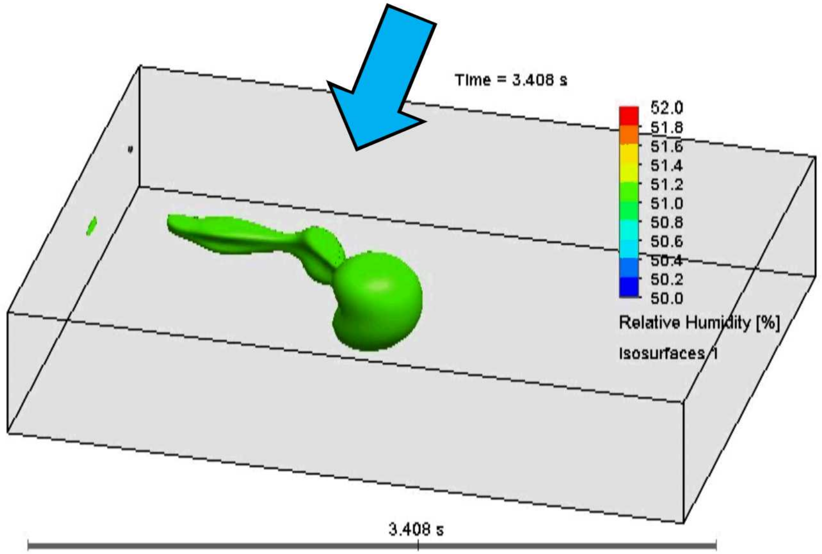
Comparison of Exposure Probabilities for a Cough/Sneeze

Crosswind





0.25 m/s* crosswind



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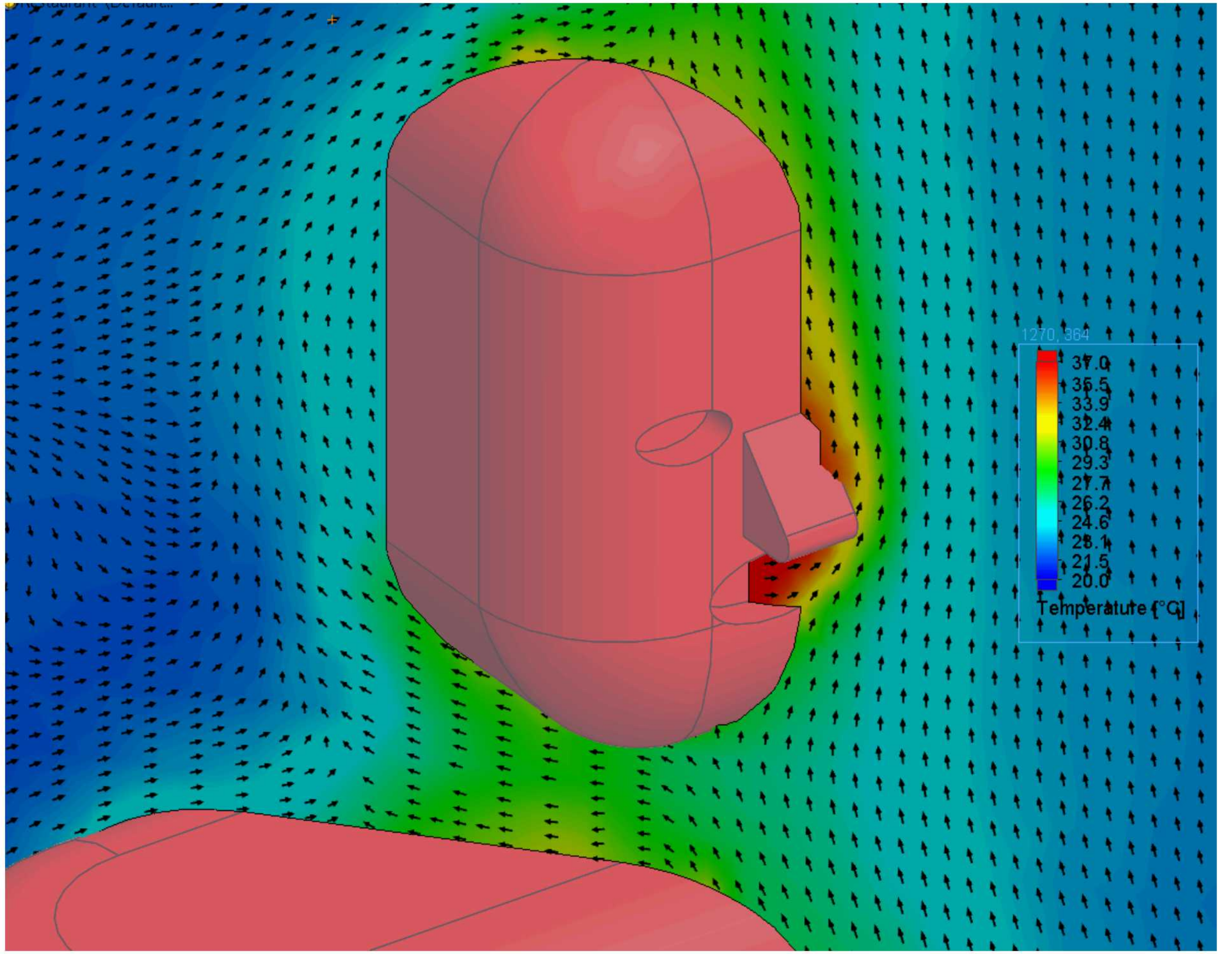
COVID-19 Outbreak in Restaurant in Guangzhou, China

Exhaling and Inhaling

Source Exhalation



Receptor Inhalation