Dispersion of Radioactive Aerosols in Nuclear Facilities: From Worker Protection to Homeland Security

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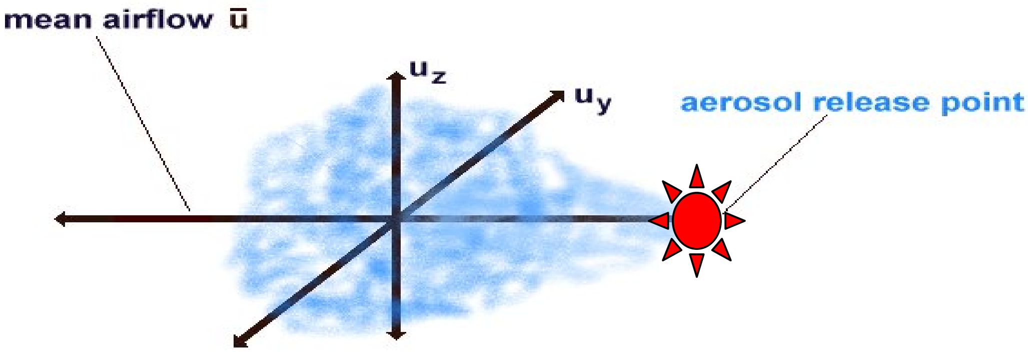
Presentation main points:

- General background on airflow and aerosol dispersion
- Knowledge of ventilation-driven airflow patterns in a room is critical for effective worker protection
- Despite challenges, significant improvements in protection can be made- *New Developments*
- The scale of worker protection has increased to public safety and homeland defense

Topic 1

General Background on airflow and aerosol dispersion

Gas and aerosol dispersion dynamics

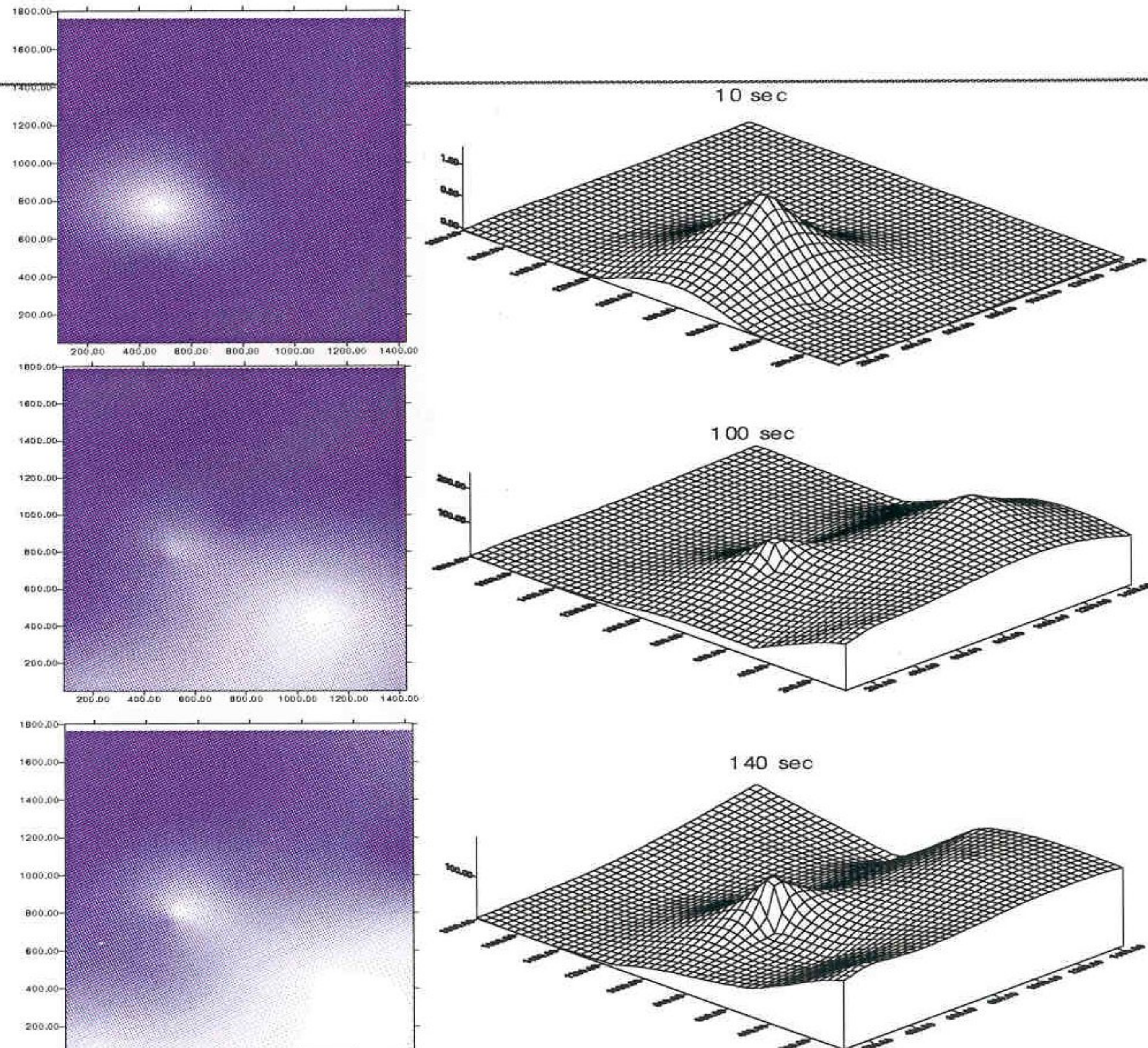


Transport Mechanisms*

1) Molecular Diffusion (0.0008 cm/s)
2) Gravitational Settling (0.003 cm/s)
3) Room Airflow (> 1 cm/s)
4) Turbulent Diffusion (> 0.2 cm/s)

*Rates based on 1 μm diameter particles at STP

Particle cloud transport



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100 sec

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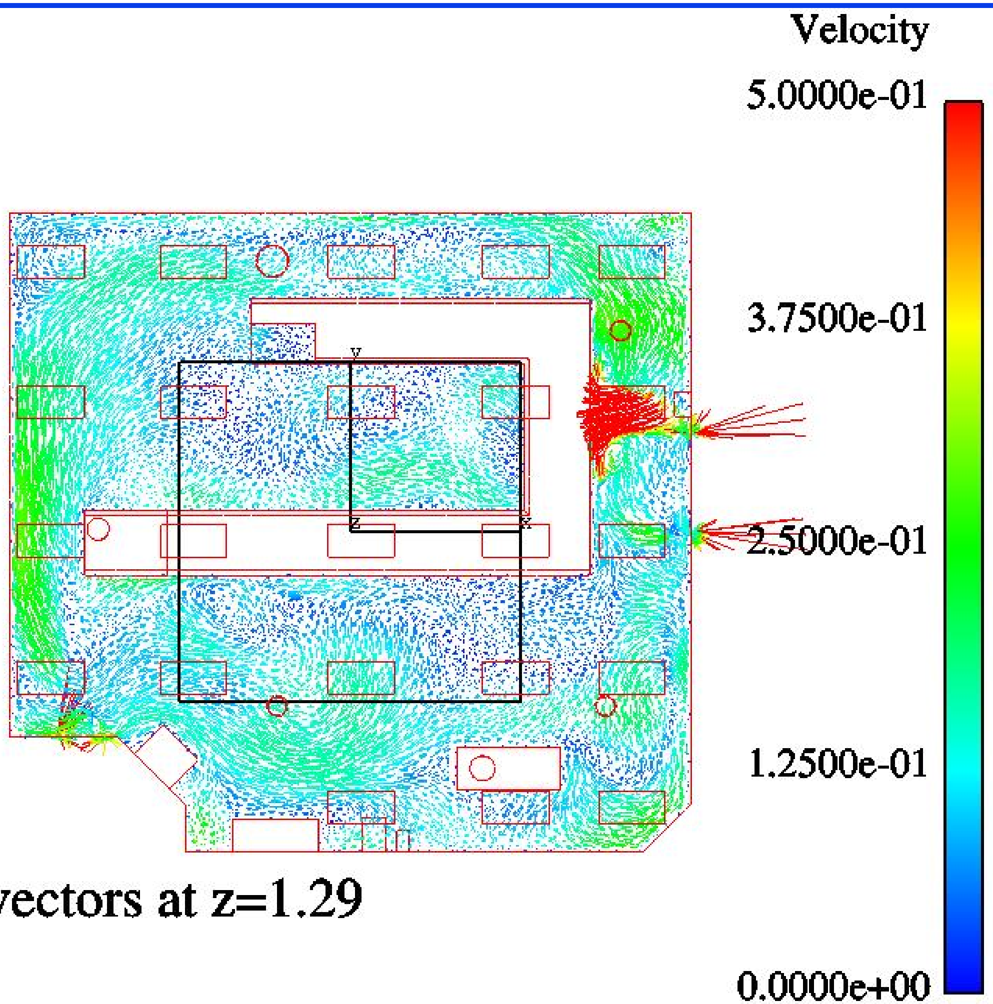
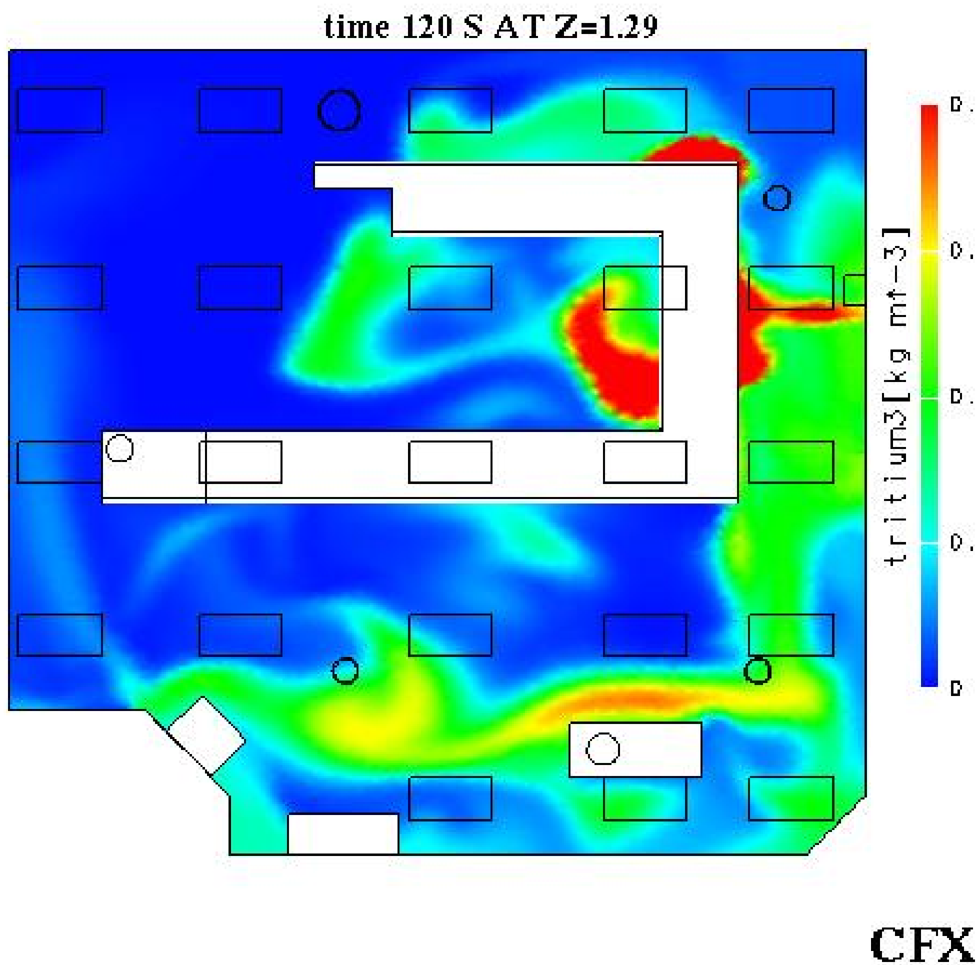
Airflow and aerosol dispersion indoors is highly complex and poorly understood

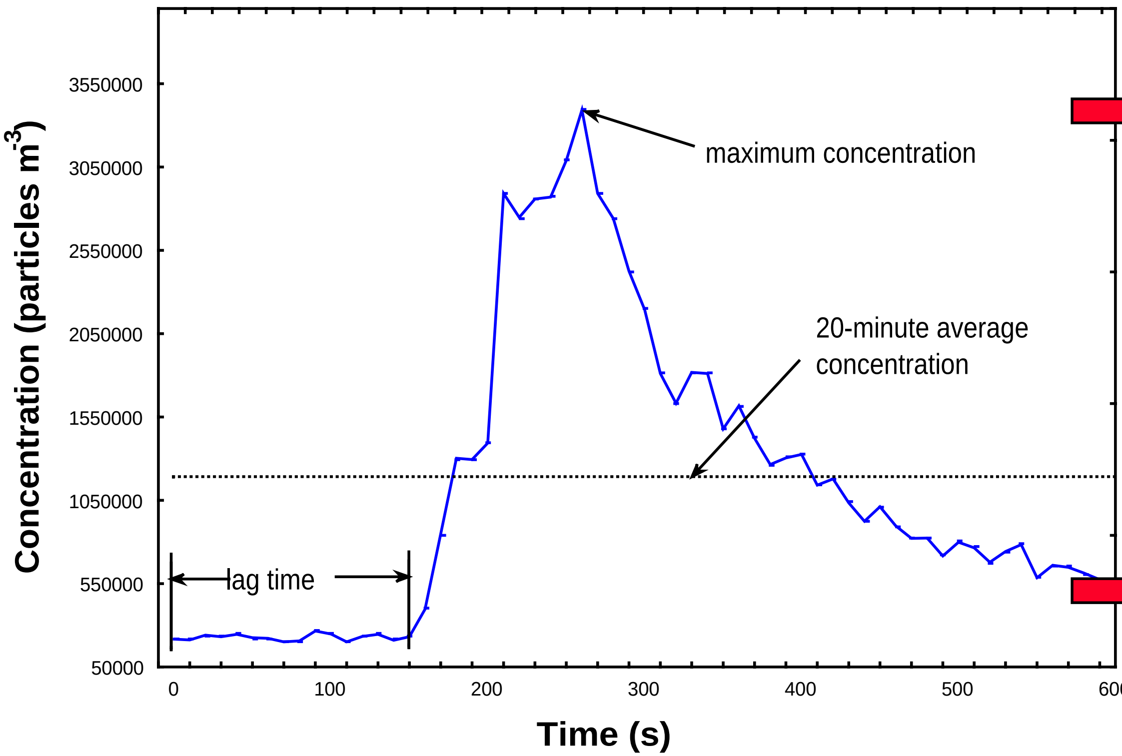


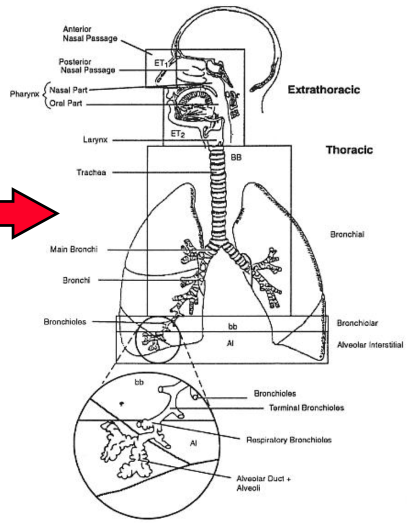
velocity vectors at z=1.29

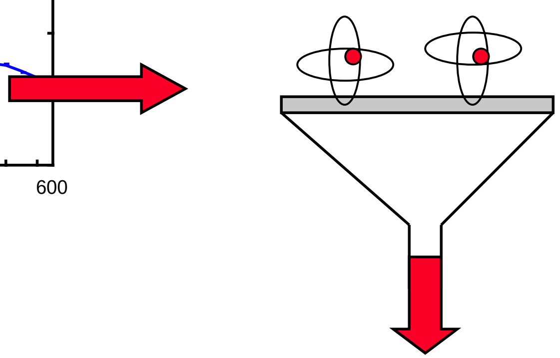
Complex airflow pattern= Complex aerosol dispersion patterns



Complex airflow patterns determine the temporal and spatial aspects of aerosol/gas dispersion the room. The patterns of this dispersion drive instrument response and internal dose.

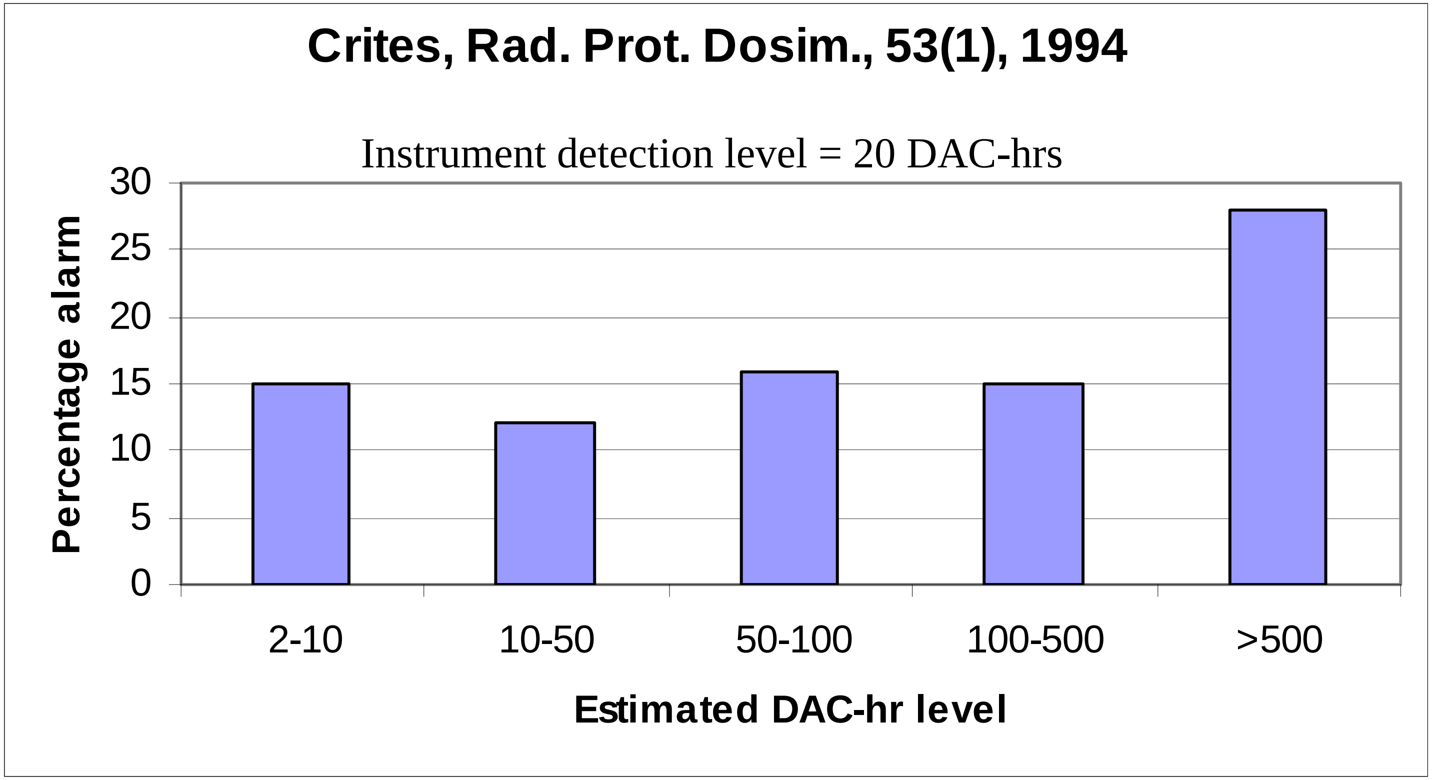




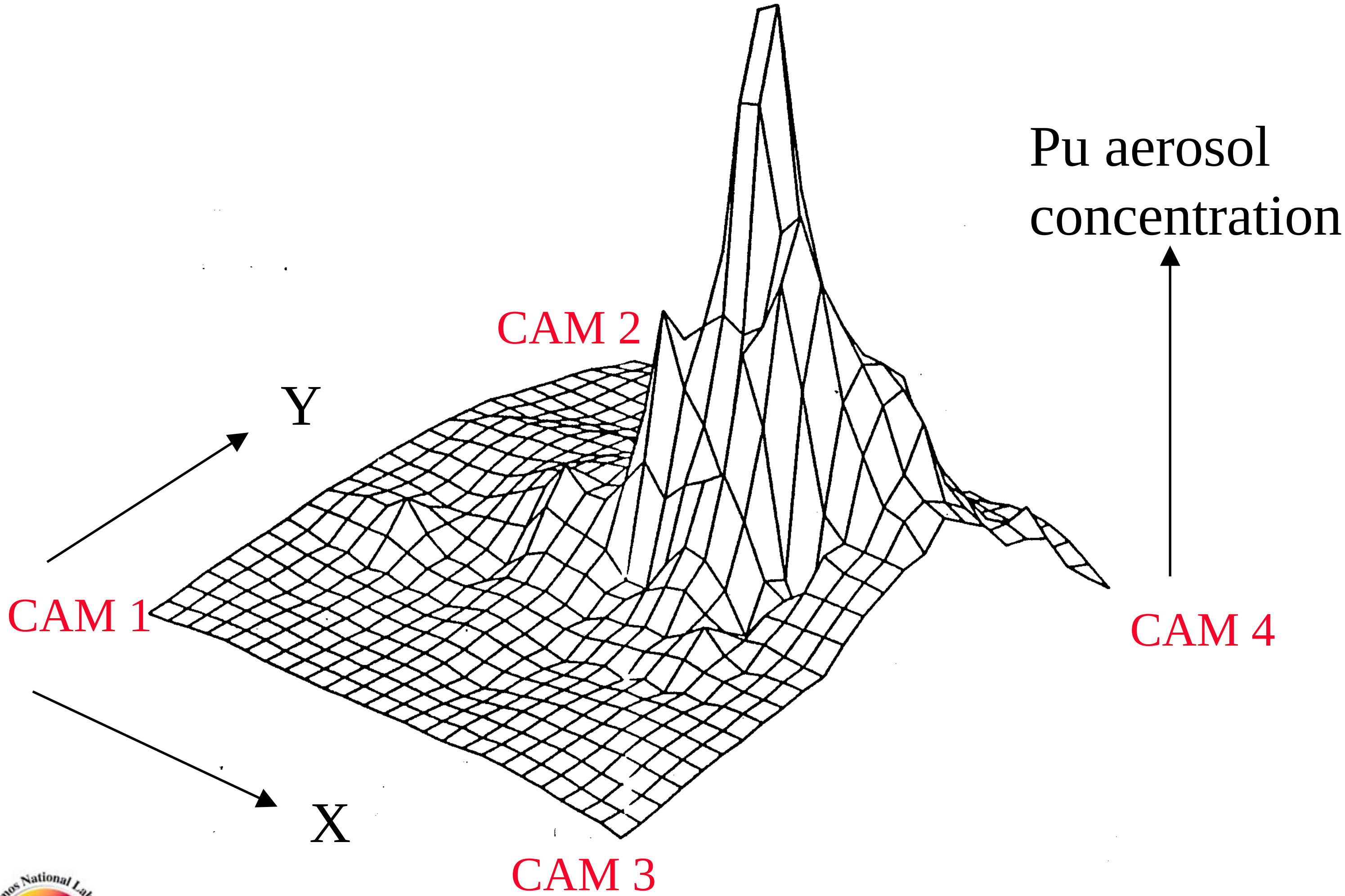


Point 2: Knowledge of indoor ventilation-driven airflow patterns are important for worker protection

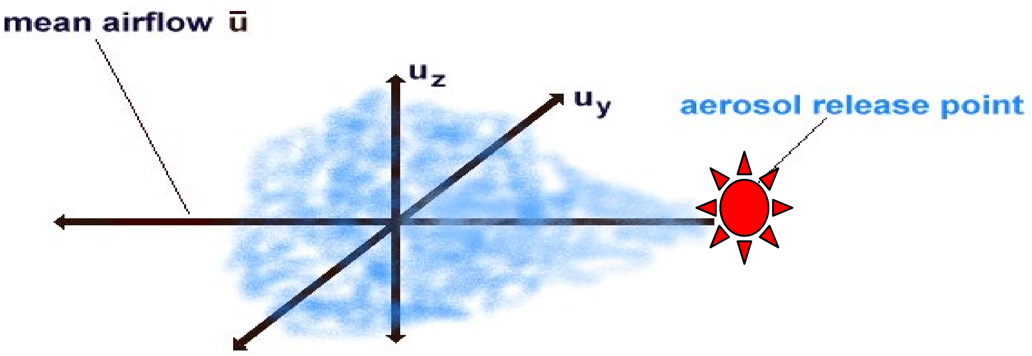
High concentrations of plutonium aerosol can exist in a room without a monitor alarm



Significant dilution can occur



Gas and aerosol dispersion dynamics are driven primarily by room ventilation



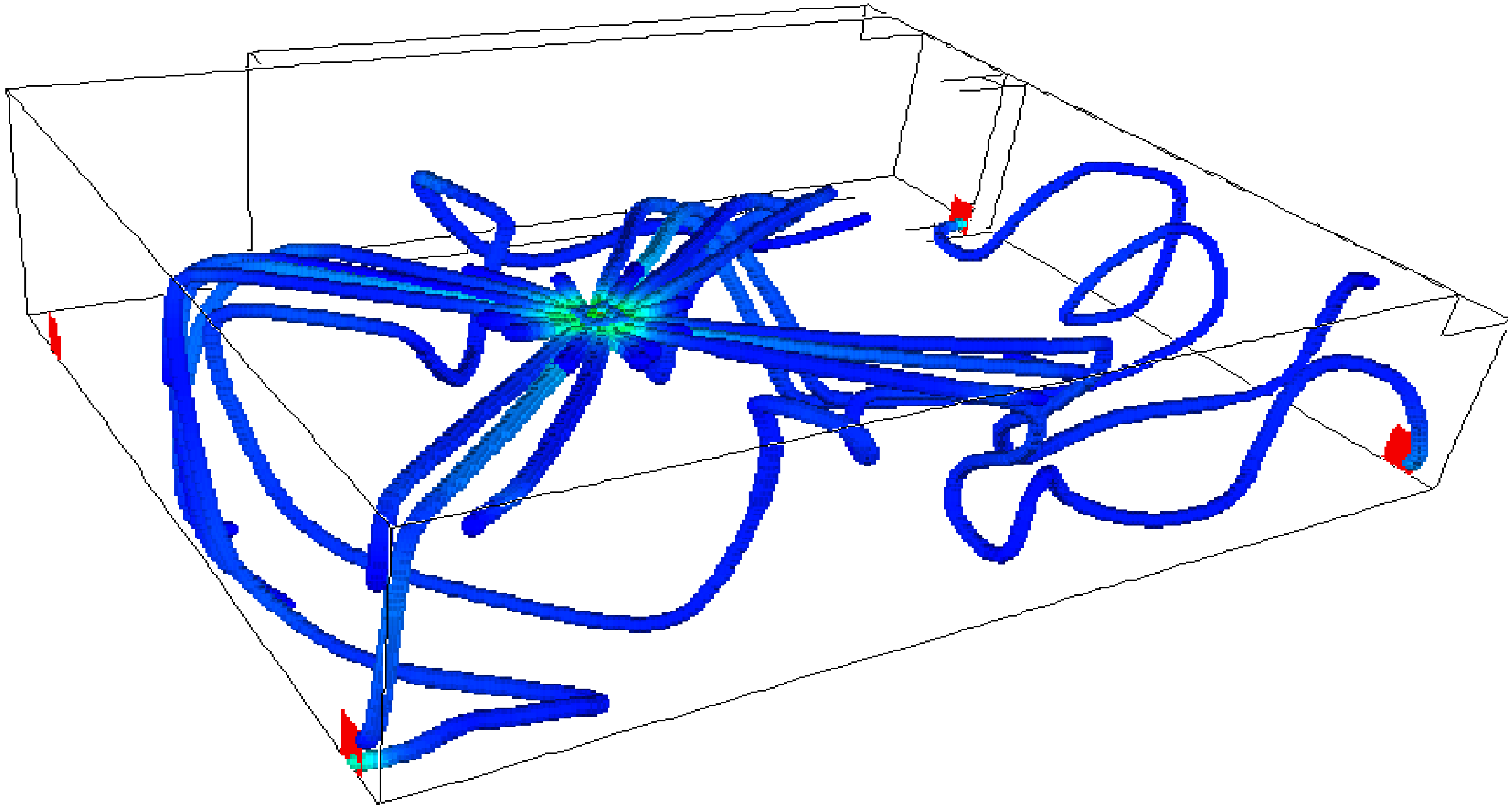
Not a simple problem: Common sense can be wrong

- Original assumptions for ventilation design
  - rapidly clear room air to protect workers
  - ceiling supply and floor-level exhausts would enhance worker protection
- Original assumptions for CAM placement
  - Any released Pu aerosol has to go through one or more room exhausts, so these are good places to put CAMs

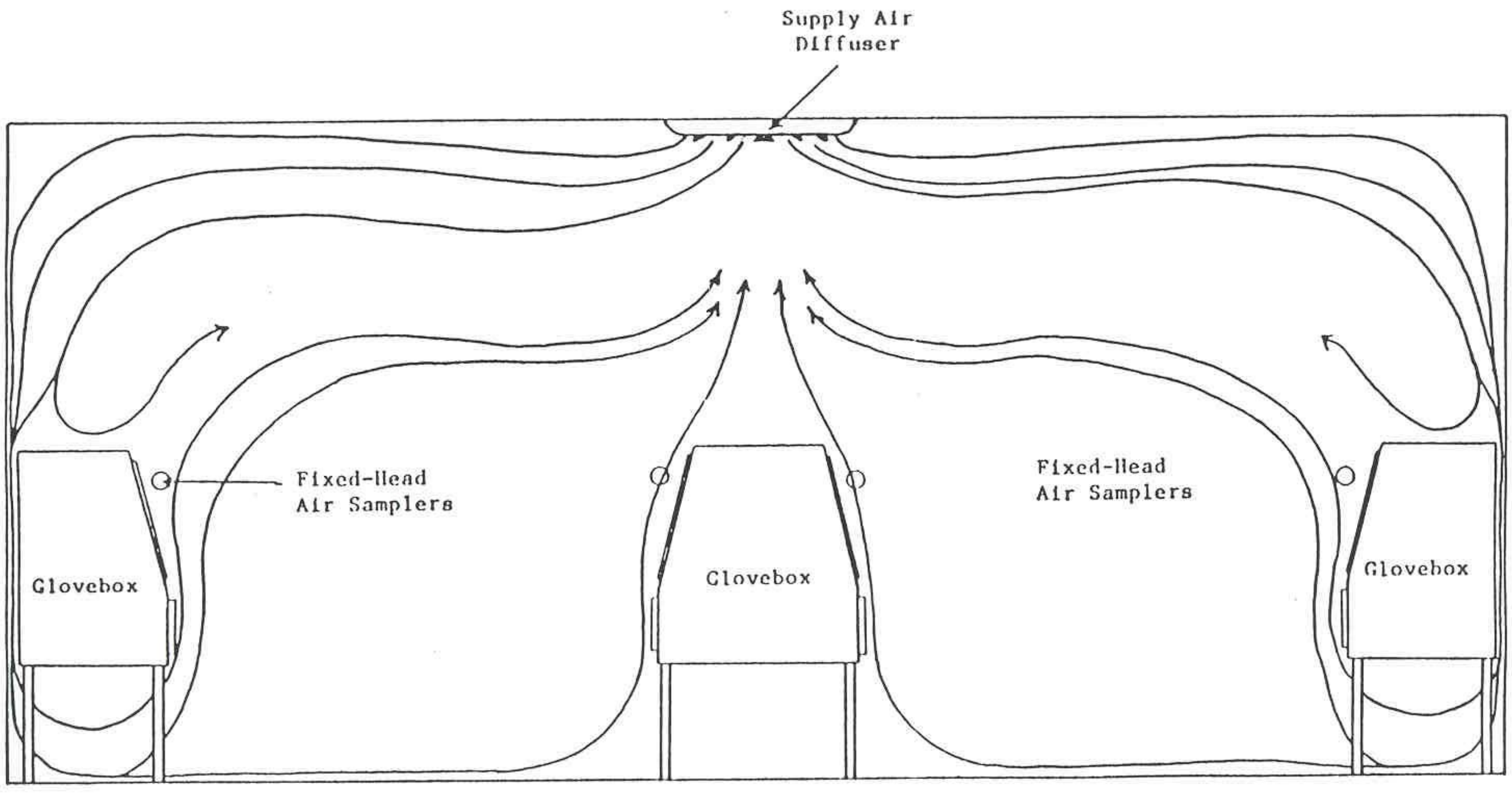
"The great tragedy in science- the slaying of a beautiful hypothesis by an ugly fact."

Thomas Huxley

Not a straight path from supply to exhaust



Ventilation patterns in Pu facility generally create upward airflow at work locations

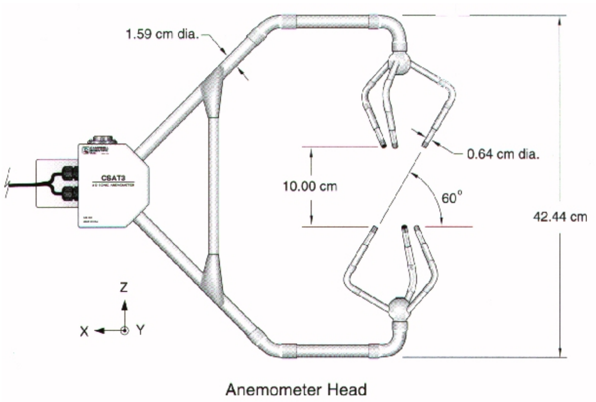


What do we know about airflow characteristics in nuclear facilities?

- Not much
  - Velocities?
  - Directions?
  - Turbulence (intensity, structure)?
  - Role of turbulent diffusion relative to molecular diffusion for particles verses gases?
  - Effects of room furnishings?

Airflow measurements: Sonic anemometer

Principle of operation: acceleration or slowing down sound waves by moving air



f: 1 do 60 Hz
sensitivity: 0.1 cm/s
range: +/-65.5 m/s

$$t_{out} = \frac{d}{c+u_a} \qquad t_{back} = \frac{d}{c-u_a}$$

$$\Longrightarrow \quad u_a = \frac{d}{2}\left(\frac{1}{t_{out}} - \frac{1}{t_{back}}\right)$$

$$\begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} = A \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

u_a- air velocity component in sonic coordinates

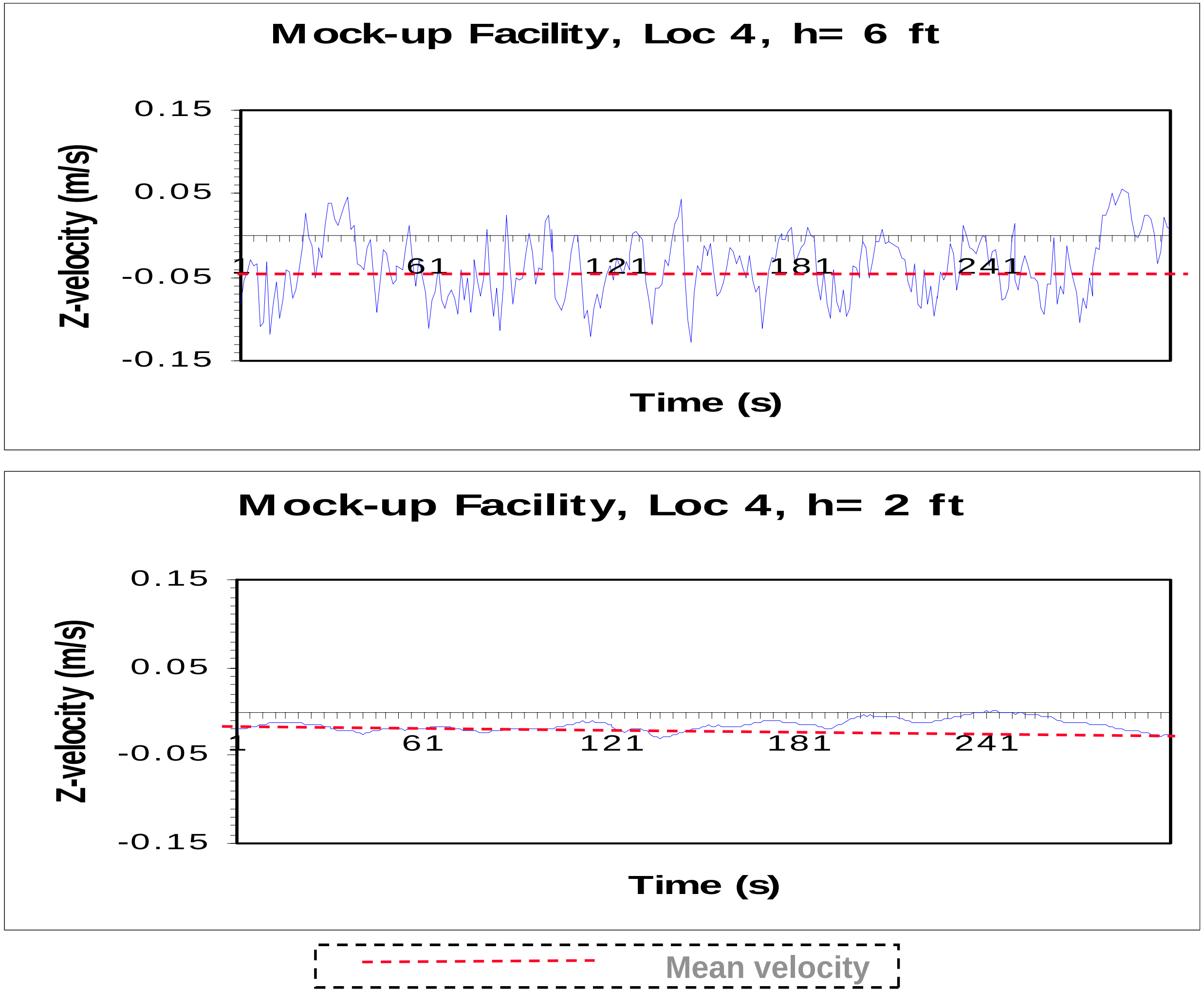
d-sensing distance (10cm)

c- speed of sound

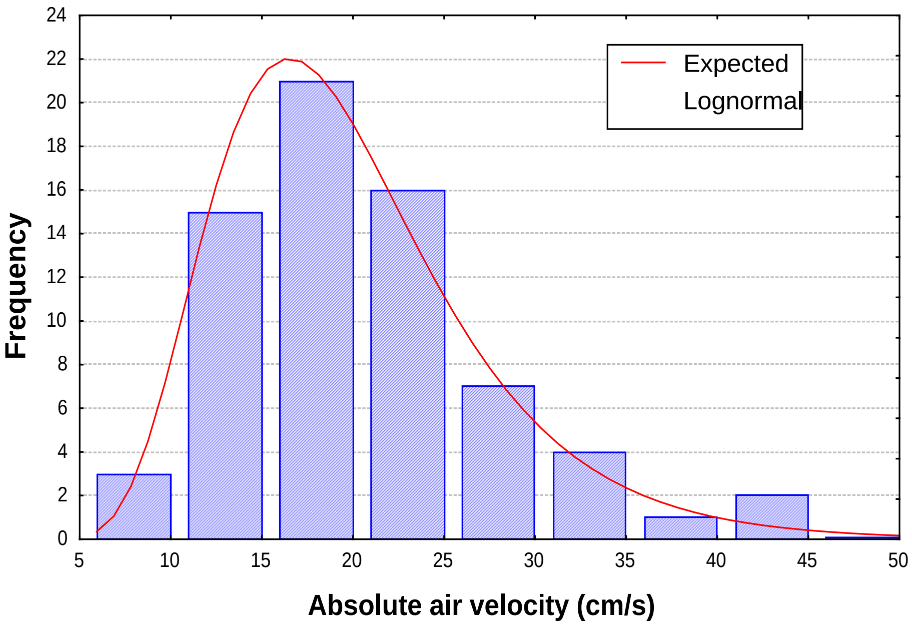
t_{out}, t_{back}- time of flight

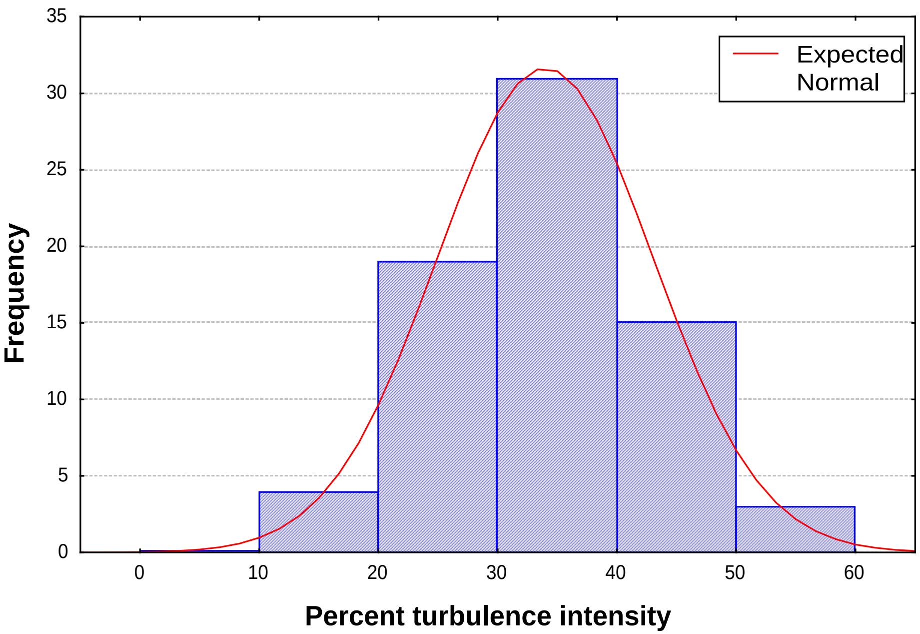
A - rotational matrix

Examples of changes in air velocity

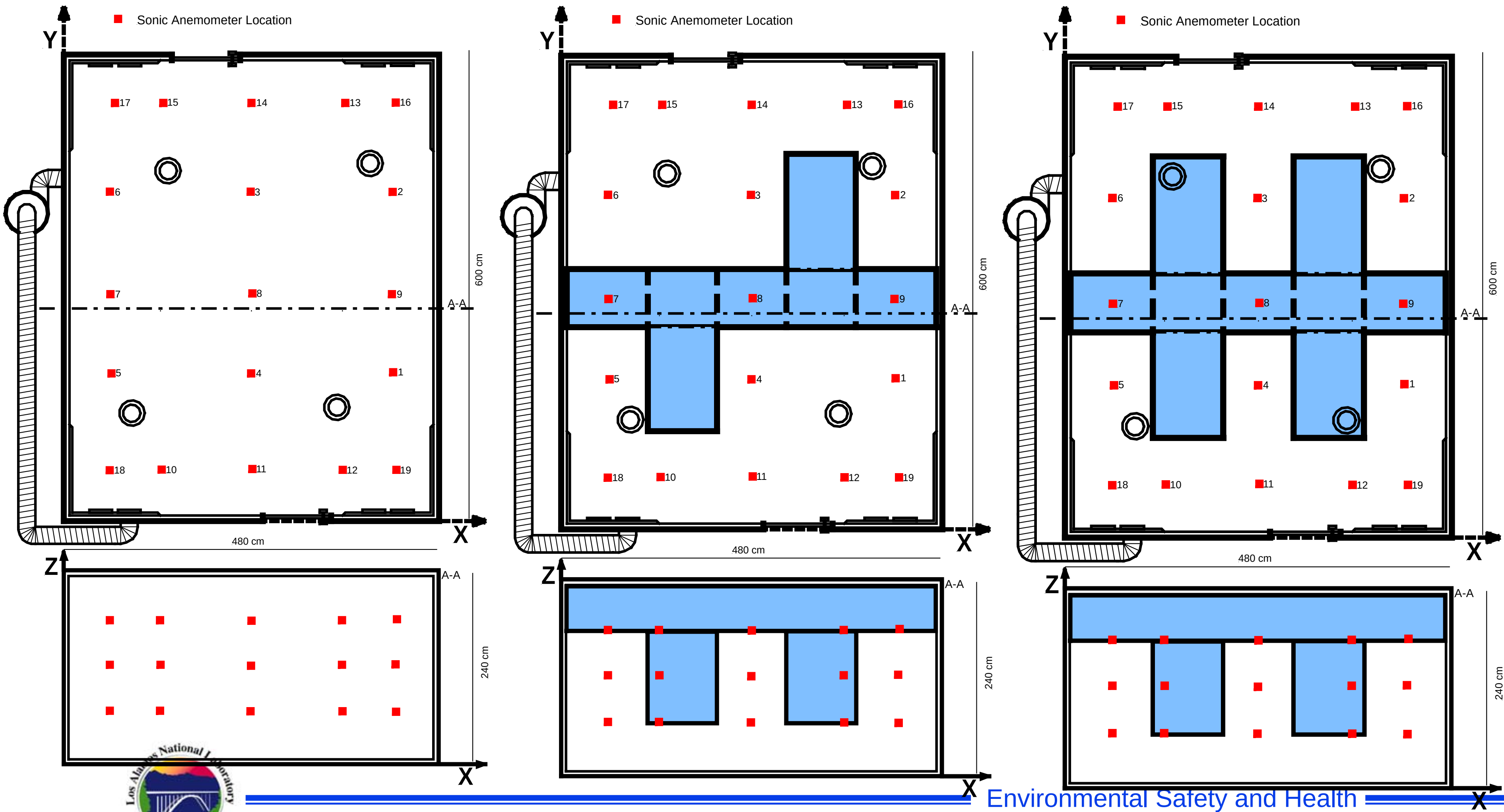


Room air velocities and turbulence intensities

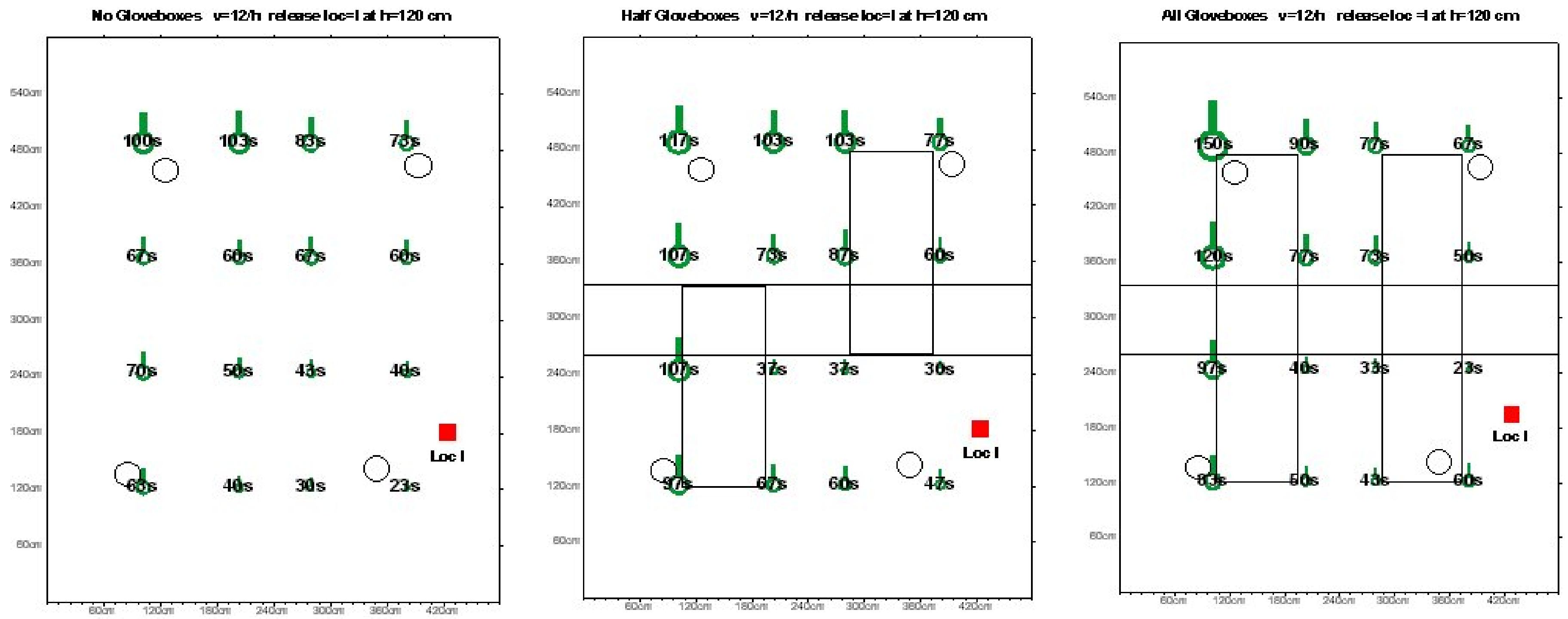




Variations in test room geometry- from empty to full glovebox configuration

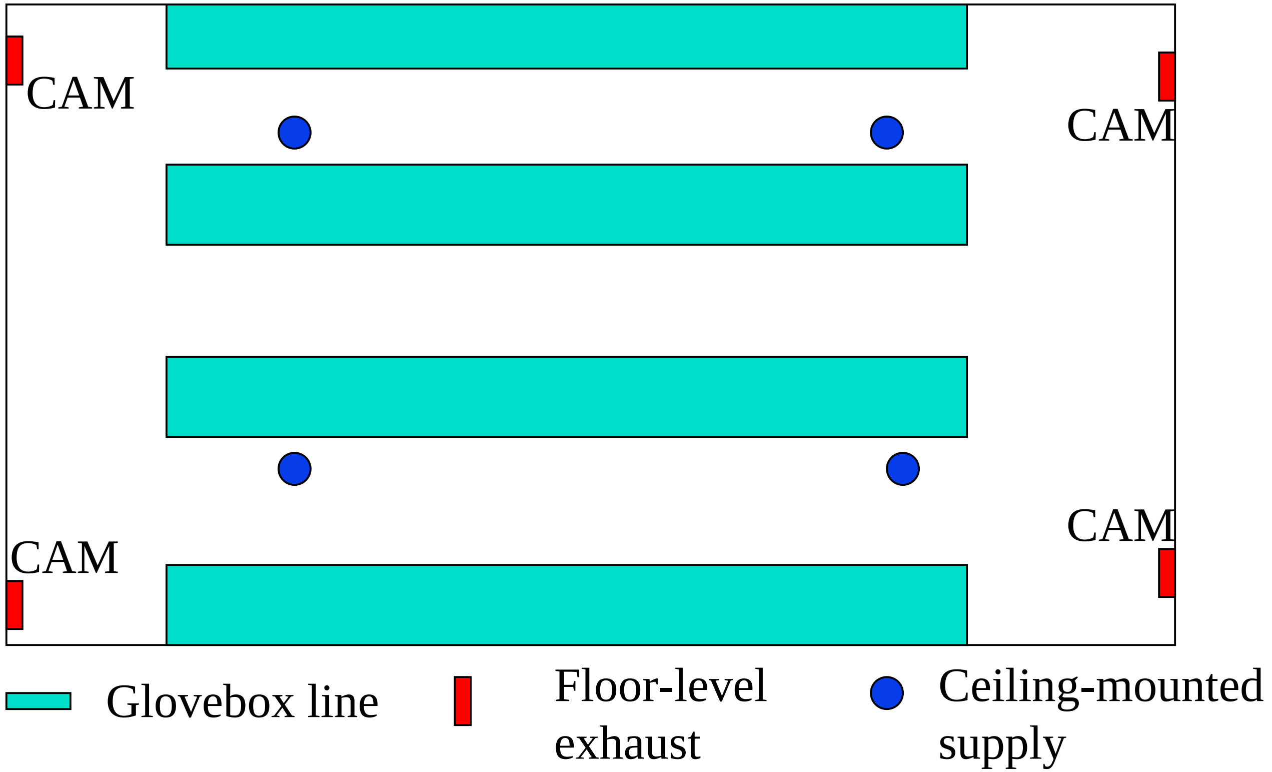


Influence of room geometry on lag time

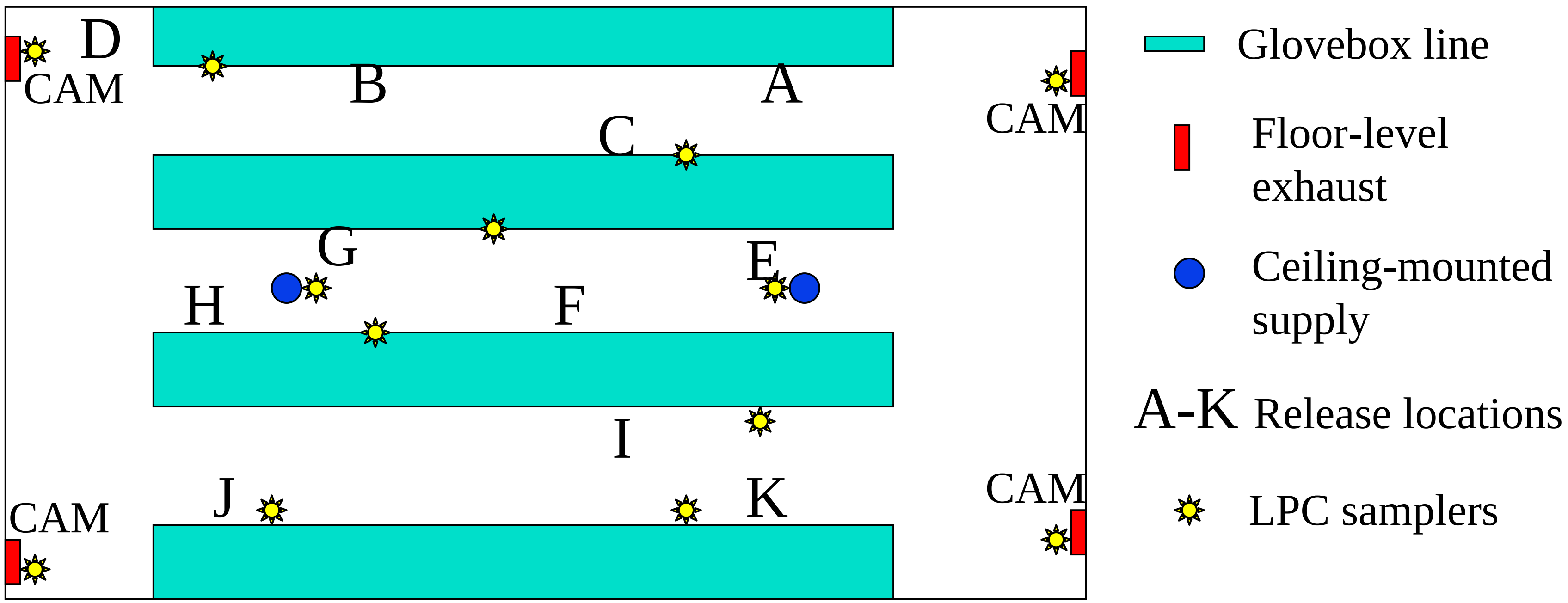


Test of monitor placement in a plutonium facility at LANL

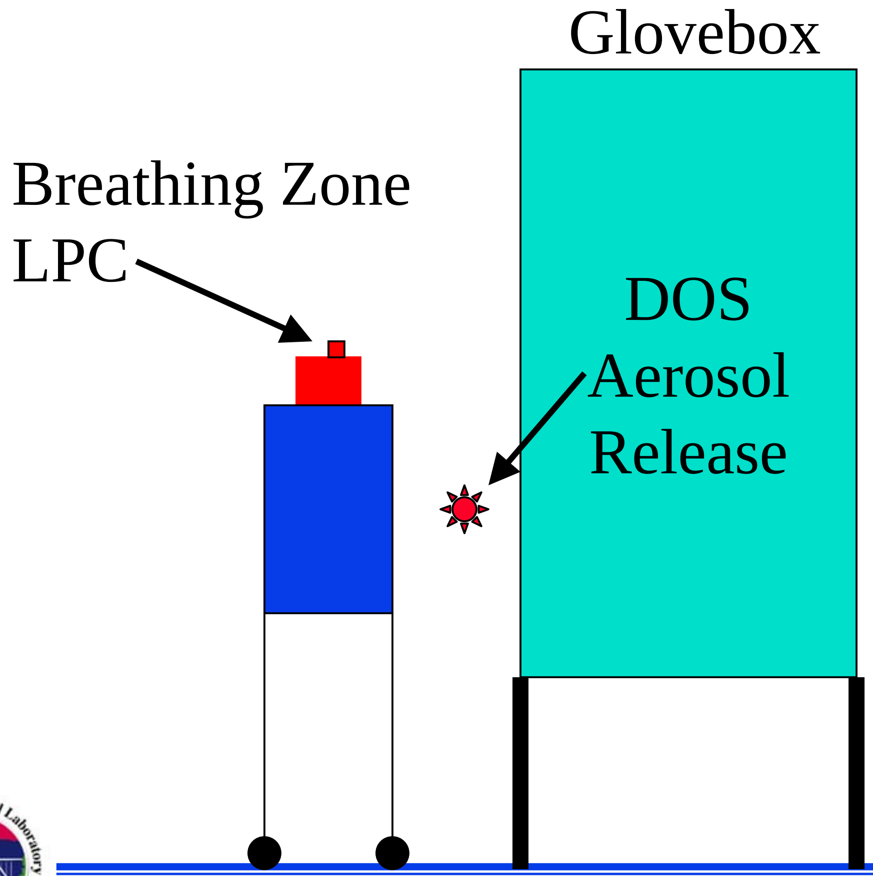
Typical Layout of Pu Laboratory



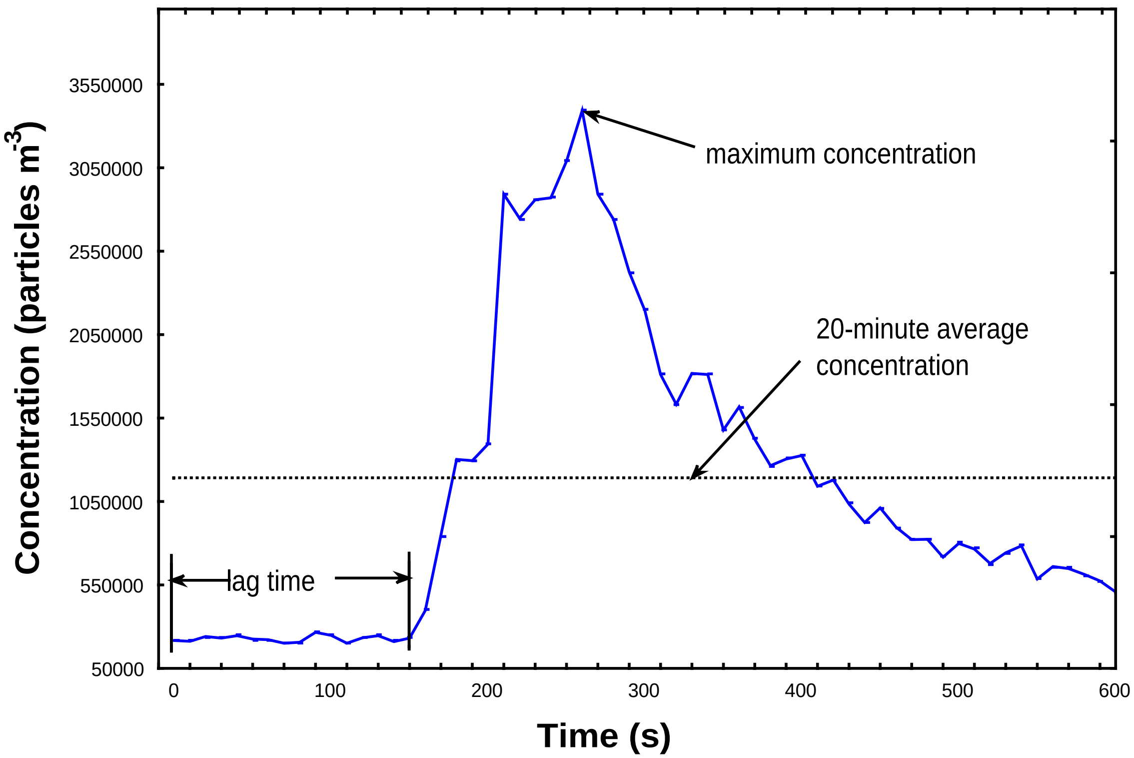
Experimental setup



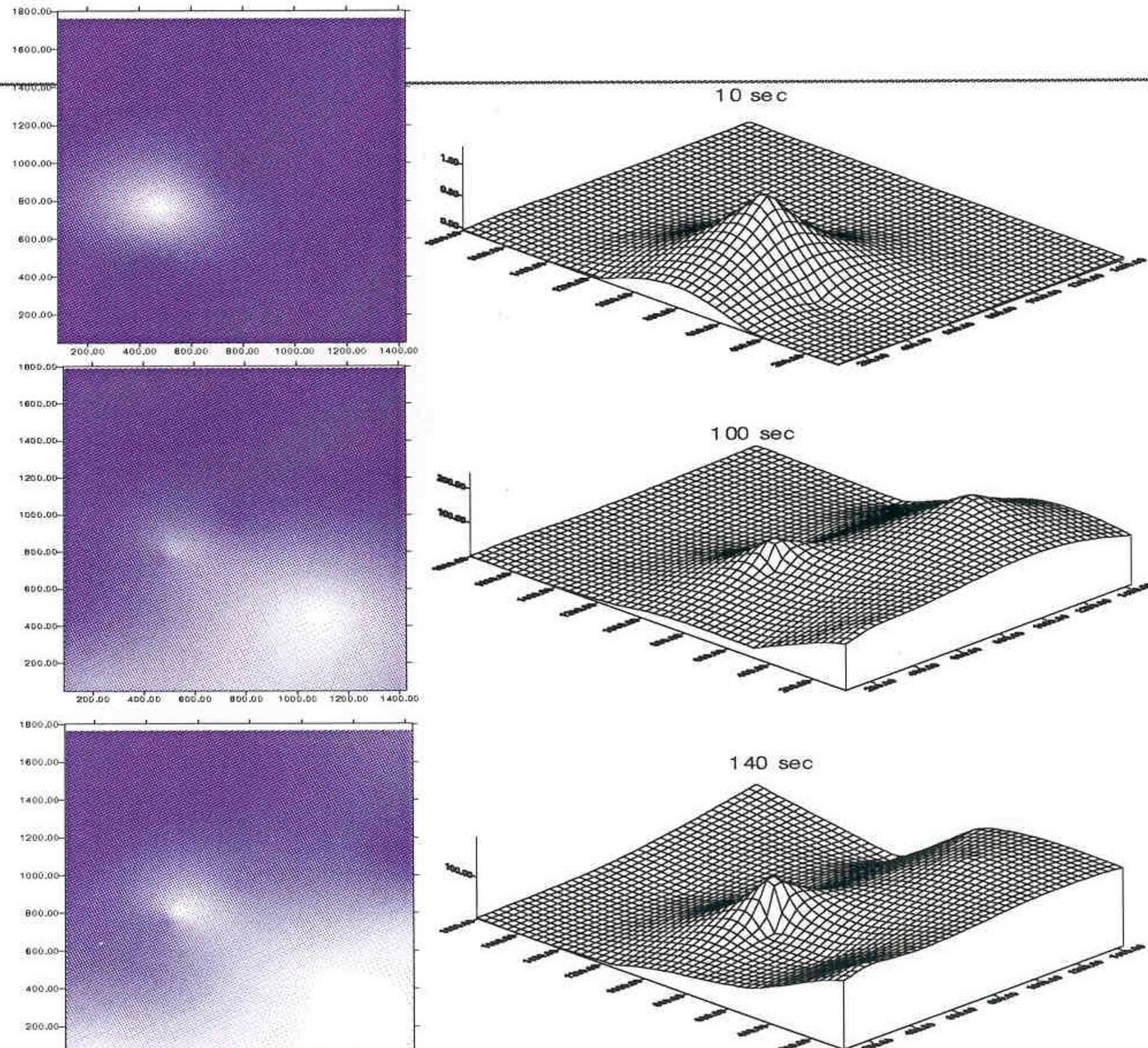
Simulated glove failure



Results: Aerosol concentrations resolved in time (10s) and space



Particle cloud transport

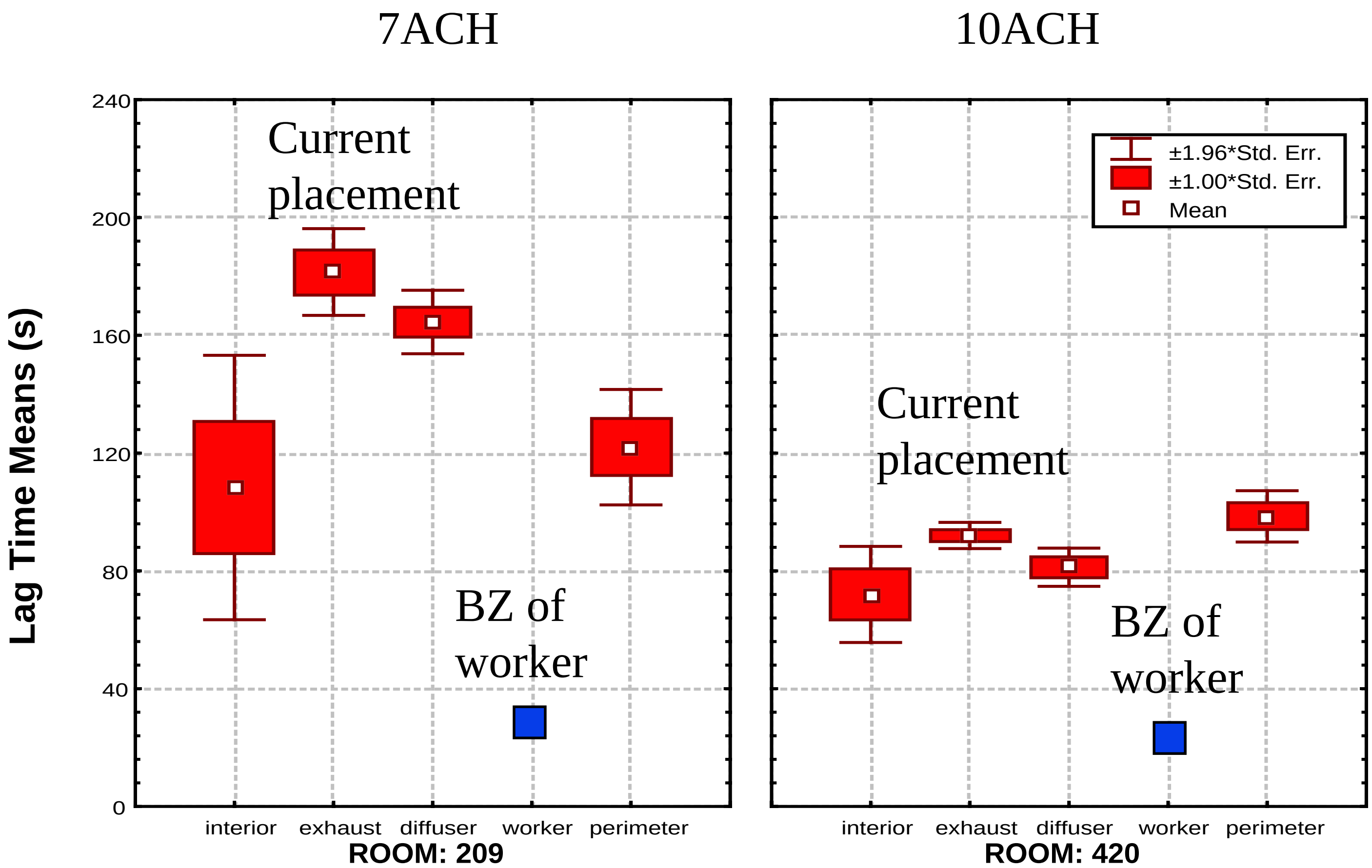


10 sec

100 sec

140 sec

Faster alarms, through short lag times, could be achieved at different locations



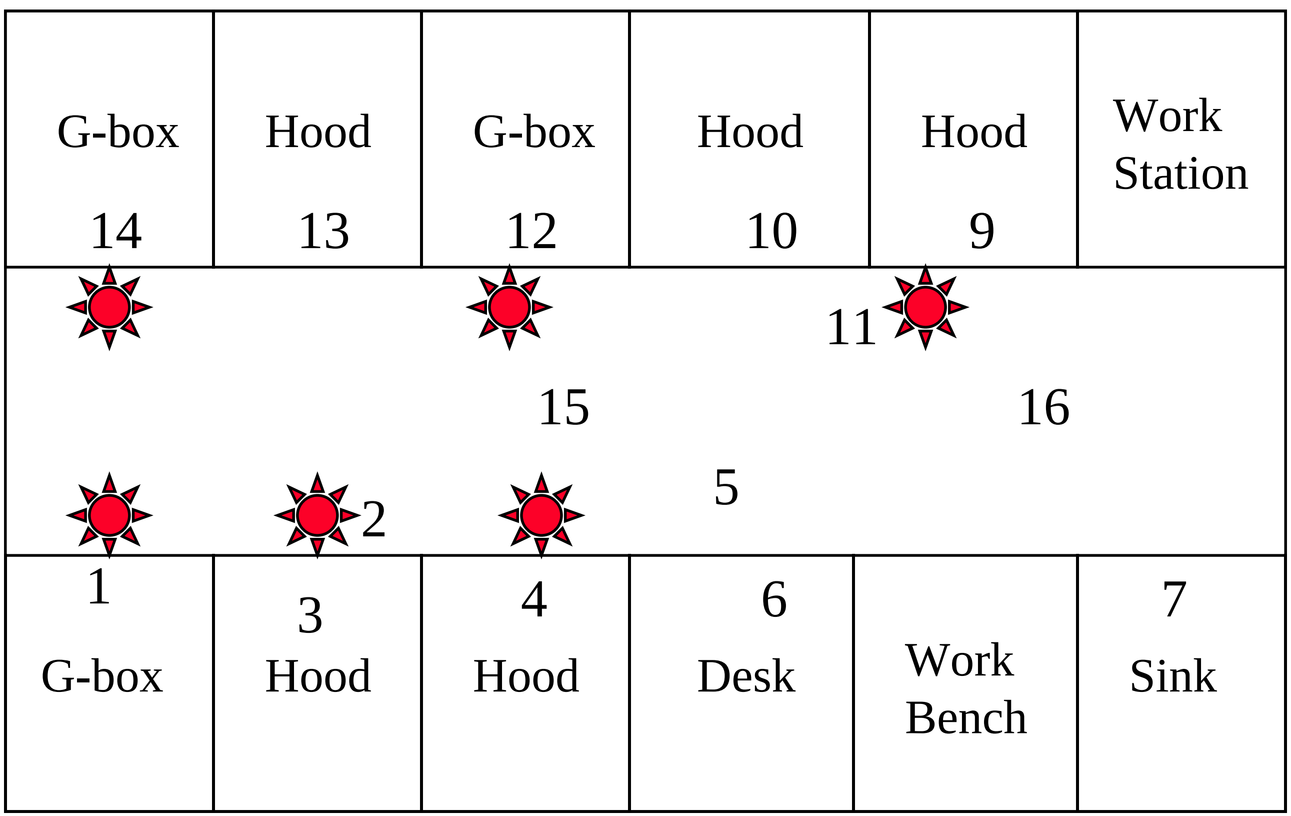
Point 3: Despite challenges, significant improvements in health protection can be made

- CAM placement
- Ventilation design

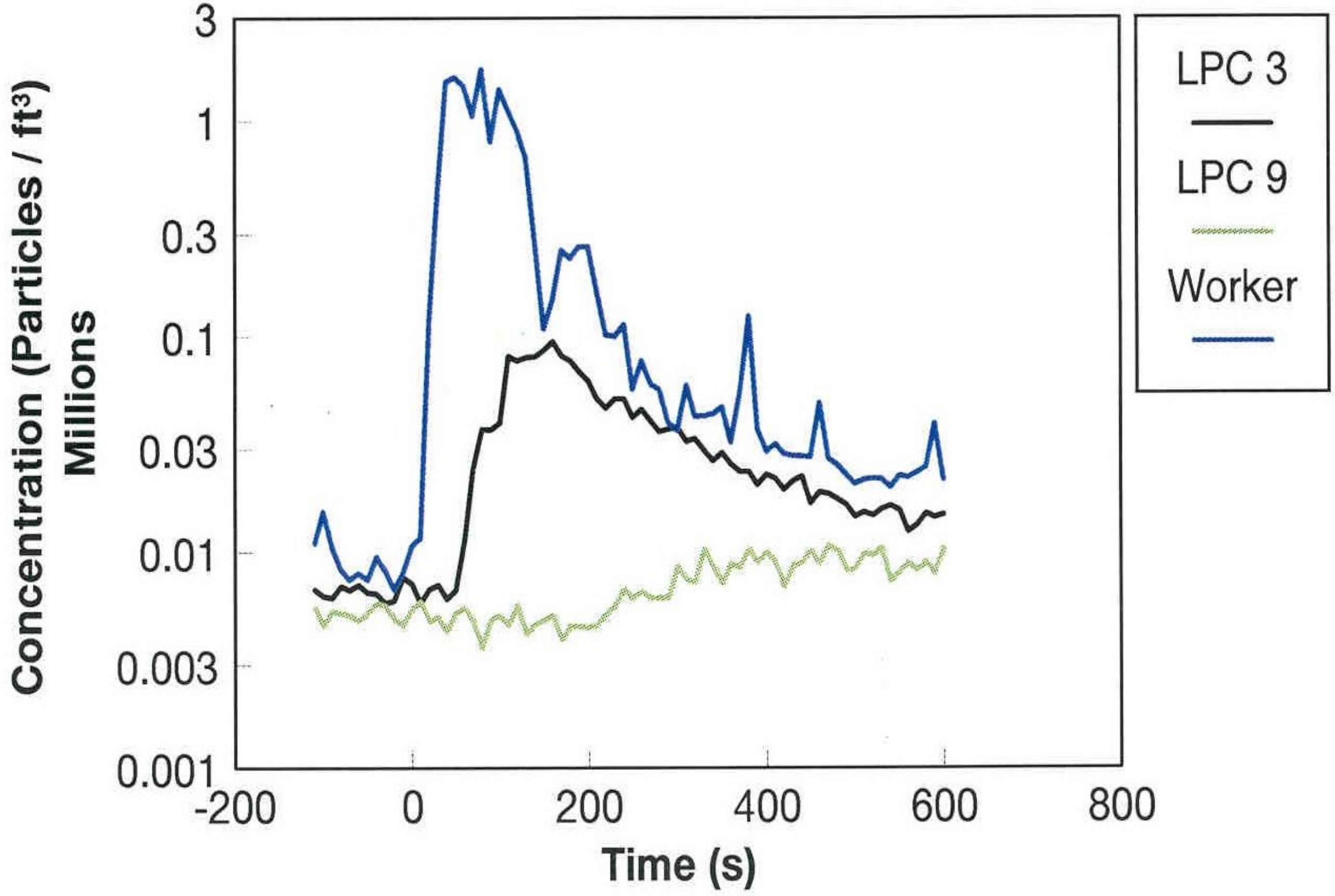
Optimized placement Strategy

-Aerosol release locations

1-16 Potential monitor locations
(8 - nearest worker)

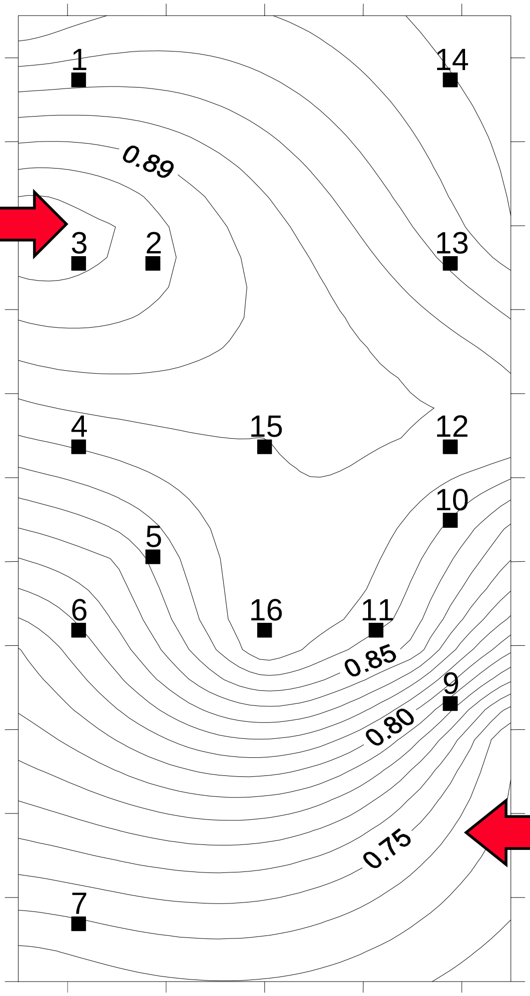


Representative concentration profiles in various locations in room



Spatial distribution in a room of the fractional dose savings averaged over all releases

Area of highest protection

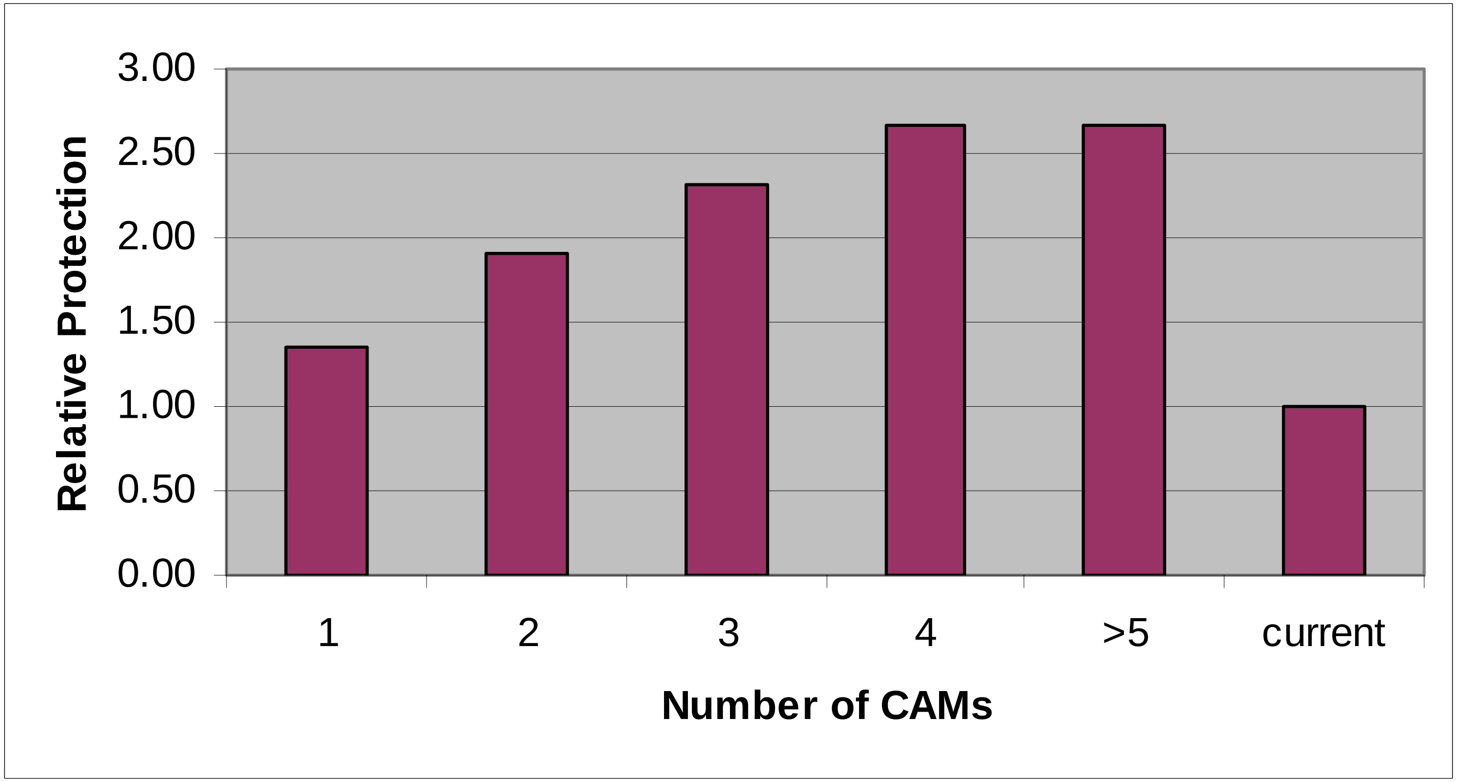


Squares 1-16: sampling locations

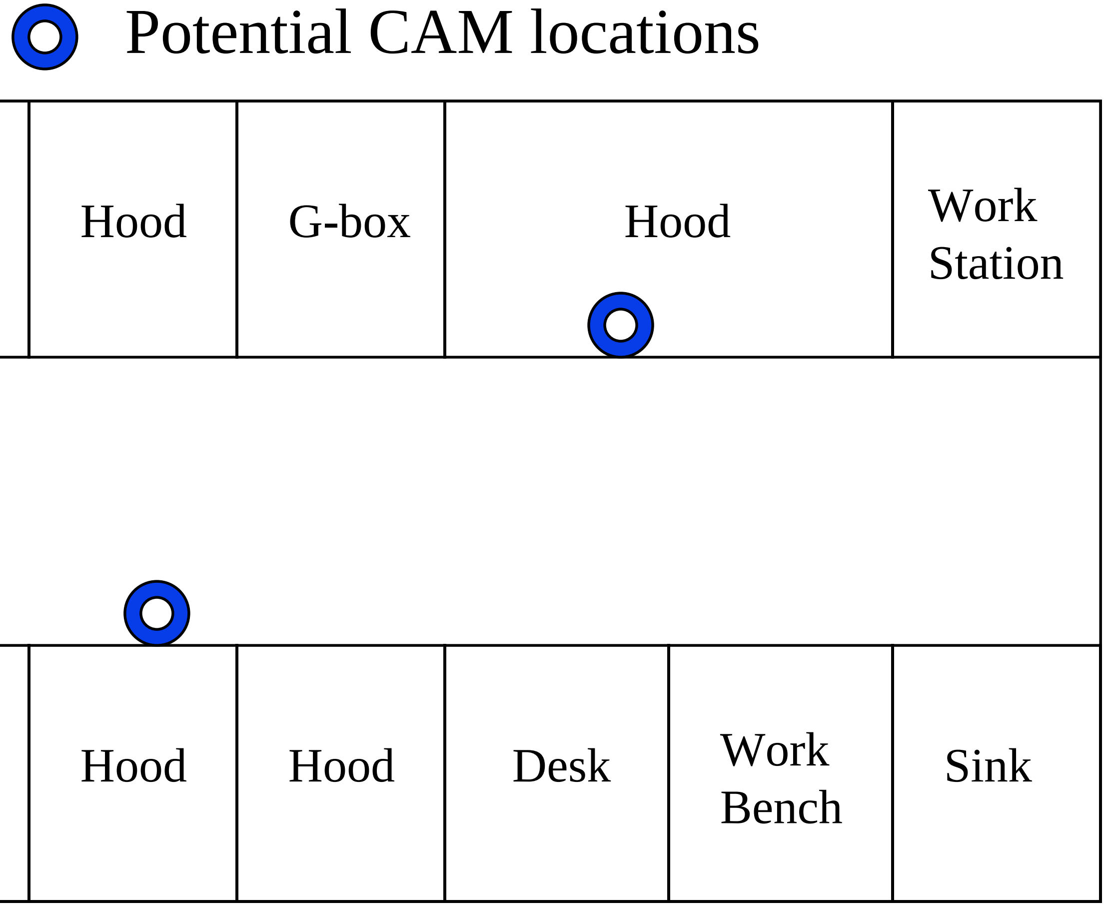
Isocurves: fractional dose savings

Area of lowest protection

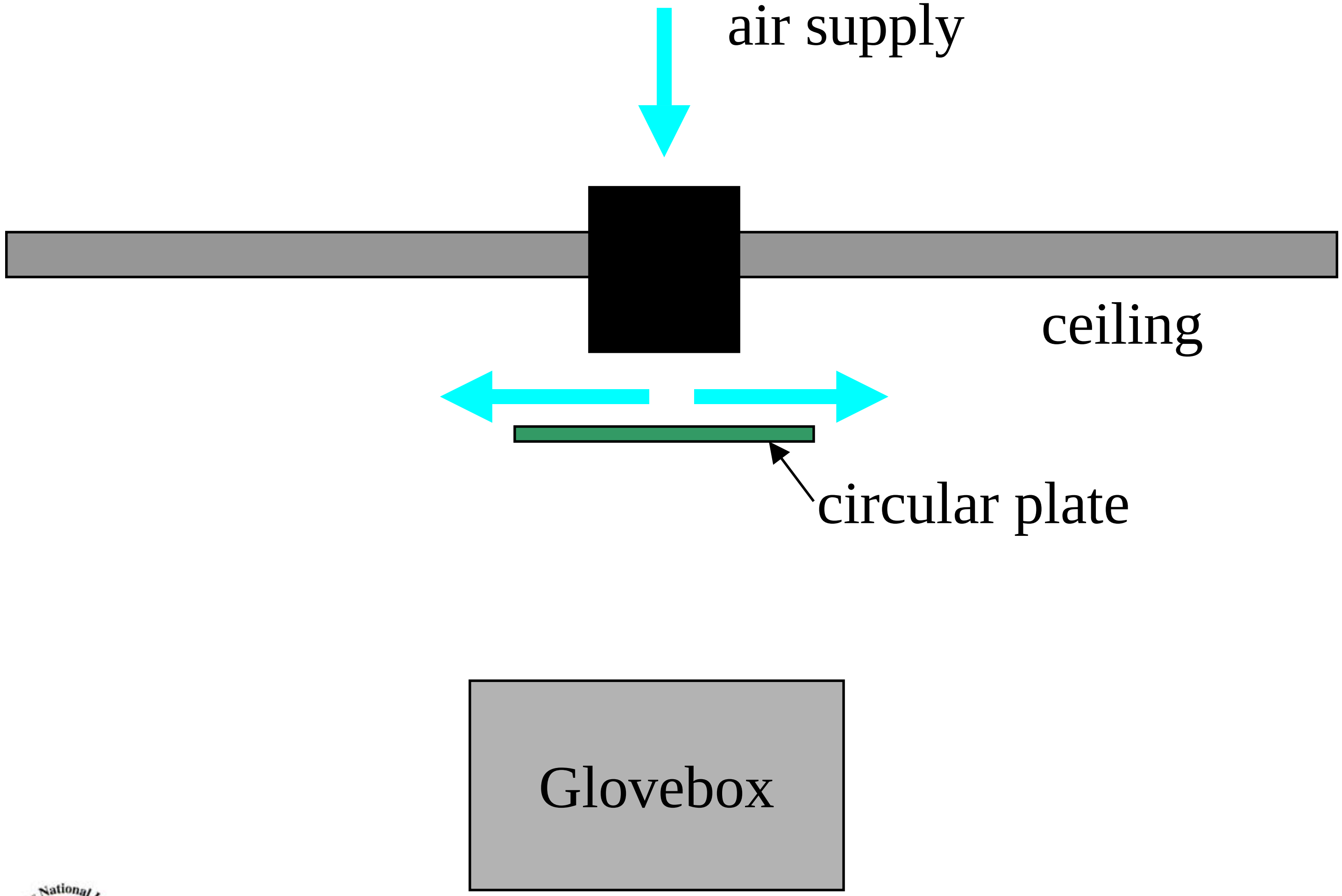
Relative protection for various placement strategies



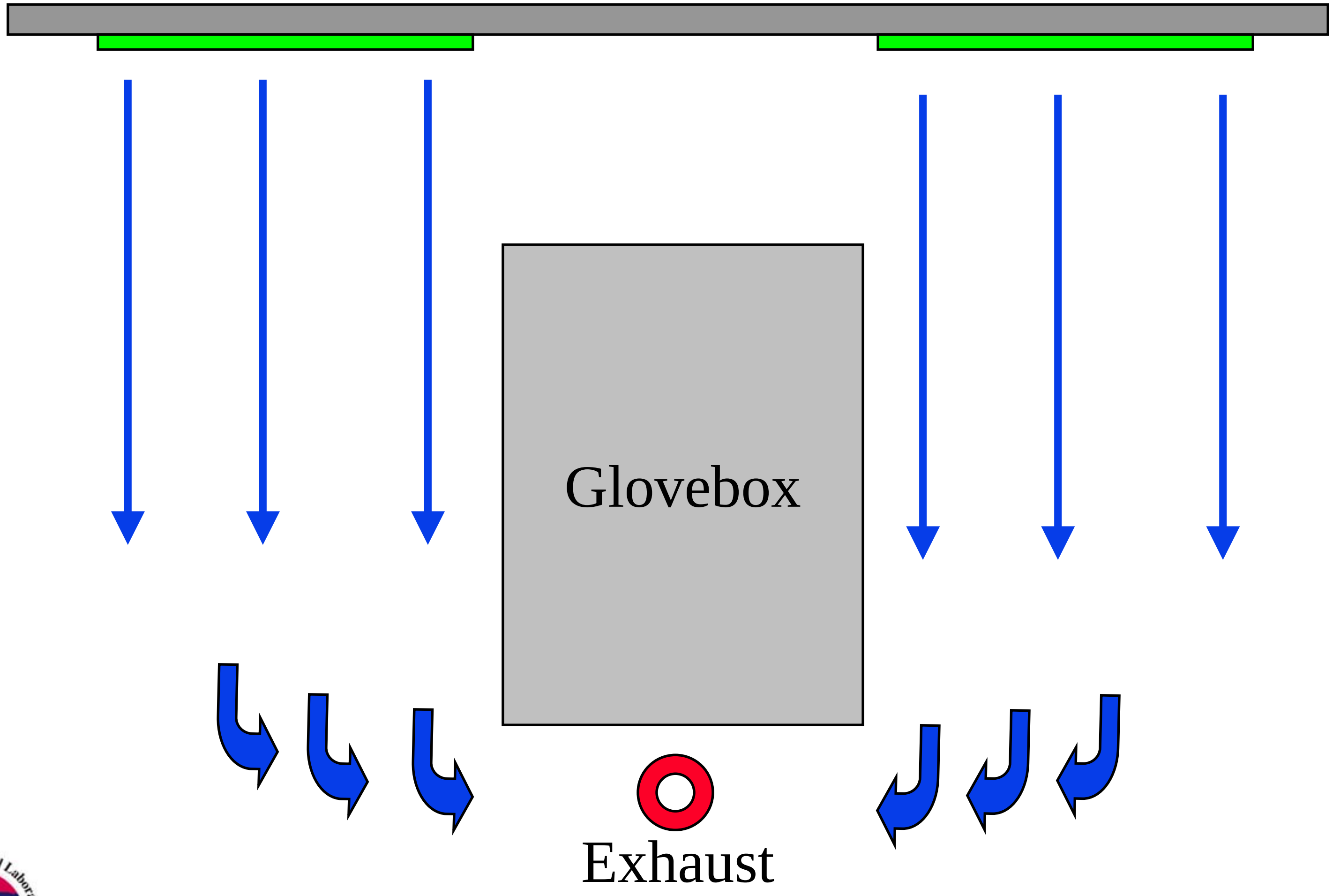
Optimized number an placement of CAMs:



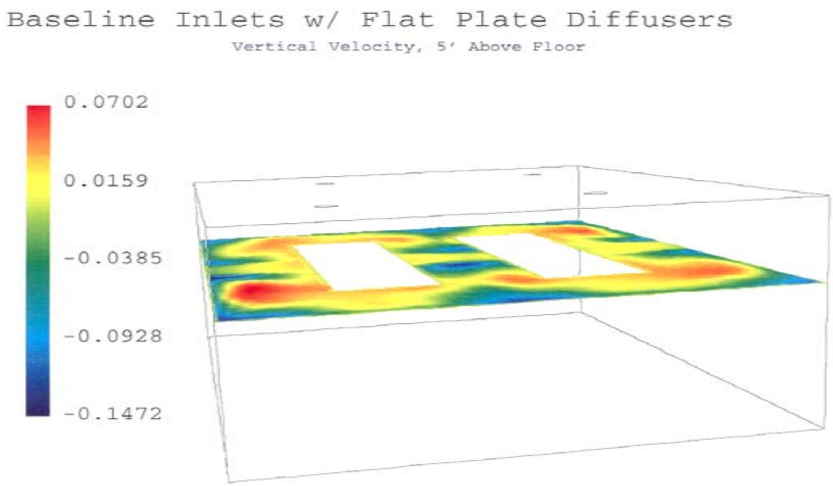
Supply diffuser designs:Flat plate design (current design)



Air shower design



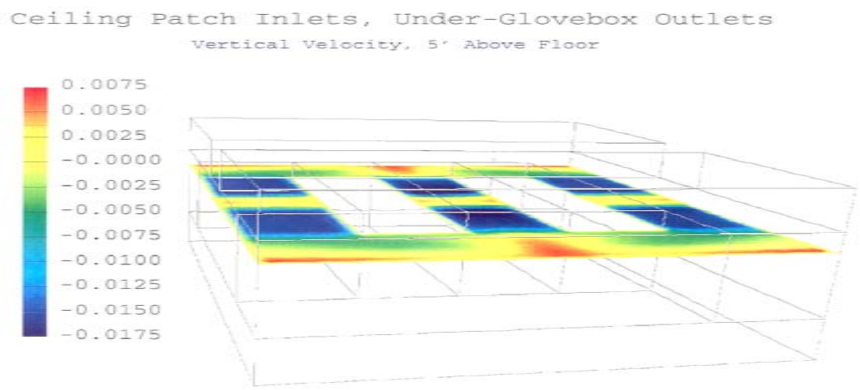
CFD results for different diffuser designs



Current design

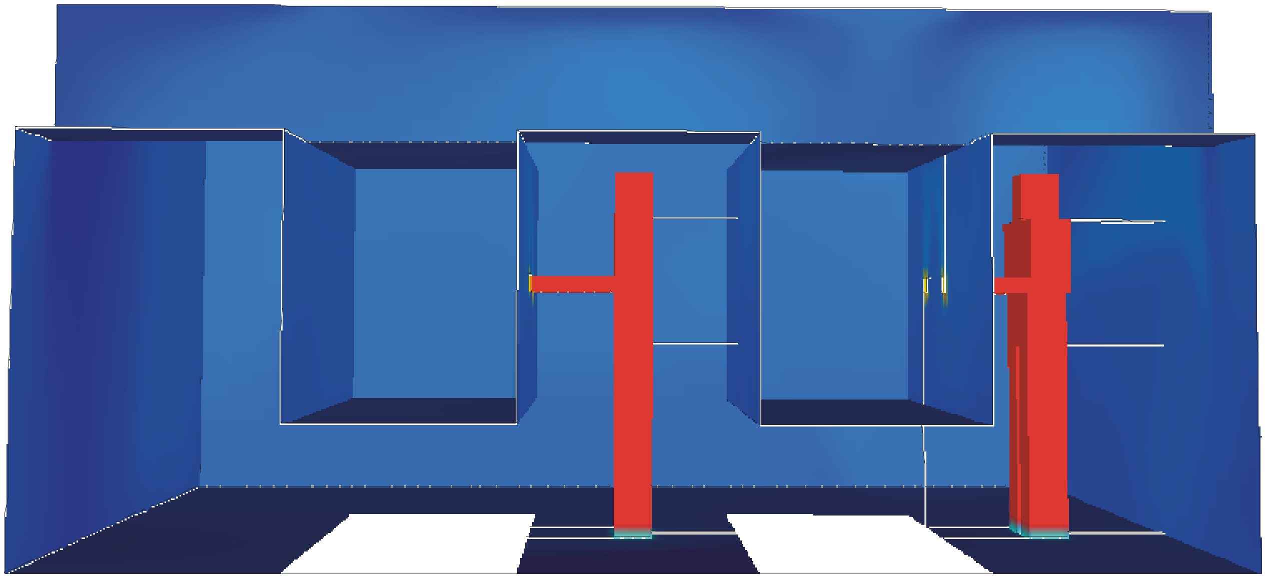
+

(m/s)

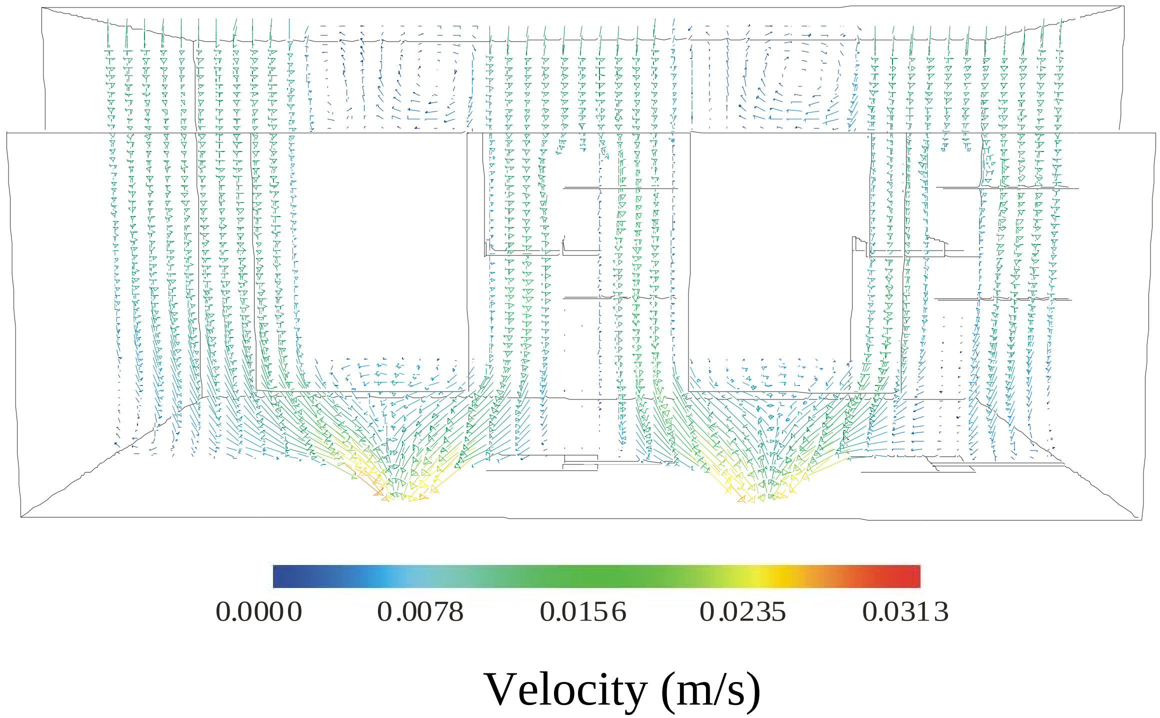


Air shower design

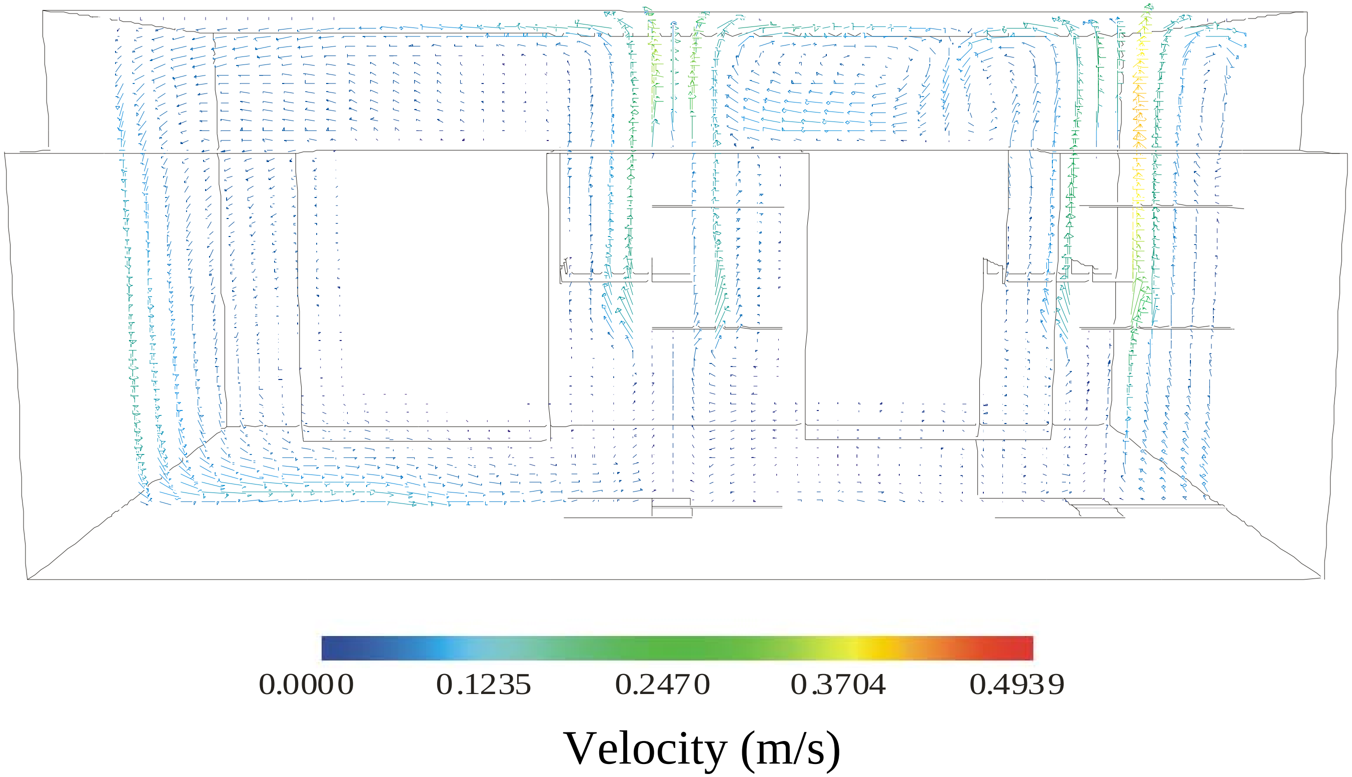
Influence of humans on airflow direction



Velocity Vectors for Unheated Humans



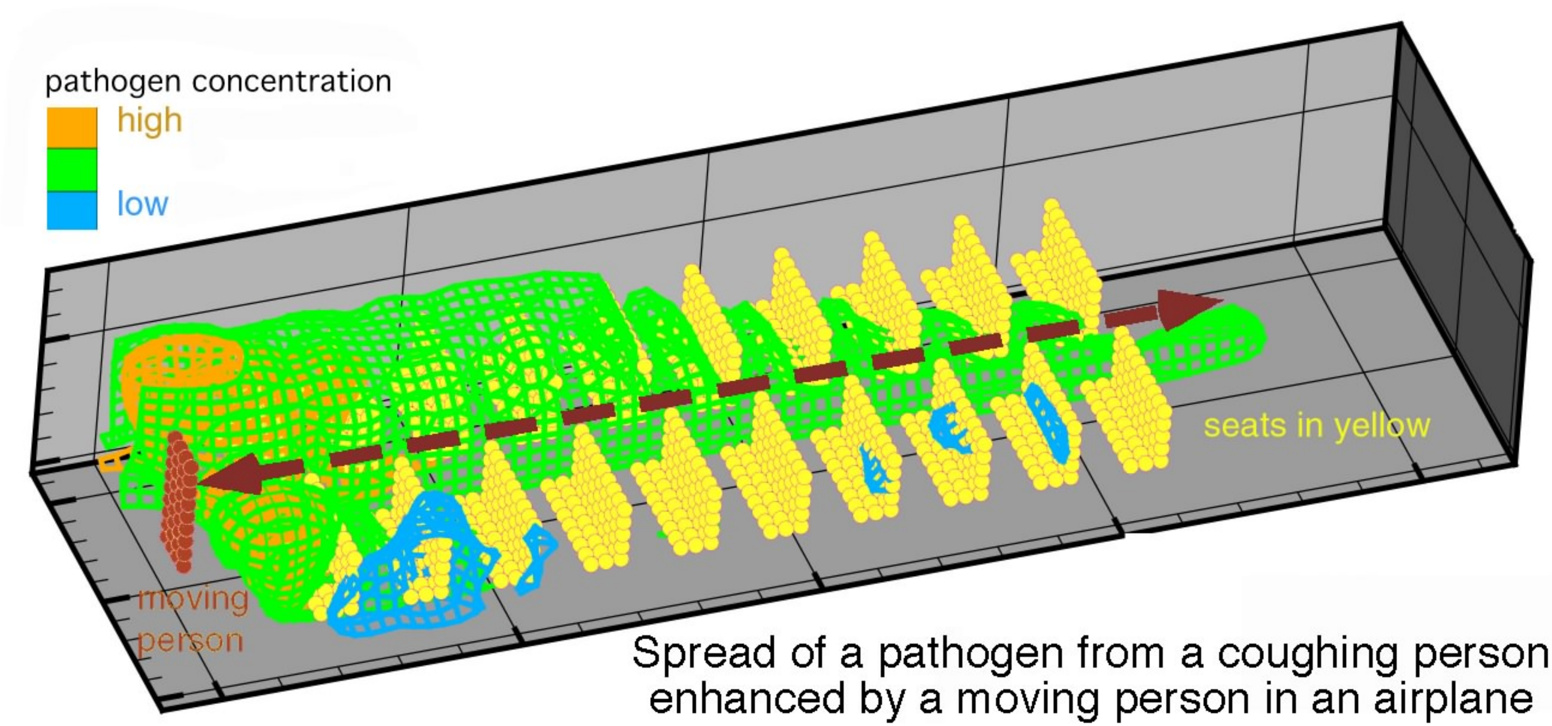
Velocity Vectors for Heated Humans



Point 4: The scale of the study of airflow and aerosol dispersion has expanded from the occupational setting to public safety and homeland defense

Applications for public safety

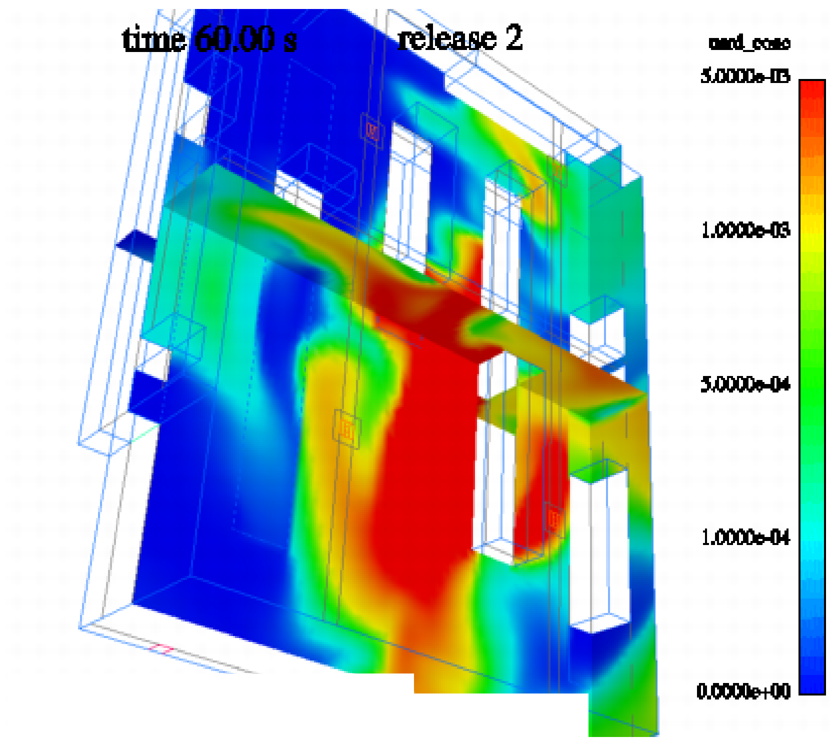
- Prediction of levels of human exposure under a variety of exposure conditions



Spread of a pathogen from a coughing person enhanced by a moving person in an airplane

Applications for homeland defense

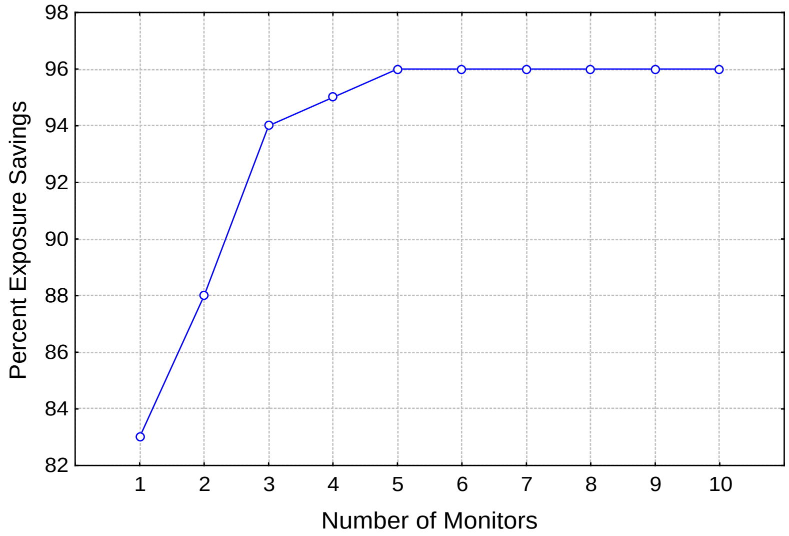
- Vulnerability assessments and investigations
  - Assess risk at public venues of concern
  - investigations (amount, release location)



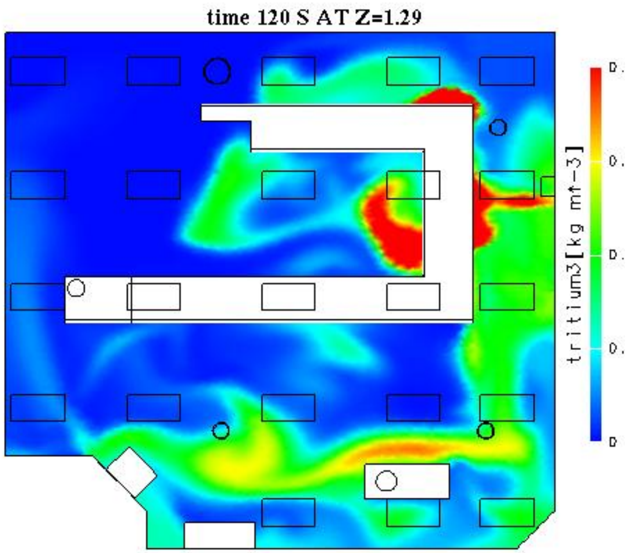
Applications for homeland defense

- Optimize detector quantity and placement
  - balance cost with protection

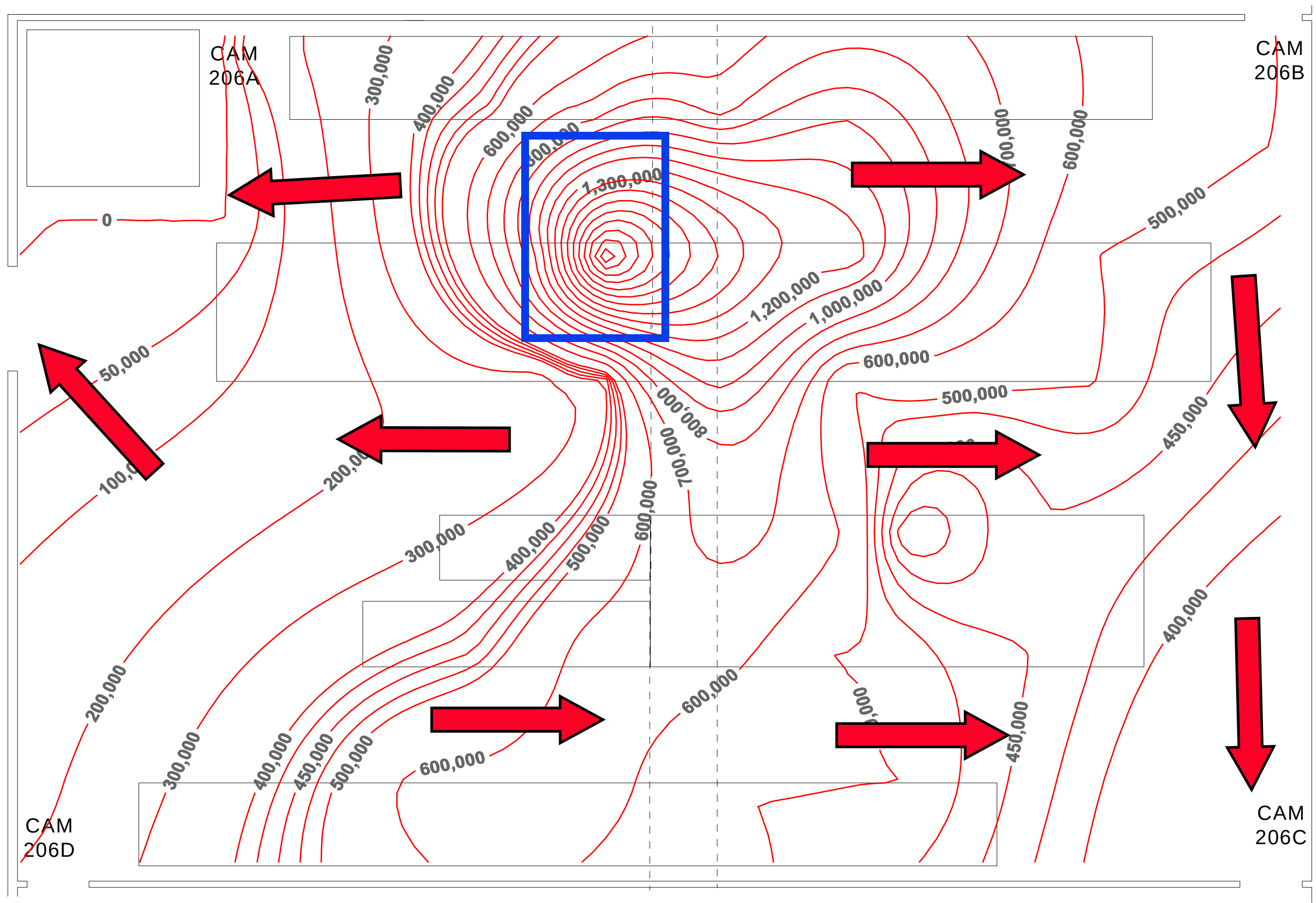
Optimization based on point measurements



Optimization based on model predictions



Real-time information integration and analysis



Legend:

- Most probable release location
- Isoconcentration lines
- Exit routes

In Summary:

- Airflow and aerosol dispersion are highly complex and poorly understood
- Proper placement of air quality instruments is critical for effective protection
- Despite challenges, significant improvements can be made (e.g., better ventilation designs)
- The challenge of fast and sensitive detection of extremely hazardous aerosols has expanded beyond the occupational setting to public safety and homeland defense