# *Best Practices for Modeling Exhaust Dispersion*

**Presented at Labs for the 21st Century**

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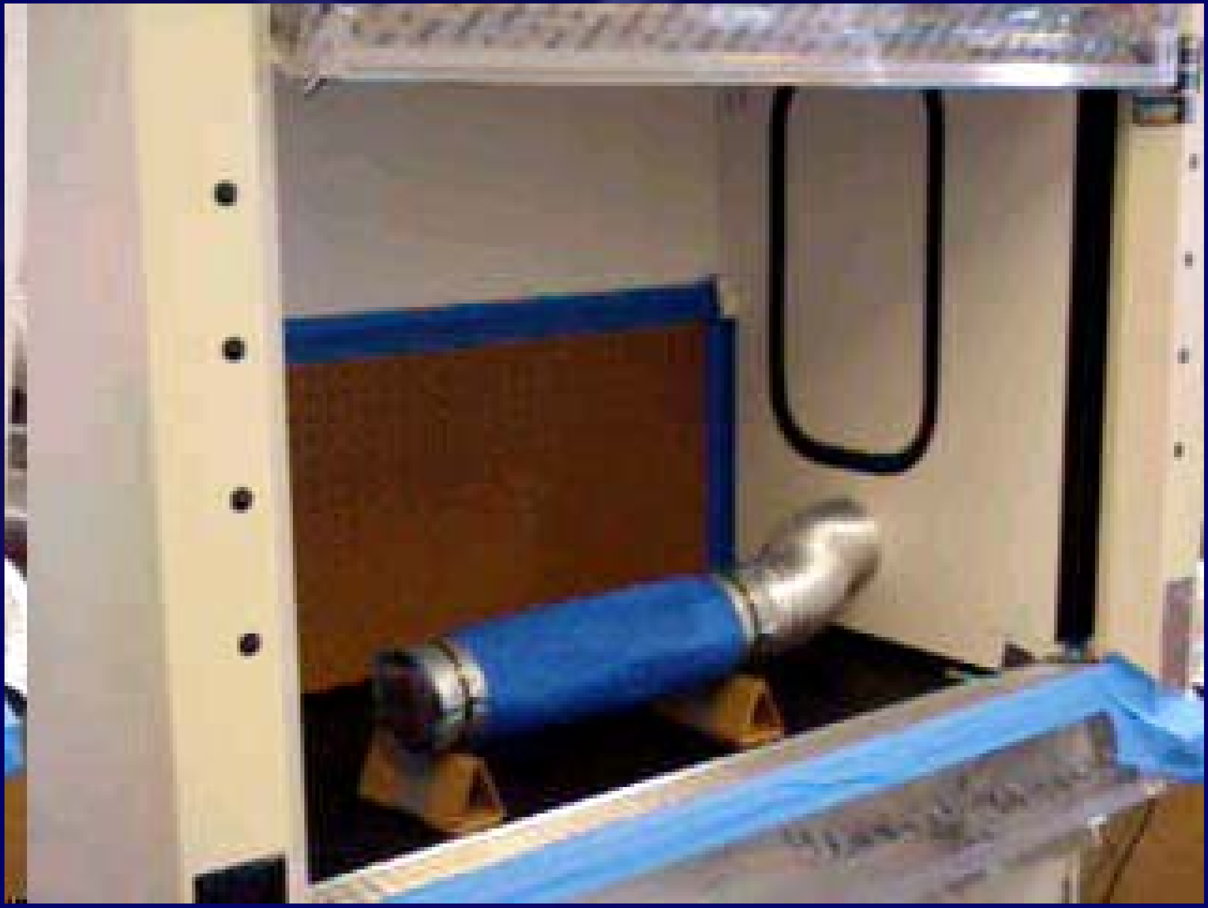
# OUTLINE

- Background Information
- General Description of Air Flow Around Building
- Qualitative Information on Acceptable Exhaust/Intake Designs
- Concentration Design Criteria
- Dispersion Modeling Methods
- Typical Results

# Accidental Spills



# *Exhaust Dispersion*

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# Exhaust Evaluation Approach

Air quality acceptability question:

$$C_{\max} <? \, C_{health/odor}$$

*Environmental Performance Criteria (LEEDS) Credit 9.1 -- Meet all standards and generally accepted guidelines for outdoor protection of workers and general public from airborne chemical, radioactive and biological hazards. Use mathematical modeling, physical modeling and/or post construction testing and certification to prove compliance.*

# *Knowledge Needed*

- *Air flow around buildings*
- *Concentration design criteria for health and odors*
- *Dispersion model predictions*

# *Airflow Around Buildings*

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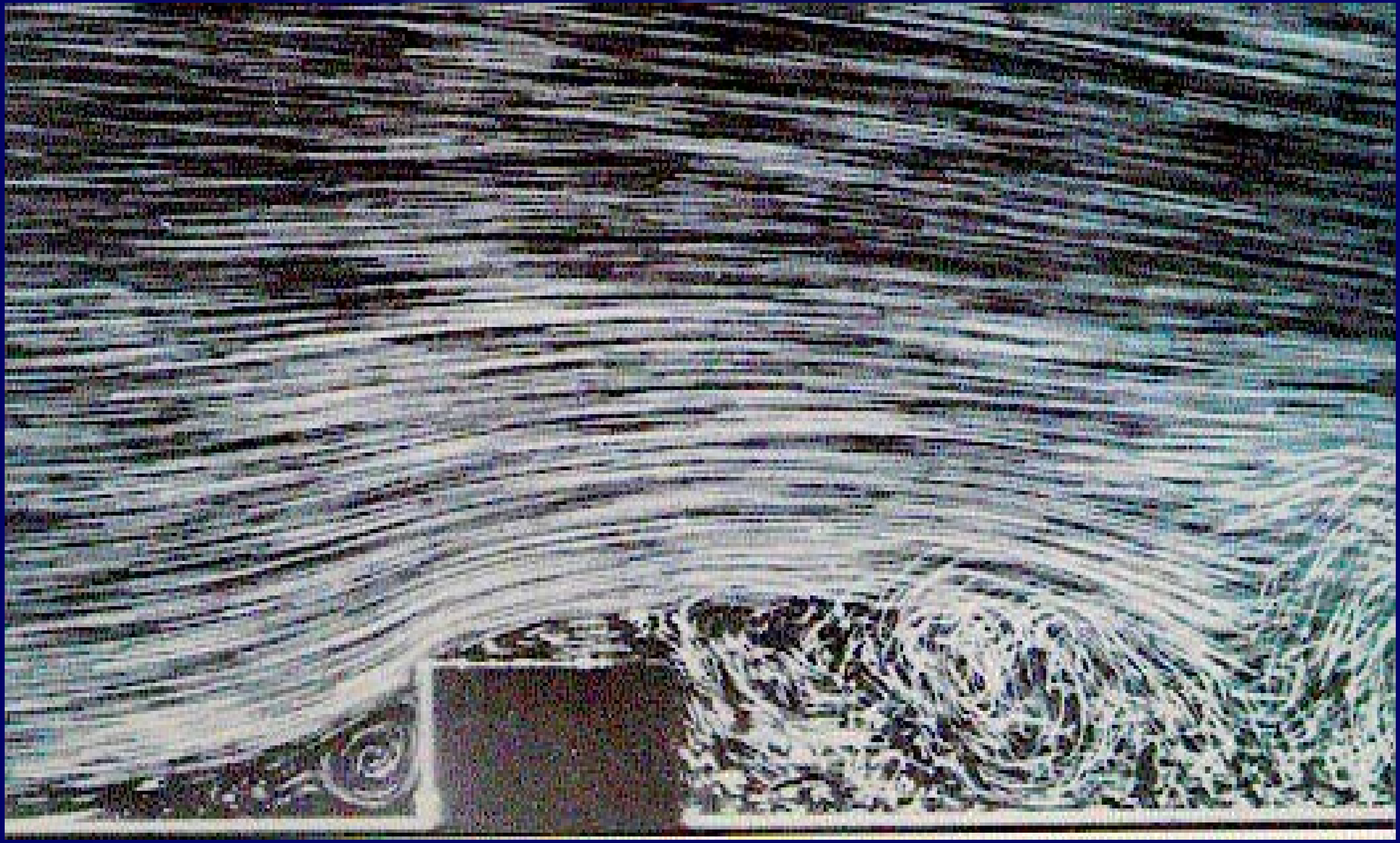
# *Visual of Air Flow Around Building*



# *Corner Vortex*

# *Plume impact on taller downwind building*

# *Plume impacting taller upwind building*

# *Qualitative Information on Exhaust/Intake Designs*

# *Stack Design Standards/Codes/Practices*

- *Exhaust system shall discharge at a point where it will not cause a nuisance and from which it cannot be readily drawn in by a ventilating system (IMC).*
- *ANSI/AIHA Z9.5 & NFPA 45 – minimum of 10 ft to protect rooftop workers.*
- *EPA - GEP stack height (2.5 times the building height above ground).*

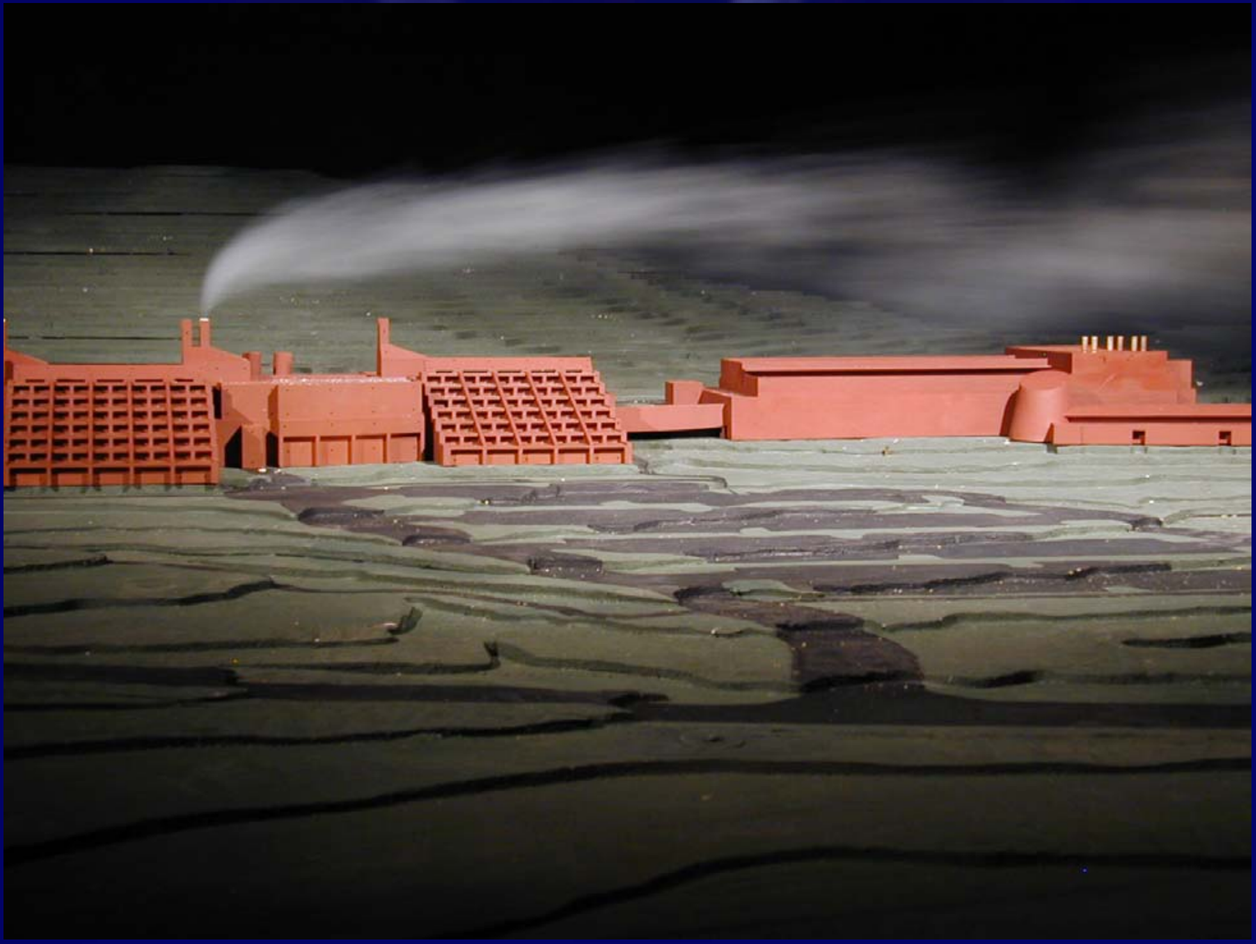
# *Manifolded exhaust system*

# *Ganged Stacks*

# *Increased stack height*

# *On tallest building*

# *Increased separation distance*



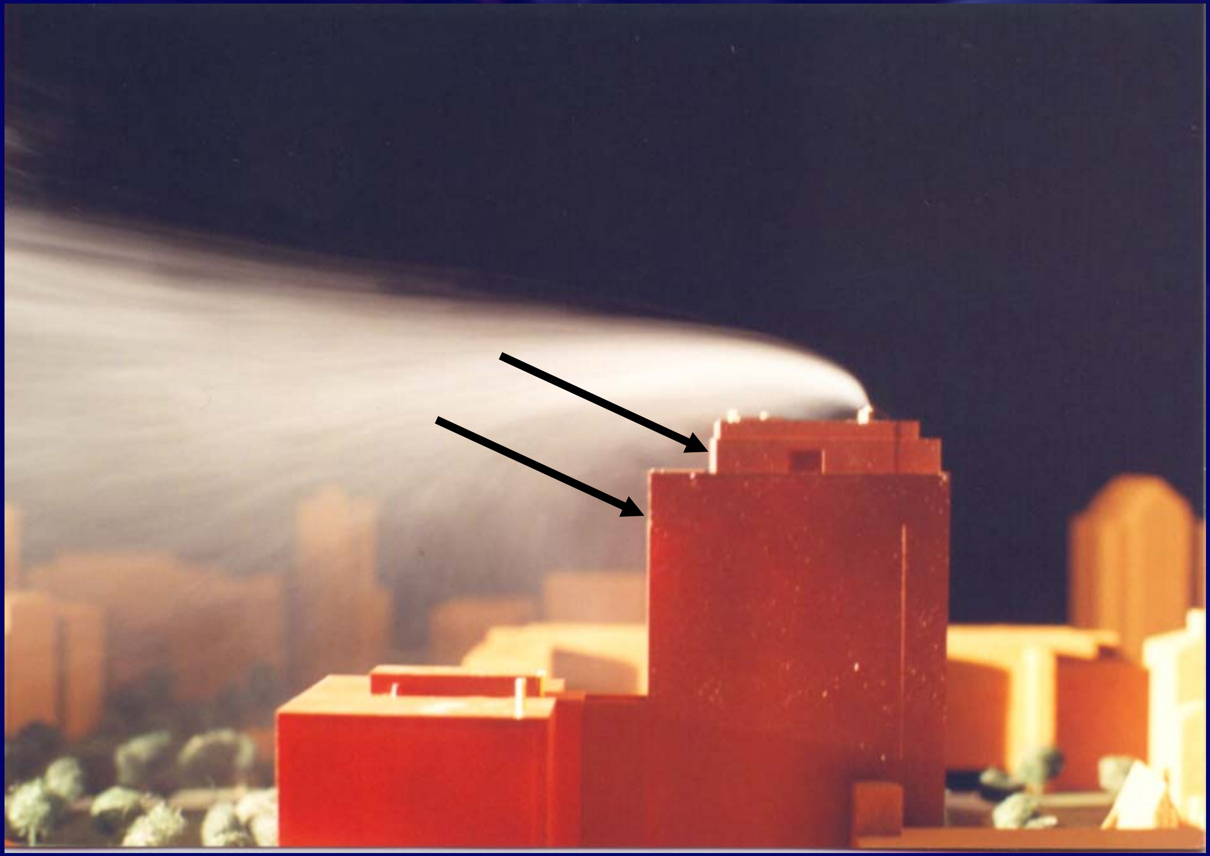
# Vertically Directed and No Caps

*Consider effect of screens (ASHRAE – Chapter 43)*

# *High Enough Exhaust Velocity*

- *3000 fpm (ANSI/AIHA Z9.5 – 2003)*
- *1.5 times the 1 % wind speed at stack top (ASHRAE 2003, Chapter 43).*

# *Locate intakes behind building feature (current ASHRAE research)*



# *Air intake locations – below stack for centralized exhausts*

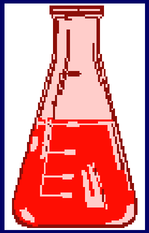
# *Air intake locations – not in mechanical well with exhausts*

# *Air intake locations – away from loading docks*

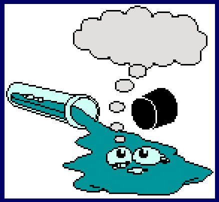
# *Concentration Design Criteria for Health and Odor*

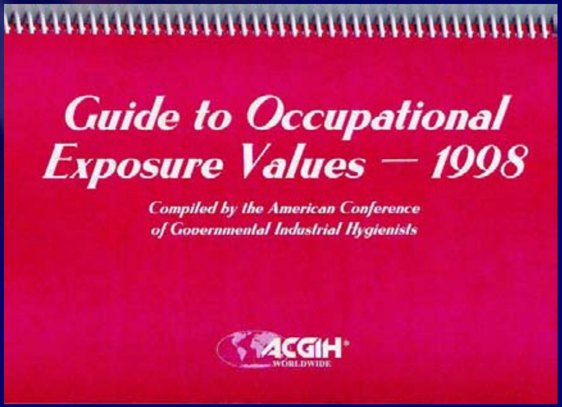
# Concentration Design Criteria

- *Information to develop* ***(C/m)***$_{health/odor}$



  - ***C*** $_{health}$ *&* ***C*** $_{odor}$ *for each substance*
  - *Maximum* ***m*** *for each substance*





# ASHRAE 110 Fume Hood Manikin Test

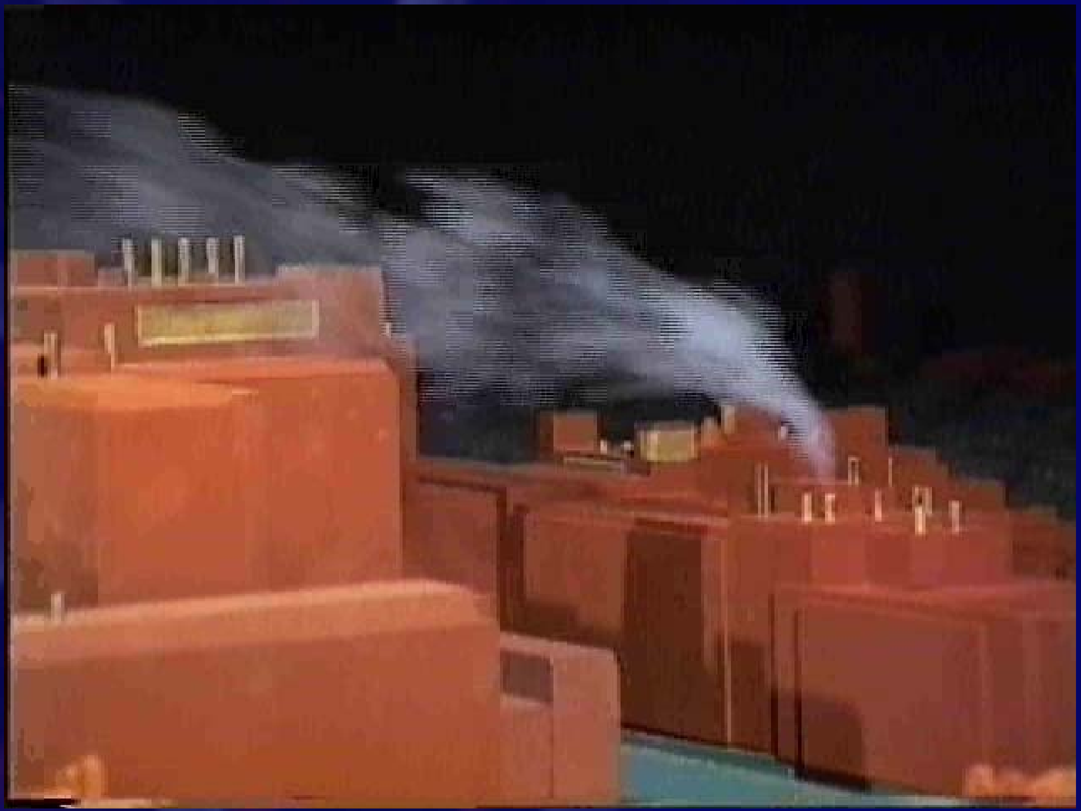
4 lpm spill
0.05 ppm at
Manikin
1:3000 dilution or
700 ug/m3 per g/s

# *ASHRAE 1999 Fume Criteria for Intake*

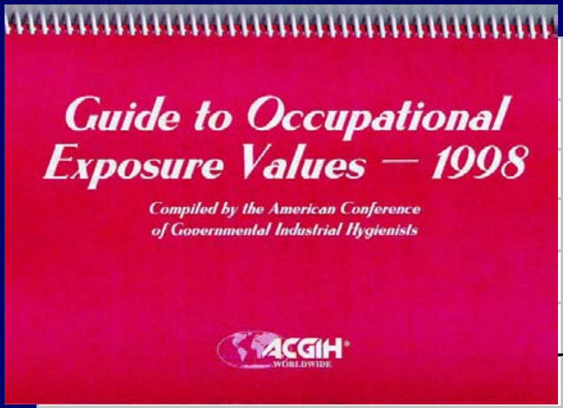
*7.5 L/s and*
*3 ppm at*
*Intake*

*Equivalent to*

*400 ug/m3 per g/s*



# *Problem 1 Liter Spills for Health*



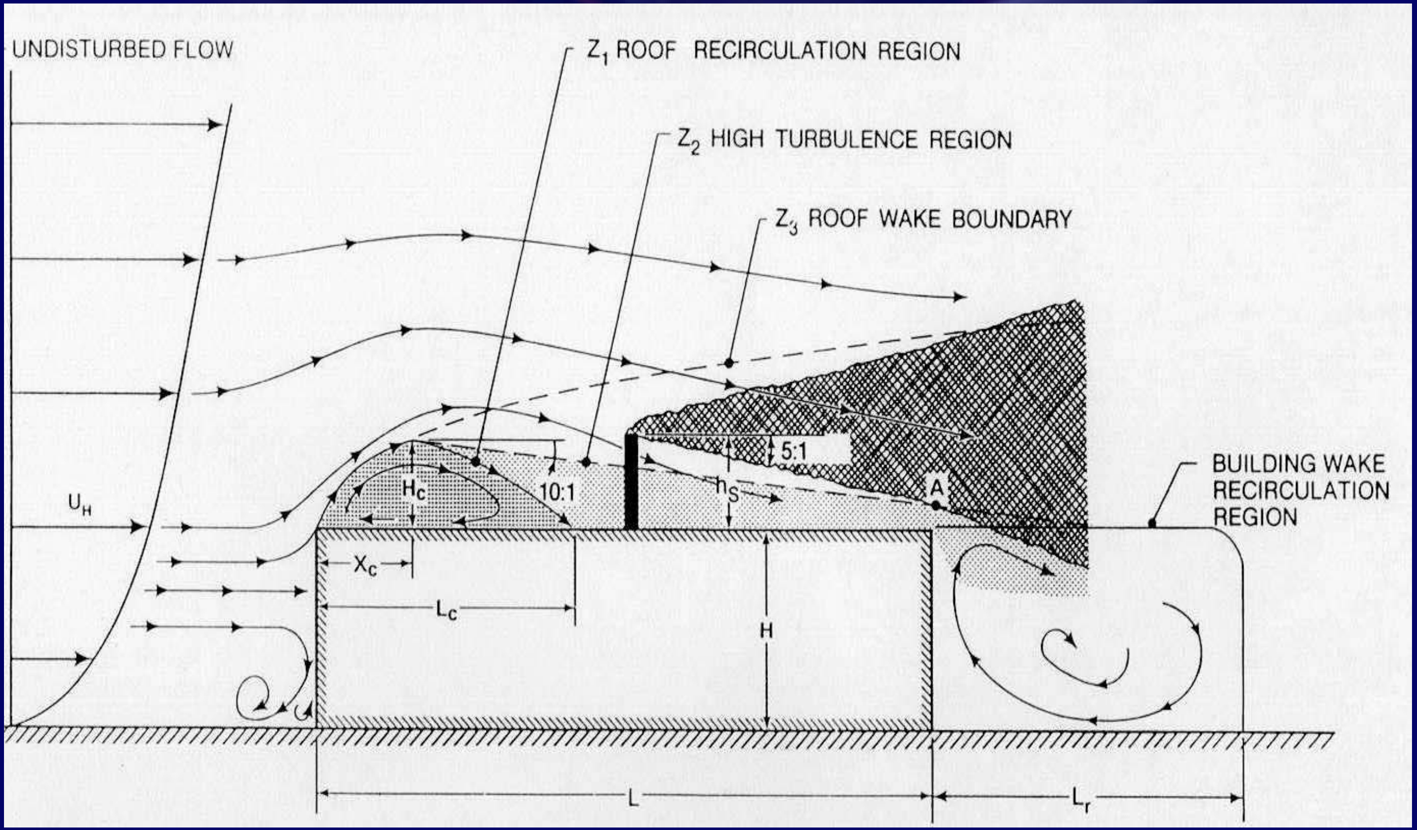

| | CAS # | *m* 1-liter Emission Rate (g/s) | Occup Expos Limit ($mg/m^3$) | Occup Expos Limit Type | Occup Expos Limit Agency | *HL* ANSI/AIHA Z9.5 Health Limit ($mg/m^3$) | *HL/m* Normalized Concen Limit ($\mu g/m^3$)/(g/s) |
|---|---|---|---|---|---|---|---|
| Nickel carbonyl (as Ni) | 13463-39-3 | 5.841 | 0.01 | TWA | OSHA | 0.021 | 3.6 |
| Sulfur pentafluoride | 5714-22-7 | 15.485 | 0.10 | Ceil | ACGIH | 0.100 | 6.5 |
| Chromyl chloride | 14977-61-8 | 0.437 | 0.00 | TWA | NIOSH | 0.003 | 6.9 |
| Osmium tetroxide | 20816-12-0 | 0.304 | 0.00 | STEL | ACGIH | 0.005 | 15.5 |
| Pentaborane | 19624-22-7 | 1.371 | 0.03 | STEL | NIOSH | 0.030 | 21.9 |
| Chloromethyl ether(bis-) | 542-88-1 | 0.375 | 0.00 | TWA | ACGIH | 0.014 | 37.6 |
| Methyl isocyanate | 624-83-9 | 2.158 | 0.05 | TWA | ACGIH | 0.141 | 65.3 |
| Dimethylhydrazine(1,1-) | 57-14-7 | 1.025 | 0.15 | STEL | NIOSH | 0.150 | 146.3 |
| Methyl hydrazine | 60-34-4 | 0.250 | 0.08 | STEL | NIOSH | 0.080 | 319.5 |
| Bromine pentafluoride | 7789-30-2 | 6.273 | 0.70 | TWA | NIOSH | 2.100 | 334.8 |
| Tetramethyl lead (as Pb) | 75-74-1 | 0.668 | 0.08 | TWA | OSHA | 0.225 | 336.9 |
| Tungsten hexafluoride | 7783-82-6 | 24.519 | 10.00 | STEL | OSHA | 10.000 | 407.8 |
| Bromine | 7726-95-6 | 2.986 | 1.30 | STEL | ACGIH | 1.300 | 435.4 |
| Ethyl mercaptan | 75-08-1 | 2.982 | 1.30 | Ceil | NIOSH | 1.300 | 436.0 |
| Acrolein | 107-02-8 | 1.280 | 0.69 | STEL | ACGIH | 0.690 | 539.2 |
| Tetranitromethane | 509-14-8 | 0.170 | 0.04 | TWA | ACGIH | 0.120 | 704.5 |

# Dispersion Modeling Methods

- ASHRAE Graphical Method
- EPA/ASHRAE Dispersion Equations
- CFD Modeling
- Wind Tunnel Modeling

# *ASHRAE Graphical Method – **Not Recommended**.*

*No Comparison with Health or Odor Limits Provided – No Dispersion Modeling*



# EPA and ASHRAE Dispersion Equations

$$C = \frac{m}{\{\pi \ \sigma_y \sigma_z U_s\}} \exp[-\frac{H^2}{2\sigma_z^2}] x 10^6$$

$$\frac{1}{\{\pi \ \sigma_y \sigma_z U_s\}}$$

*Site and Design Effects Term*

$$m \times \exp[-\frac{H^2}{2\sigma_z^2}]$$

*Energy Term*

# Plume Rise Predictions
# Also an Main Energy Factor

$$H = h_s + [3\ F_m\ x/\ (\beta_j^{\,2} U_s^{\,2})]^{1/3}$$

$$\sim h_s + \text{Fan Horsepower}$$

# *Analytical Methods With Concentration Estimates*

- Applicable for simple buildings with no taller surrounding buildings/features with air intakes on the building roof.
- Experienced professional can develop conservative exhaust designs.
- Method may not be conservative if used by inexperienced practitioner.
- Concentration estimates on building sidewalls highly inaccurate.

# *CFD (Computational Fluid Dynamics) Solving The Basic Equations of Motion*

- *Some say this is the latest and greatest.*

- *What does the scientific community say?*

# *Evaluation of Modeling Uncertainty*
## *European Commission Contract*
## *WS Atkins 1997 Report*

### ***STUDY OBJECTIVES***

- *Evaluate the variability of results due to the way in which a CFD code is applied.*
- *Evaluate the accuracy of CFD predictions in large, complex dispersion scenarios.*

# *APPROACH*

## *Evaluation of Modeling Uncertainty*

- *Four organization used CFD to evaluate the same realistic test cases.*
- *Same CFD code used (STAR-CD)*
- *Wind tunnel experiments of test cases carried out.*
- *CFD results compared to wind tunnel.*

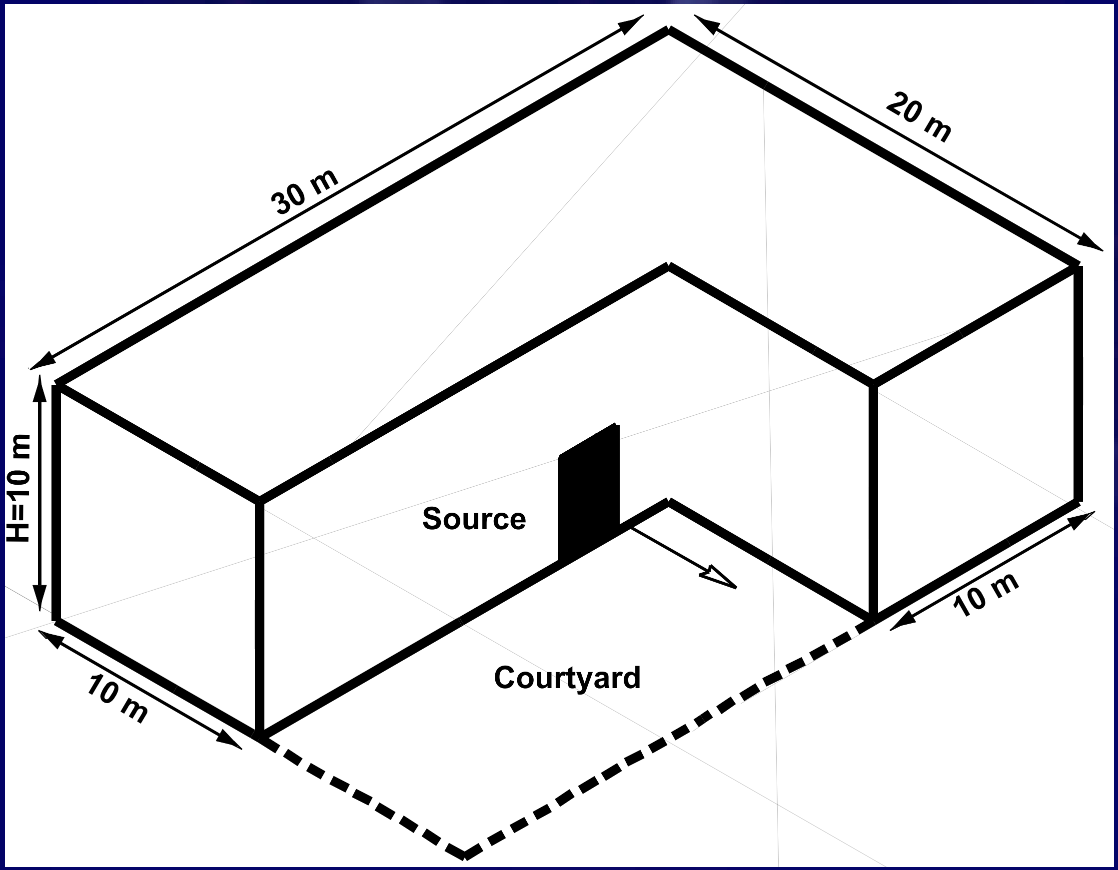
# *RESULTS*
# *Evaluation of Modeling Uncertainty*

- *Variability between different modeller's results was substantial*
- *CFD calculations varied between a factor of 5 and 100 from experiment*
- *Best agreement for simpler problems*

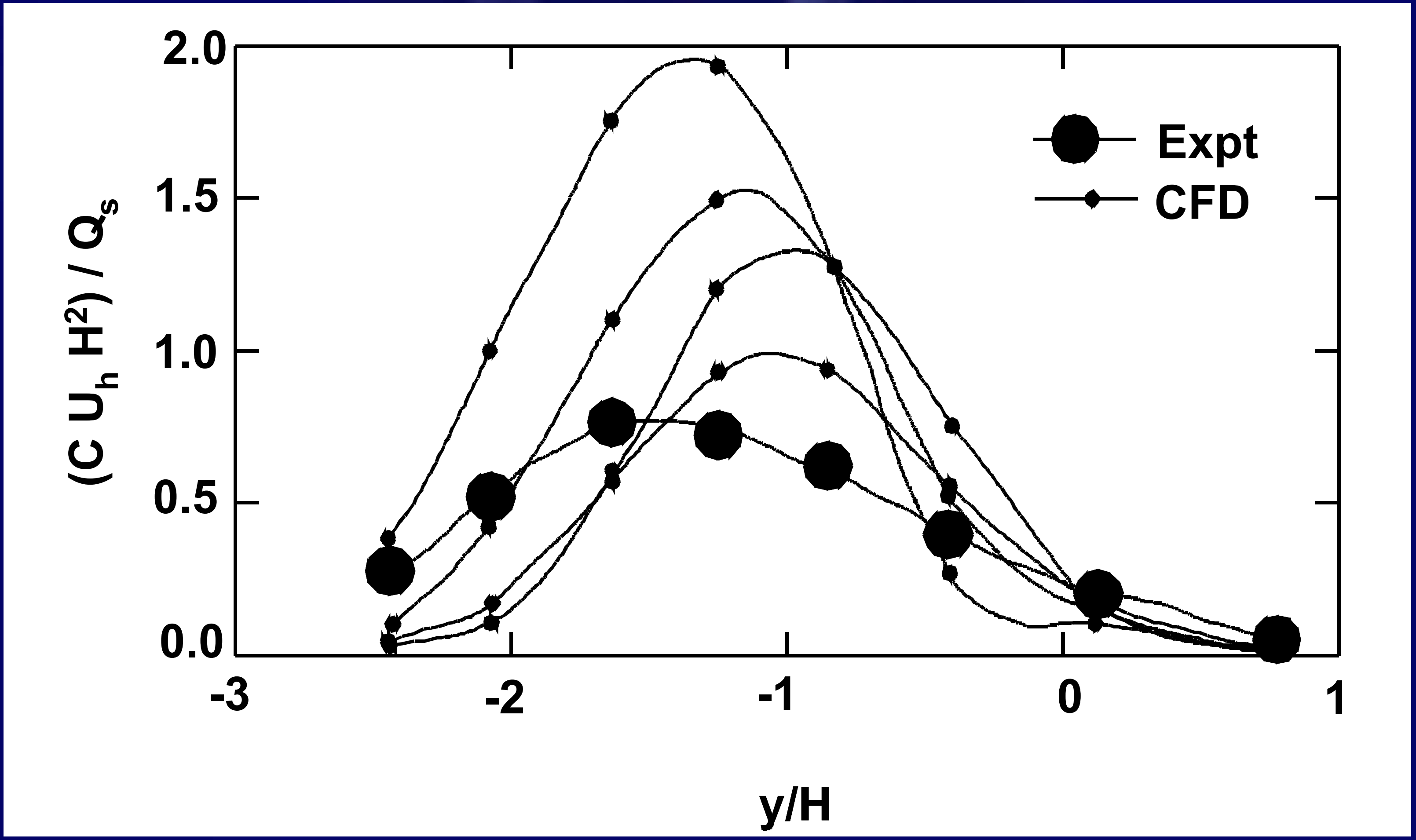
# *RESULTS (CONTINUED)*

- *Human factors (familiarity with code, user errors)*
- *Numerical accuracy (different meshes and numerical schemes, available computing power)*
- *The atmospheric boundary layer.*

# *Simple Building Results - Cowan, Castro and Robins, 1997*



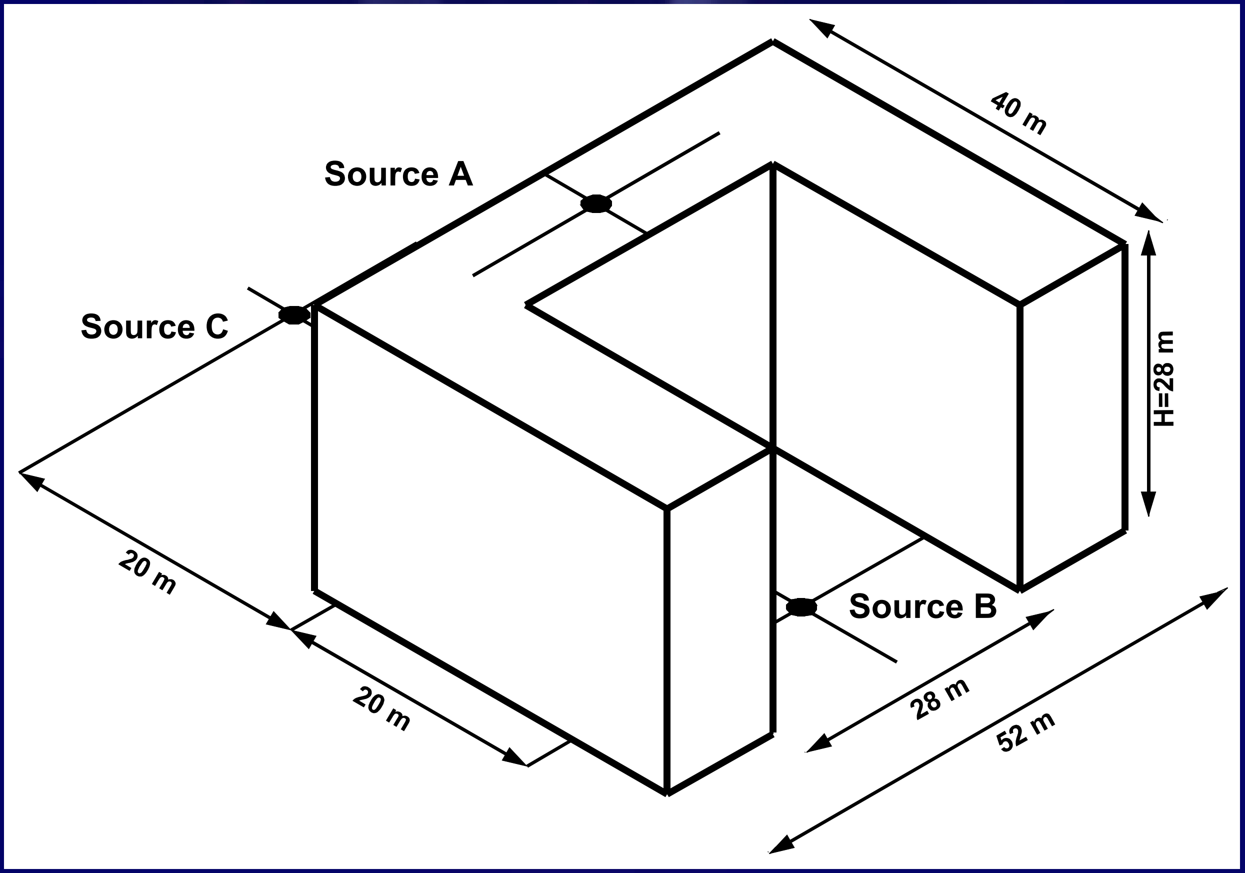
# *Simple Building Results*
## *Cowan, Castro and Robins, 1997*



## *Computational Wind Engineering 2000 – T. Stathopoulos, Centre for Building Studies, Concordia University*

- *"In spite of some interesting and visually impressive results produced with CWE, the numerical wind tunnel is still virtual rather than real"*
- *"Practitioners should be warned about the uncertainties of the numerical wind tunnel (CFD) results and urged to exercise caution in their utilization"*

# *CWE97 - Leitl, Kline, Rau and Meroney*



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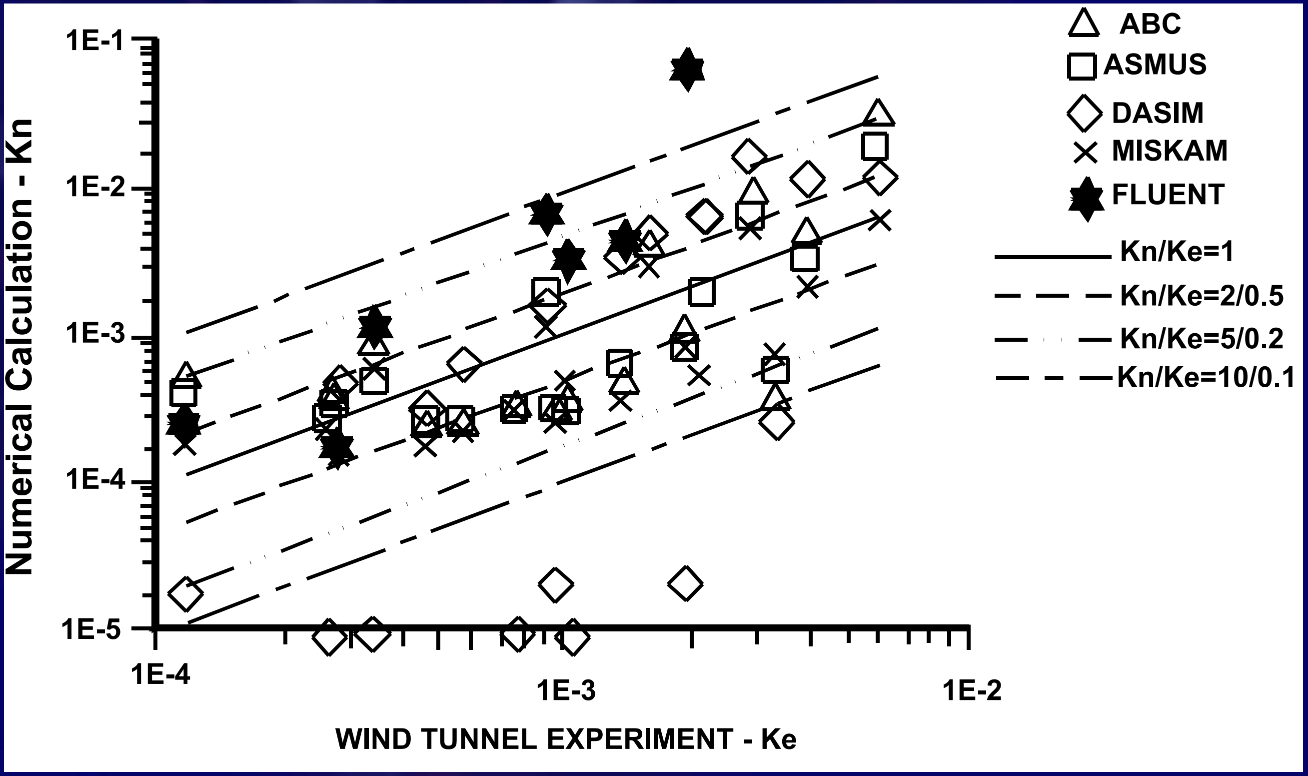


# *Wind Tunnel Modeling*

# *Accurate - From EPA Fluid Modeling Guideline, 1981*

- *Basic equations are solved by simulating the flow at a reduced scale, then measuring the desired quantity*
- *An analog computer with near infinitesimal resolution and near infinite memory.*
- *If a mathematical model cannot simulate the results of an idealized laboratory experiment, how can it possibly be applicable to the atmosphere."*

# Compares Well With the Atmosphere

- Wind and turbulence profiles consistent with underlying surface roughness.
- Plume height and width match boundary layer theory and consistent with surface roughness.
- Measured concentrations are steady-state averages (e.g. 15 minutes)
- The above has been documented.

# *Wind Tunnel Modeling*

- Used to Validate CFD and Analytical Methods
- Controlled Meteorological Conditions
- Results Sensitive to Design Changes
- Like a Field Study

# *CFD and Wind Tunnel Comparison*

- *Basic equations of motion solved*
  - *CFD: yes but turbulence closure is approximate.*
  - *WT: yes and turbulence is accurately modeled.*
- *Validation against field data bases*
  - *CFD: ?*
  - *WT: yes. The wind tunnel is also used to validate CFD and analytical techniques.*
- *Dispersion comparability with atmosphere demonstrated.*
  - *CFD: ? EPA is working on this*
  - *WT: yes*

# *CFD and Wind Tunnel Comparison*

- *Standard method of application.*
  - *CFD: no. EPA is working on this.*
  - *WT: yes. EPA has guidelines.*
- *Provides conservative estimates*
  - *CFD: ?*
  - *WT: yes.*

# *Steps in Conducting a Wind Tunnel Study*

- Construct Scale Model
- Specify Model Operating Conditions
- Setup and Visualization
- Measure Concentrations
- Compare Results with Design Criteria
- Reporting


LBL Molecular Foundry

# *NREL Model in Tunnel*

# *Steps in Conducting a Wind Tunnel Study*

- Construct Scale Model
- Specify Model Operating Conditions

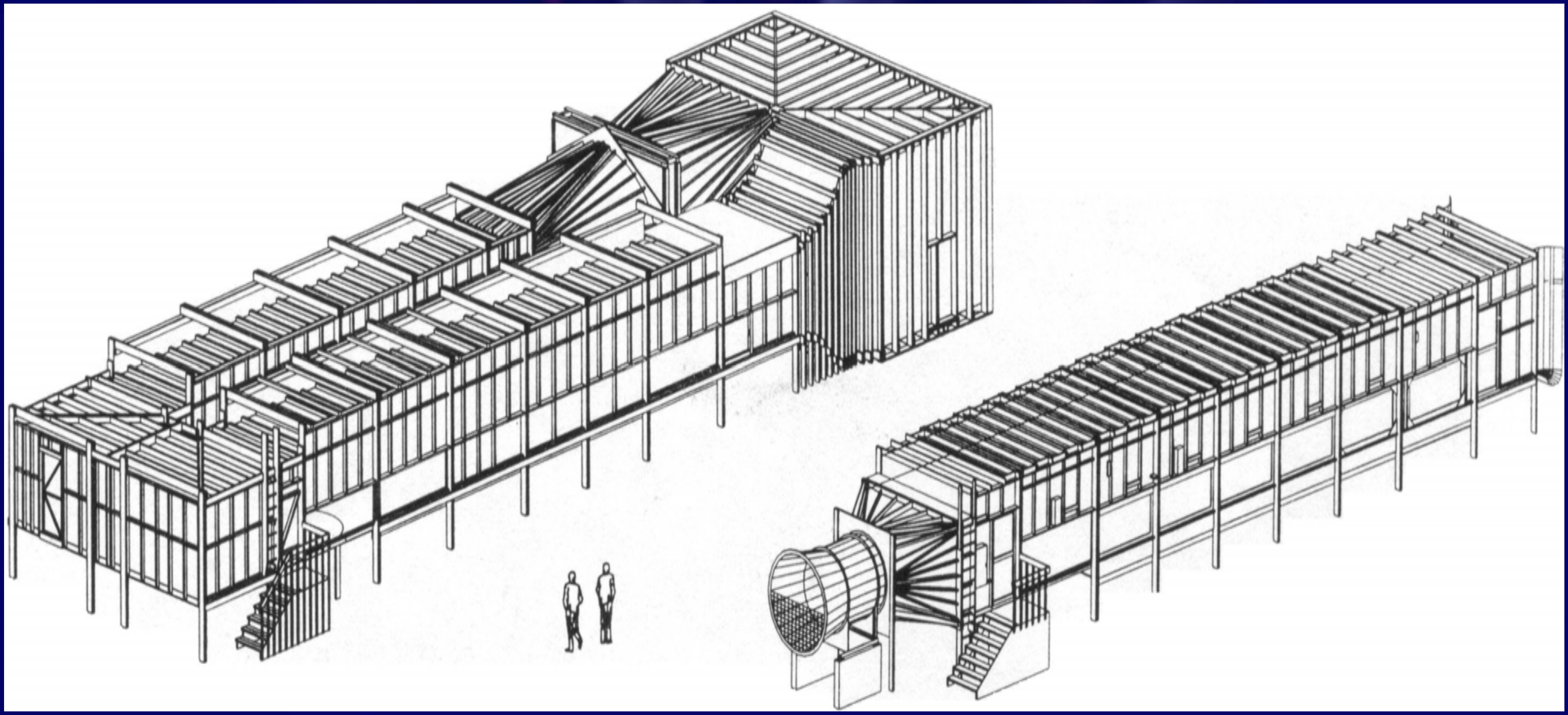
# *Inputs that are needed*

- *Stack height/location*
- *Exhaust flow*
- *Exhaust velocity*
- *Exhaust temperature*
- *Intake locations/flows*
- *Site wind conditions*

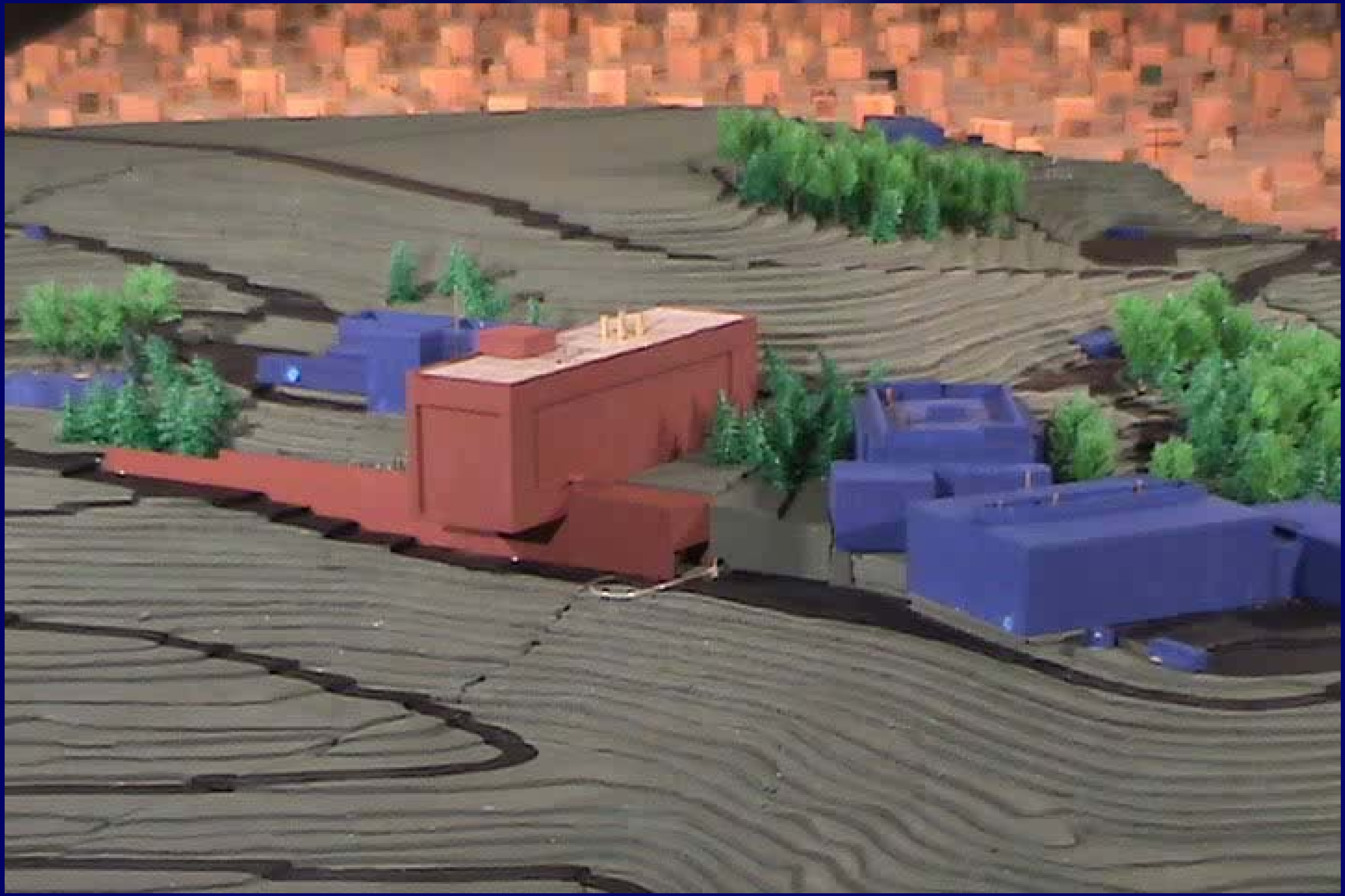
# *Steps in Conducting a Wind Tunnel Study*

- **Construct Scale Model**
- **Specify Model Operating Conditions**
- **Setup and Visualization**

# *Wind tunnel*

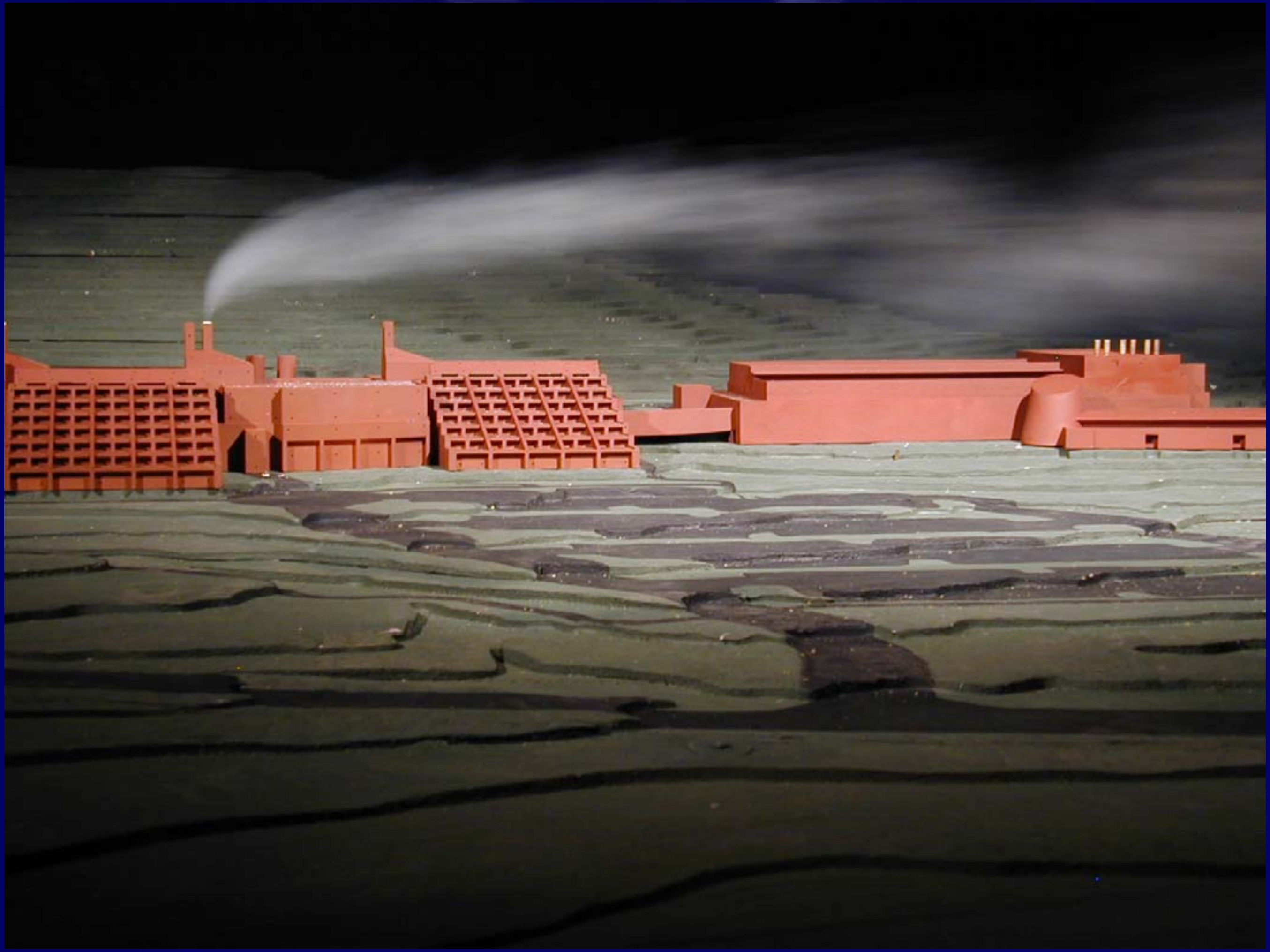


# LBL MF
# In CPP Wind Tunnel

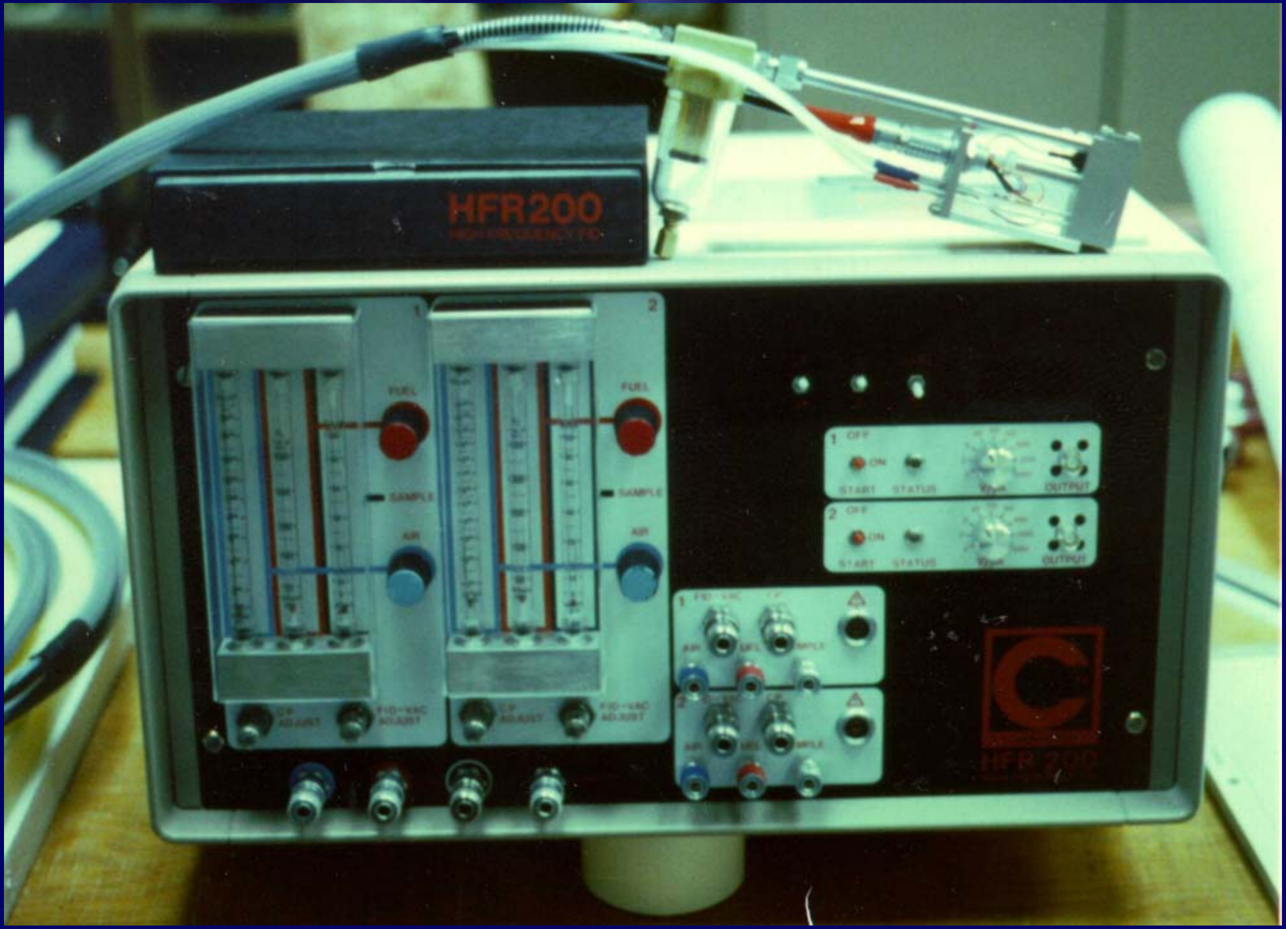


# Model QA

# NREL Flow Visualization



# Concentration Measurements
## Continuous Total Carbon Analyzer



# Concentration Measurements

*Tracer from stack*

*Sample withdrawn from intake*

# *Typical Results Referenced to the ASHRAE 400 ug/m3 per g/s Criteria*

*LBL MF*

*20 ft, 28000 cfm, 3579 fpm; Max C/m = 457 @ Roof*

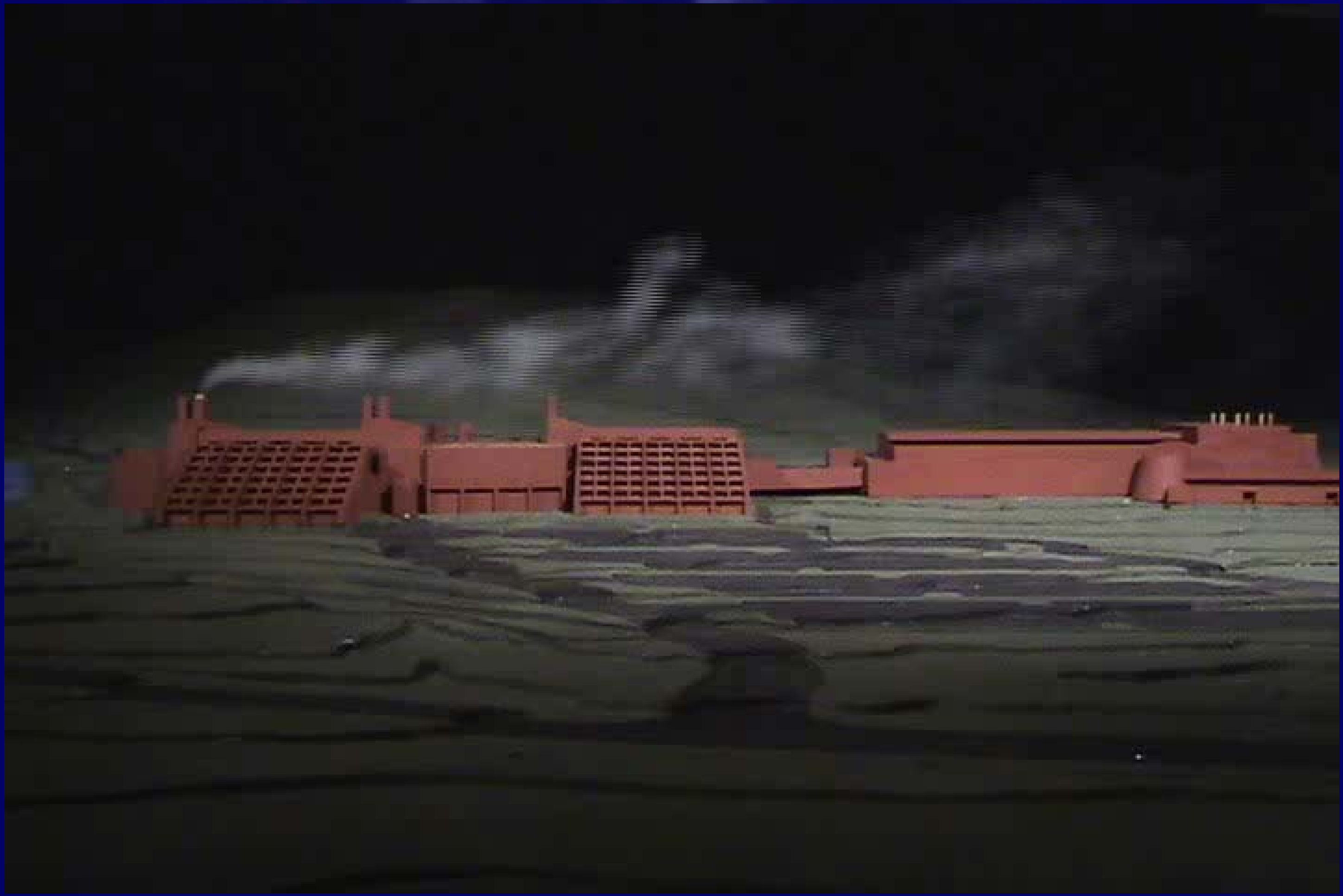
*Wind Direction – S; Wind Speed = 8 m/s*

*LBL MF*
*30 ft, 28000 cfm, 3579 fpm; Max C/m = 209 @ Roof*
*Wind Direction – S; Wind Speed = 8 m/s*

*LBL MF*
*10 ft high, 10000 cfm, 1930 fpm; Max C/m = 552 @ Plaza*
*Wind Direction – S; Wind Speed = 2 m/s*

*NREL S&TF*
*20 ft, 16500 cfm, 2954 fpm; Max C/m = 313 @ Intake*
*Wind Direction – ESE; Wind Speed = 12 m/s*

# *NREL SERF*
# *35.8 ft, 35000 cfm, 3033 fpm; Max C/m = 89 @ Intake*
# *Wind Direction – WSW; Wind Speed = 5 m/s*



*New Lab*

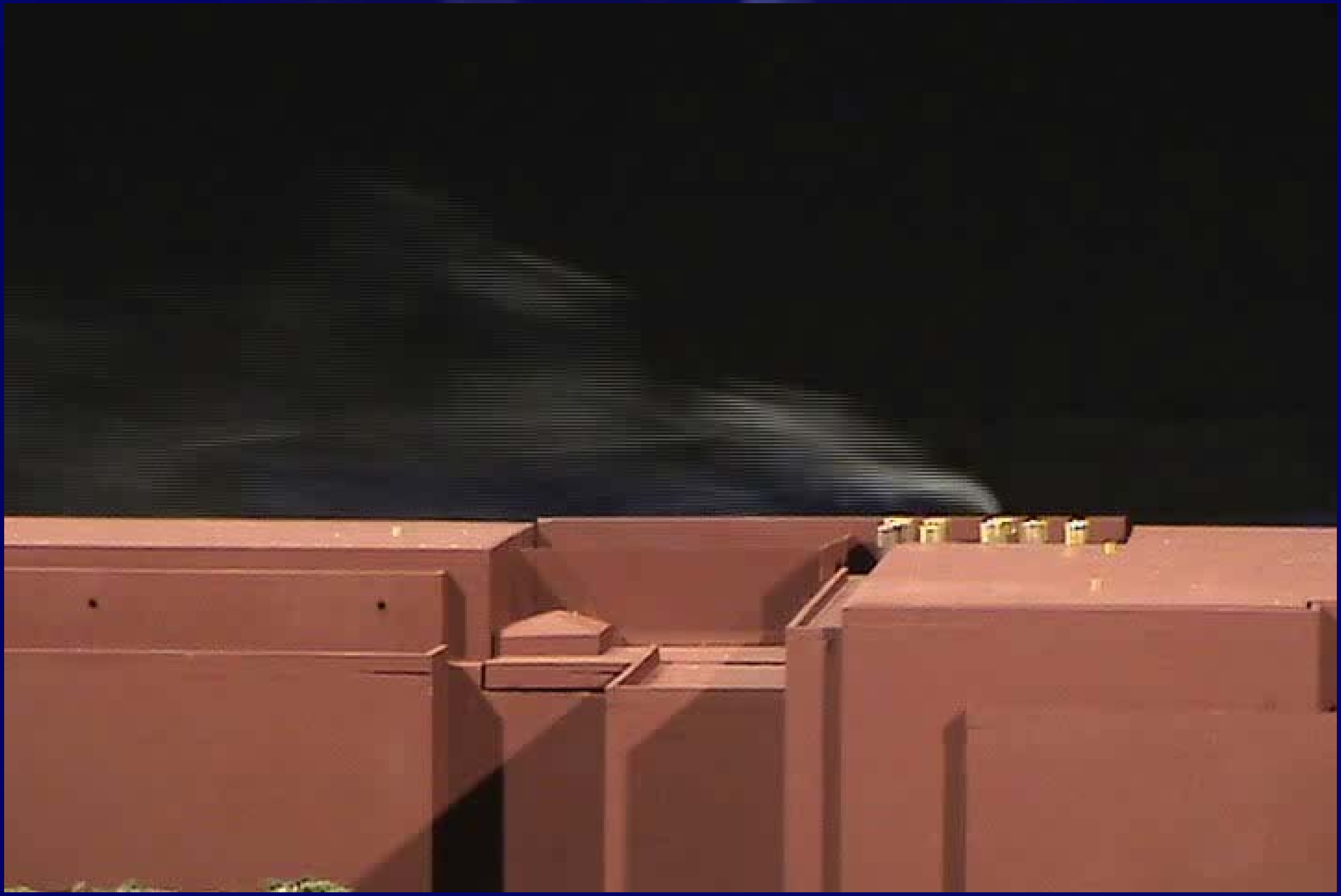
*Strobic Exhaust (46,000 cfm); Max C/m = 184 @ Roof*

*Wind Direction – NE; Wind Speed = 11.3 m/s*

New Lab

Strobic (4500 cfm) alone; Max C/m = 1410 @ Roof

Wind Direction – SW; Wind Speed = 9 m/s



*New Lab*
*Strobic (4500 cfm) with others; Max C/m = 393 @ Roof*
*Wind Direction = SW; Wind Speed = 11.3 m/s*

*New Lab*
*Strobic (28,500 cfm); Max C/m = 635 @ Intake*
*Wind Direction – NE; Wind Speed = 7 m/s*

*New Lab*
*Upblast (1000 cfm); Max C/m = 2836 @ intake*
*Wind Direction – SE; Wind Speed = 9 m/s*

# Where Does This Fit in to Benefits of Labs21 Approach

- ✓ Reduced operating costs.
- ✓ Improved environmental quality.
- ? Expanded capacity.
- ✓ Increased health, safety, and worker productivity.
- ✓ Enhanced community relations.
- ✓ Superior recruitment and retention of scientists.

# *Summary – Modeling Exhaust Dispersion*

- *Understand complexity of air flow*
- *Use general guidelines to start*
- *Avoid graphical methods*
- *Caution when using analytical or CFD methods*
- *Wind tunnel modeling most accurate*
- *Use dispersion modeling to ensure concentration design criteria are met*