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Assessment of the Toxicity of Coal-Fired Power Plant Emissions: Preliminary Results from the TERESA Study

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The Team

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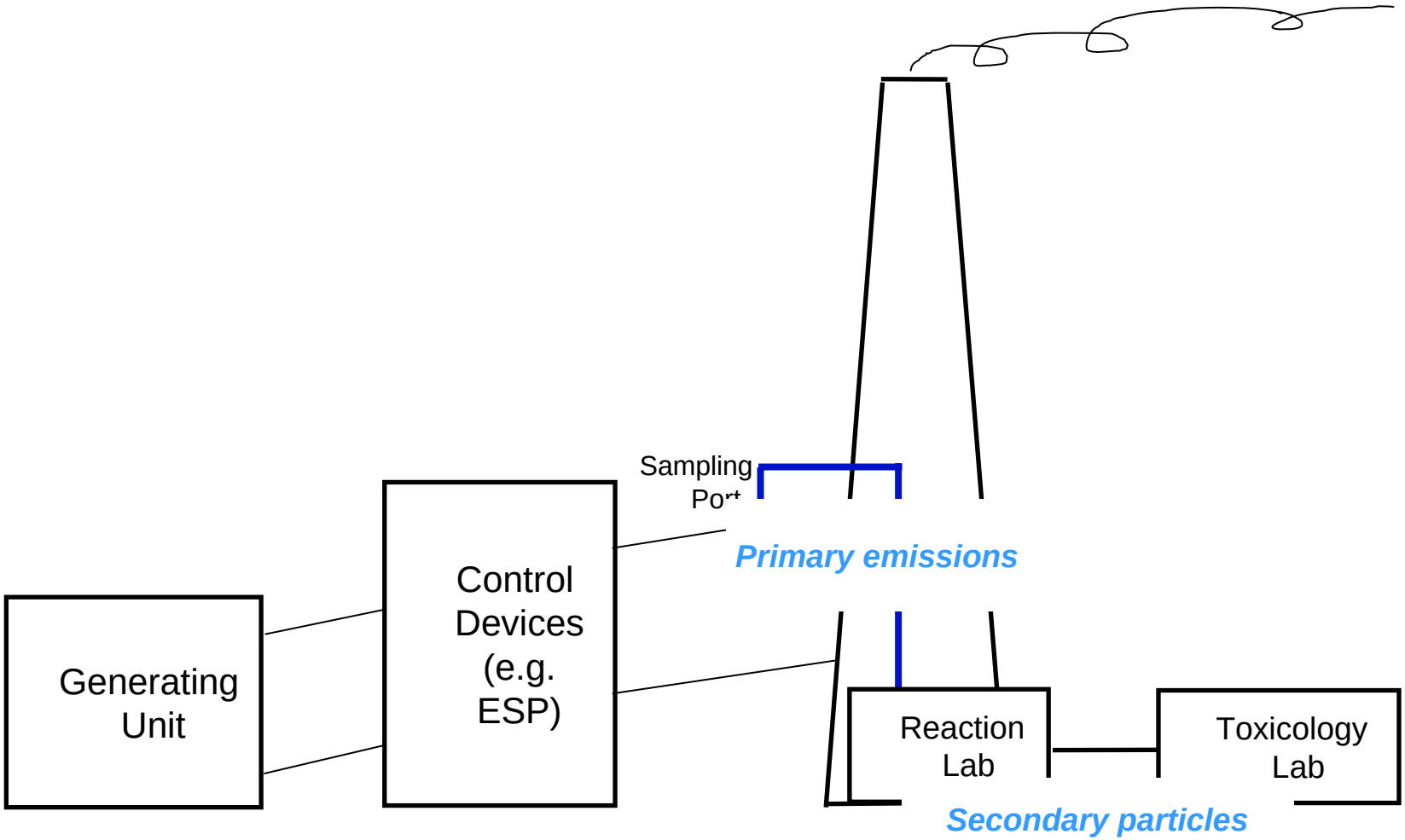
TERESA: Overview

TERESA: Toxicological Evaluation of Realistic Emissions of Source Aerosols

Approach:

- Evaluate toxicity of *secondary* particles from power plants, at power plants
- Expose rats to multiple atmospheric scenarios
- Later: examine mobile source emissions using same methods

Study Schematic



Why is TERESA Important?

- Highly innovative and ground-breaking
  - First study to evaluate both primary and secondary particles at power plants
- Previous studies:
  - Collected primary coal fly ash
  - Inhalation exposure studies using primary emissions from pilot combustors

Objectives

Investigate:

- Relative toxicity of coal-fired power plant emissions, mobile source emissions, and ambient particles
- Effect of atmospheric conditions on formation/toxicity
- Impact of coal type and pollution control technologies on toxicity

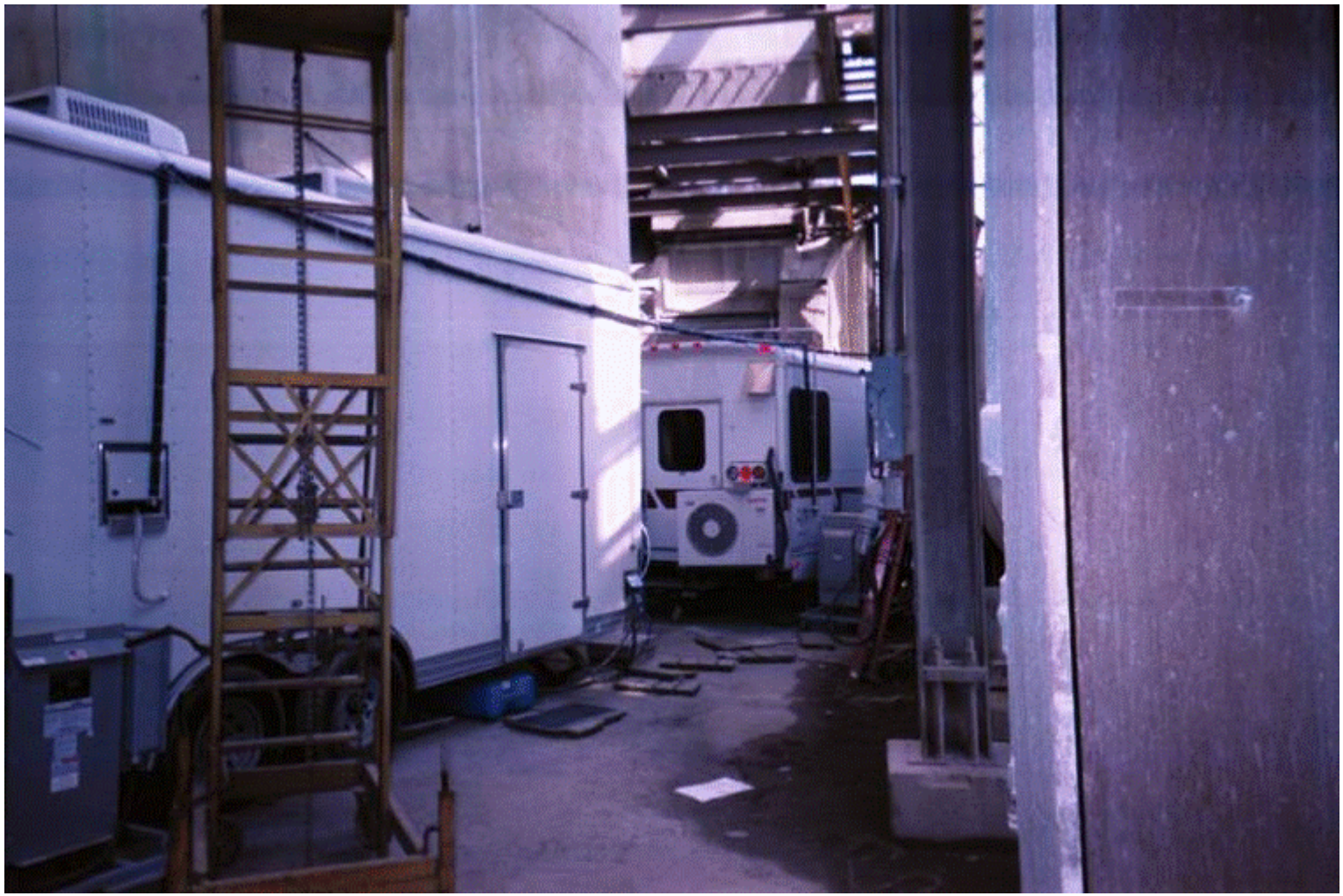
Three Plants in Program

1. Midwest: Powder River Basin coal (low sulfur, low ash), no SCR for NOx removal. Fieldwork completed November 2004.

2. Southeast: Low sulfur (<1%) eastern bituminous coal, no scrubber for SO_2 removal, with SCR. Fieldwork in progress.

3. Midwest: Medium-to-high sulfur (>2-3%) eastern bituminous coal, scrubbed unit, with SCR. Fieldwork scheduled for summer 2006.

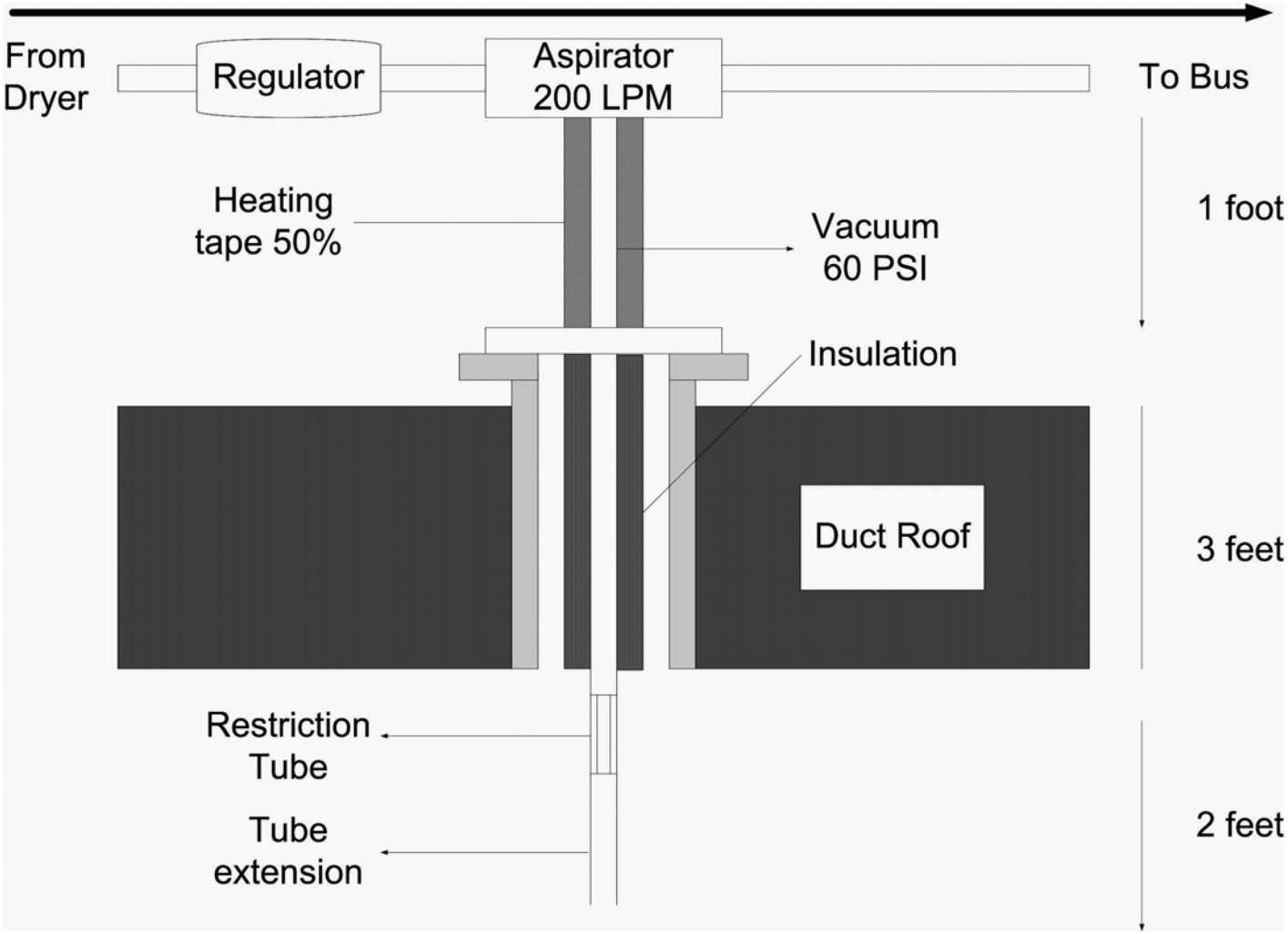
Field Operations at Plant 1



Study Methods

- Stack Sampling and Dilution
- Emissions Aging and Atmospheric Simulation
- Exposure Characterization
- Animal Exposures
- Toxicological Methods

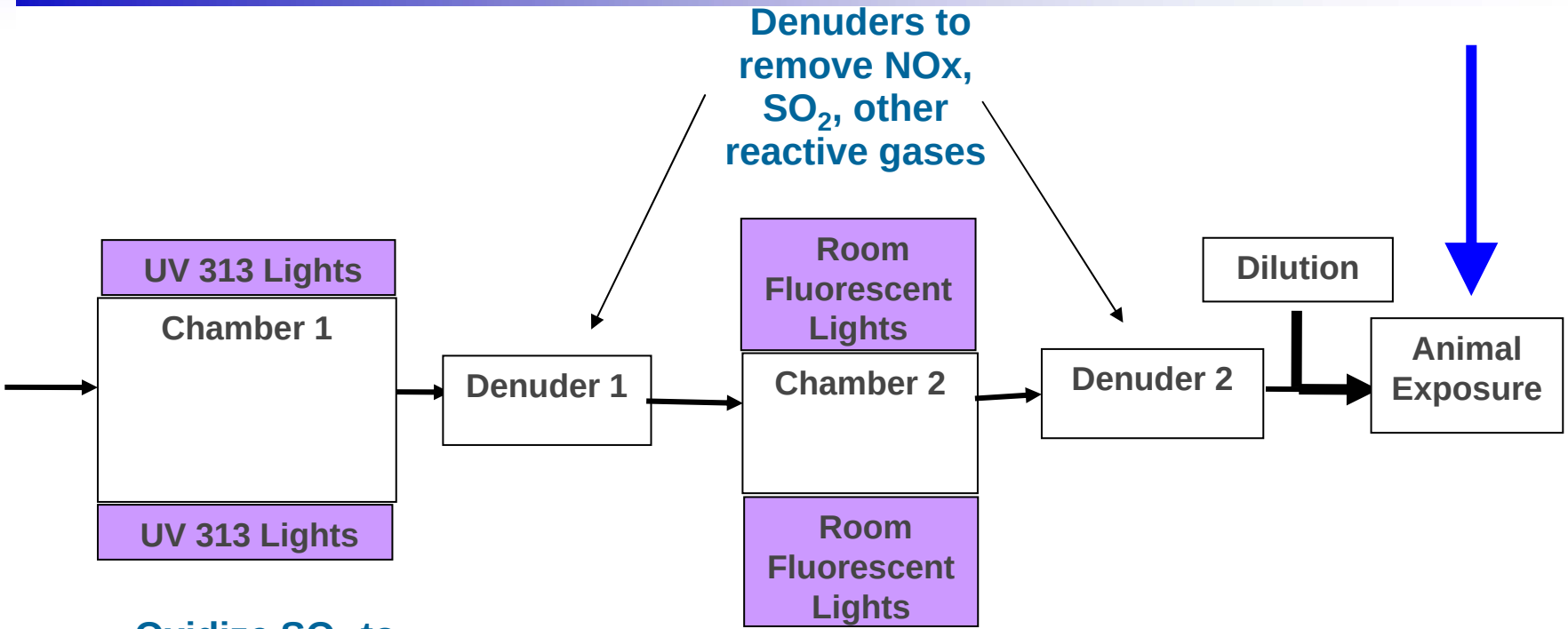
Stack Sampling and Dilution



Emissions Aging and Atmospheric Simulation: Technical Requirements

- Large, stable, and reproducible aerosol mass
- Consistent size distribution
- Sufficient aerosol flow
- Stable output in a short period of time
- Secondary PM generated under typical atmospheric conditions
- Aerosol components in ratios consistent with aged plumes
- Low concentrations of unreacted gases (SO_2, NOx, O_3)
- Small photochemical chamber for use in mobile laboratory
- Minimal particle losses

Emissions Aging and Atmospheric Simulation



Oxidize SO_2 to sulfuric acid with hydroxyl radicals.

Coat particles with secondary organic aerosol (SOA) through addition of α-pinene + ozone. Add NH_3 to partially neutralize strong acidity.

Exposure Characterization

	Parameter	Medium and Method
Integrated	$PM_{2.5}$ mass	47 mm Teflon filter; gravimetric
	Elements	Teflon filter; XRF
	Sulfate, nitrate, NH_4, NH_3, SO_2, HNO_3, HONO	Diffusion denuder + Teflon filter; ion chromatrography
	Strong acidity	Teflon filter; pH analysis
	EC/OC	47mm Quartz filter; TOR method
	SOA species (pinonic acid, pinic acid, etc.)	47mm teflon filter
	α-Pinene	Tenax Tubes
	Ketones and aldehydes	DNPH cartridges
Continuous	$PM_{2.5}$ mass	R&P TEOM
	Particle number	CPC TSI 3022
	O_3	UV absorbance method
	NOX	Chemiluminescence method
	SO_2	Pulsed fluorescence method
	RH and T	Omega

Animal Exposures

- 6-hour exposures
- Animals maintained in accordance with the Harvard Standing Committee on Animal Use
- Outside support from local universities

Toxicological Assessment

Stage I Assessment (normal rats):

- Pulmonary function/breathing pattern
- *In vivo* oxidative stress via chemiluminescence
- Blood cytology (CBC/differential)
- Bronchoalveolar lavage (LDH, βNAG, total protein)
- Pulmonary histopathology

Stage II Assessment (rat MI model; Wellenius *et al*., 2002):

- Telemetry: cardiac function (ECG, HR, HRV), BP, temperature
- Blood chemistry (endothelin-1, CRP, IL-1, IL-6, TNFα)
- Pulmonary function/breathing pattern

Exposure Scenarios

Scenario	Composition	Simulated Atmospheric Condition
1	Filtered air	Sham exposure
2	Primary (un-aged) emissions, diluted to ~ 1 ppm SO_2	Primary stack emissions
3	Primary emissions + hydroxyl radicals	Aged plume, oxidized stack emissions, sulfate aerosol formation from nucleation
4	Primary emissions + hydroxyl radicals + ammonia	Aged plume, sulfate aerosol partially neutralized by ammonia
5	Primary emissions + hydroxyl radicals + α-pinene/ozone	Aged plume, unneutralized particle strong acidity, plus secondary organic aerosol (SOA) derived from biogenic emissions
6	Primary emissions + hydroxyl radicals + ammonia + α-pinene/ozone	Aged plume, mixture of neutralized sulfate and SOA

Exposures Performed at Plant 1

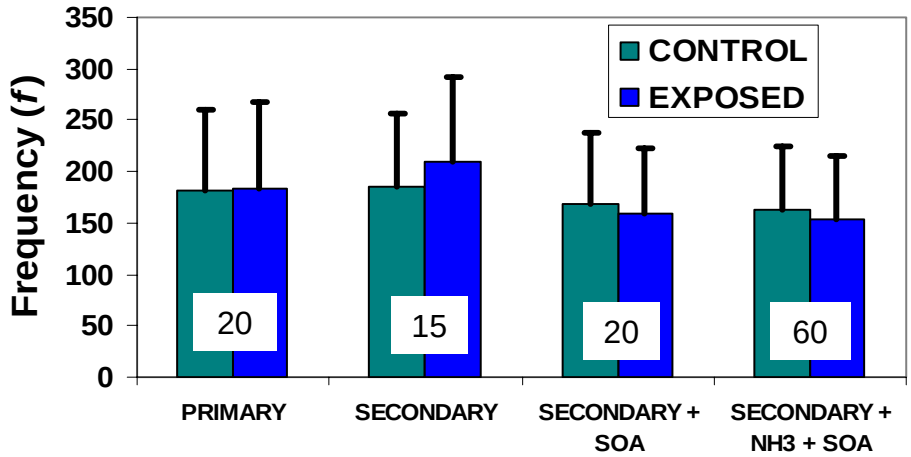
Exposure Round	Scenario	Dates
1	Primary	May 10, 11, 12 and 13
2	Secondary + NH_3 + SOA (run 1)	June 22, 23, 25 and 26
3	Secondary + NH_3 + SOA (run 2)	June 27, 28, 29 and 30
4	Secondary + SOA	October 4, 5, 6 and 7
5	Secondary + NH_3 + SOA (run 3)	October 11, 12, 13 and 14
6	Secondary	November 13, 14 and 15

Exposure Data, Plant 1
Fall 2004

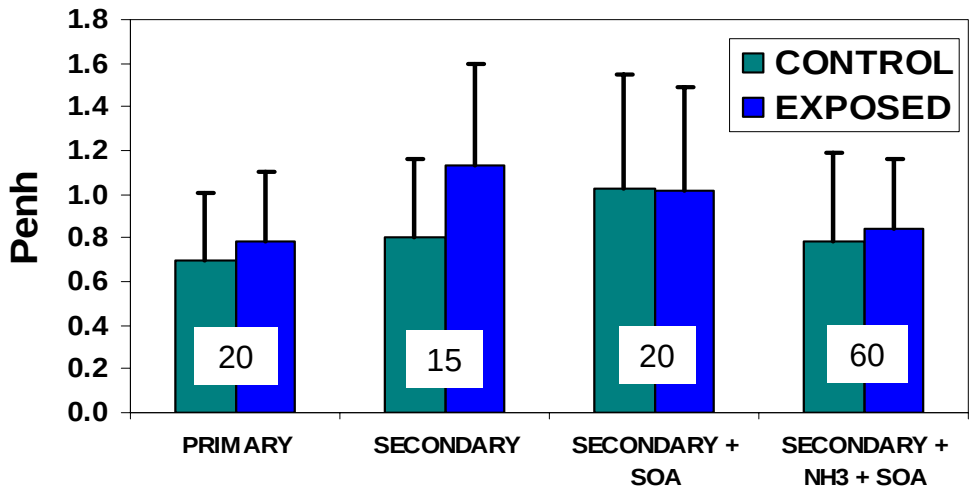
	Round 1: October 4-7 (oxidized emissions + SOA) *n*=4	Round 2: October 11-14 (oxidized, neutralized emissions + SOA) *n*=4	Round 3: November 3-5 (oxidized emissions only) *n*=3
Mass (μg/m^3)	193 (73)	141 (16)	69 (10.4)
SO_4 (μg/m^3)	57.1 (24)	38.7 (11)	31.8 (1.3)
NO_3 (μg/m^3)	1 (0.4)	37.7 (6.2)	1.1 (1.2)
NH_4^+ (μg/m^3)	3.1 (1.2)	14.7 (4.1)	3.3 (1.7)
Acidity (μg/m^3 H_2SO_4)	49.1 (22.7)	1.6 (1.7)	22.5 (4)
SO_2 (ppb)	17.5 (4.4)	16 (3)	9.3 (3.5)
HNO_3 (ppb)	1.6 (0.3)	2.3 (0.6)	0.6 (0.1)
HONO (ppb)	11.2 (5.1)	7.8 (1.5)	5 (1)
NH_3 (ppb)	20.8 (3.8)	16.1 (6.2)	9.9 (6.2)
Organic carbon (μg/m^3)	130.7 (7.1)	100.6 (6.6)	54.9 (6.9)
Elemental carbon (μg/m^3)	12.1 (9.4)	4.3 (0.7)	2.8 (1.6)
Formaldehyde (μg/m^3)	16.1 (3.6)	18.1 (3.9)	N/A
Acetaldehyde (μg/m^3)	5.2 (1)	4.8 (0.6)	N/A
Acetone (μg/m^3)	15.5 (5.2)	13 (2.9)	N/A
Pinene (μg/m^3)	0.6 (0.1)	0.8 (0.3)	N/A

Results from Plant 1: Respiratory Effects

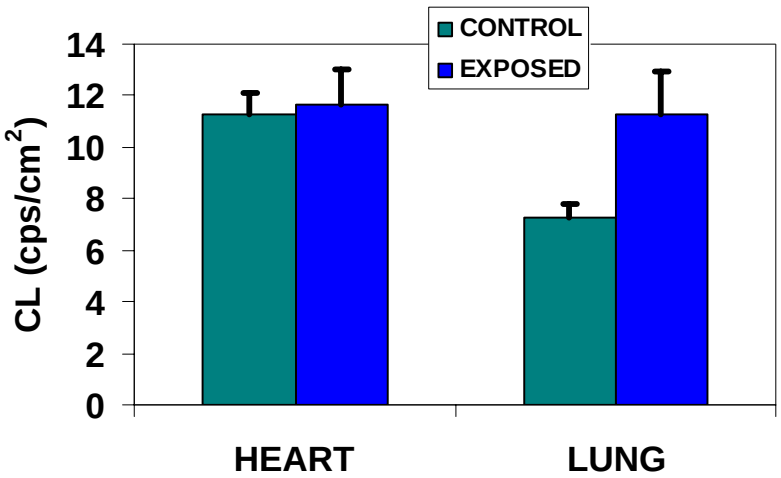
Respiratory Frequency: Indicator of Irritation

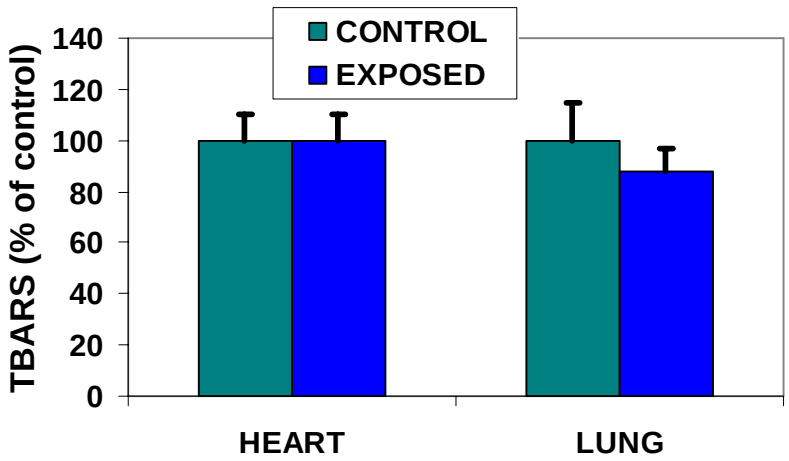


Enhanced Pause: Indicator of Airway Restriction



Results from Plant 1: Oxidative Stress Oxidized, Neutralized Emissions + SOA





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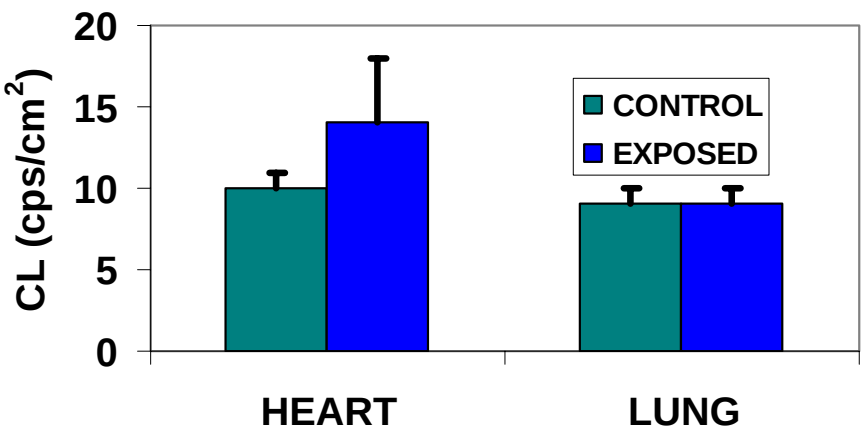
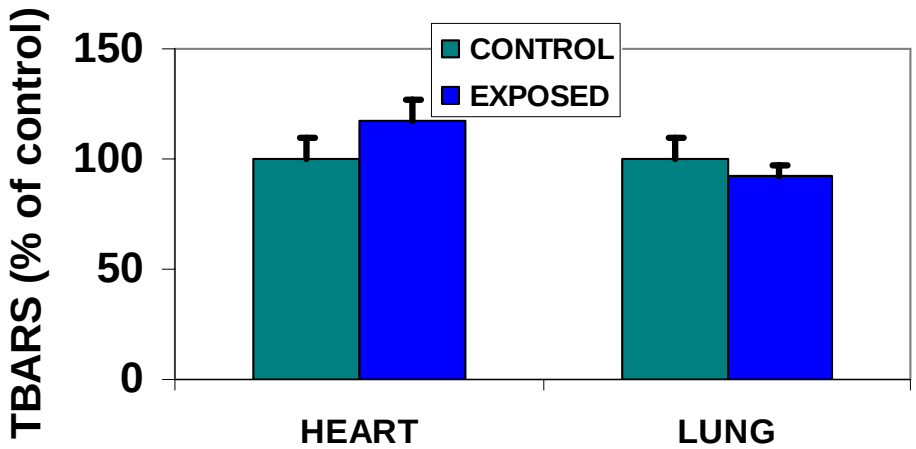
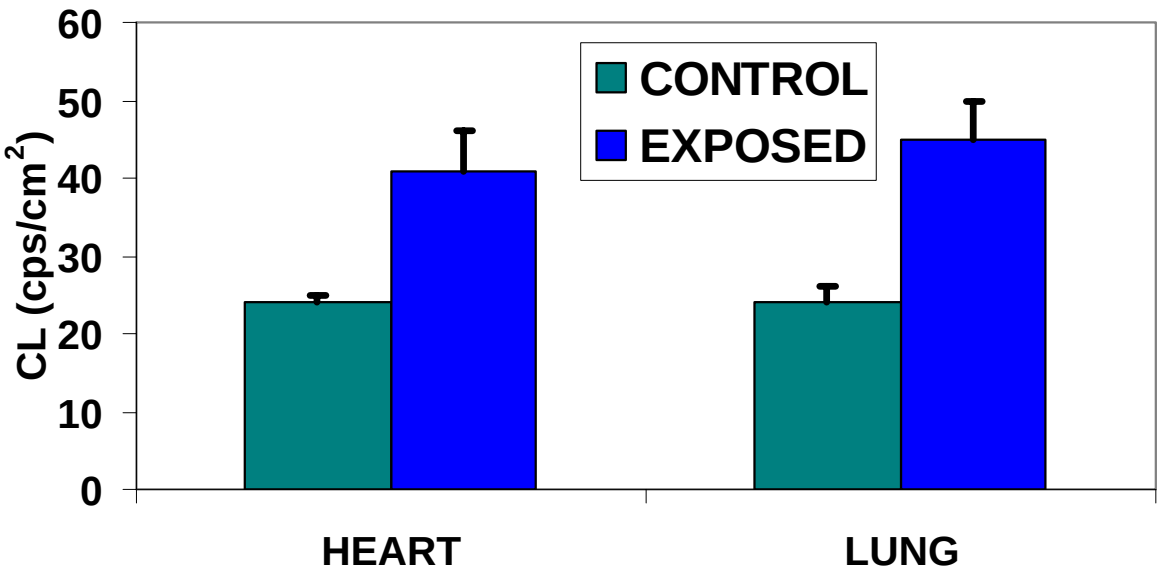




Boston CAPs: Oxidative Stress

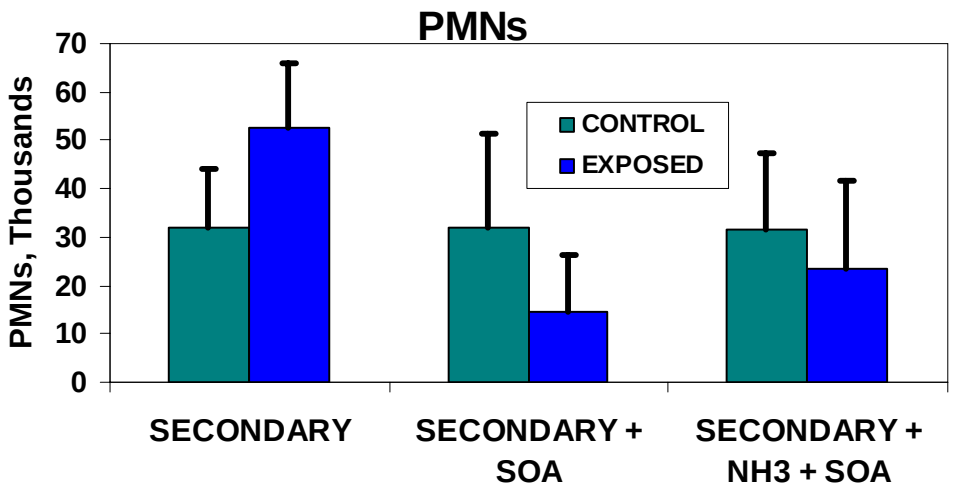


Gurgueira et al., 2002

Results from Plant 1: BAL Fluid Analysis

Total Cell Count
Neutrophils
Macrophages
Lymphocytes
Eosinophils
Epithelial cells
LDH
βNAG
Total protein

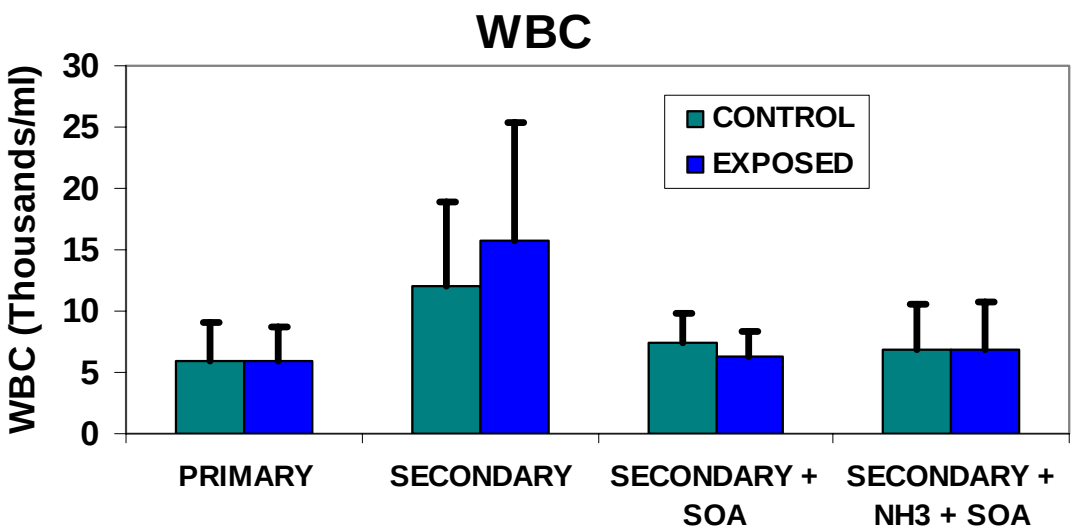
All no significant differences



Results from Plant 1: Blood Cytology

Hgb & Hcrt
Platelet count
WBC count
PMNs
Lymphocytes
Monocytes
Eosinophils

All no significant differences



Results from Plant 1: Histopathology

- No histopathological changes in lung parenchyma, airways, or pulmonary vessels
- No differences between exposed and control animals

Conclusions

- Little biological activity observed at Plant 1
- Low primary particles

Future Directions

- More exploration of exposure results
- Fieldwork now at Plant 2 (Southeast)
- Preliminary results “more interesting”
- Plant 3 next summer
- Mobile source component funded through the Harvard/EPA PM Center