That Gunk in MY House?

Personal Exposure to Indoor Air Pollution

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ABSTRACT:

Many, perhaps most, of the air pollutants of concern are more of a risk from indoor sources than from the "usual suspects"—industry, mobile sources, hazardous waste sites. For example, the three volatile organic compounds (VOCs) at highest carcinogenic risk all have important, sometimes even exclusive, indoor sources. Semivolatile organics (e.g., pesticides) have even greater indoor/outdoor ratios. Airborne particles, implicated in respiratory and cardiovascular morbidity and mortality, have smaller indoor-outdoor ratios, but still a large percentage of children grow up in homes breathing secondhand smoke at about twice the level of the outdoor standard for fine particles. "Deep dust" in carpets seems to concentrate lead and pesticides compared to the upper portion of the carpet—and then typical vacuuming removes the upper portion but raises the "deep dust" to a more bioavailable spot. I used to think ozone was one major exception to the rule that indoors>outdoors, since outdoor ozone is chewed up by chemical reactions as soon as it enters the home, but now companies are aggressively marketing "air cleaners" that raise the level of ozone in homes above the outdoor standard. Lead from gasoline is gone but the lead from paint lingers on in windowsills for children to ingest. The data supporting these statements will be briefly presented and some individual actions that can be taken to reduce exposures will be discussed.

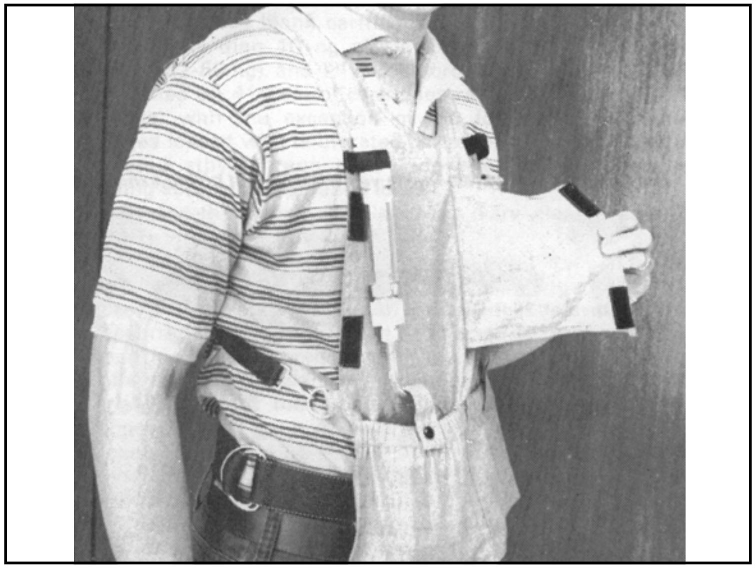
Measuring Personal Exposure

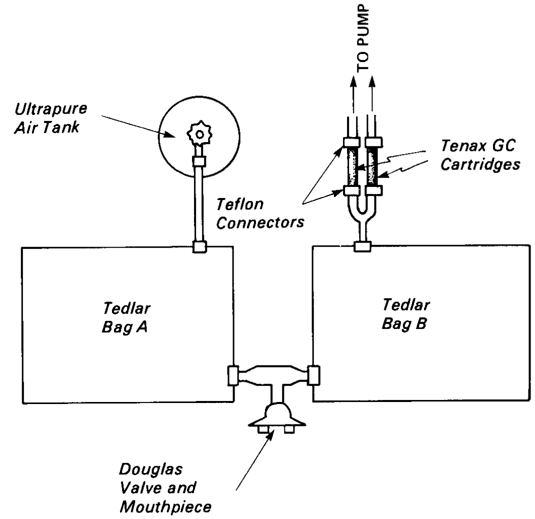
- Direct Method
  – Personal Monitors
- Indirect Method
  – Fixed Indoor and/or Outdoor Monitors
  – Time Budgets/Activity Diaries
  – Calculate the Time-Weighted Average

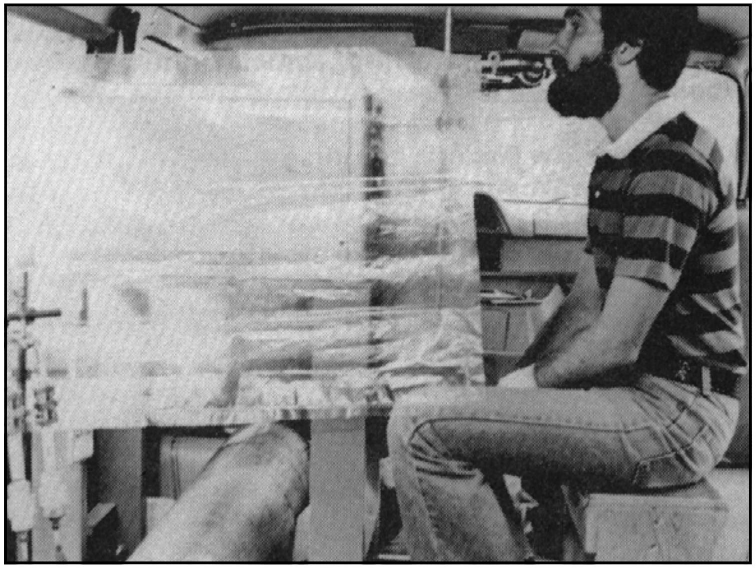
TEAM Approach

(Total Exposure Assessment Methodology)

- Probability-Based Selection of Participants
- Use of Personal Monitors
- Measure All Contributing Pathways
- Activity Diaries
- Ancillary Fixed Monitors
- Exhaled Breath (if possible)

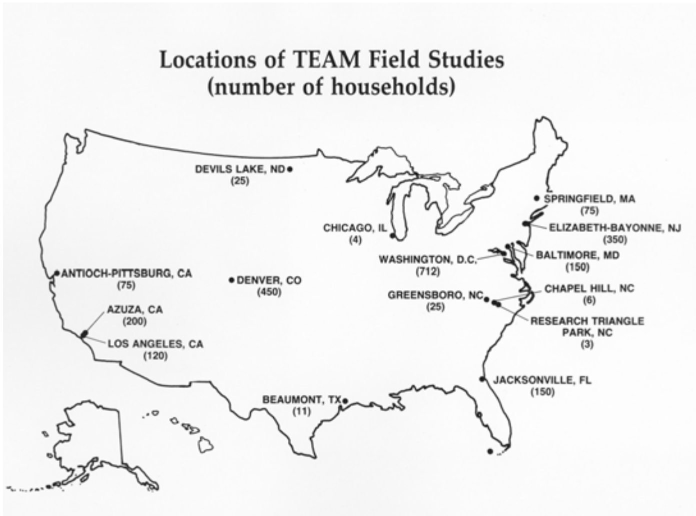


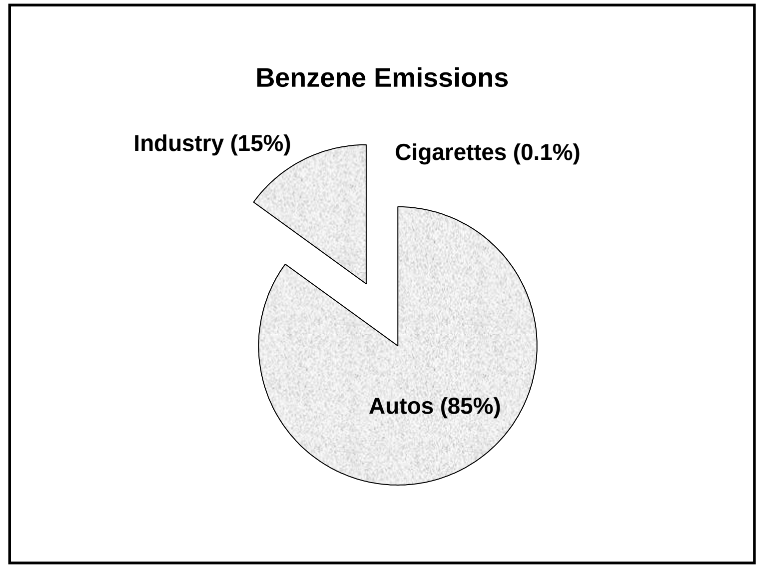


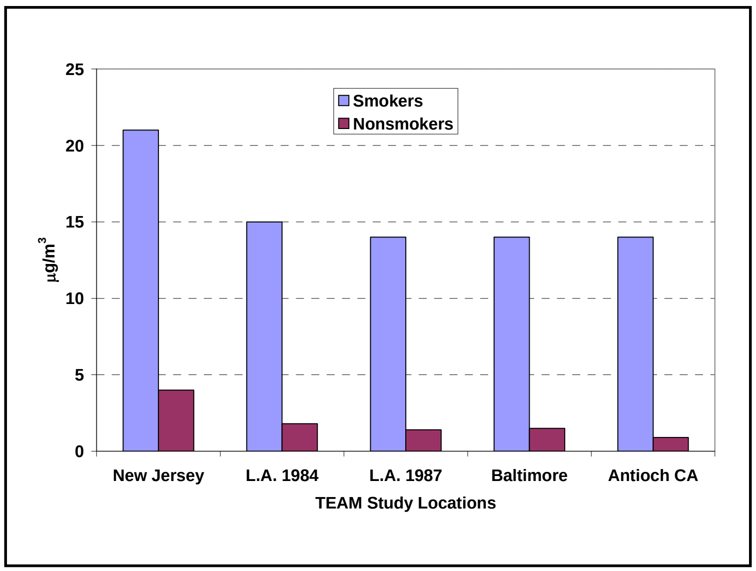


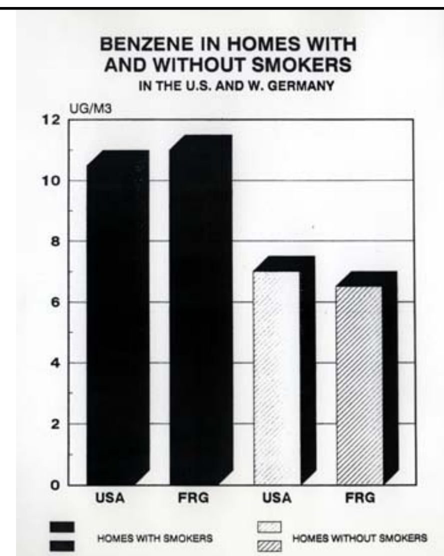
Major TEAM Studies

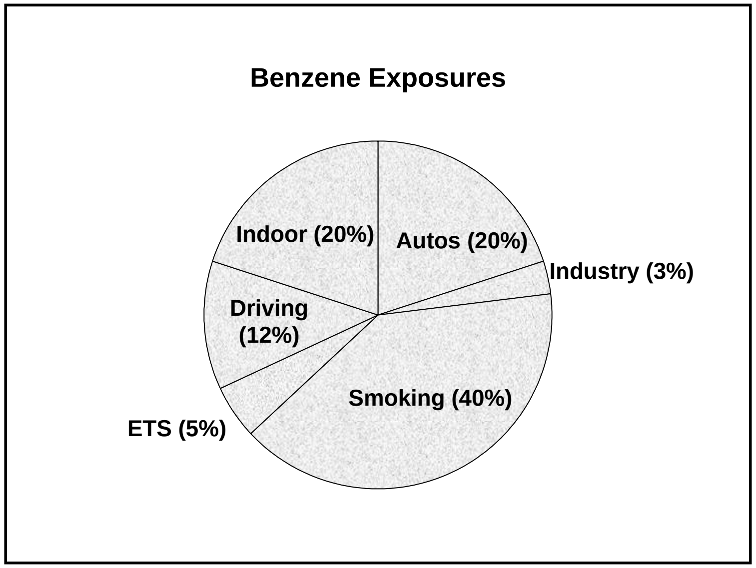
- VOCs (8 cities, 800 persons)
- CO (2 cities, 1200 persons)
- Pesticides (2 cities, 250 persons)
- Particles (2 cities, 196 persons)

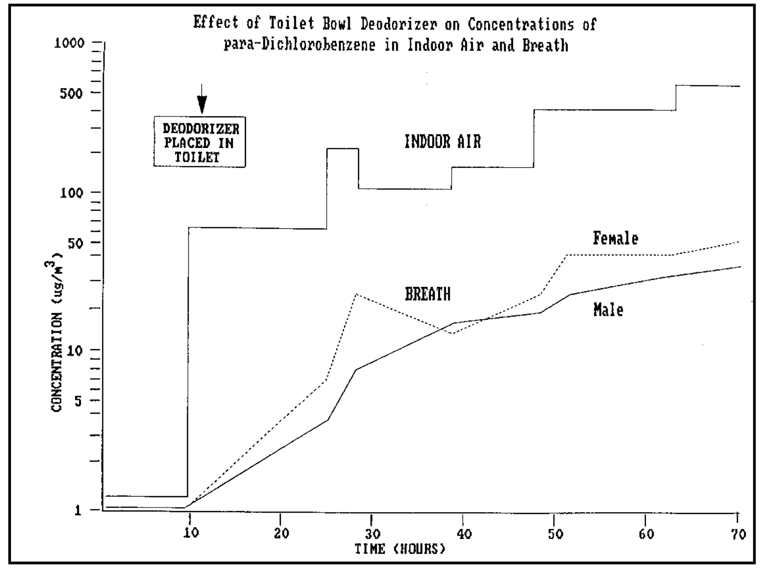

Locations of TEAM Field Studies
(number of households)
DEVILS LAKE, ND (25)
SPRINGFIELD, MA (75)
CHICAGO, IL (4)
ELIZABETH-BAYONNE, NJ (350)
WASHINGTON, D.C. (712)
BALTIMORE, MD (150)
ANTIOCH-PITTSBURG, CA (75)
DENVER, CO (450)
GREENSBORO, NC (25)
CHAPEL HILL, NC (6)
AZUZA, CA (200)
RESEARCH TRIANGLE PARK, NC (3)
LOS ANGELES, CA (120)
JACKSONVILLE, FL (150)
BEAUMONT, TX (11)

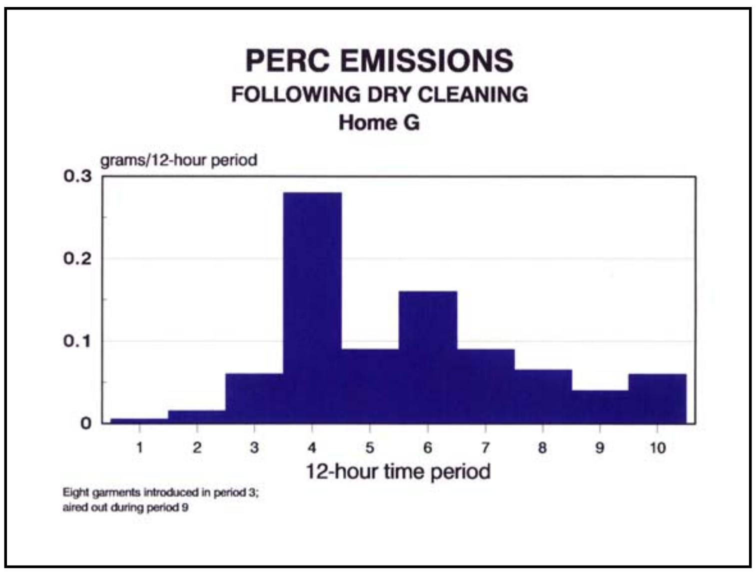

Benzene Emissions
Industry (15%)
Cigarettes (0.1%)
Autos (85%)

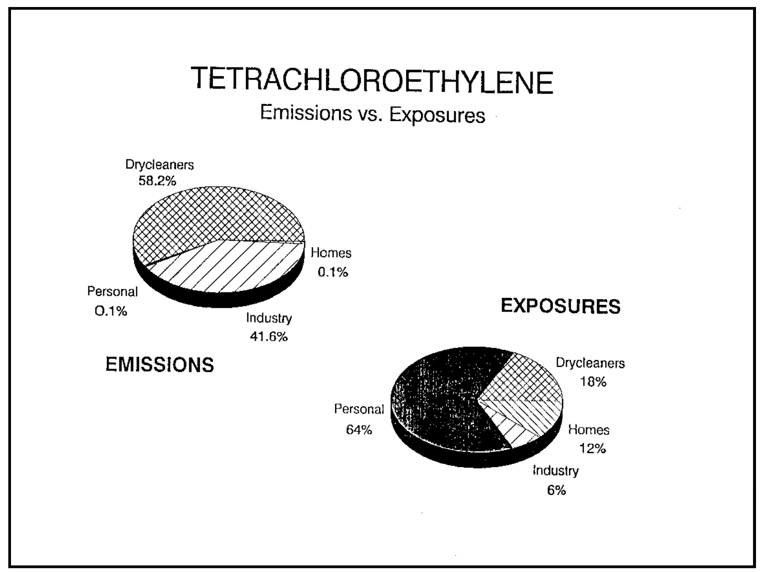

25
20
15
10
5
0
µg/m3
Smokers
Nonsmokers
New Jersey
L.A. 1984
L.A. 1987
Baltimore
Antioch CA
TEAM Study Locations

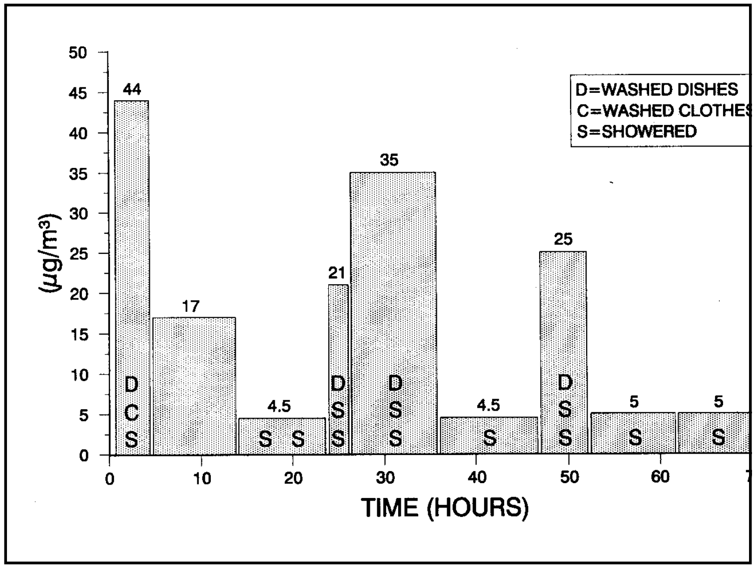

BENZENE IN HOMES WITH AND WITHOUT SMOKERS
IN THE U.S. AND W. GERMANY
UG/M3
12
10
8
6
4
2
0
USA
FRG
USA
FRG
HOMES WITH SMOKERS
HOMES WITHOUT SMOKERS

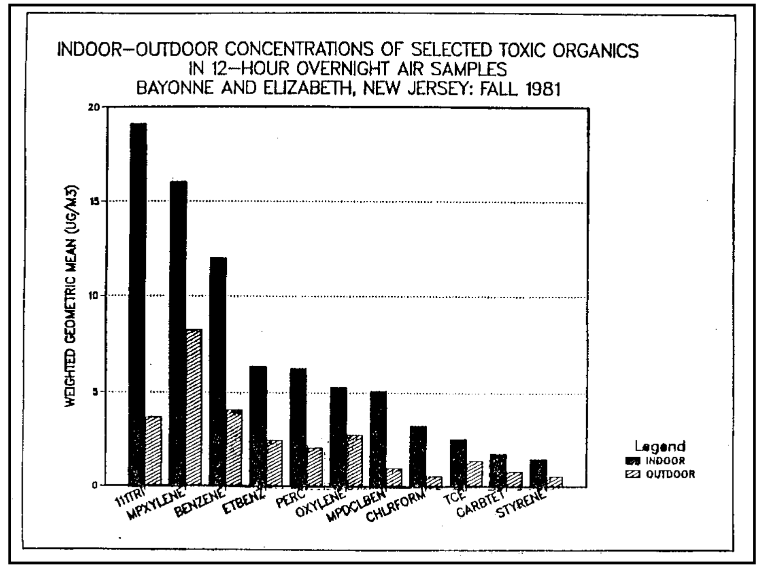

Benzene Exposures
Indoor (20%)
Autos (20%)
Industry (3%)
Driving (12%)
Smoking (40%)
ETS (5%)


Effect of Toilet Bowl Deodorizer on Concentrations of para-Dichlorobenzene in Indoor Air and Breath
DEODORIZER PLACED IN TOILET
INDOOR AIR
BREATH
Female
Male
CONCENTRATION (ug/m3)
1000
500
100
50
10
5
1
10
20
30
40
50
60
70
TIME (HOURS)


PERC EMISSIONS
FOLLOWING DRY CLEANING
Home G
grams/12-hour period
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
12-hour time period
Eight garments introduced in period 3;
aired out during period 9


TETRACHLOROETHYLENE
Emissions vs. Exposures
Drycleaners 58.2%
Homes 0.1%
Personal 0.1%
Industry 41.6%
EMISSIONS
EXPOSURES
Drycleaners 18%
Personal 64%
Homes 12%
Industry 6%



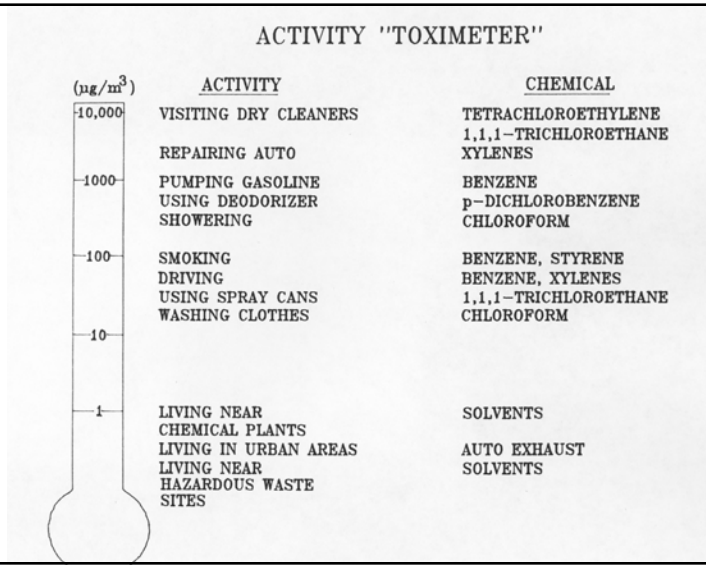


INDOOR-OUTDOOR RATIOS
BY CHEMICAL CLASS OR USE

• SCENTS AND FRESHENERS	8-20
• ALIPHATICS	2-5
• AROMATICS	1.5-3
• CHLORINATED	2-10
• CARBON TETRACHLORIDE	1

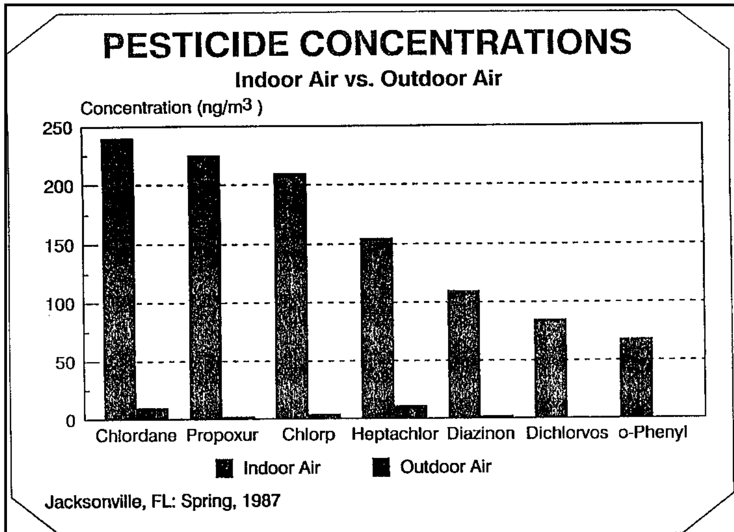
MAJOR SOURCES OF EXPOSURE
TEAM STUDY FINDINGS

- BENZENE
  - Smoking (90% for smokers)
  - Driving
  - Passive smoking
  - Attached garage
- p-DICHLOROBENZENE
  - Moth cakes/crystals
  - Toilet deodorizers
  - Room air fresheners
- TETRACHLOROETHYLENE
  - Wearing/storing dry-cleaned clothes
- CHLOROFORM
  - Water use in home



CO Concentrations in Indoor Microenvironments - Denver, CO
(In descending order of mean CO concentration)

Microenvironment	n	Mean (ppm)	Std. Dev. (ppm)
Public Garages	116	13.46	18.14
Service Stations or Vehicle Repair Facilities	125	9.17	9.33
Other Locations	427	7.40	17.97
Other Repair Shops	55	5.64	7.67
Shopping Malls	58	4.90	6.50
Residential Garages	66	4.35	7.06
Restaurants	524	3.71	4.35
Offices	2287	3.59	4.18
Auditoriums, Sports Arenas, Concert Halls	100	3.37	4.76
Stores	734	3.23	5.56
Health Care Facilities	351	2.22	4.25
Other Public Buildings	115	2.15	3.26
Manufacturing Facilities	42	2.04	2.55
Homes	21,543	2.04	2.55
Schools	426	1.64	2.76
Churches	179	1.56	3.35



WE LIVE INDOORS

- National Human Activity Pattern Survey (NHAPS) and ARB surveys of children & adults
- >11000 interviews over 2-year period
- INDOORS 89%
- OUTDOORS 6%
- IN VEHICLES 5%

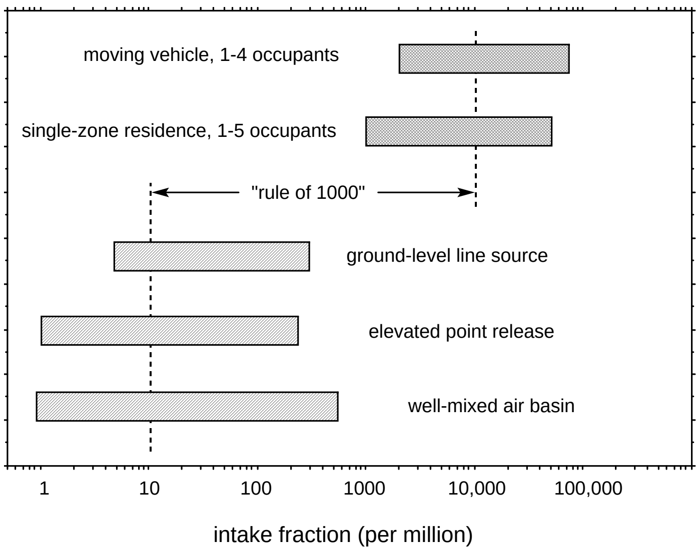
INDOOR AIR QUALITY: A NATIONAL PRIORITY

- Three Nationwide Task Forces Compared Environmental Priorities
- All Find Indoor Air/Consumer Products Very High Priority
- All Conclude "No One Minding the Store"

"RULE OF A THOUSAND"

A pollutant released indoors is about 1000 times more likely to be inhaled than that same amount released outdoors

(Nazaroff, 2000)



Particles and Health

- Fine particles implicated in daily mortality
- But possibly ultrafines, coarse, CO, SO2….
- High-risk groups are known
  --COPD
  --Cardiovascular signaling problems
- Mechanism unknown

Are Indoor Particles Dangerous?

- Major Indoor Source is Combustion
  - Smoking
  - Cooking
  - Candles, incense
  - Space heaters

Combustion is often specified as the likely source of toxicity of outdoor particles

Are Indoor Particles Toxic?

- Little is known about relative Toxicities of Indoor vs Outdoor Particles
- One study finds Toxicities about equal (Long, 2001)

Can Indoor Particles Cause Short-Term Mortality?

- Concentrations are comparable to outdoors
- Toxicity may be comparable to outdoors
- If short-term peaks are important, they are more readily encountered indoors
- Strong sources exist in some homes of high-risk subpopulations

Particle TEAM (PTEAM) Study

- First probability-based particle exposure study
- 178 Residents of Riverside, California
- Two 12-hour samples (Day and Night)
- Personal, indoor and outdoor PM_{10}
- Indoor and outdoor $PM_{2.5}$
- Air change rate measured in 3 rooms

Probability-Based Studies

- Survey design as in polls
- The sampling universe is completely known (e.g., Census information)
- Each person in the universe has a known probability of being selected
- The only accepted method by which one can extrapolate to larger populations

Examples of probability-based studies

- TEAM Study of VOCs: 1980-85 (Pellizzari 1985; Wallace 1985)
- PTEAM 1989-90 (Ozkaynak 1996)
- Toronto Study 1996 (Clayton 1997; Pellizzari 1999)
- Indianapolis Study 1996 (Pellizzari 2001)
- EXPOLIS (many pubs)

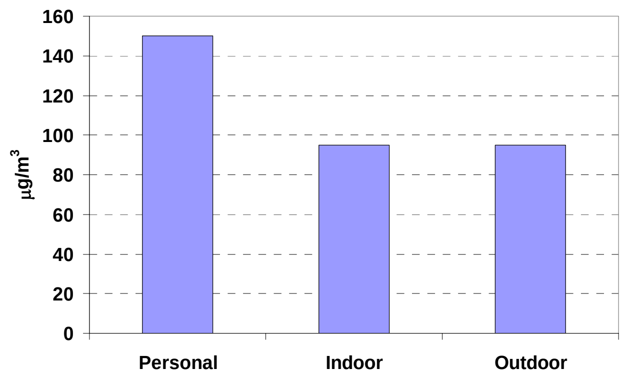
PTEAM Study: Results

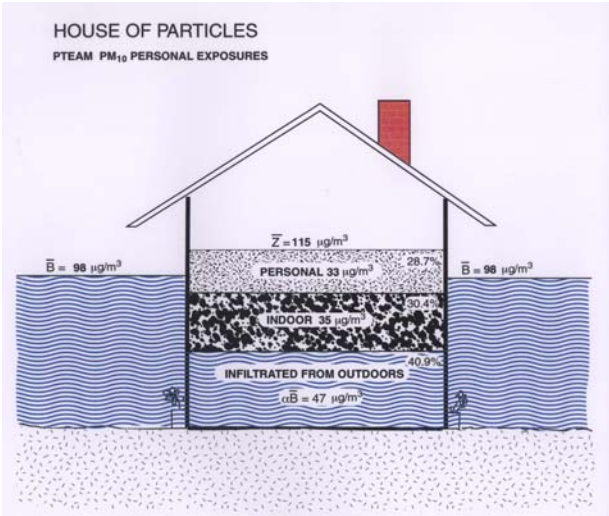
- Personal >> Outdoor > Indoor
- "Personal Cloud" (Personal – Indoor) First Observed: About 35 $\mu g/m^3$
- Smoking Again the Major Indoor Source
- Cooking the Second Largest Indoor Source

PTEAM: More Results

- Regression Results
  - Indoor vs Outdoor $R^2 = 0.27$
  - Personal vs Outdoor $R^2 = 0.16$
  - Personal vs Indoor $R^2 = 0.49$

Daytime PM_{10} Concentrations: PTEAM Study





The Personal Cloud

- Source unknown; possibilities include
  - Resuspension off clothes, other indoor surfaces
  - Proximity to indoor sources (vacuuming, dusting, cooking)
- Probably NOT
  - Skin flakes
  - Clothes fibers

PMF Results from PTEAM

- First study to differentiate personal cloud crustal material from indoor crustal material (about 30% from personal activities, 15% from indoor soil)
- Strong correlations of indoor and personal exposure with ETS
  - Yakovleva, Hopke & Wallace, 1999

The Toronto Study

- Sponsored by Ethyl Corp. (MMT makers)
- Largest Probability-Based Study of Particle Exposures (180 PM_{10}; 750 $PM_{2.5}$)
- Personal > Indoor > Outdoor
- Personal Cloud for PM_{10} 35 $\mu g/m^3$; for $PM_{2.5}$ 15 $\mu g/m^3$
- Mean $Mn_{2.5}$ = 14.4 ng/m^3

The Indianapolis Study

- Sponsored by Ethyl (pre-MMT background)
- 250 Subjects
- $PM_{2.5}$ only
- Personal = Indoor > Outdoor
- Small Personal Cloud (< 3 $\mu g/m^3$)
- Mn Mean = 7.2 ng/m^3; GM = 2.8 ng/m^3

Exposures of High-Risk Groups

- EPA Sponsored Four Major Studies
  - --Harvard (Atlanta, Boston, LA.)
  - --University of Washington (Seattle)
  - --New York Univ. School of Medicine (New York, Anaheim, Seattle)
  - --Research Triangle Institute (RTP,NC)

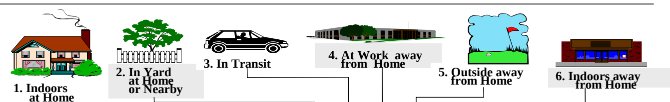
Goal

- Determine relationships between personal exposure, indoor air concentrations and outdoor air concentrations of fine particles ($PM_{2.5}$) for persons at risk

Study Design

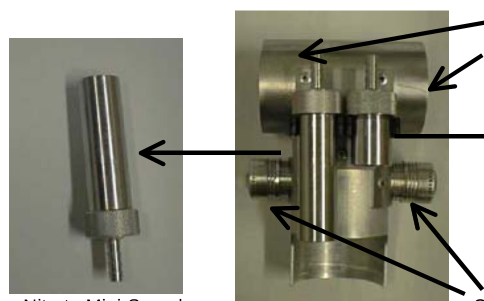
- Samples Drawn from High-Risk Groups (COPD, CV, some healthy controls)
- Personal, Indoor, Outdoor Samples of
  - --PM-2.5 and PM-10
  - --Associated gases (SO2, NO2, CO)
- 10-14 days per person, 2-4 seasons

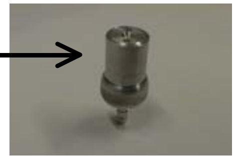
Subject ID: __________ **Date:** __________ **Technician:** __________



		Activity Description	1	2	3	4	5	6	Nearby Smoker Minutes	Cooking Minutes Self	Cooking Minutes Other
AM	8:00										
	:15										
	:30										
	:45										
	9:00										
	:15										
	:30										
	:45										
	10:00										
	:15										
	:30										
	:45										
	11:00										
	:15										
	:30										
	:45										
PM	12:00										
	:15										
	:30										
	:45										
	1:00										
	:15										
	:30										
	:45										

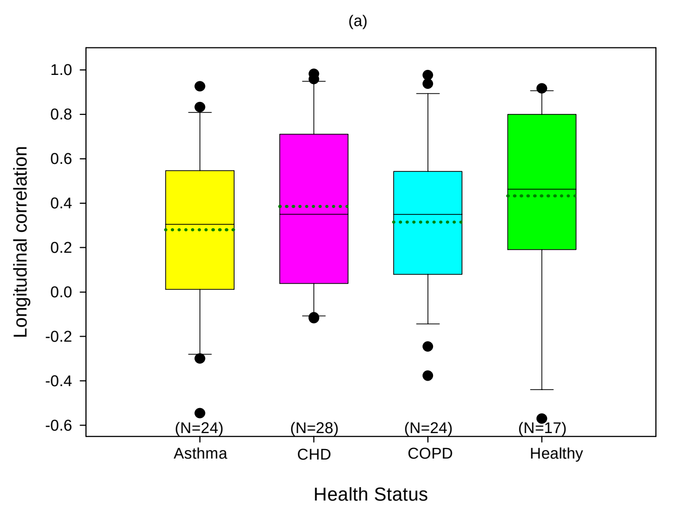
A New Personal Monitor





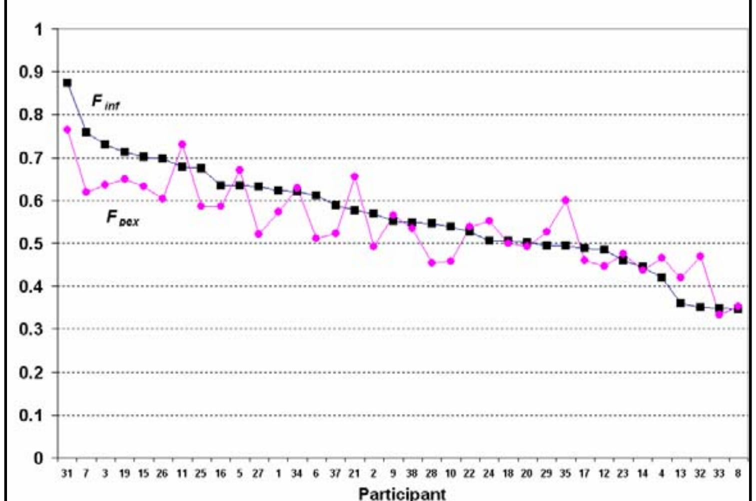
Nitrate Mini-Sampler

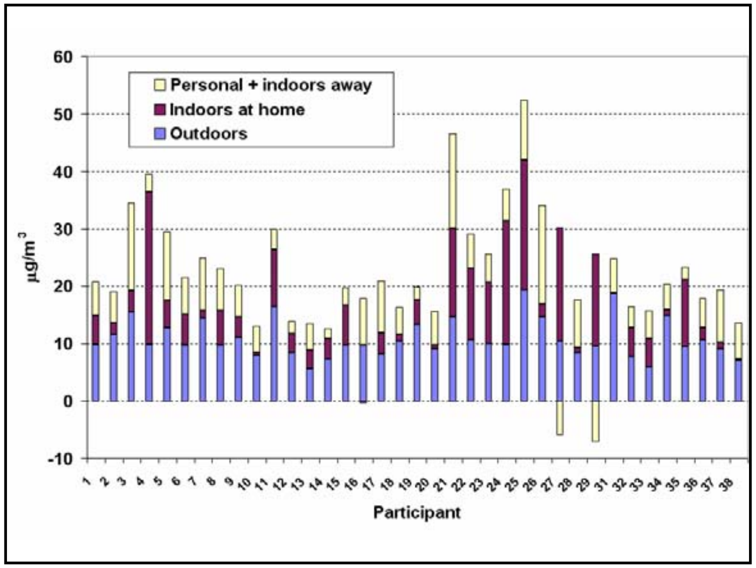
EC/OC Mini-Sampler



Group	City	N	r>0.5 (%)	p<0.05 (%)
NERL -RTI	RTP	112	43	14
Univ. Wash.	Seattle	98	50	16
Harv. Univ.	At-Bos L.A.	105	47	21

City	**N**	Winter Finf	**SE**	**N**	**Summer** Finf	**SE**
RTP	29	0.46	0.05	25	0.40	0.04
Los Angeles	15	0.42	0.08	15	0.70	0.11
Boston	14	0.40	0.1	15	0.67	0.10
Bos. sulfate	N/A	N/A	N/A	15	0.75	0.03
Atlanta	24	0.43	0.1	22	0.49	0.14
Atl. sulfate	24	0.40	0.04	22	0.45	0.04
Seattle	55	0.53	0.2	55	0.79	0.18





Conclusions

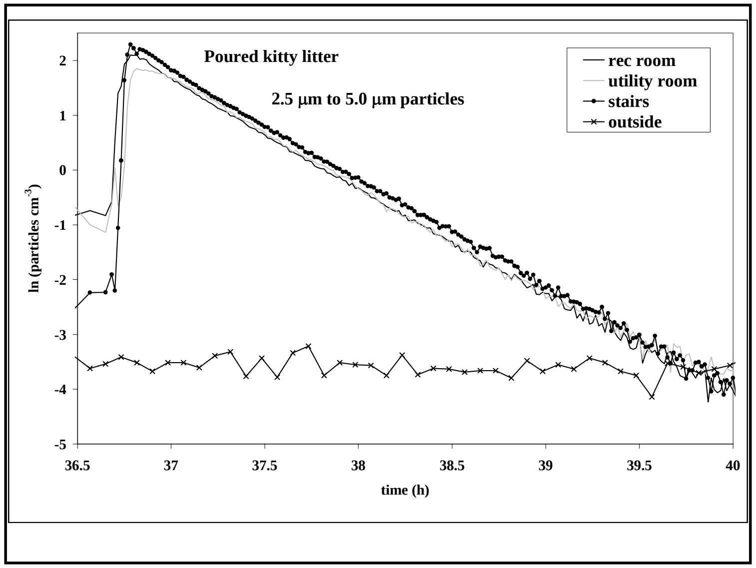
- Personal monitors performed well
- New personal monitor developed
- Personal exposures were similar for healthy and sick cohorts
- Difficulties in calculating proportion of exposure due to particles from outdoors

Conclusions (cont.)

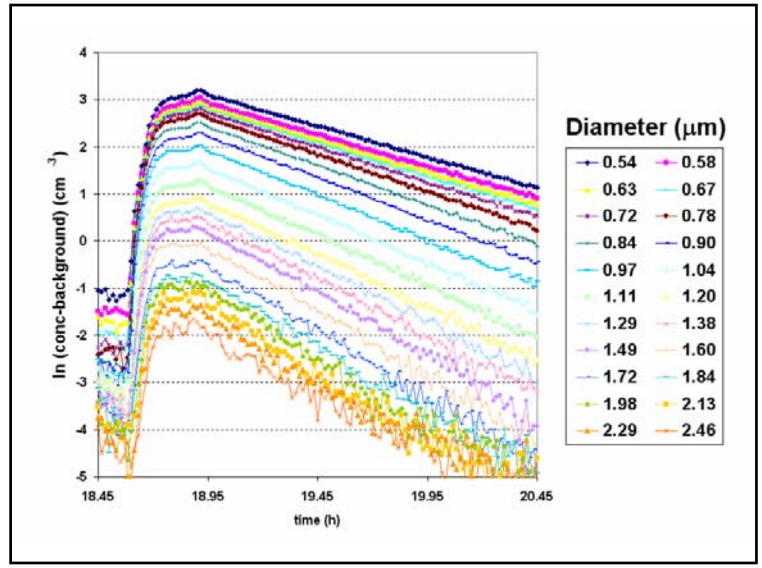
- Fewer than ½ the persons had longitudinal personal-outdoor correlations >0.5
- Fewer than ¼ had significant correlations
- Some persons in all cohorts had negative correlations
- Sampling for more days might not improve correlations

Indoor Air Characterization

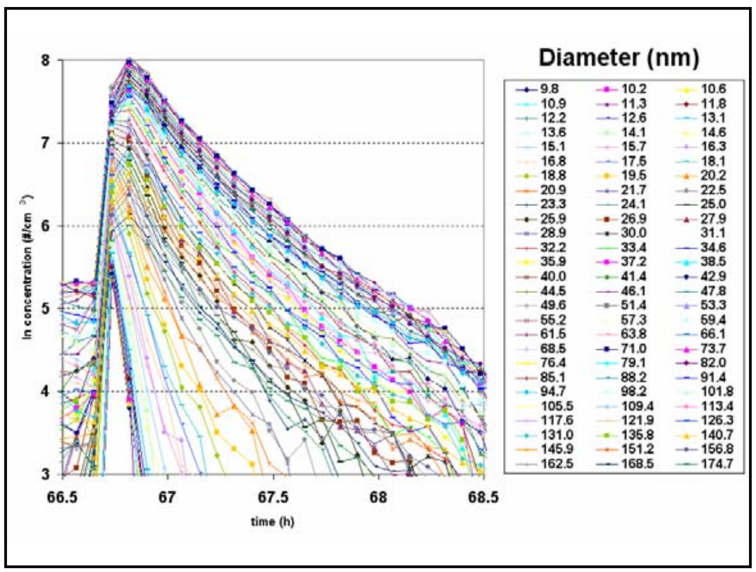
- Size Distribution Important—Affects…
  - Penetration
  - Deposition
- Air exchange rates—Affect…
  - Infiltration
  - Exfiltration



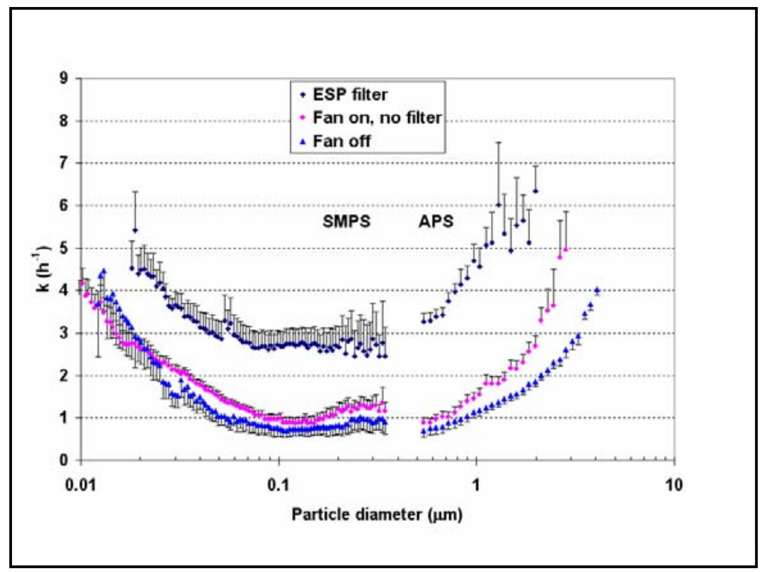
Poured kitty litter
2.5 µm to 5.0 µm particles
rec room
utility room
stairs
outside
ln (particles cm^{-3})
time (h)
36.5
37
37.5
38
38.5
39
39.5
40
2
1
0
-1
-2
-3
-4
-5



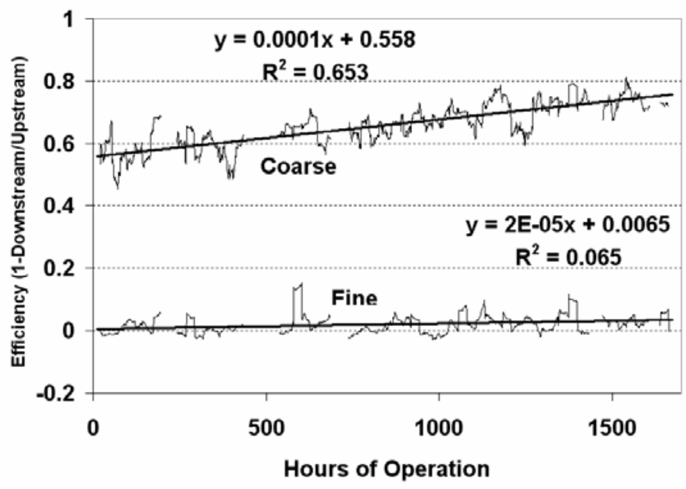
Diameter (µm)
0.54
0.58
0.63
0.67
0.72
0.78
0.84
0.90
0.97
1.04
1.11
1.20
1.29
1.38
1.49
1.60
1.72
1.84
1.98
2.13
2.29
2.46
ln (conc-background) (cm^{-3})
time (h)
18.45
18.95
19.45
19.95
20.45

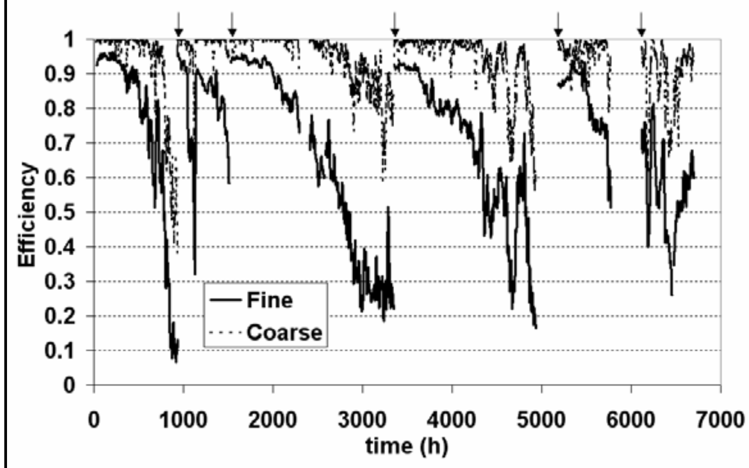


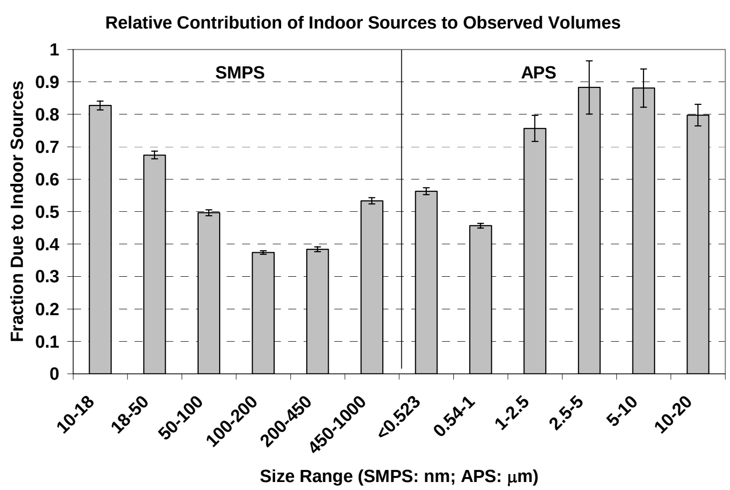
Diameter (nm)
9.8
10.2
10.6
10.9
11.3
11.8
12.2
12.6
13.1
13.6
14.1
14.6
15.1
15.7
16.3
16.8
17.5
18.1
18.8
19.5
20.2
20.9
21.7
22.5
23.3
24.1
25.0
25.9
26.9
27.9
28.9
30.0
31.1
32.2
33.4
34.6
35.9
37.2
38.5
40.0
41.4
42.9
44.5
46.1
47.8
49.6
51.4
53.3
55.2
57.3
59.4
61.5
63.8
66.1
68.5
71.0
73.7
76.4
79.1
82.0
85.1
88.2
91.4
94.7
98.2
101.8
105.5
109.4
113.4
117.6
121.9
126.3
131.0
135.8
140.7
145.9
151.2
156.8
162.5
168.5
174.7
ln concentration (#/cm^{-3})
time (h)
66.5
67
67.5
68
68.5



ESP filter
Fan on, no filter
Fan off
SMPS
APS
k (h^{-1})
Particle diameter (µm)
0.01
0.1
1
10







Controlling Indoor Particles

- "Tightening" (weatherstripping) home
  - Reduces ambient intrusion but increases levels due to indoor sources
- Using filters/air cleaners
  - Ordinary filters do little
  - In-duct electrostatic precipitators shown to be very effective (Wallace et al., 2004)
  - Reduce BOTH indoor/outdoor-origin particles

Future Work

- Split Exposure into Indoor and Outdoor-Generated Components
  - Use of Sulfates as Tracers
  - Calculate Infiltration Factors
    - RCS Model (provides average value for all homes in a given area)
    - Least-squares analysis of individual homes
    - Drawbacks include single-zone well-mixed assumption—how good is it?

Future Work (Cont.)

- Determine Toxicity of Indoor Air Particles
  - Few studies (Long et al., 2001)
  - Particles from frying would be of interest
  - ETS is still the major player
- Develop/Employ Instruments to Measure More than Mass
  - Surface Area (diffusion charger)--Siegmann
  - PAHs (Ecochem?)
  - Ultrafines

Future Work (cont.)

- More Detailed Short-term Studies
  - Calculating Finf, P and k for Individual Homes
  - ARB-Harvard and EPA studies being analyzed
- Control Technology for Individual Homes
  - Mechanical Ventilation (ASHRAE 62.2)
  - Air Filters