The UCB Particle Monitor: A Stab at the Holy Grail*

*A small, smart, cheap, fast, & reliable PM monitor

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Presentation at the
California Air Resources Board
September 4, 2007

Purpose of this Presentation

- To inaugurate the newly funded project at the UCB School of Public Health by the CARB to develop, test, and validate a “UCB-California”
  - With more sensitivity, i.e., closer to typical California ambient levels
  - With GPS capability for “walk throughs”
  - With software designed for community environmental justice groups
  - With demonstration of use in West Oakland

Main Partners

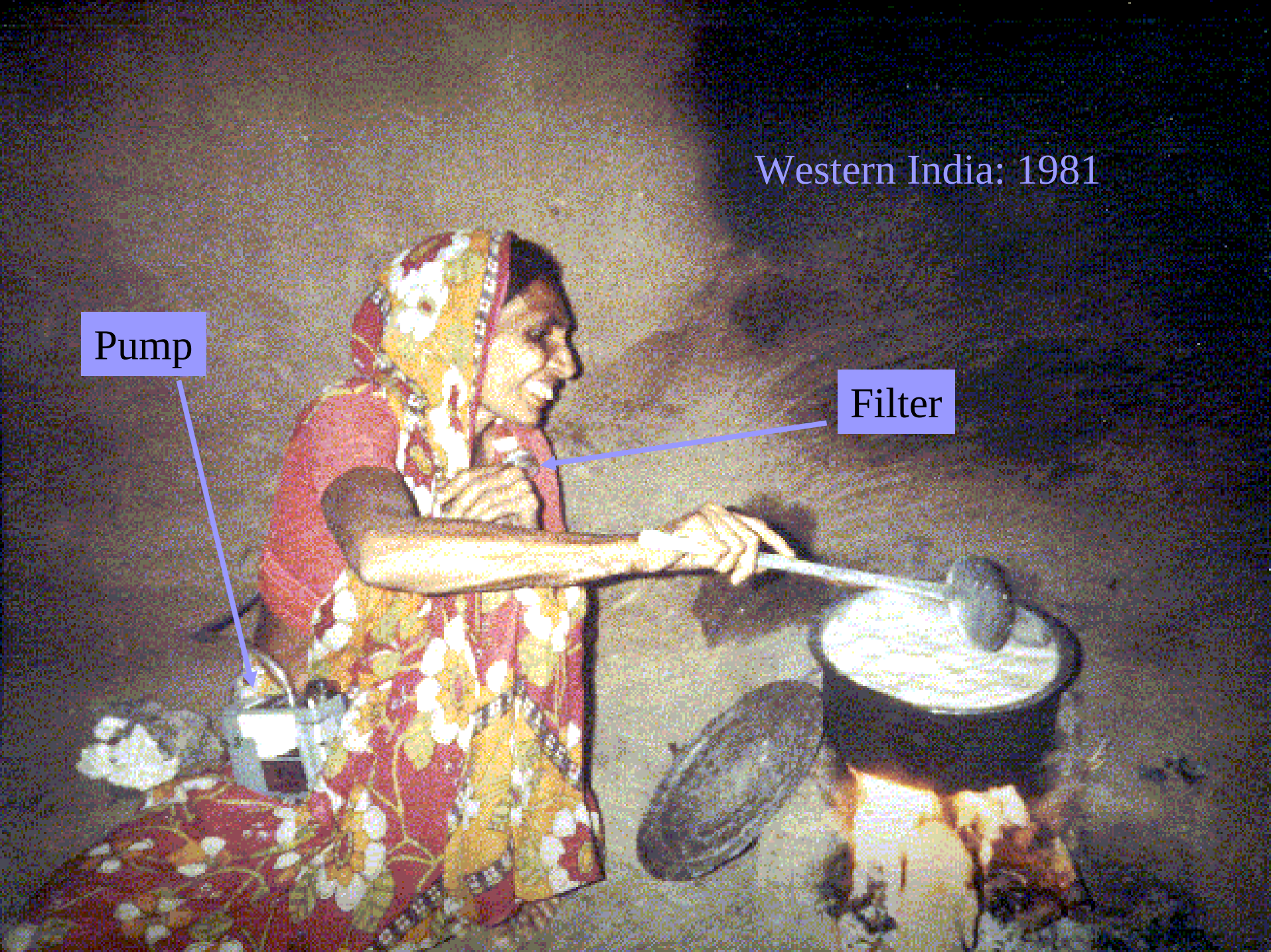
- **Tracy Allen**, President, Electronically Monitored Ecosystems (EME Systems), Berkeley
- **Rufus Edwards**, Epidemiology Division, Department of Medicine, UC Irvine
- **Zohir Chowdhury,** Environmental Health Sciences, School of Public Health, San Diego State University
- **Charles D. Litton**, Dust and Toxic Substances Control Branch, Pittsburgh Research Laboratory, NIOSH/CDC

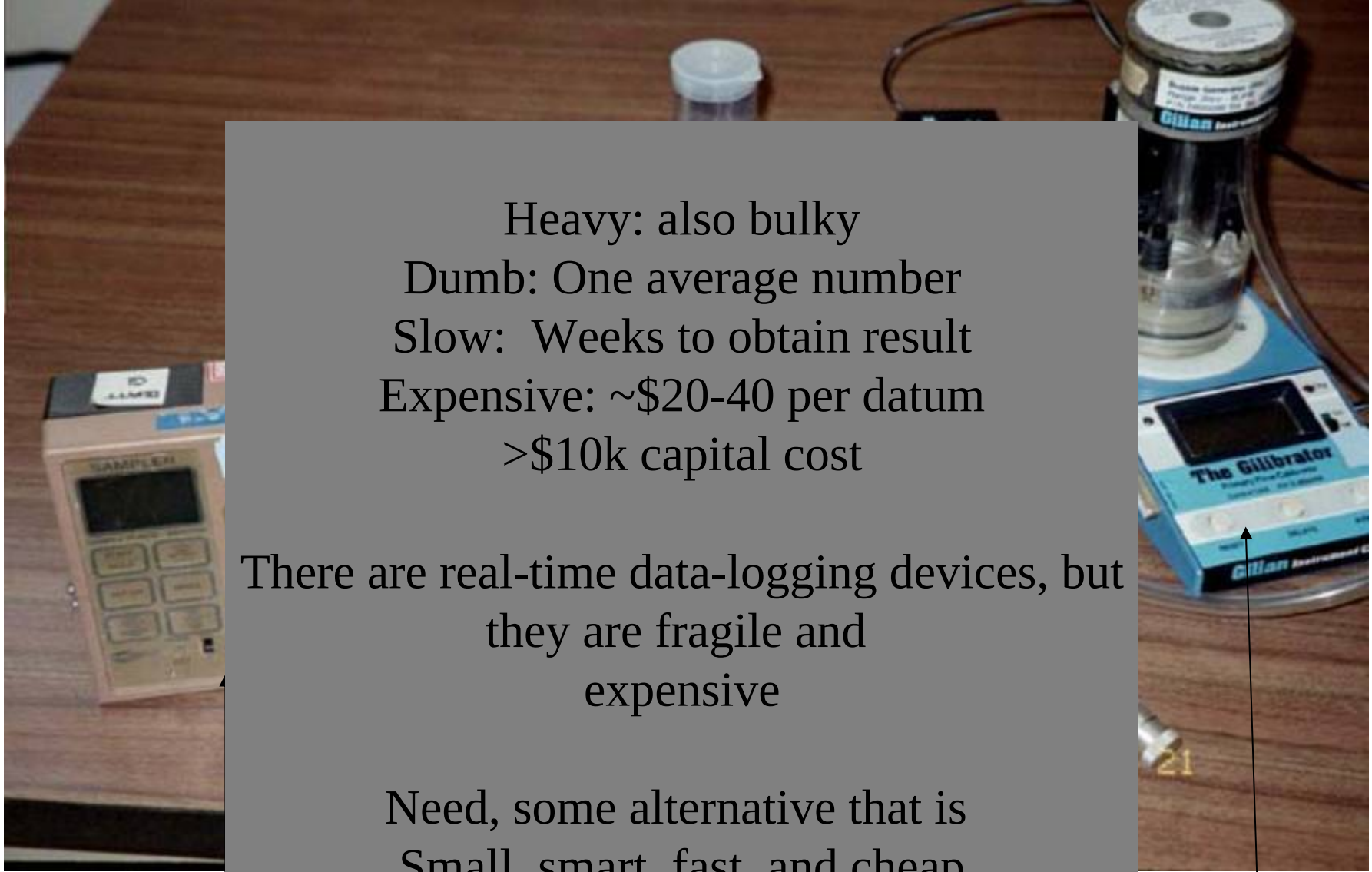
Independent Testing and Review

- **Susanne Hering**, President,
  Aerosol Dynamics, Berkeley, CA
- Others in USA and Europe

The Problem

- For indicating health effects from combustion pollution, small particles are the best single measure.
- Small particles are difficult to measure, particularly under third-world conditions
  - No true passive monitors – basic physics
  - Electronic monitors using light-scattering or other techniques are expensive
  - “Gold standard” technology, pumps and filters, is feasible, but just.


Western India: 1981
Pump
Filter



Heavy: also bulky
Dumb: One average number
Slow: Weeks to obtain result
Expensive: ~$20-40 per datum
>$10k capital cost

There are real-time data-logging devices, but they are fragile and expensive

Need, some alternative that is
Small, smart, fast, and cheap

Self governing p
grammable pum

(battery charger not shown)

Petri dishes for transporting filters

Airflow calibrator

Realization in 1993

There is actually a cheap reliable particle detector in use in hundreds of millions of locations throughout the world.

Idea in 1993:

Combine 3 separate technologies into a cheap particle monitor for third-world application

Funding

- Funding sought for 7 years, and finally achieved in 2001
- Household Energy and Health Programme, Shell Foundation, London
- Sent out RFP to 100+ organization asking for bids for a device
  - Received few responses: all said it could not be done
  - Decided to do ourselves

Three Major Technological Trends

- 1. Development of smoke alarm technology: 100s of millions of units sold, highly competitive market, major investments in engineering and cost conscious manufacture.
  - Costs went from $125/unit in 1975 dollars to $3/unit in 2007 dollars, a factor of ~100 decrease in constant dollars or 16% per year increase in cost effectiveness.
  - Development costs rapidly amortized in large productions runs

History of Household Smoke Detectors

- Heat-sensitive alarms available since 1950s: were not nearly as effective as smoke detectors, but the latter had to be individually licensed for each application
- 1967/1969: BRK Electronics (later to become First Alert®) designed and successfully submitted the first battery-operated ion smoke alarm for general UL approval (marketed to electrical contractors).
- 1974: Sears put its name on a BRK device for household sales: its great success prompted many others to join field.
- 1976: first First Alert device marketed – now the most recognized name. More than 85% of US homes have at least one.
- 1993: Carbon monoxide alarms first introduced by First Alert.
- 1996: First combined smoke/CO alarm by First Alert

Horn

Classic
Ionization
Smoke
Alarm

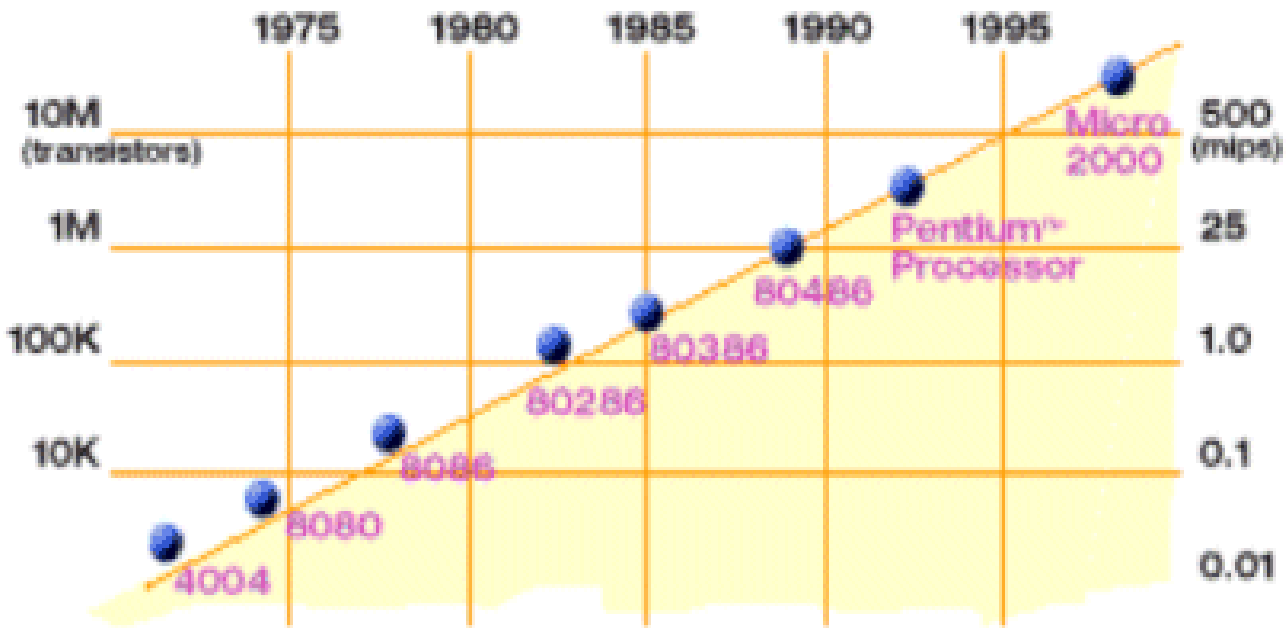
Ion Chamber

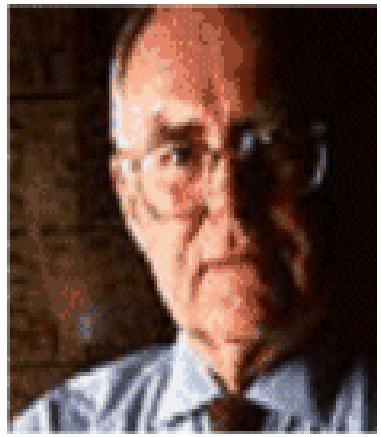
One of the most cost-effective and successful public health interventions in the 20th century

- 94% of US households have at least one
- 50% of fire deaths occur in the 6% that do not
- Mortality rate for smoke-alarmed homes are 40-50% less than those without them, adjusted for other factors.
- Even so, in 30% of fires in homes with smoke alarms the alarms do not work
- Main reason is dead, disconnected, or missing batteries. Trend improving.

Three Major Technological Trends

- 1. Development of smoke alarm technology: 100s of millions of units sold, highly competitive market, major investments in engineering and cost conscious manufacture.
  - Costs went from $125/unit in 1975 dollars to $5/unit in 2003 dollars, a factor of 80x in constant dollars or 17% per year.
- 2. Development of computer chip technology:
  - Moore's Law, doubling every 18 months. A factor of 50,000x since mid-1970s.
  - Cheap, fast, high-capacity programmable dataloggers

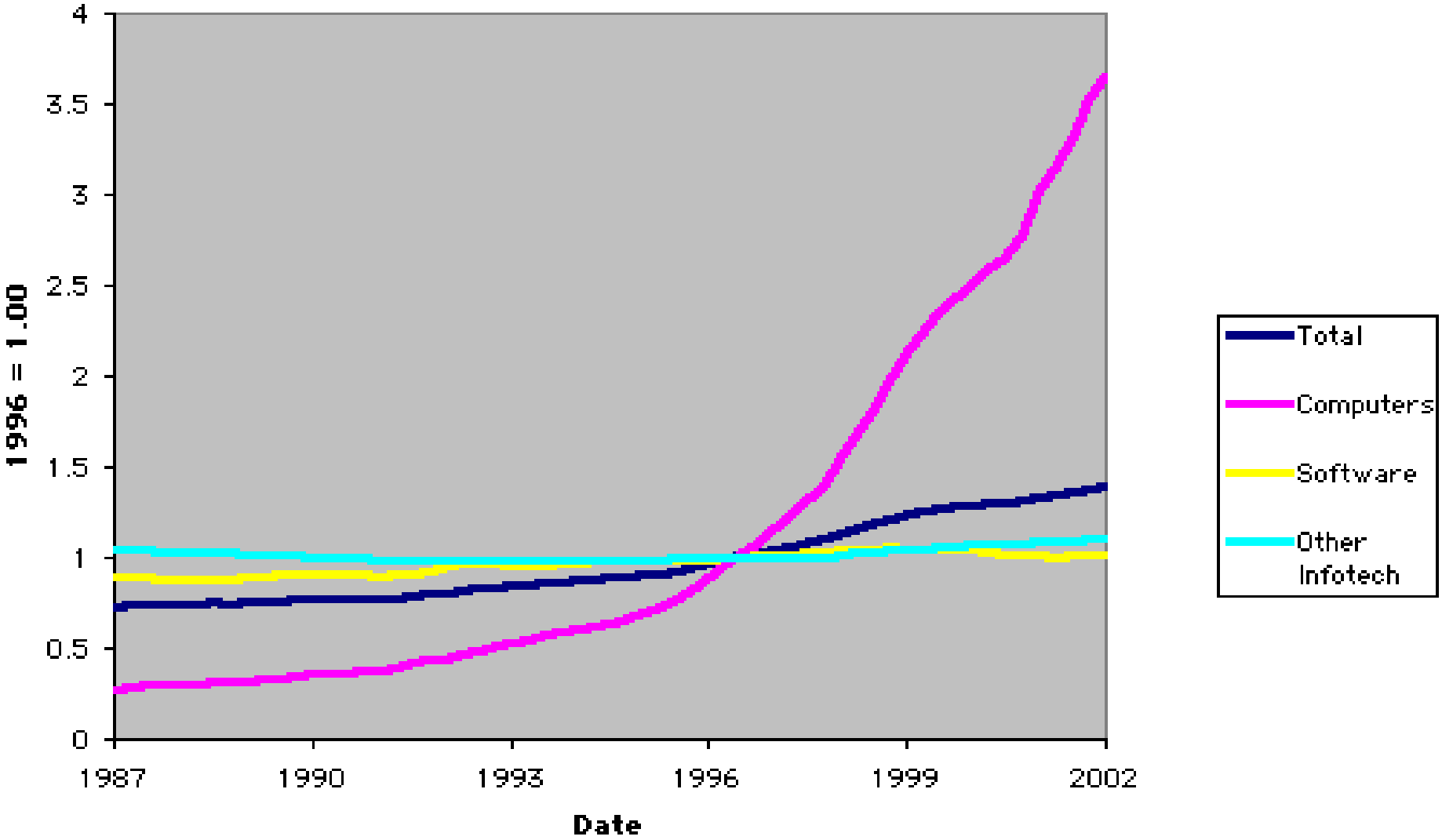




Gordon Moore, Intel co-founder

Moore’s Law, Computer Capacity Doubles Every 18 Months

Value Indices (How Much Real Investment You Get for a Dollar)



Three Major Technological Trends

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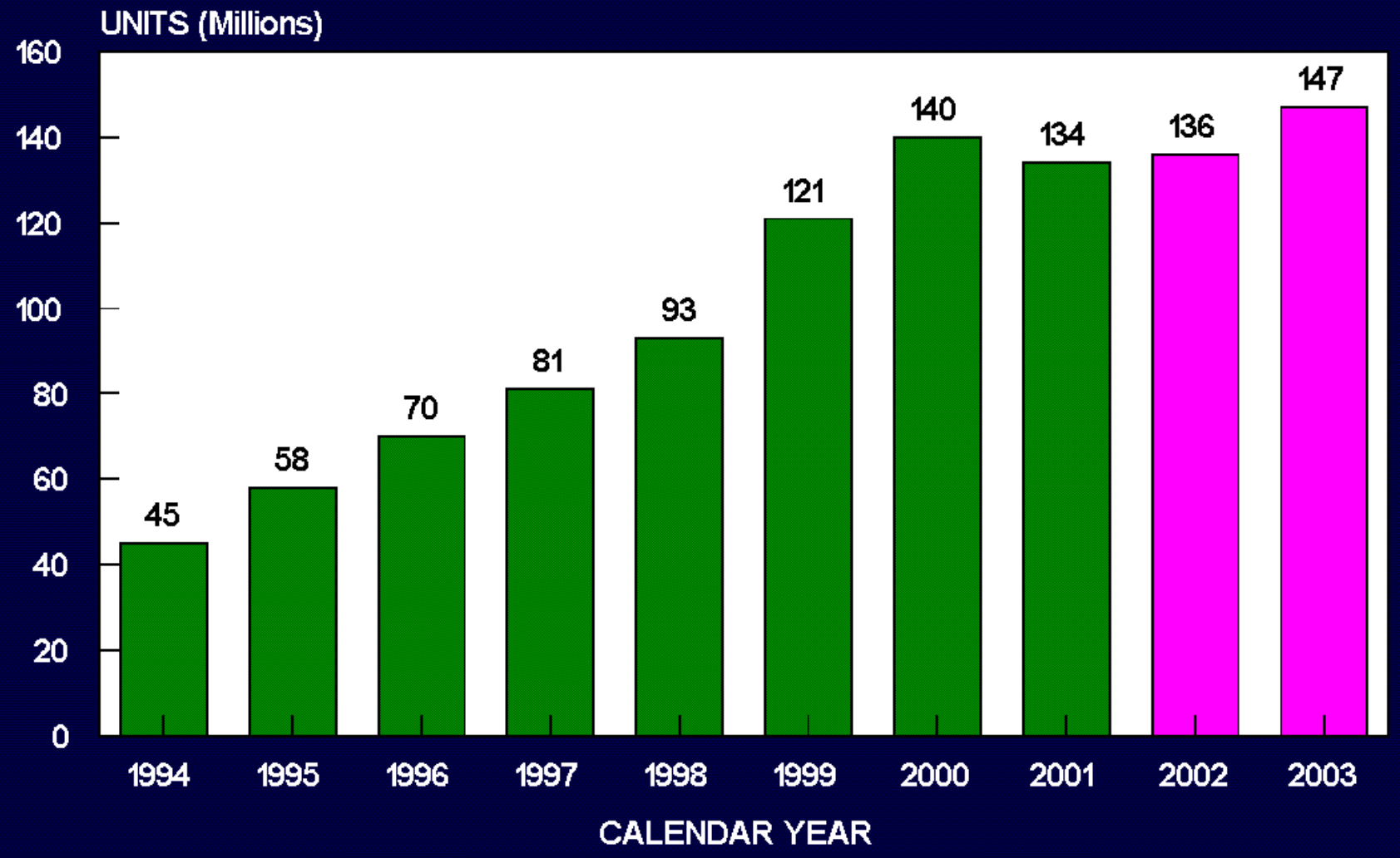
- 2. Development of computer chip technology:
  - Moore's Law, doubling every 18 months. A factor of 50,000x since mid-1970s.
  - Cheap, fast, high-capacity programmable dataloggers
- 3. Widespread dissemination of personal computers and associated software
  - Even small universities and NGOs in the third world now have computers
  - Data handling capability now high as well in many places

PERSONAL COMPUTER GROWTH

GLOBAL SALES

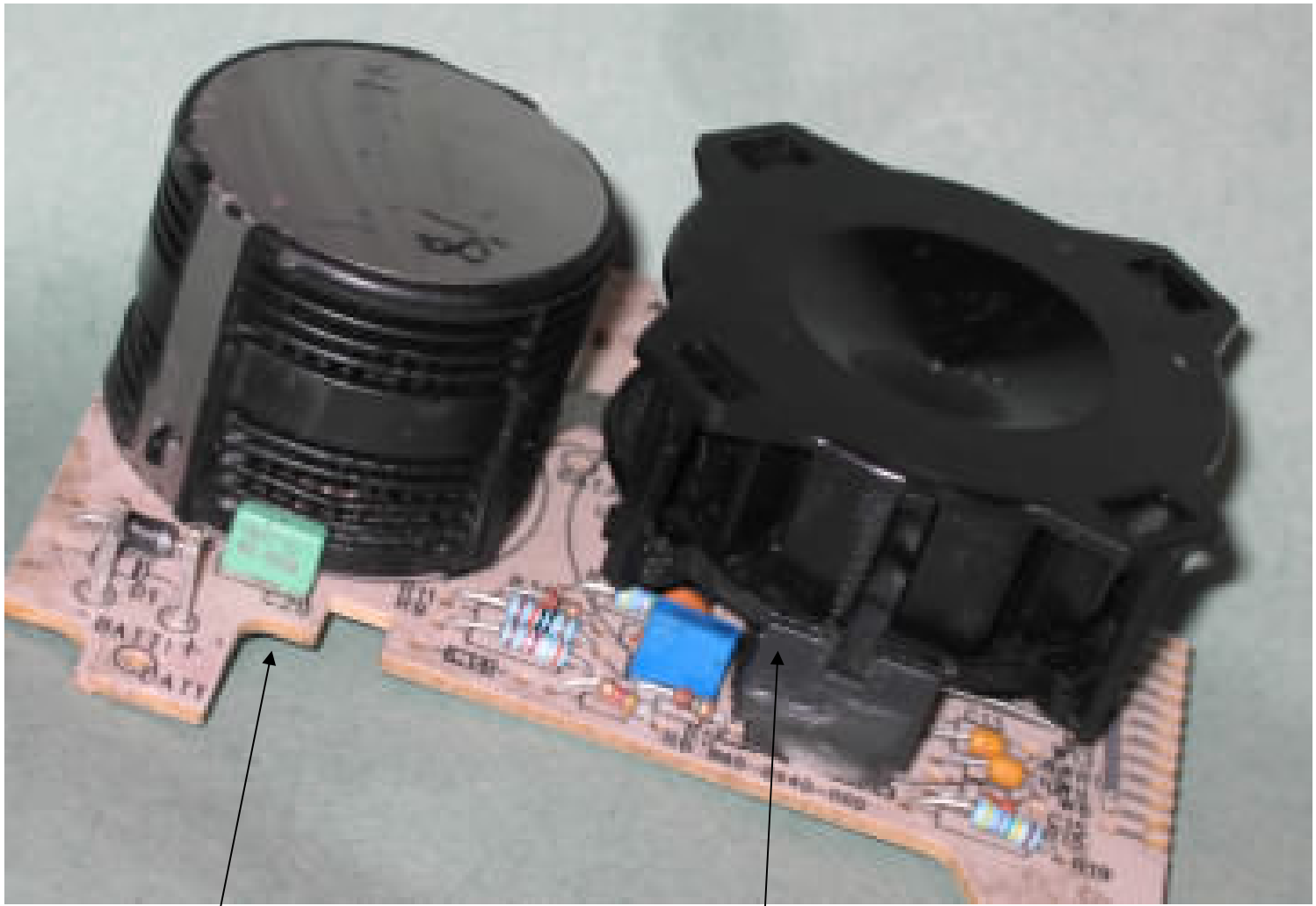


Gartner Dataquest 1/2002, IDC 9/2002
Desktops, Notebooks, Ultraportables - does not include Servers

Choice of Commercial Device to Be Base Unit

- Looked at many, but chose SA302 by First Alert
- Highest quality, dual chamber model
- Excellent access to circuits
- Excellent cooperation by company
- Retails for $30-$45, we obtain for $18, but do not use a large portion of it

First Alert SA302 Ultimate Smoke and Fire Alarm



Ion Chamber

Photoelectric (light-scattering) Chamber

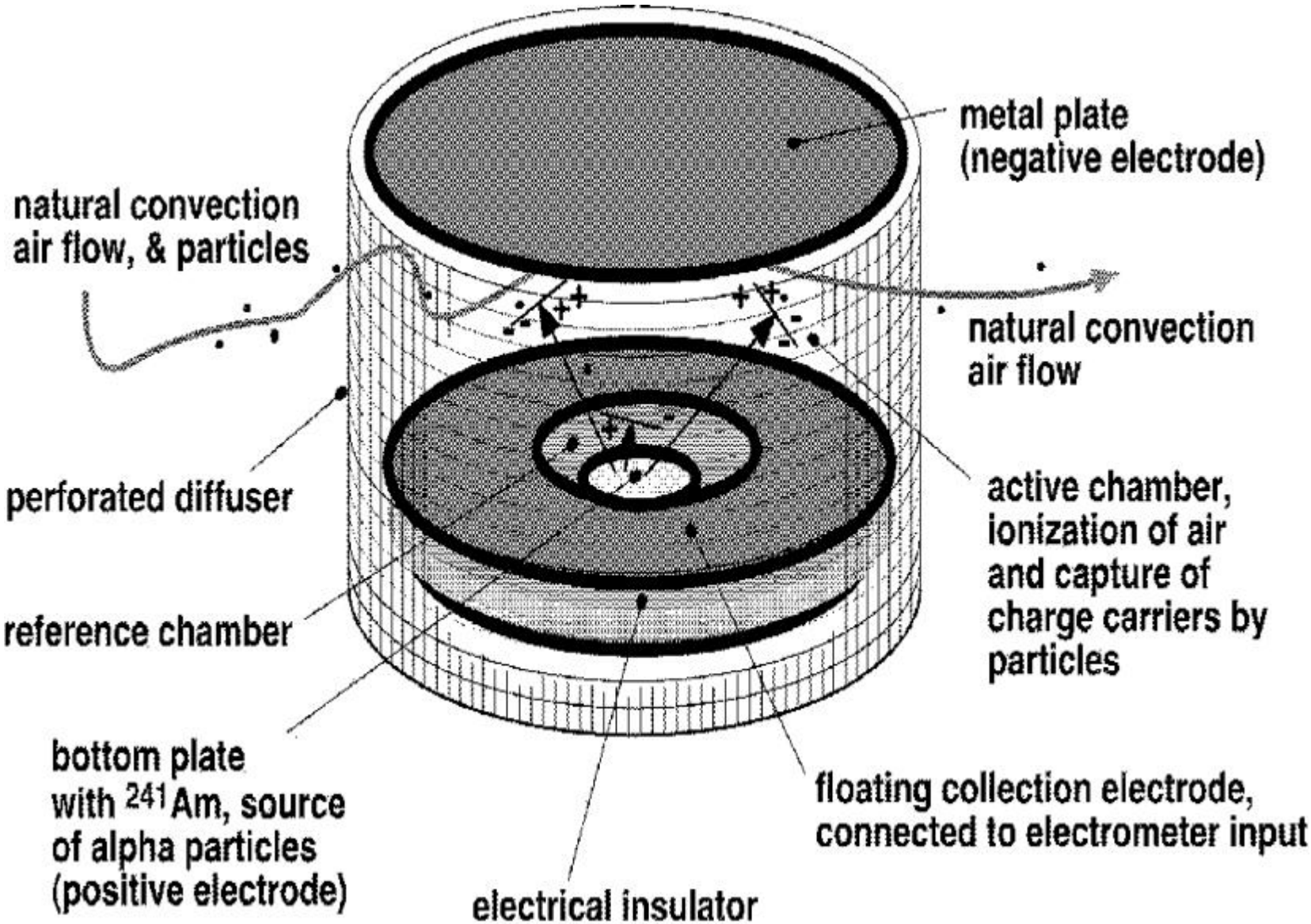
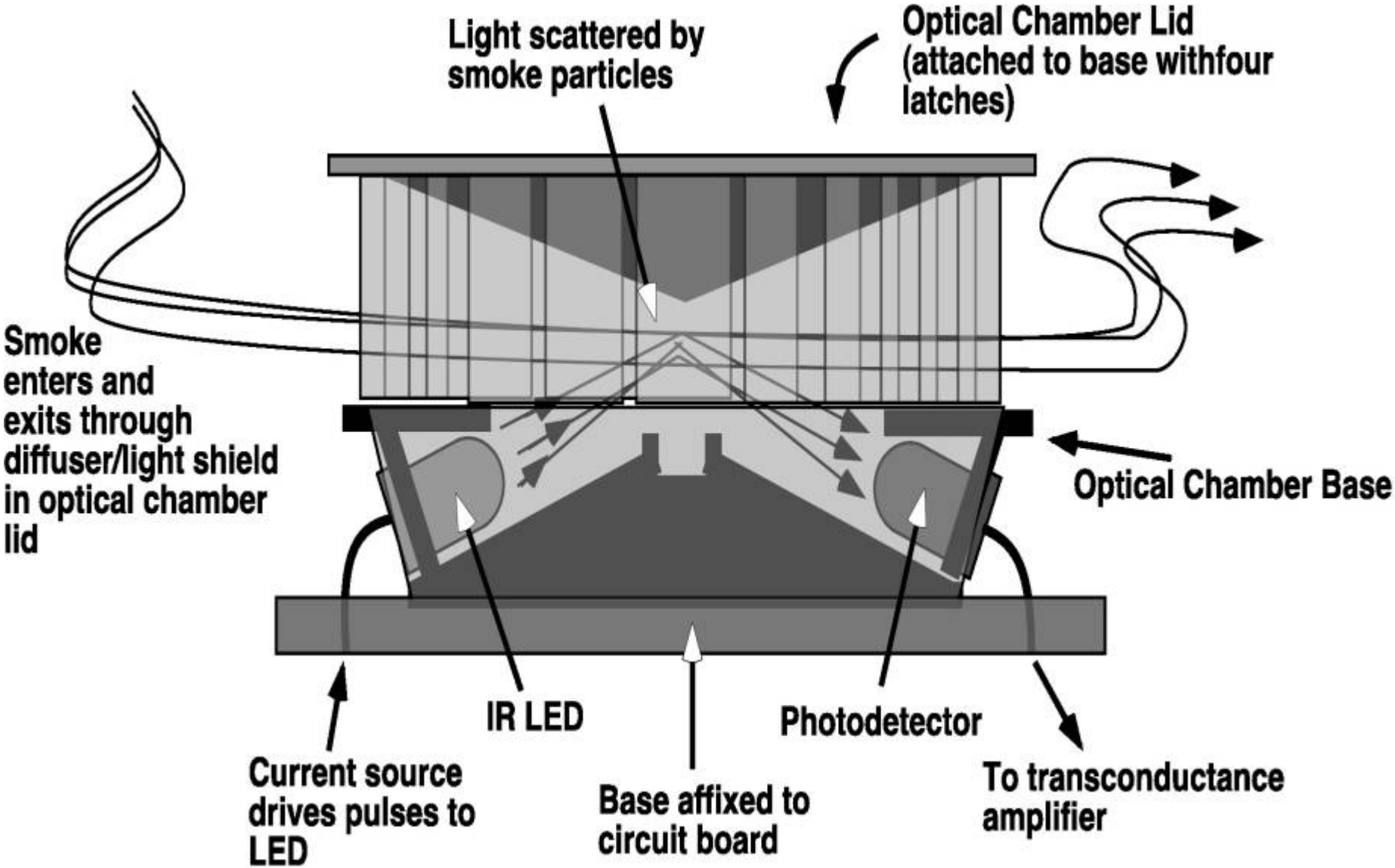
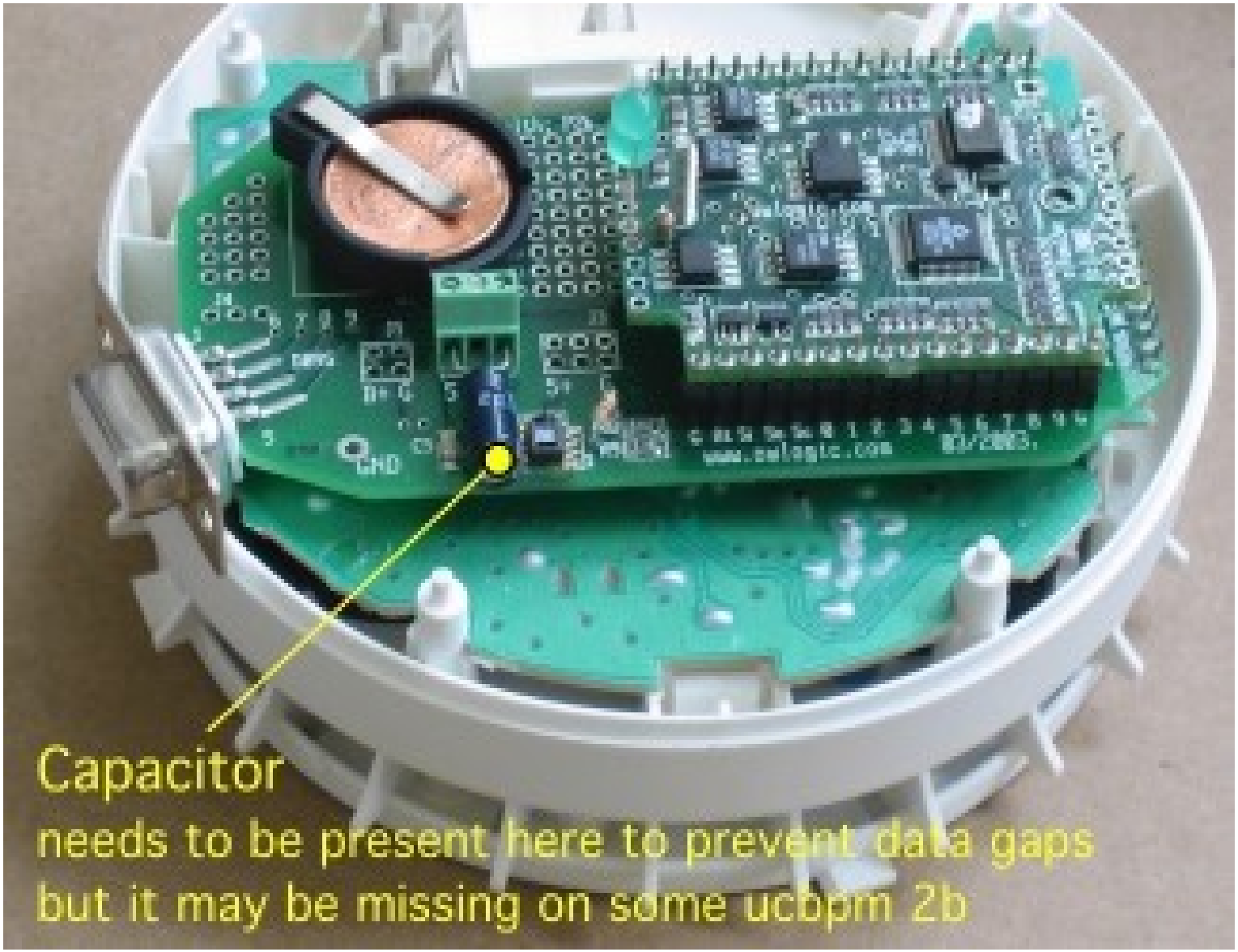

metal plate
(negative electrode)
natural convection
air flow, & particles
natural convection
air flow
perforated diffuser
active chamber,
ionization of air
and capture of
charge carriers by
particles
reference chamber
bottom plate
with 241Am, source
of alpha particles
(positive electrode)
floating collection electrode,
connected to electrometer input
electrical insulator

Photo-electric (light-scattering) Chamber



UCB Development

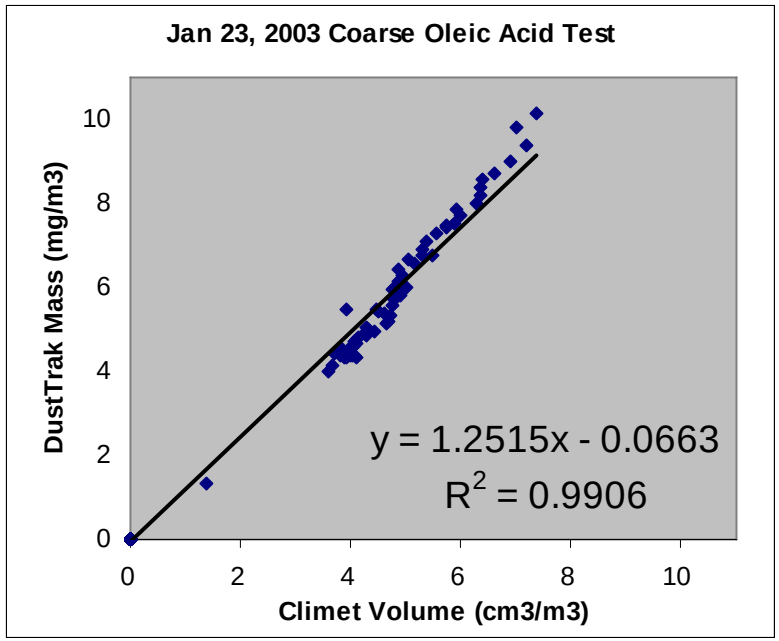
- Substitute our own programmable datalogger and control circuit for FA circuit board and horn
- Add temperature and humidity sensors
- Change frequency of sensor operation and other electronic parameters
- Develop firmware for controlling device
- Develop software for launching and downloading device.
- Develop software for manipulating, displaying, and processing data.
- Test and validate repeatedly in lab and field

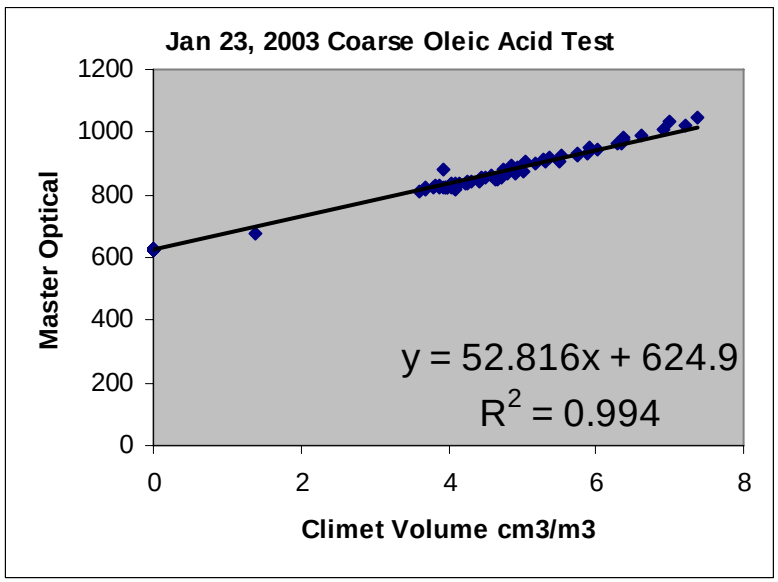

Capacitor
needs to be present here to prevent data gaps
but it may be missing on some ucbpm 2b

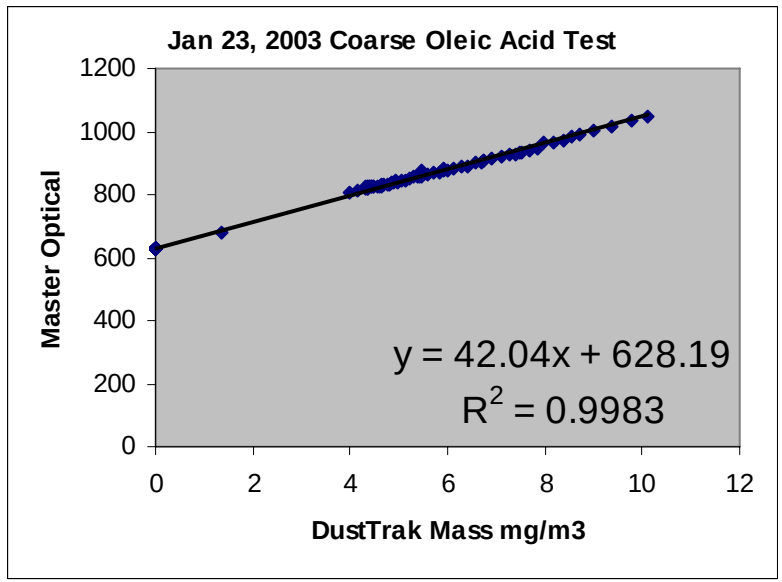
Aerosol Dynamics Laboratory validation tests


Slave #1
Slave #2

Coarse Test Instrument Comparisons





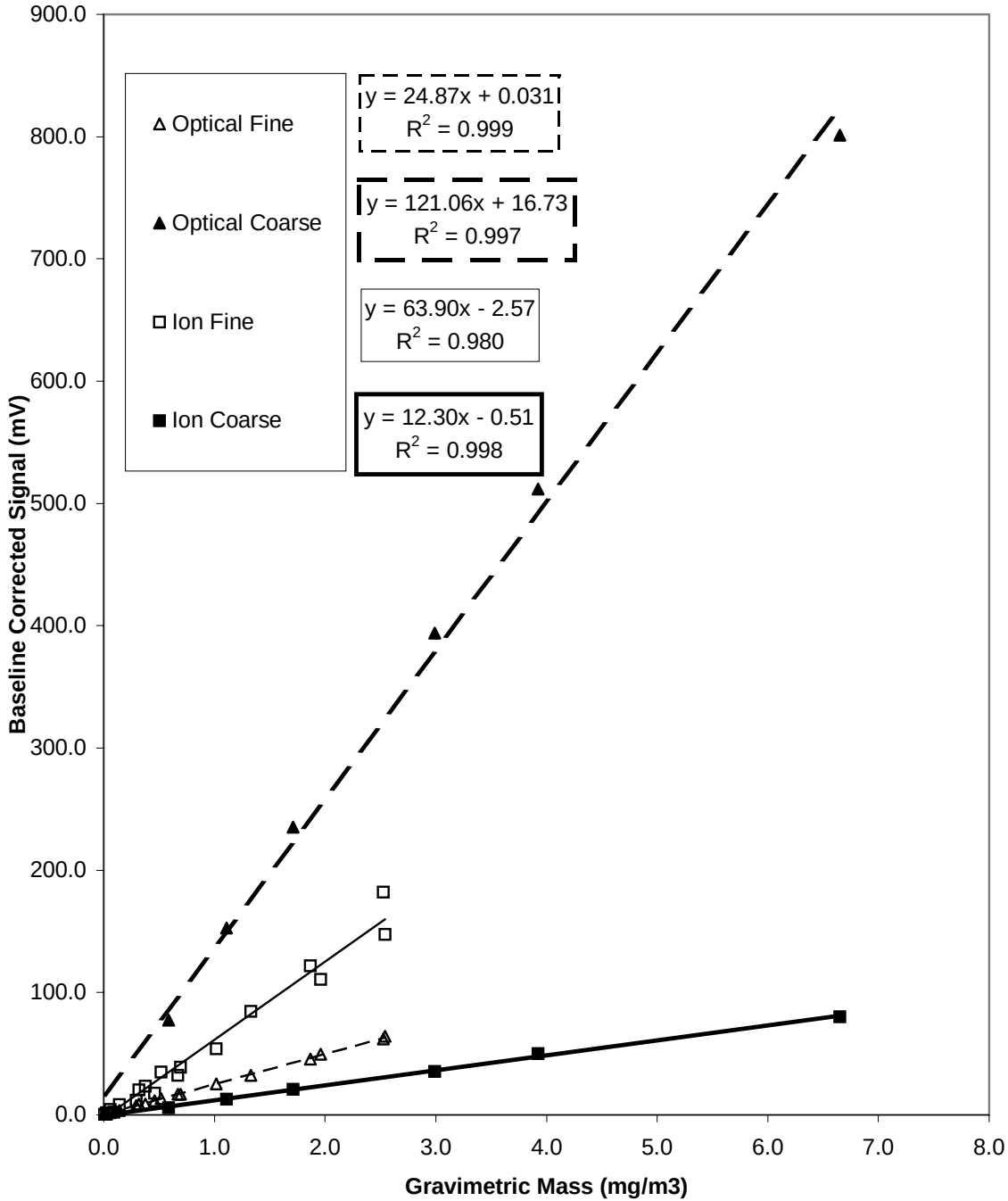


Chamber Tests
of UCB

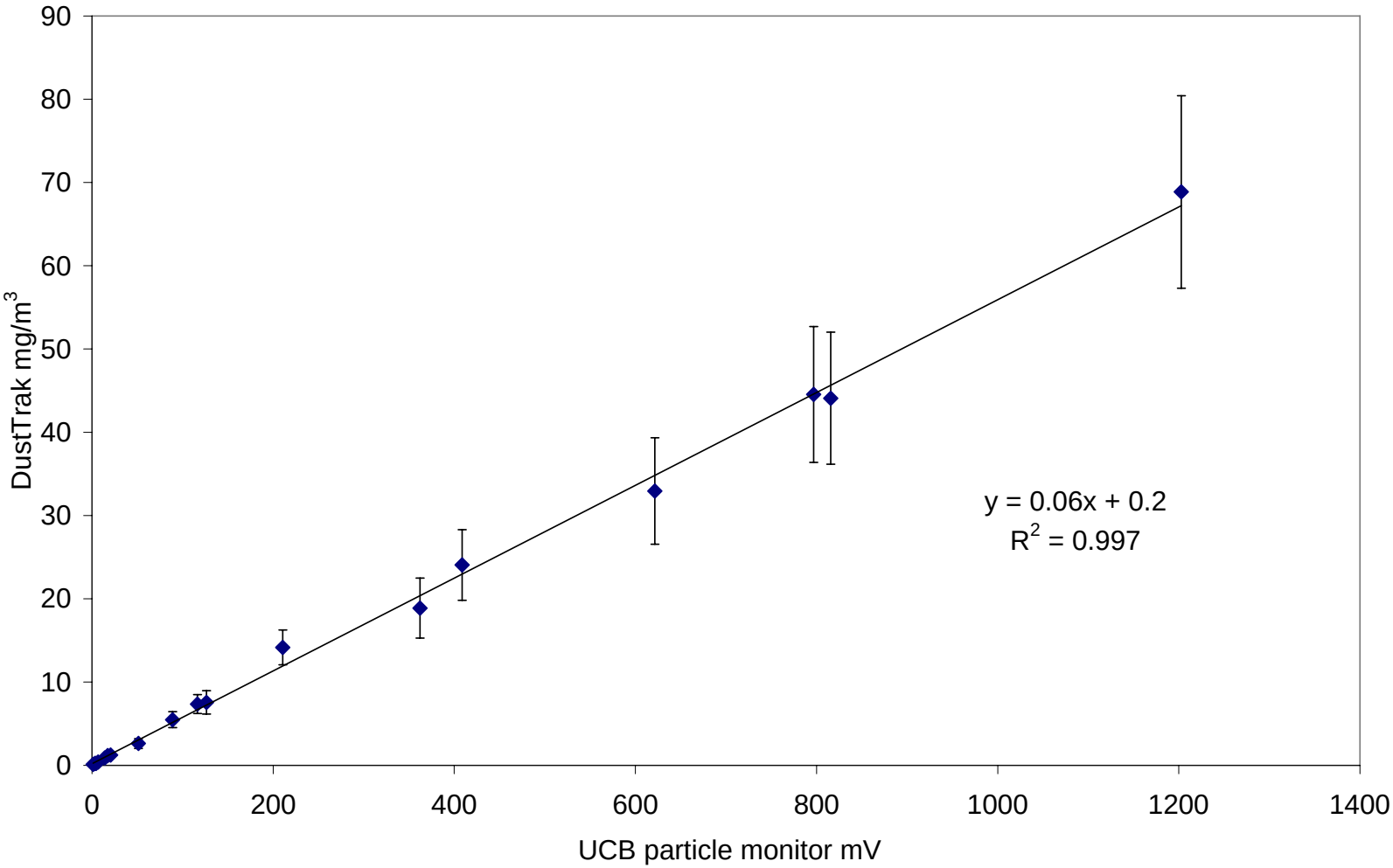
Aerosol Dynamics
Jan 2003

Two particle size ranges:
Coarse (2.1 μm) and
Fine (0.35 μm)

Separate results shown
For Ion and
Optical sensors



Chamber tests in Mexico with woodsmoke



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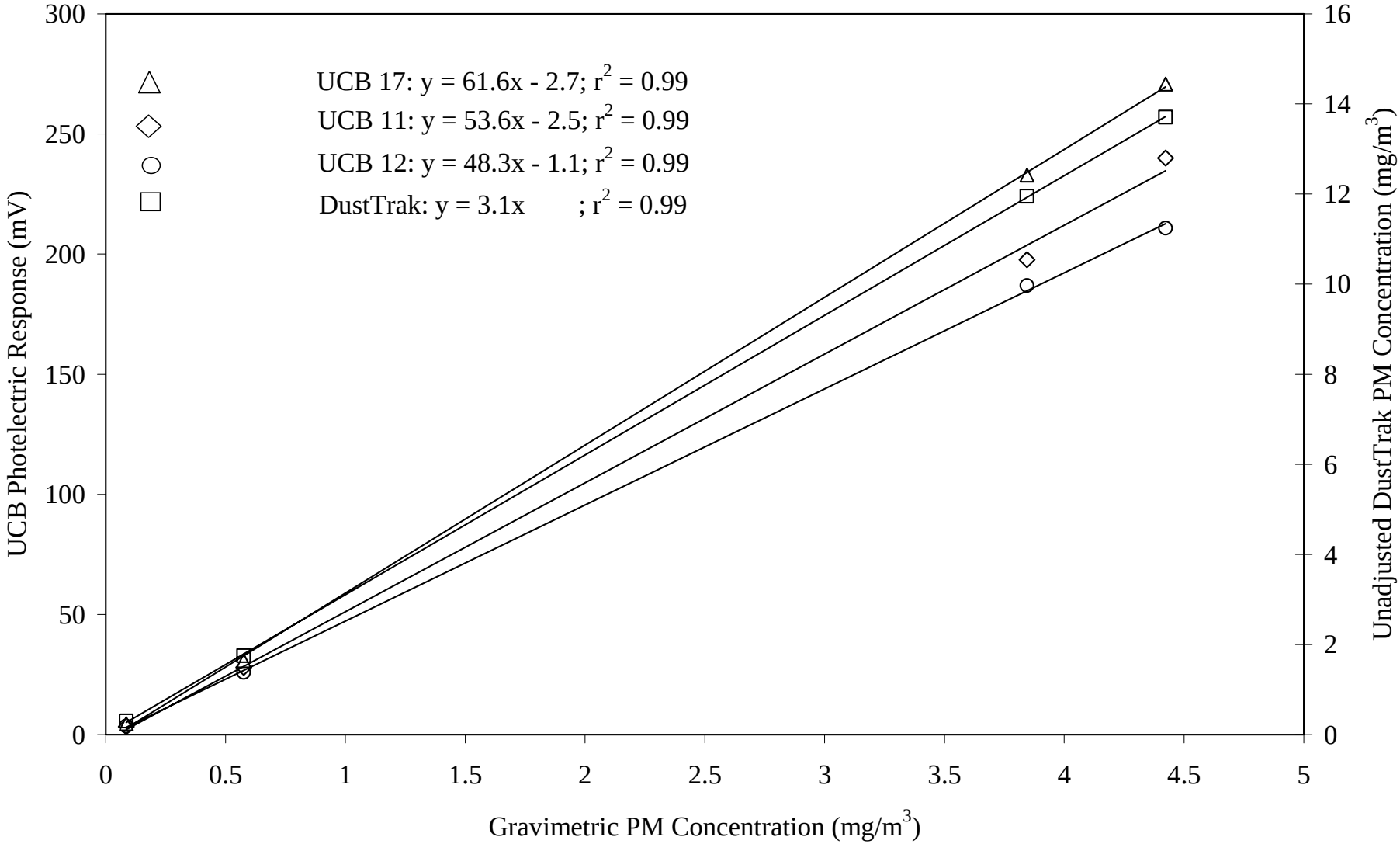

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UCB and DustTrak correlation matrix in field co-location chamber tests.

April 28, 2006

	UCB1	UCB2	UCB3	UCB4	UCB5	UCB6	UCB7	UCB8	UCB9	UCB10	UCB11	UCB12	UCB13	UCB14	UC
UCB1	1														
UCB2	0.990	1													
UCB3	0.994	0.998	1												
UCB4	0.995	0.998	0.999	1											
UCB5	0.994	0.997	0.999	0.999	1										
UCB6	0.992	0.996	0.999	0.998	0.999	1									
UCB7	0.991	0.996	0.999	0.998	0.999	1.000	1								
UCB8	0.995	0.997	0.999	0.999	0.999	0.999	0.999	1							
UCB9	0.992	0.998	0.999	0.999	0.999	0.999	0.999	0.999	1						
UCB10	0.995	0.999	0.999	0.999	0.999	0.998	0.998	0.999	0.999	1					
UCB11	0.995	0.998	0.999	0.999	0.999	0.998	0.998	1.000	0.999	1.000	1				
UCB12	0.990	0.997	0.999	0.998	0.999	0.999	0.999	0.999	1.000	0.998	0.998	1			
UCB13	0.992	0.997	0.999	0.998	0.999	1.000	1.000	0.999	1.000	0.998	0.999	1.000	1		
UCB14	0.995	0.997	0.999	0.999	1.000	0.999	0.999	0.999	0.999	0.999	0.999	0.998	0.999	1	
UCB15	0.992	0.998	0.999	0.998	0.999	0.999	0.999	0.999	1.000	0.999	0.999	1.000	1.000	0.999	
UCB16	0.991	0.998	0.997	0.998	0.996	0.995	0.995	0.997	0.997	0.998	0.998	0.995	0.995	0.996	0.
UCB17	0.993	0.999	0.998	0.999	0.998	0.997	0.997	0.998	0.998	0.999	0.999	0.997	0.997	0.998	0.
UCB18	0.989	0.999	0.998	0.998	0.998	0.997	0.997	0.998	0.999	0.999	0.998	0.998	0.998	0.997	0.
UCB19	0.995	0.998	0.998	0.999	0.997	0.996	0.996	0.998	0.997	0.999	0.999	0.996	0.996	0.998	0.
DustTrak	0.981	0.993	0.994	0.992	0.993	0.995	0.995	0.993	0.995	0.993	0.993	0.996	0.996	0.993	0.

	UCB:UCB	UCB:DustTrak
Average	0.998	0.993
Standard Deviation	0.002	0.003

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Correlations between 19 UCBs and a DustTrak for 4 chamber tests.

Pearson r	Co-location 1	Co-location 2	Co-location 3	Co-location 4
Average inter UCB correlation (N = 19)	0.993 ± 0.003	0.998 ± 0.002	0.994 ± 0.009	0.998 ± 0.001
Correlation between 19 UCBs and DustTrak	0.986 ± 0.002	0.993 ± 0.003	0.989 ± 0.010	0.998 ± 0.001

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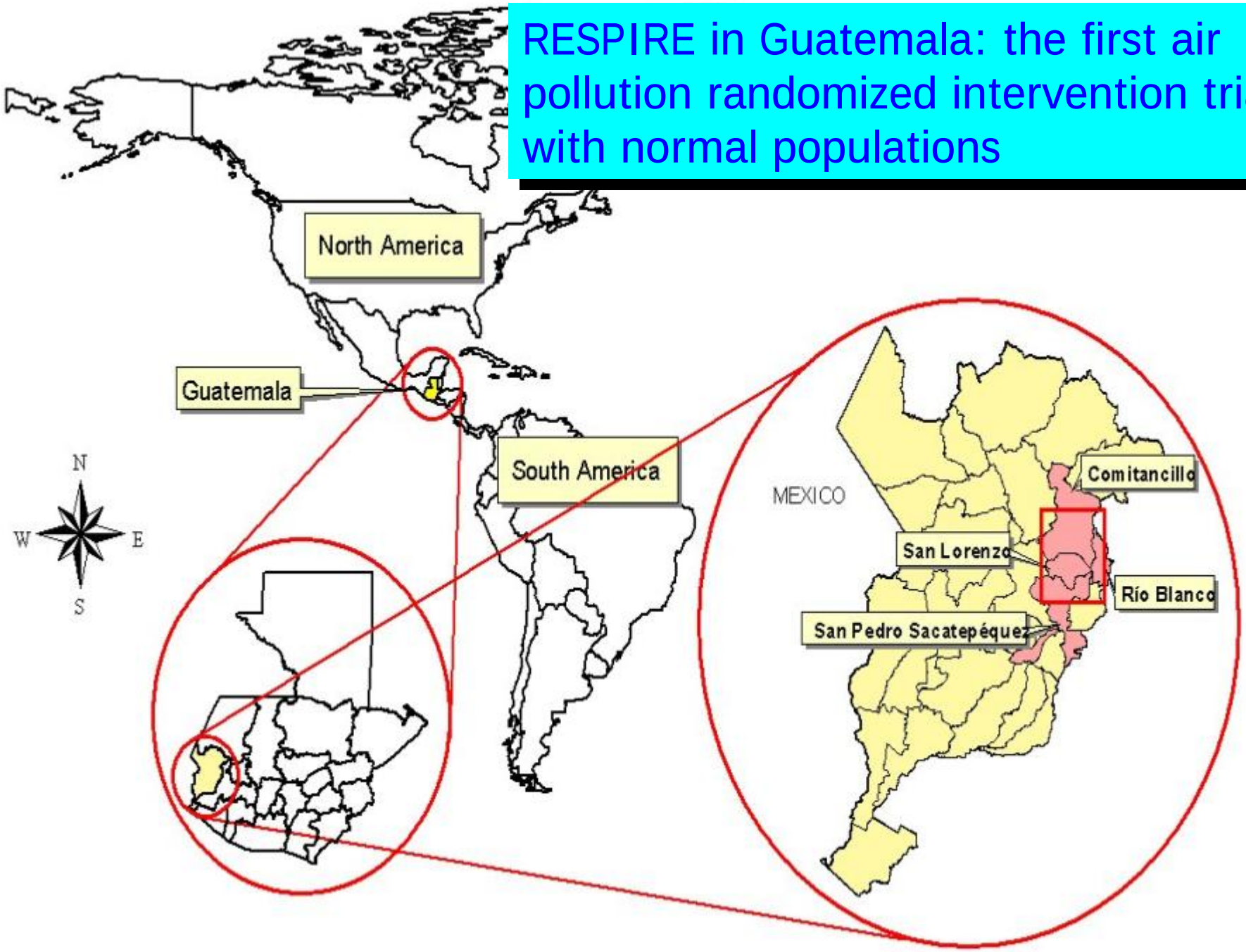
RESPIRE in Guatemala: the first air pollution randomized intervention trial with normal populations



Traditional open fire and improved stove

Traditional open 3-stone fire

The *plancha* chimney wood stove

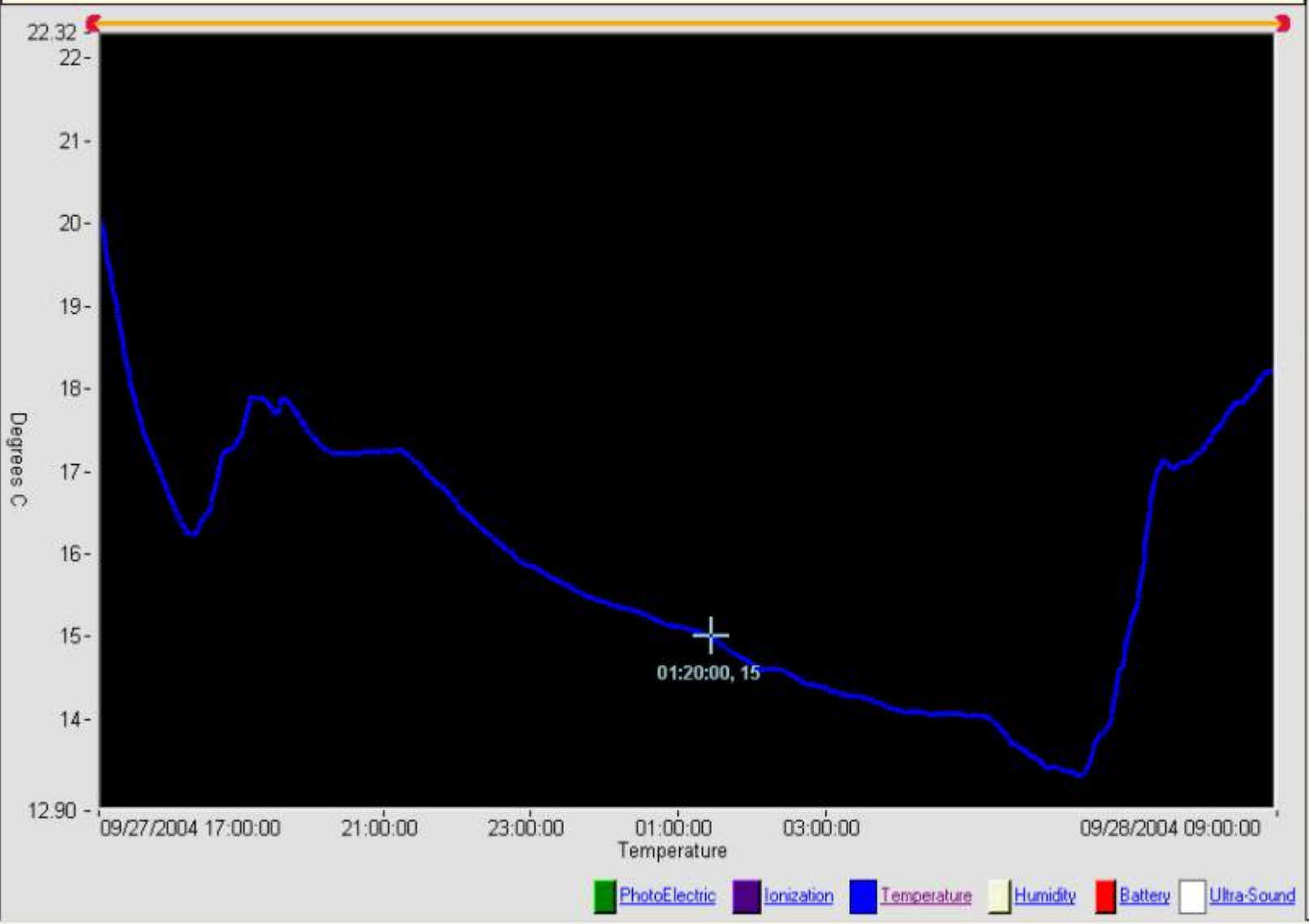
UCB Particle Monitor Data Browser - [C:\Work\PM Monitor\Field Trials\Guatemala\Sep 04\Off load of Sep 27 test\RAWDATA (UCB352) 09-27-04 14_42 to 09-28-04 12_...

File Window

Show As
- Volts
- Mass

UCB352

Calibration Start	09/27/2004 15:30:00	Sample Start	09/27/2004 17:00:00	Chamber Const	0.051
Calibration End	09/27/2004 16:30:00	Sample End	09/28/2004 09:00:11	Regression Const	-6



Temperature

arith. mean	15.834589
geo. mean	15.760762
std. dev.	1.532439
median	15.730000
75th %	17.220000
95th %	17.960000
min.	13.330000
max.	20.100000

15 minute avg

highest	19.580625
2nd highest	18.346667
3rd highest	17.936000

N = 961.00

Save Stats

UCB Particle Monitor Data Browser - [C:\Work\PM Monitor\Field Trials\Guatemala\Sep 04\Off load of Sep 27 test\RAWDATA (UCB352) 09-27-04 14_42 to 09-28-04 12_

File Window

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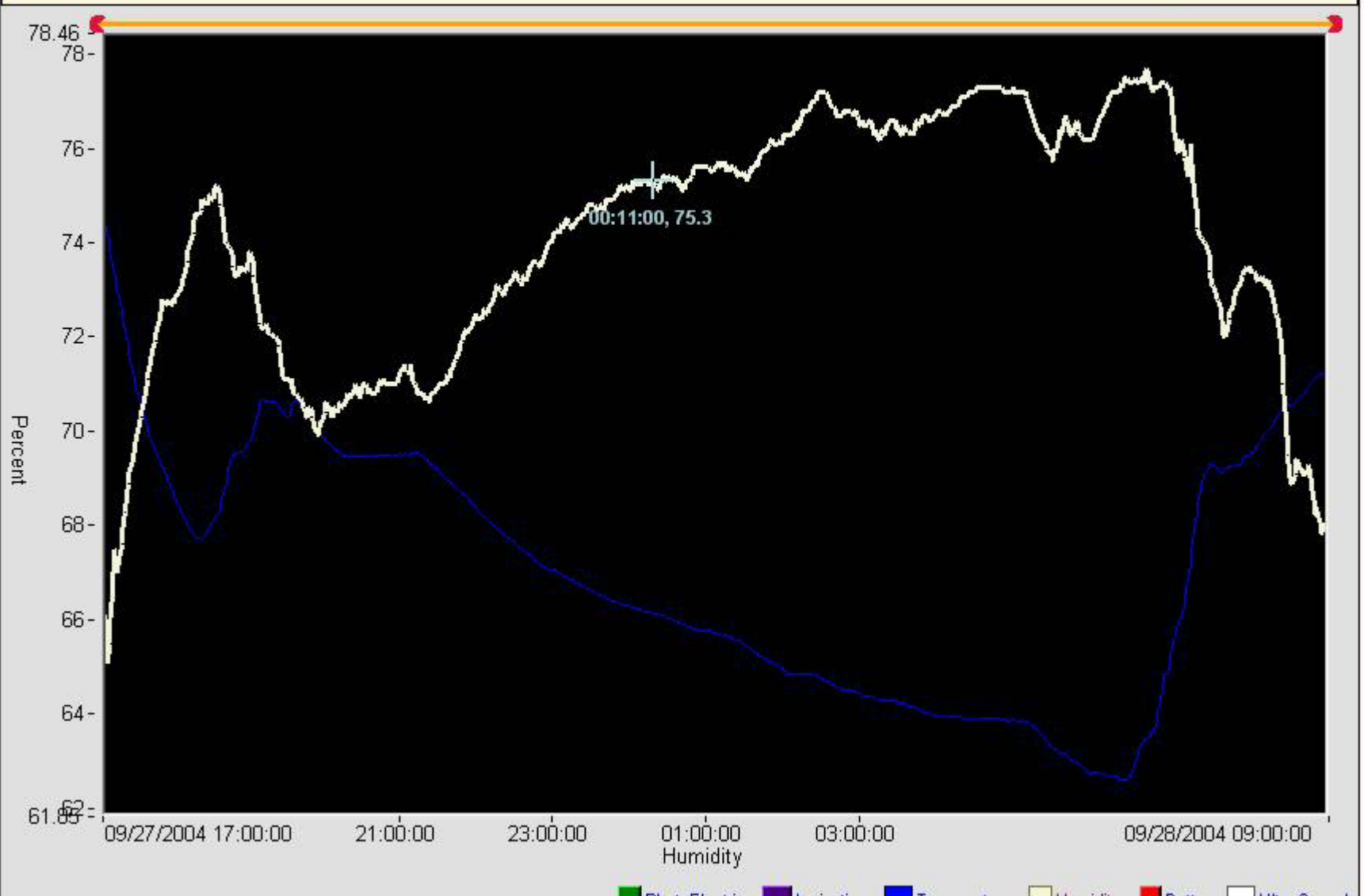


Humidity

arith. mean	7
geo. mean	7
std. dev.	2
median	7
75th %	7
95th %	7
min.	6
max.	7

15 minute avg

highest	7
2nd highest	7
3rd highest	7

N = 9

Save Stat

File Window

Show As
- Volts
- Mass

UCB352

Calibration Start	09/27/2004 15:30:00	Sample Start	09/27/2004 17:00:00	Chamber Const	0.051
Calibration End	09/27/2004 16:30:00	Sample End	09/28/2004 09:00:11	Regression Const	-6

Photo-E

arith. mea

geo. mea

std. dev

median

75th %

95th %

min.

max.

15 minute

highest

2nd highe

3rd highe

N =

Sa

294.01

250

200

150

100

50

0.00

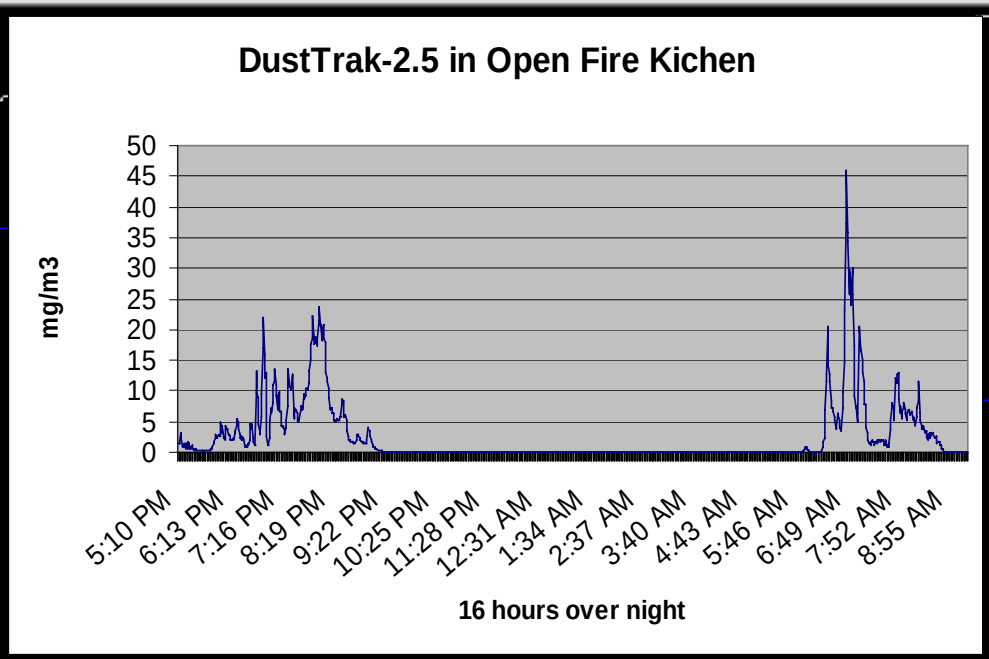
mg/m3

09/27/2004 17:00:00 21:00:00 23:00:00 01:00:00 03:00:00 09/28/2004 09:00:00

Photoelectric mass

00:26:00, 0.6534

PhotoElectric Ionization Temperature Humidity Battery Ultra-Sound

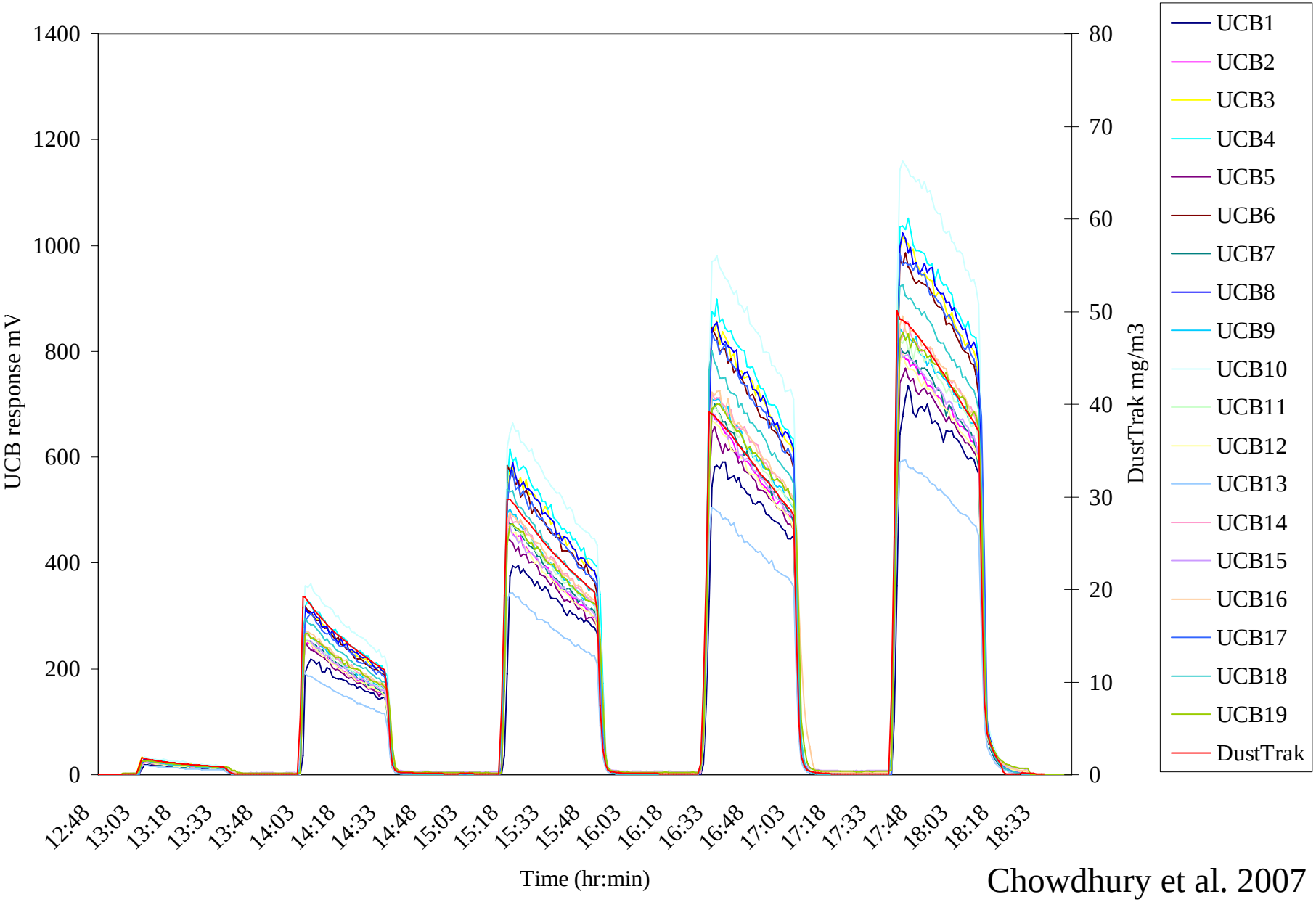


The improved stove in the kitchen

Thirty UCB P-3bs

17 hours from 5 PM Sept 24 to 10 AM Sept 25, 2004.

Comparison of multiple UCBs



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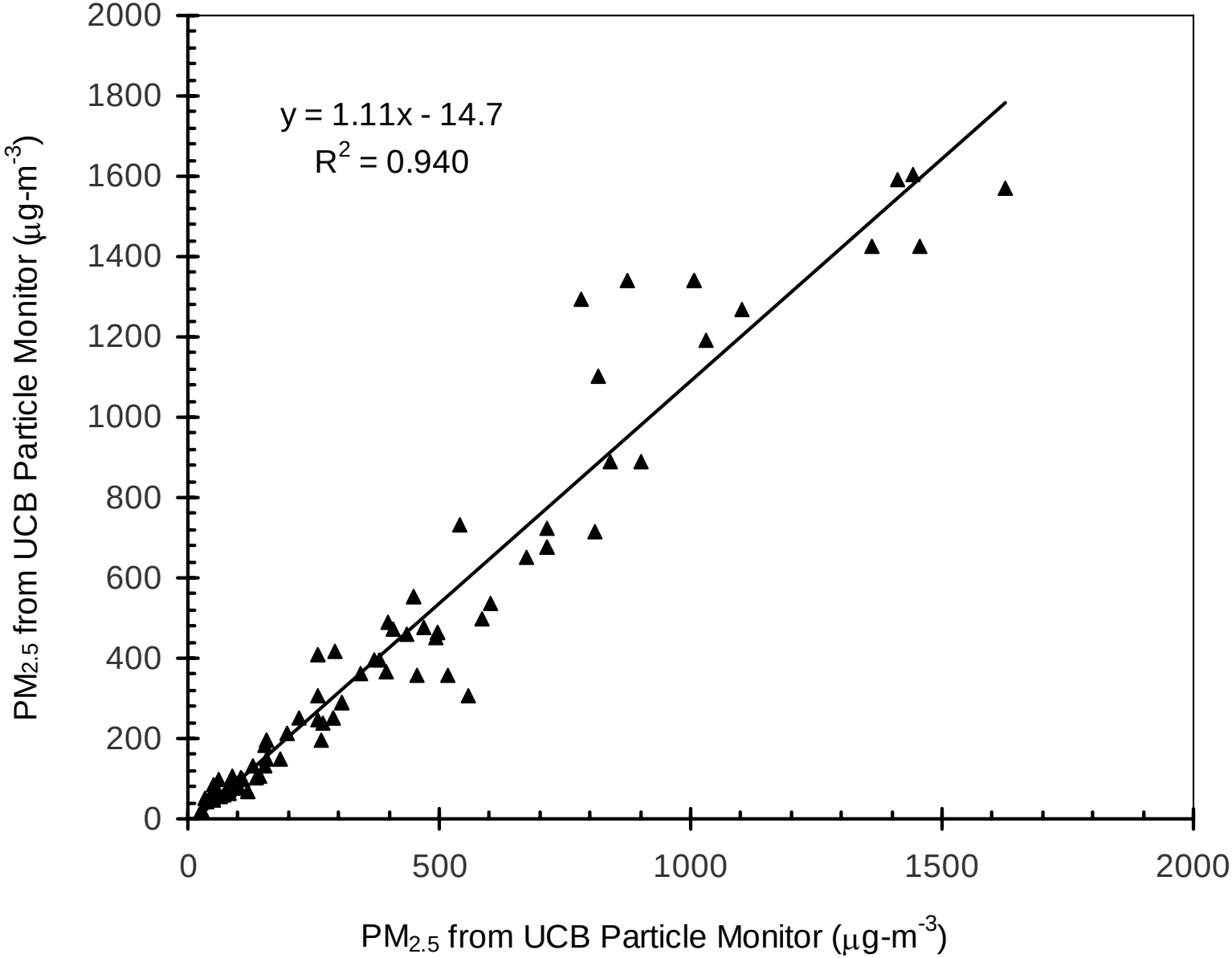
Between UCBs



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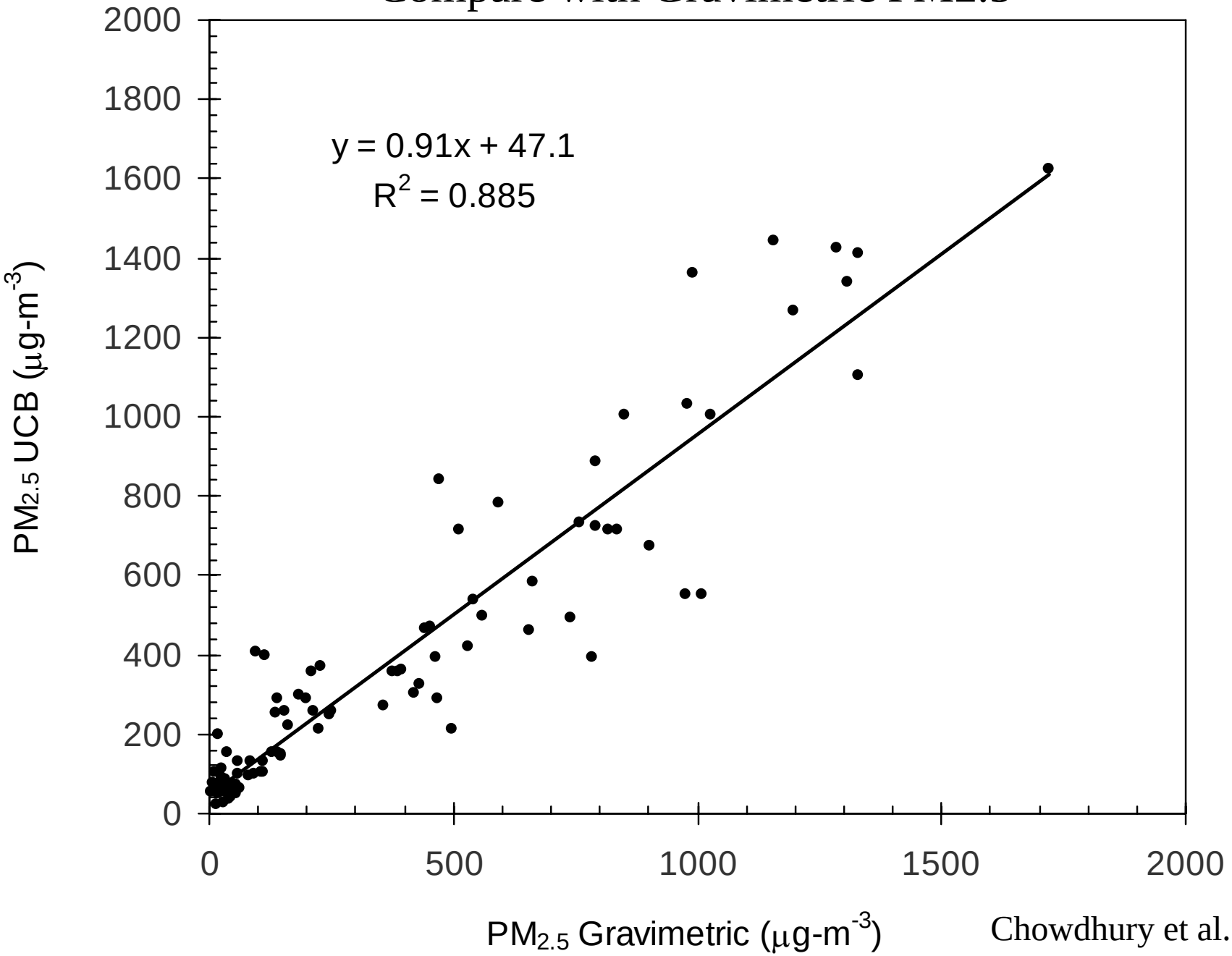
Compare with other instruments

Compare with Gravimetric PM2.5



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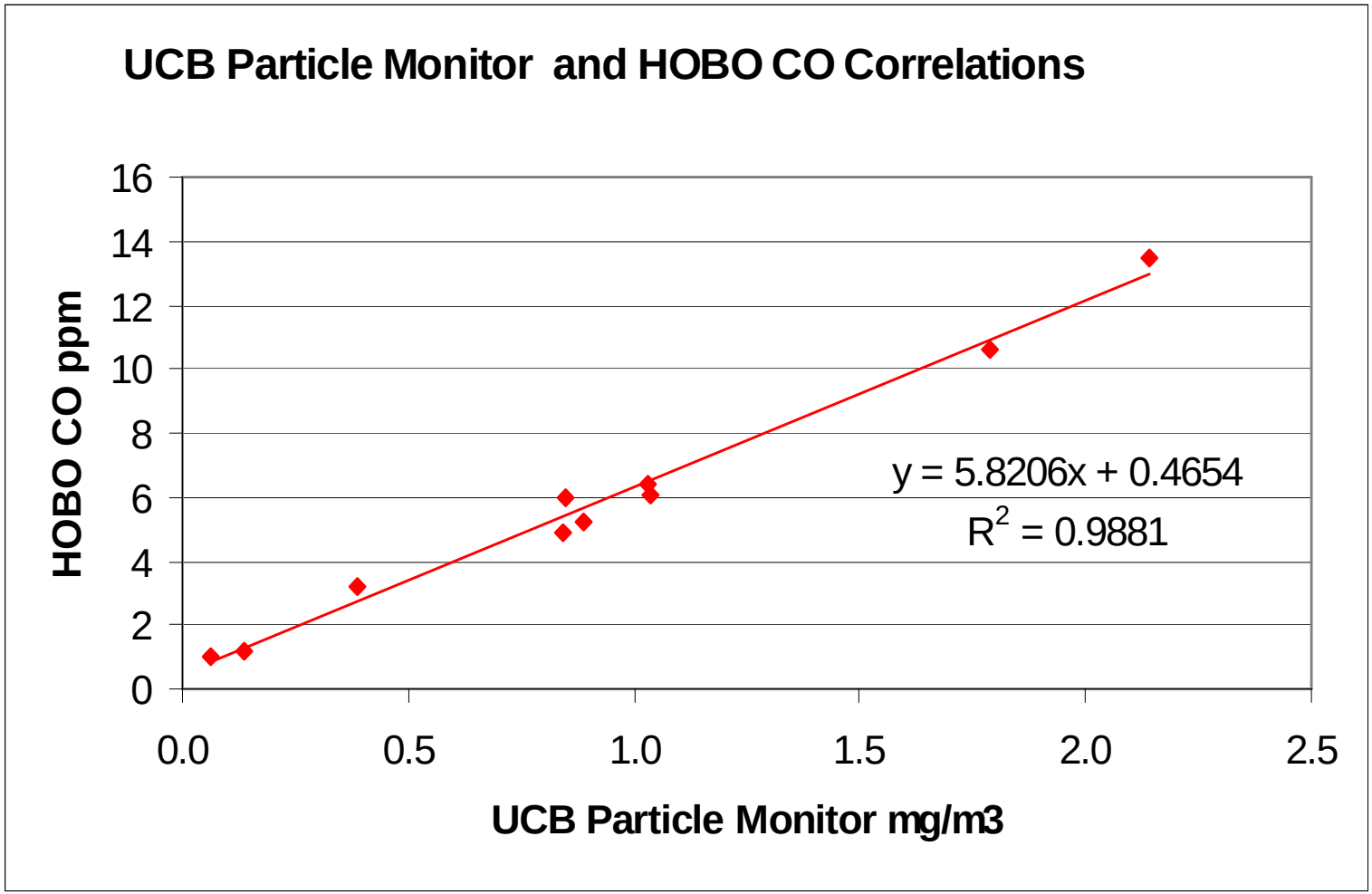
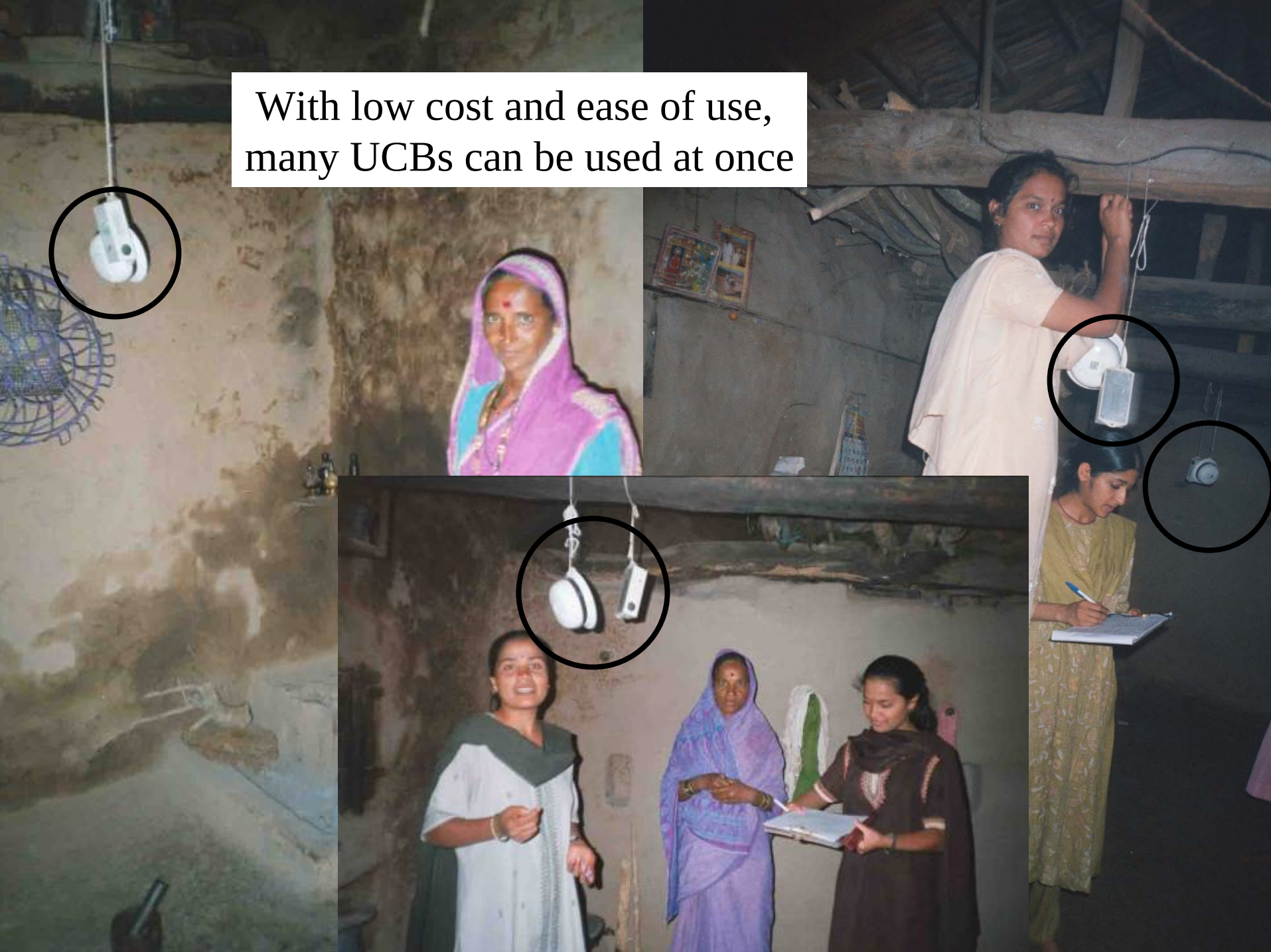
Household measurements in Mexico



With low cost and ease of use, many UCBs can be used at once



Mongolian Yurt using improved Coal Stove Jan 2004

Mexico City Street.

Remaining Issues

- Sensitivity at low (first-world) pollution levels <50 μg/m3
- Power consumption: want to keep it battery operated with at least one-week field life
- Temperature sensitivity: both chambers and battery voltage
- Humidity sensitivity of light-scattering: condensation on circuit board can occur as well
- Variation and sustainability of manufactured units from factory
- Handling large data flows
- Radioactivity an issue in some applications

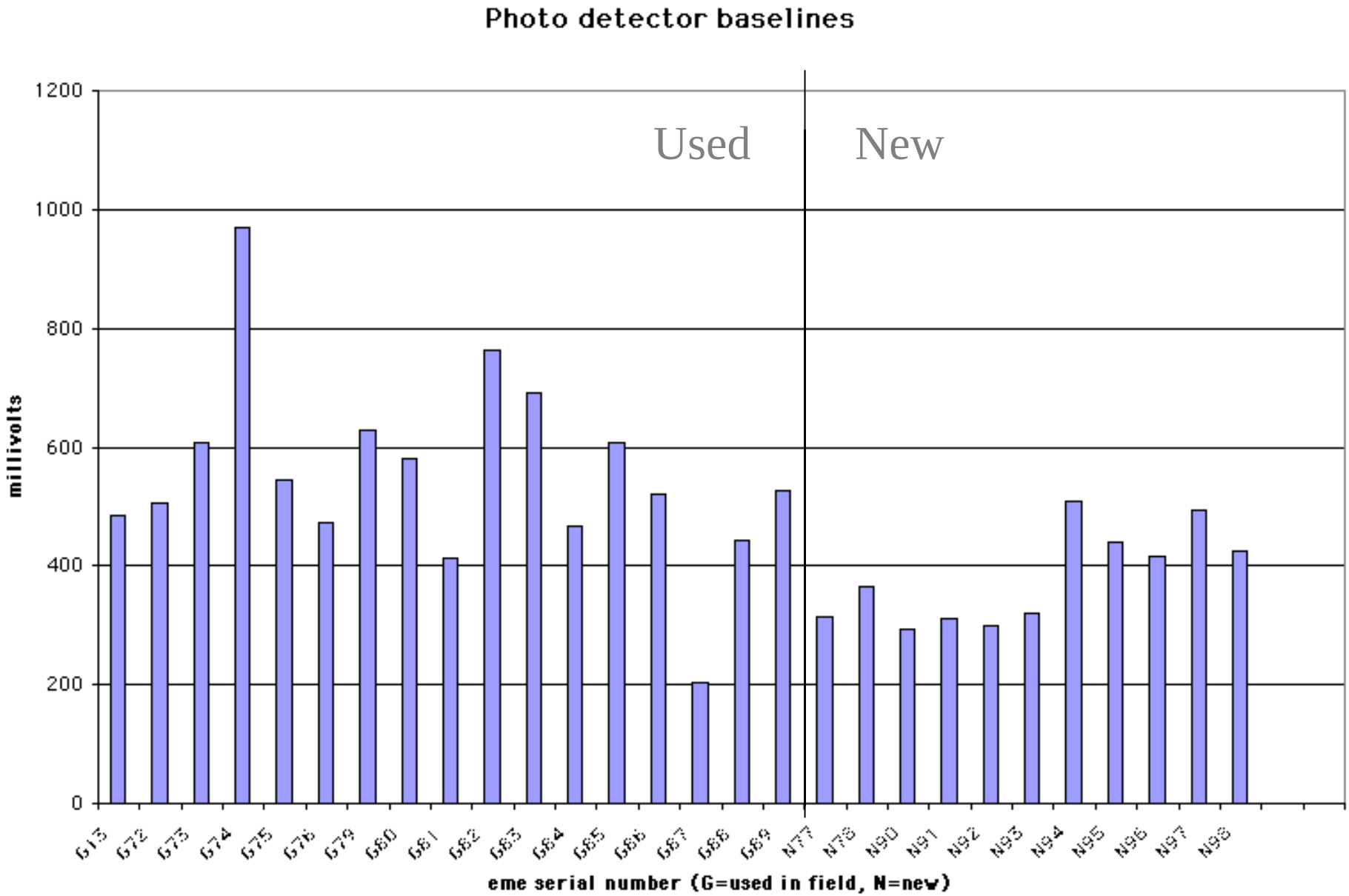


Photo detector baselines
Used
New
1200
1000
800
600
400
200
0
millivolts
G71
G72
G73
G74
G75
G76
G79
G80
G81
G82
G83
G84
G85
G86
G87
G88
G89
N77
N78
N90
N91
N92
N93
N94
N95
N96
N97
N98
eme serial number (G=used in field, N=new)

New Directions, in motion

- Single chamber version (light-scattering only) now available and sold at cost by Center for Entrepreneurship in International Health and Development (CEIHD, a Berkeley NGO)
- Personal locator using ultrasound signals: now developed and under regular use in Guatemala
- Extend lower range of sensitivity using more sophisticated laser chamber – CARB grant
- Derive estimate of particle number count from ion chamber: under development and testing

New Directions, planned

- Part of CARB grant
  - Develop own case for limiting wind effects
  - Add GPS capability
  - Improve friendliness of software
- Visual real-time display option
- Simple air mover
- Add other sensors, e.g., CO, thermocouple
- Internet and wireless data transmission

Cost of UCB-single chamber

- Parts cost ~$150 (laser chamber +~$100)
- Manufactured cost goals
  - $250 (low volume)
  - ~$150 for software, calibration, and testing
- Nearest competitor (TSI SidePak), which is dumb, noisy, short-lived (22hr) and without temp/humid, measurement ~ $3000.
- Cost difference:
  - Greatly facilitates current studies, but also
  - **Makes possible entirely new types of studies!**

Post-technical CARB Project Issues

- Making software most usable
- Calibration expectations
- Utilizing GPS
- Case and other physical characteristics
- Instruction and training manual, data analysis and graphing templates, etc.
- Manufacture and disseminate

UCB Primary Publications

- Litton CD, Smith KR, Edwards R, Allen T, Combined optical and ionization measurement techniques for inexpensive characterization of micrometer and submicrometer aerosols, Aerosol Science and Technology, 38(11): 1054-1062, 2004.

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Thank you