Coarse PM Methods Evaluation Study

Study Design and Results

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Background

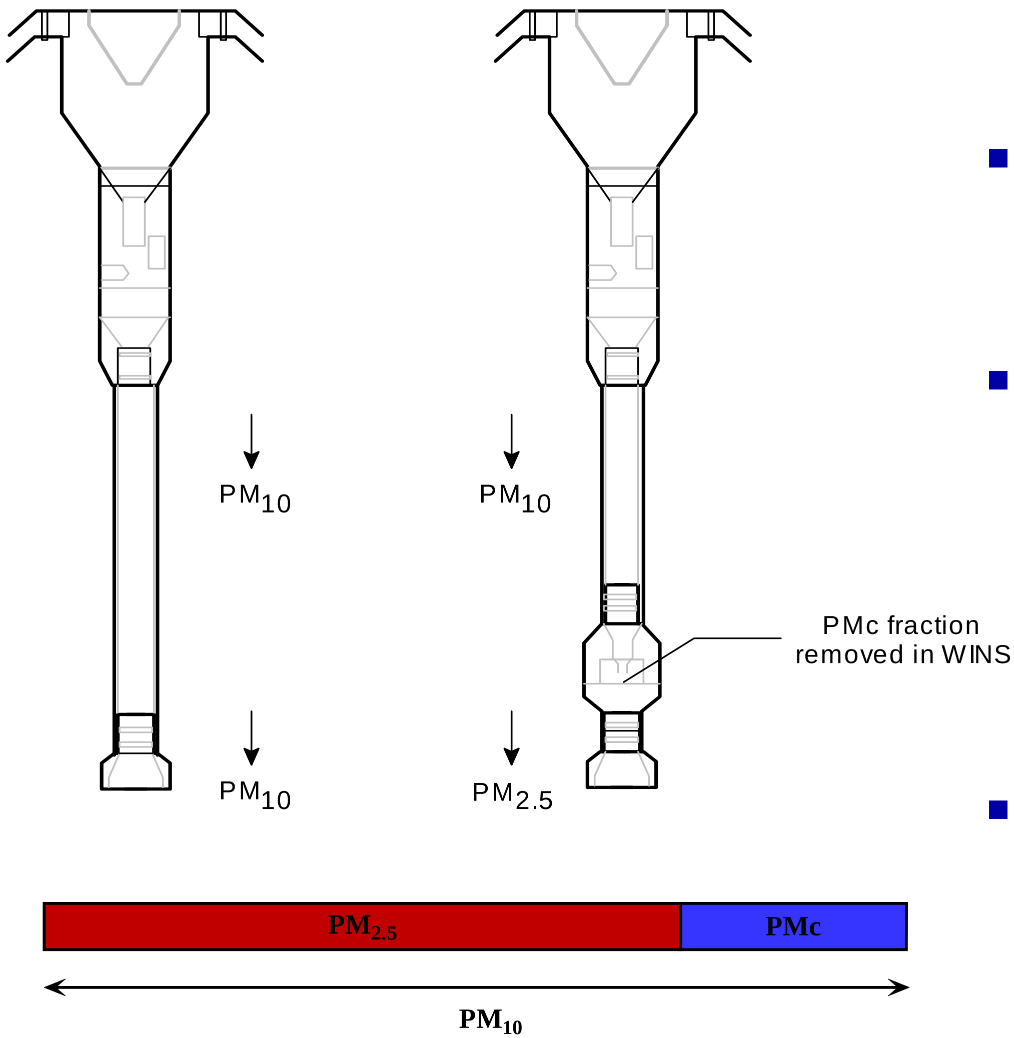
- Since the 1997 $PM_{2.5}$ promulgation, the U.S. courts have reviewed subsequent litigation and ruled that the PM_{10} metric is a "poorly matched indicator" because it includes the $PM_{2.5}$ fraction. EPA has consented to establish separate air quality standards for the fine and coarse fractions of PM_{10}

- PMc is inherently more difficult to accurately measure than either $PM_{2.5}$ or PM_{10}. Measurement issues (e.g. losses of large particles) may result in less precise PMc measurements than either $PM_{2.5}$ or PM_{10} measurements

Study Objectives

- **Evaluate the field performance of leading methods for monitoring the coarse fraction of PM_{10} ($PMc = PM_{10} – PM_{2.5}$)**
- **Evaluate samplers which are either already commercially available or in their final stages of development**
- **Include both filter-based (time-integrated) and semi-continuous measurement methods**

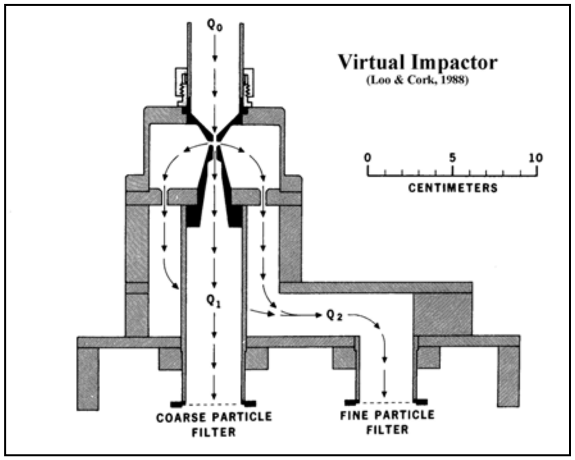
$PM_{2.5}$ and PM_{10} FRM Samplers



$PMc = PM_{10} - PM_{2.5}$

- **Standard low-vol PM_{10} inlets aspirating at 16.7 lpm (actual conditions)**
- **$PM_{2.5}$ aerosol fractionation using a WINS equipped with DOS impaction oil**
- **Filters were conditioned at 22C and 35% RH, analyzed gravimetrically. Post-sampling filters archived at -30C for subsequent chemical analysis**
- **3 FRM pairs from BGI, R&P, and Thermo-Andersen equipped with teflon filters (4^{th} FRM pair equipped with quartz filters)**

R&P Partisol-Plus 2025 Dichot

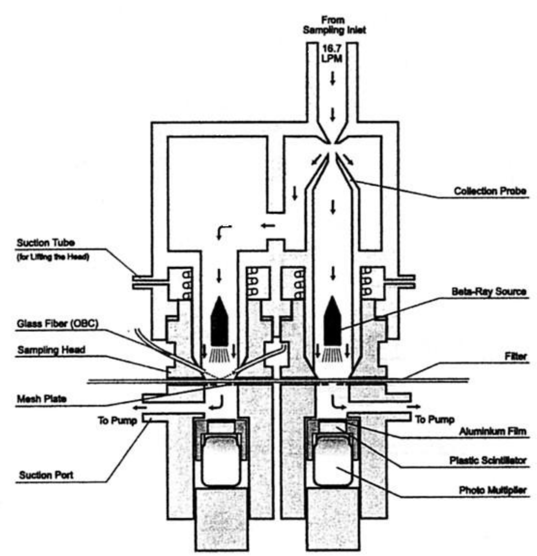


- Standard PM_{10} inlet aspirating at 16.7 lpm (actual)
- Aerosol fractionation by custom virtual impactor (15 lpm and 1.67 lpm)
- $PM_{2.5}$ and PMc mass collected on 47 mm teflon filters for gravimetric analysis
- Sequential sampler with multi-day capability
- 4 units used in our study (3 teflon and 1 quartz)

R&P Coarse Particle TEOM

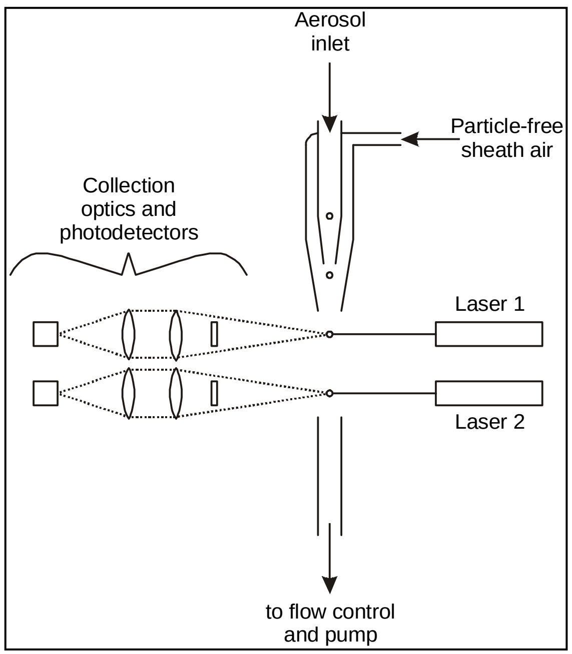
- **Modified PM_{10} inlet aspirating at 50 lpm (actual)**
- **PM_{10} aerosol is fractionated by a custom virtual impactor (2 lpm coarse flow and 48 lpm fine flow)**
- **PMc fraction is heated to 50 C to remove particle bound water**
- **Coarse aerosol is collected and quantified by a standard TEOM sensor**
- **3 units used in our study**

Tisch SPM-613D Dichot Beta Gauge



- **Standard PM_{10} inlet aspirating at 16.7 lpm (~std)**
- **Aerosol heated if <25C**
- **Aerosol fractionation by custom virtual impactor**
- **$PM_{2.5}$ and PMc mass collected on polyflon tape roll**
- **$PM_{2.5}$ and PMc mass quantified hourly using separate beta sources and detectors**
- **3 units used in our study**

TSI Model 3321 Aerodynamic Particle Sizer



- Standard PM_{10} inlet aspirating at 16.7 lpm (actual)
- Isokinetic fraction of PM_{10} aerosol removed at 5 lpm and enters the APS inlet
- APS sizes individual particles aerodynamically using time of flight approach
- Single particle volume converted to mass using mean density provided by user
- Total aerosol mass is sum of individual particle masses
- APS provides only PMc; not applicable for $PM_{2.5}$ or PM_{10}
- Only sampler in study which provides detailed size distribution information
- 2 units used in our study

Mobile Sampling Platform (Side View)

Study Design

- **Using 22 hour, daily sampling periods for comparisons (11 am to 9 am local time)**
- **Chemical analysis (XRF, IC, thermal optical) of selected archived filters will provide particle composition, which may help explain observed sampler performance**
- **The difference method will be used as the basis of comparison for the study**

Sampler Performance Issues

- Relative bias compared to collocated FRMs
- Precision (2 or 3 samplers of each type)
- Field reliability
- Evaluation under a wide range of weather conditions and aerosol types

QA/QC Initiatives

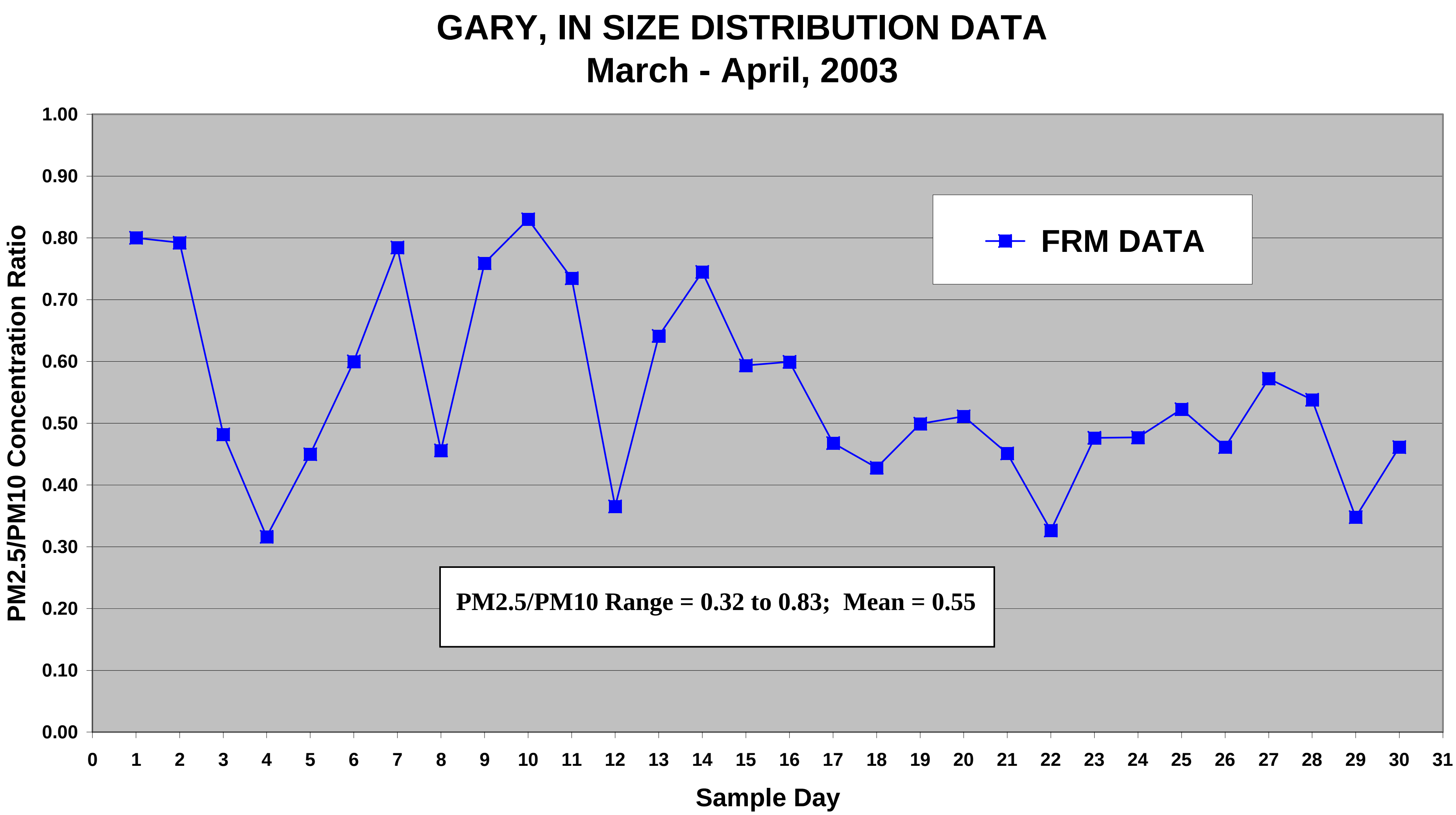
- Sampler manufacturers were very involved in the study and allowed to verify the working condition of their respective samplers at each sampling site
- Sampling and fractionation components were cleaned prior to sampling at each site
- NIST-traceable sampler calibration equipment was used for all sampler calibrations and audits
- Three performance audits and three field blank tests were conducted at each site
- Replicate weighings were conducted for all samples
- Weighings were done on-site (before shipping) and at EPA's RTP weighing facility to measure PM losses during shipment

Study Sites

- **RTP, NC (10 days of shakedown tests, Jan. 2003)**
- **Gary, IN (30 days of tests under cold, snow/rain, variable $PM_{2.5}/PM_{10}$ ratios, March-April, 2003)**
- **Phoenix, AZ (30 days of tests under hot, dusty conditions, consistently low $PM_{2.5}/PM_{10}$ ratios, May-June, 2003)**
- **Riverside, CA (30 days of tests under warm conditions, higher $PM_{2.5}/PM_{10}$ ratios than Phoenix, July-August, 2003)**
- **Phoenix, AZ (15 days of follow-up tests, January 2004)**

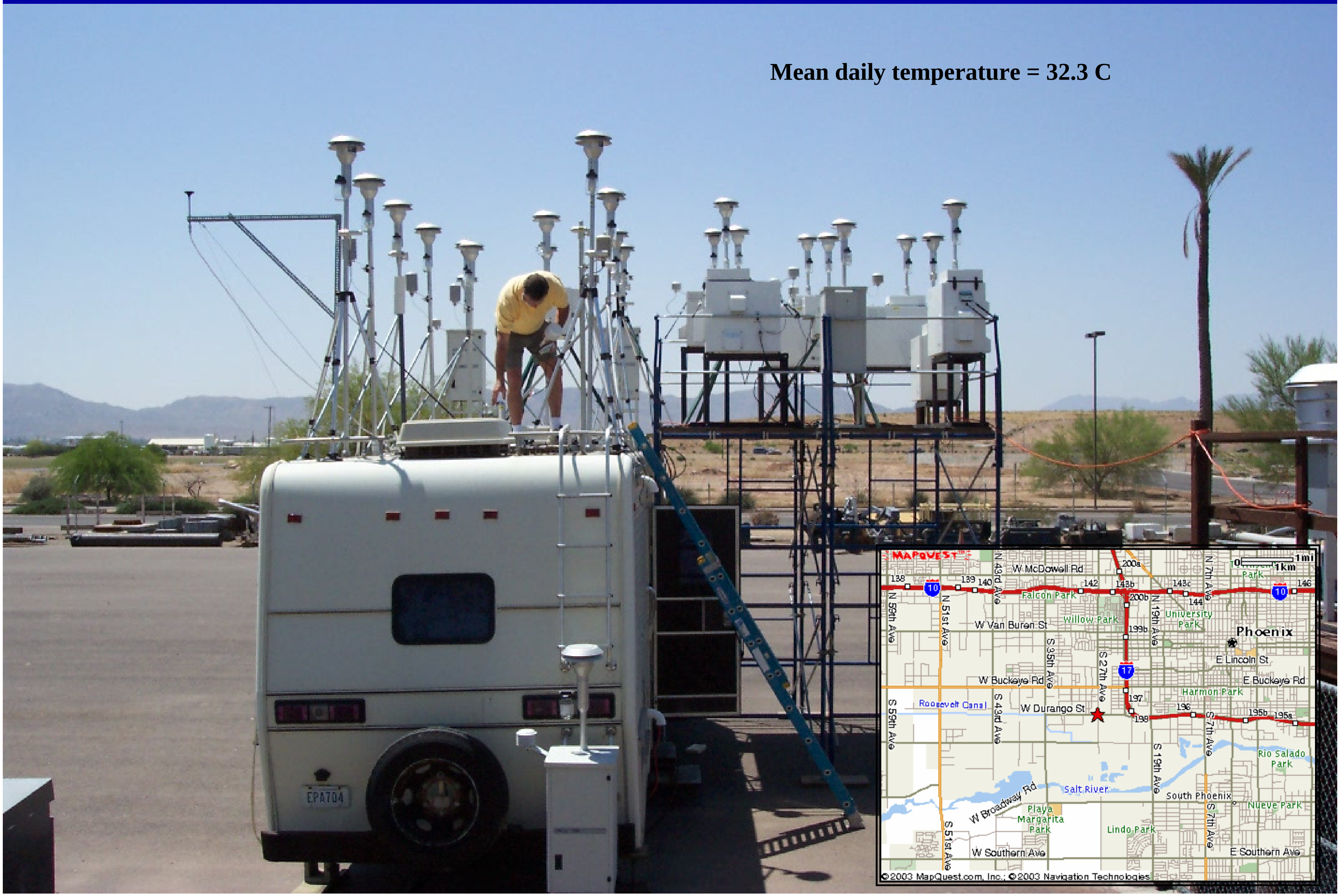
Gary, IN

Mean daily temperature = 4.6 C

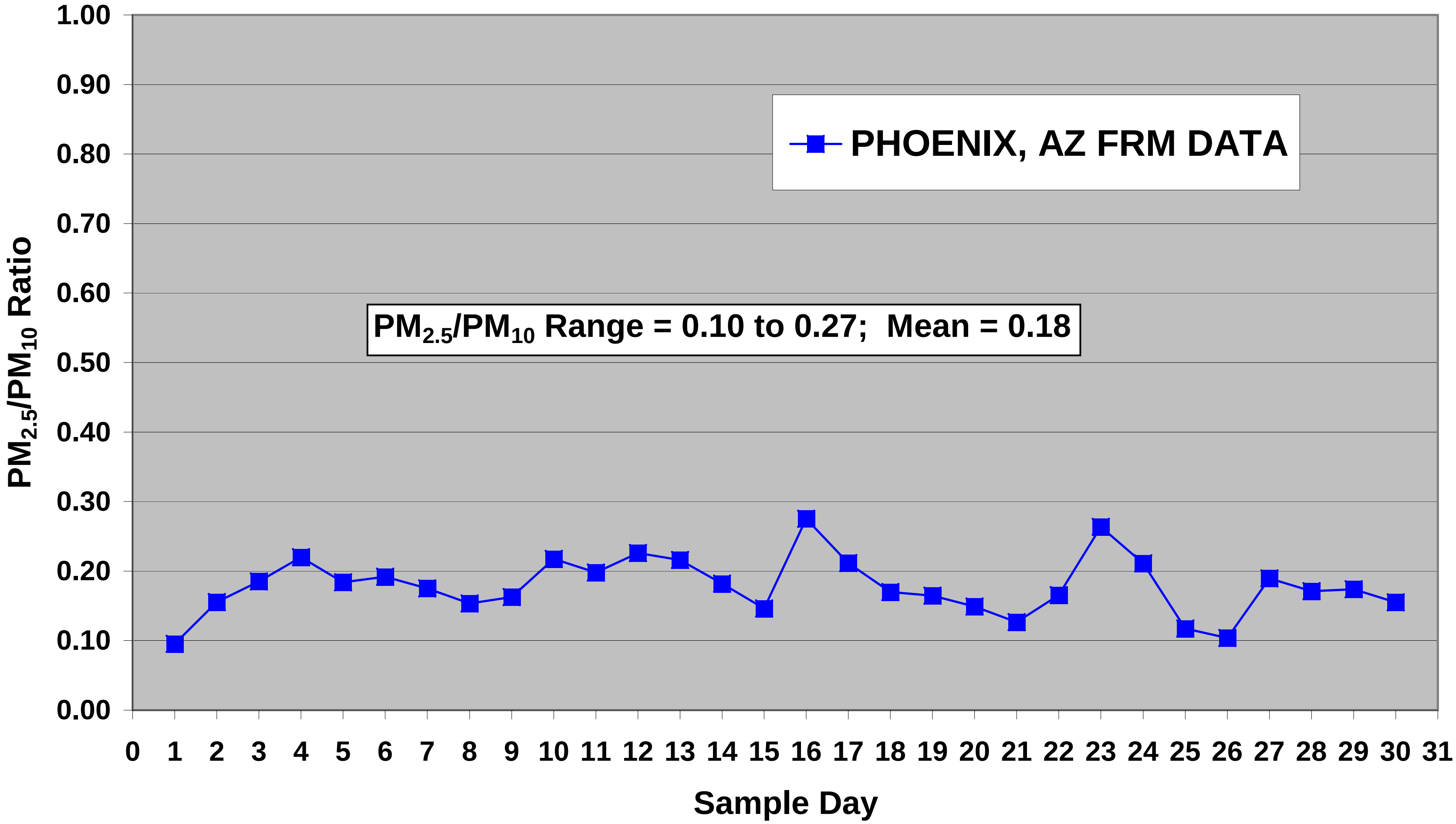

GARY, IN SIZE DISTRIBUTION DATA
March - April, 2003
FRM DATA
PM2.5/PM10 Range = 0.32 to 0.83; Mean = 0.55
PM2.5/PM10 Concentration Ratio
Sample Day
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Phoenix, AZ

Mean daily temperature = 32.3 C



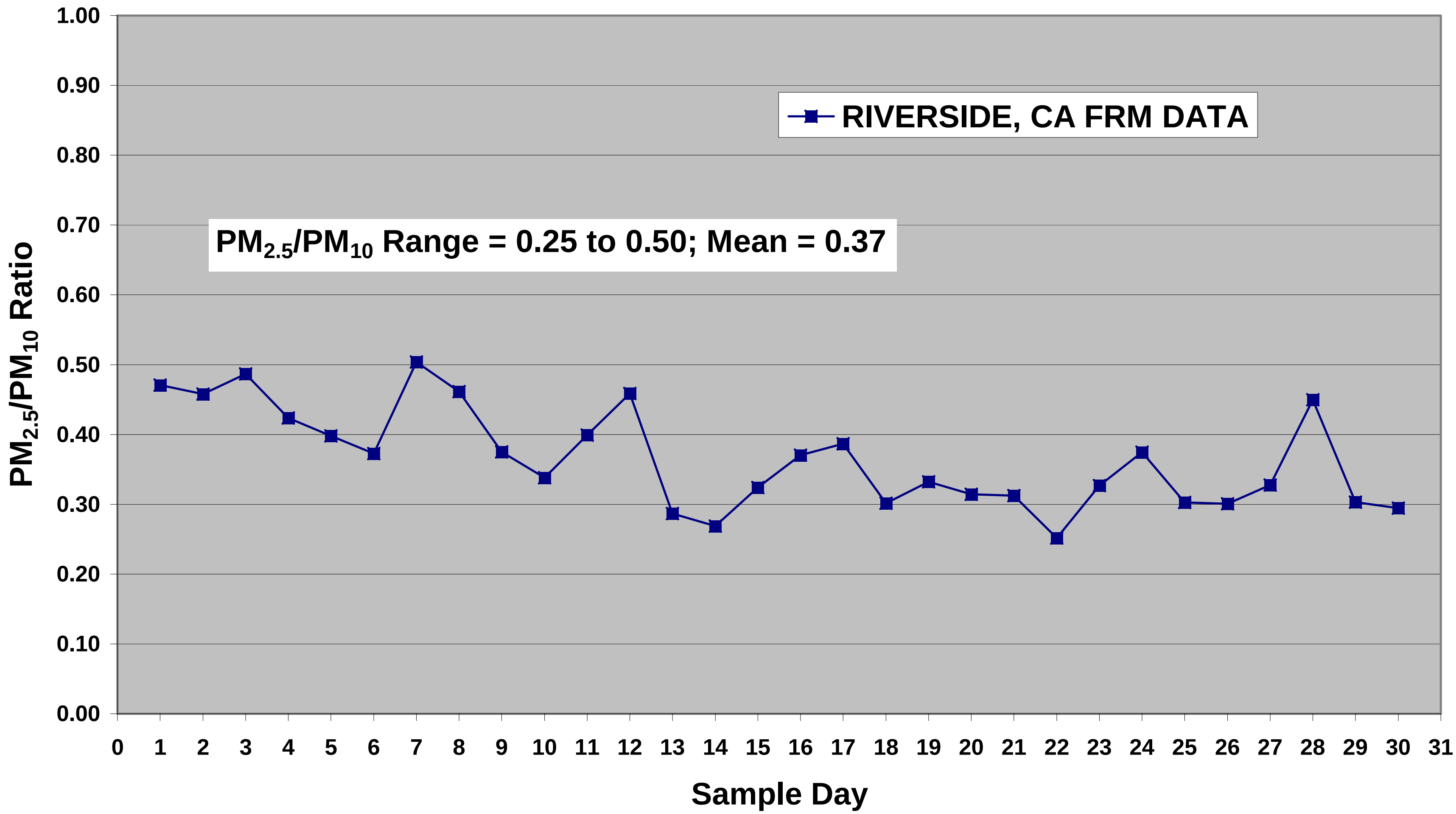
PHOENIX, AZ SIZE DISTRIBUTION DATA
May - June, 2003



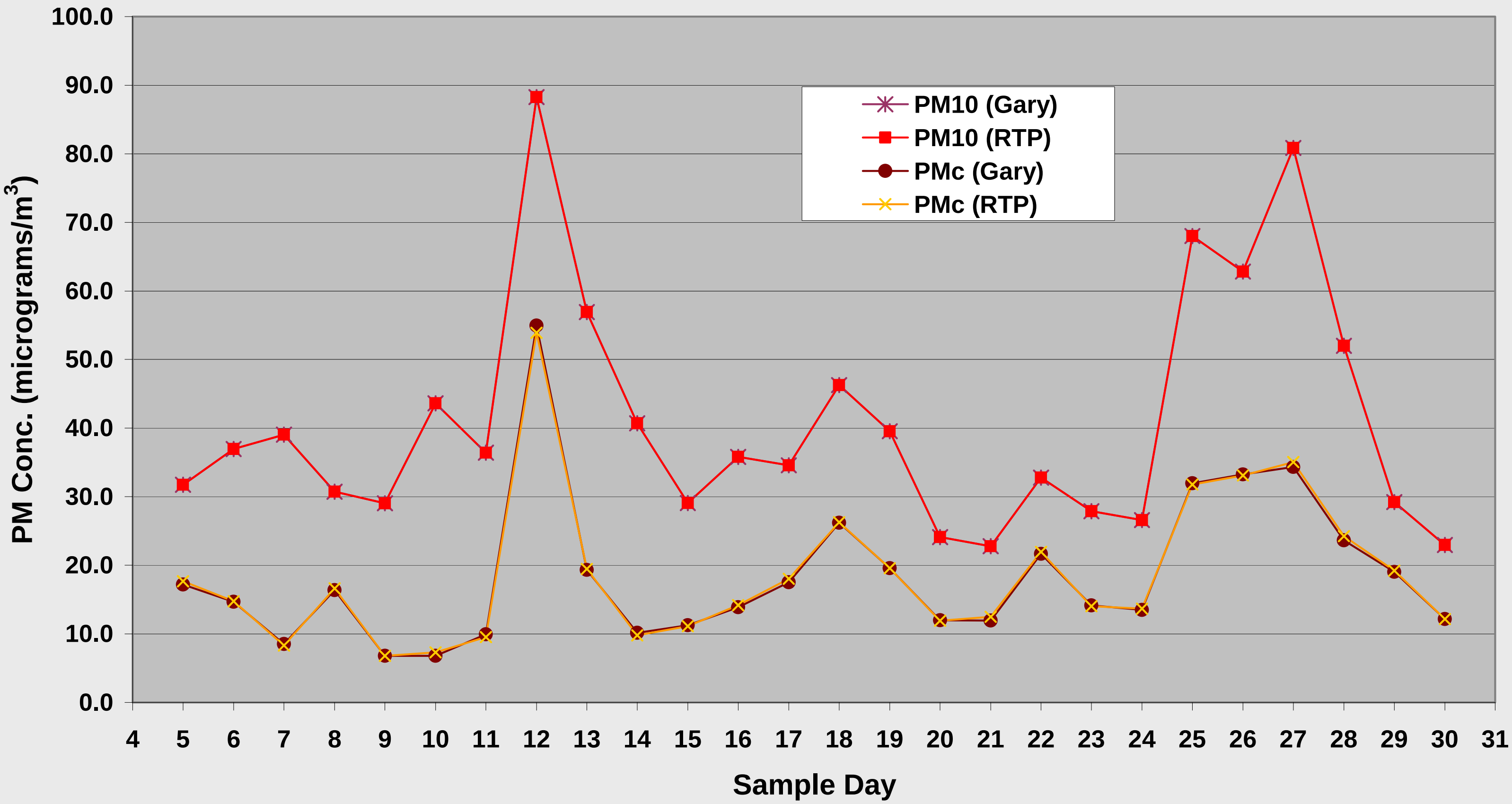
Riverside, CA

UCR Ag Ops Facility

RIVERSIDE, CA SIZE DISTRIBUTION
July - August, 2003



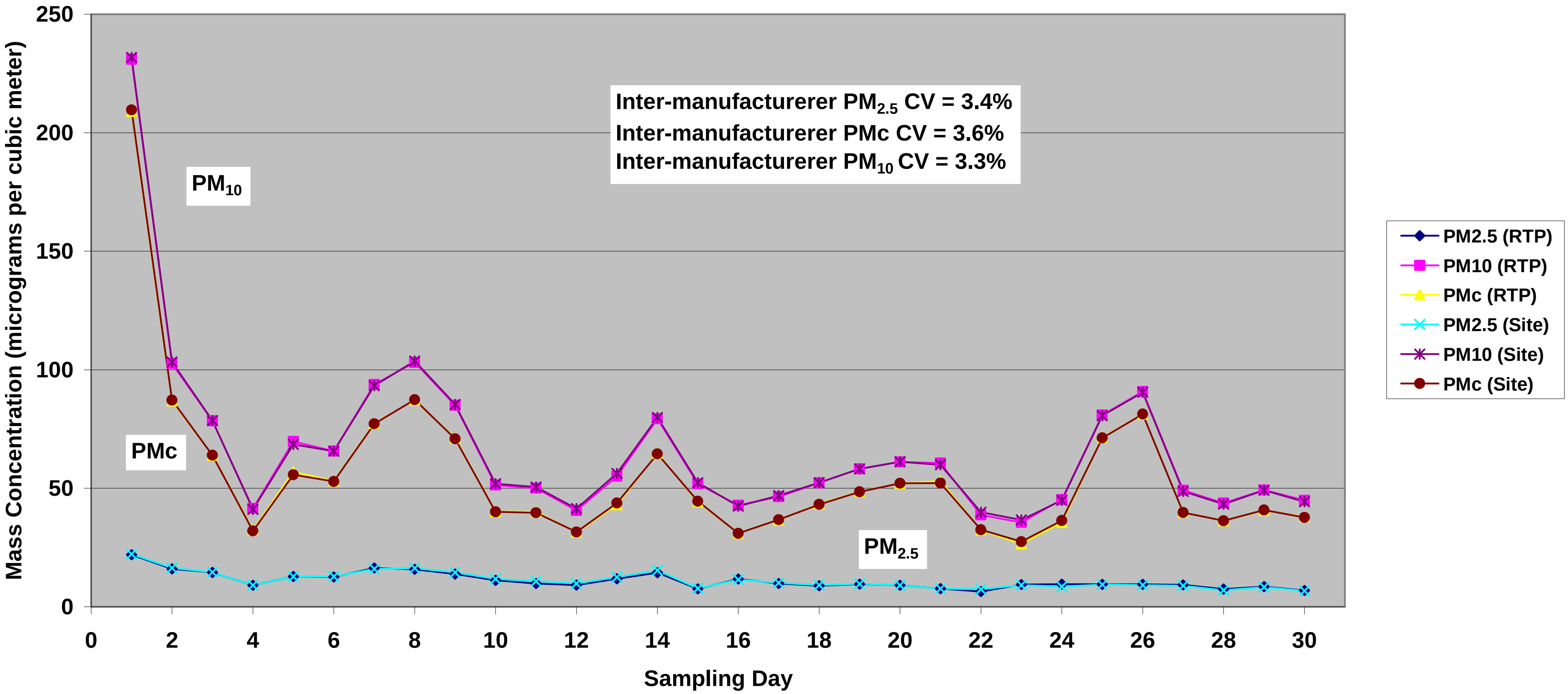
FRM MEASUREMENTS - GARY vs RTP WEIGHING
Gary, IN (March - April, 2003)



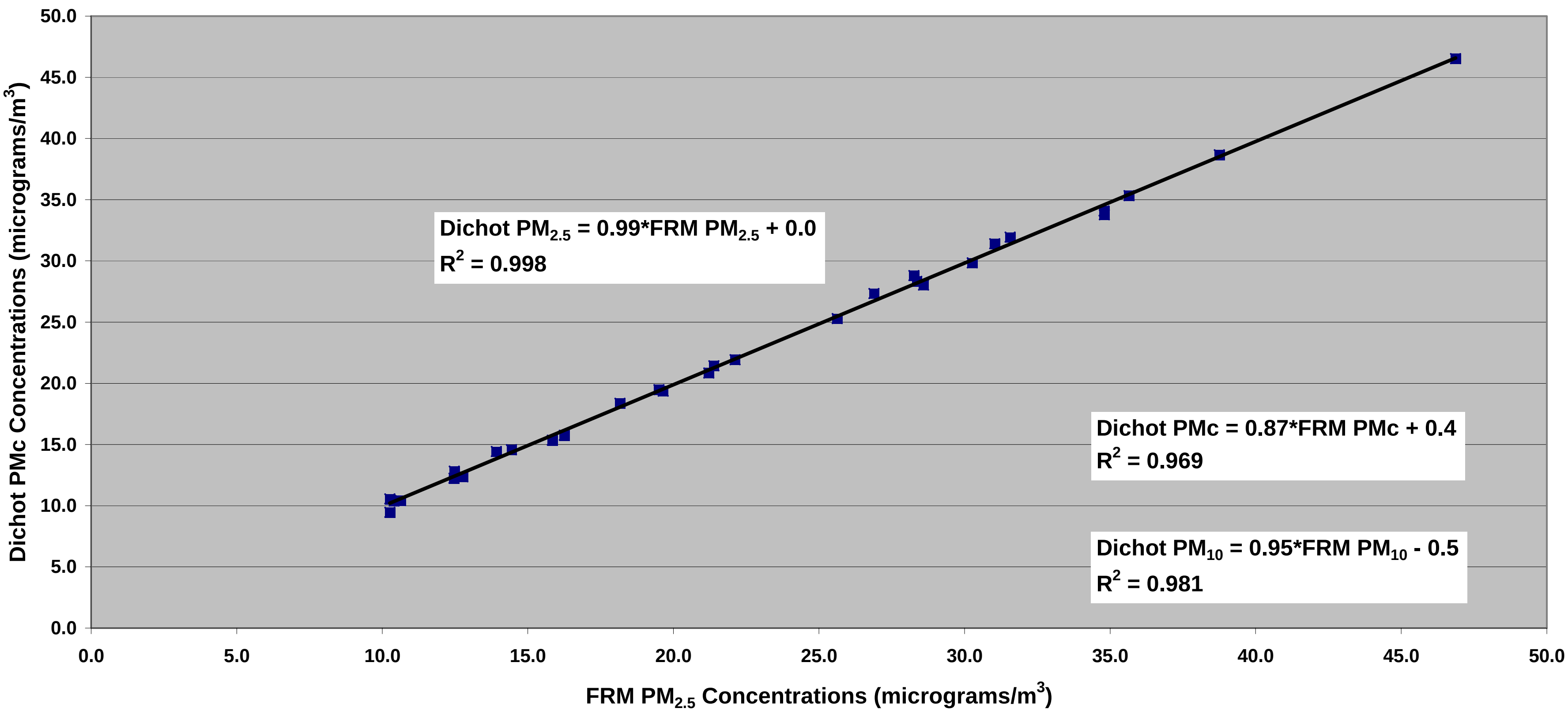
RTP/Site Test Results for Integrated Samplers

	SAMPLING SITE					
Metric	Sampler	RTP/Gary	RTP/Phoenix (May–June, 2003)	RTP/Riverside	RTP/Phoenix (Jan. 2004)	Mean
$PM_{2.5}$	FRM	0.97	0.99	1.00	1.00	0.99
	R&P Dichot (seq)	0.95	1.00	1.00	1.00	0.99
	R&P Dichot (man)				1.00	1.00
	Andersen Dichot				0.99	0.99
PM_{10}	FRM	0.98	1.00	1.00	1.00	1.00
	R&P Dichot (seq)	0.97	1.00	0.98	1.01	0.99
	R&P Dichot (man)				1.01	1.01
	Andersen Dichot				0.98	0.98
PMc	FRM	1.00	1.00	1.00	1.00	1.00
	R&P Dichot (seq)	0.99	1.00	0.96	1.02	0.99
	R&P Dichot (man)				1.02	1.02
	Andersen Dichot				0.97	0.97
					Mean =	0.99

Phoenix versus RTP FRM Weighing
May - June 2003



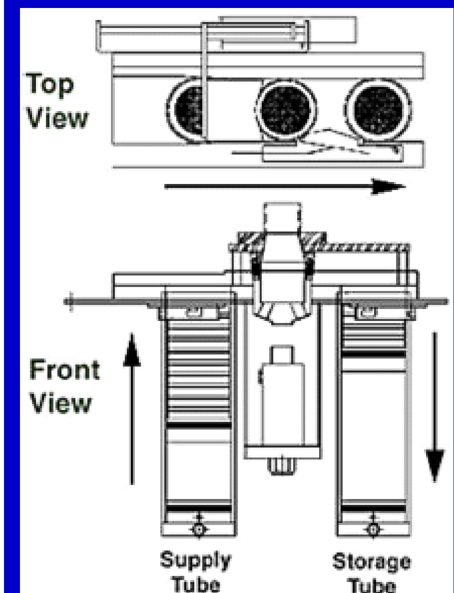
Dichot versus FRM $PM_{2.5}$ Concentrations
Gary, IN (March - April, 2003)



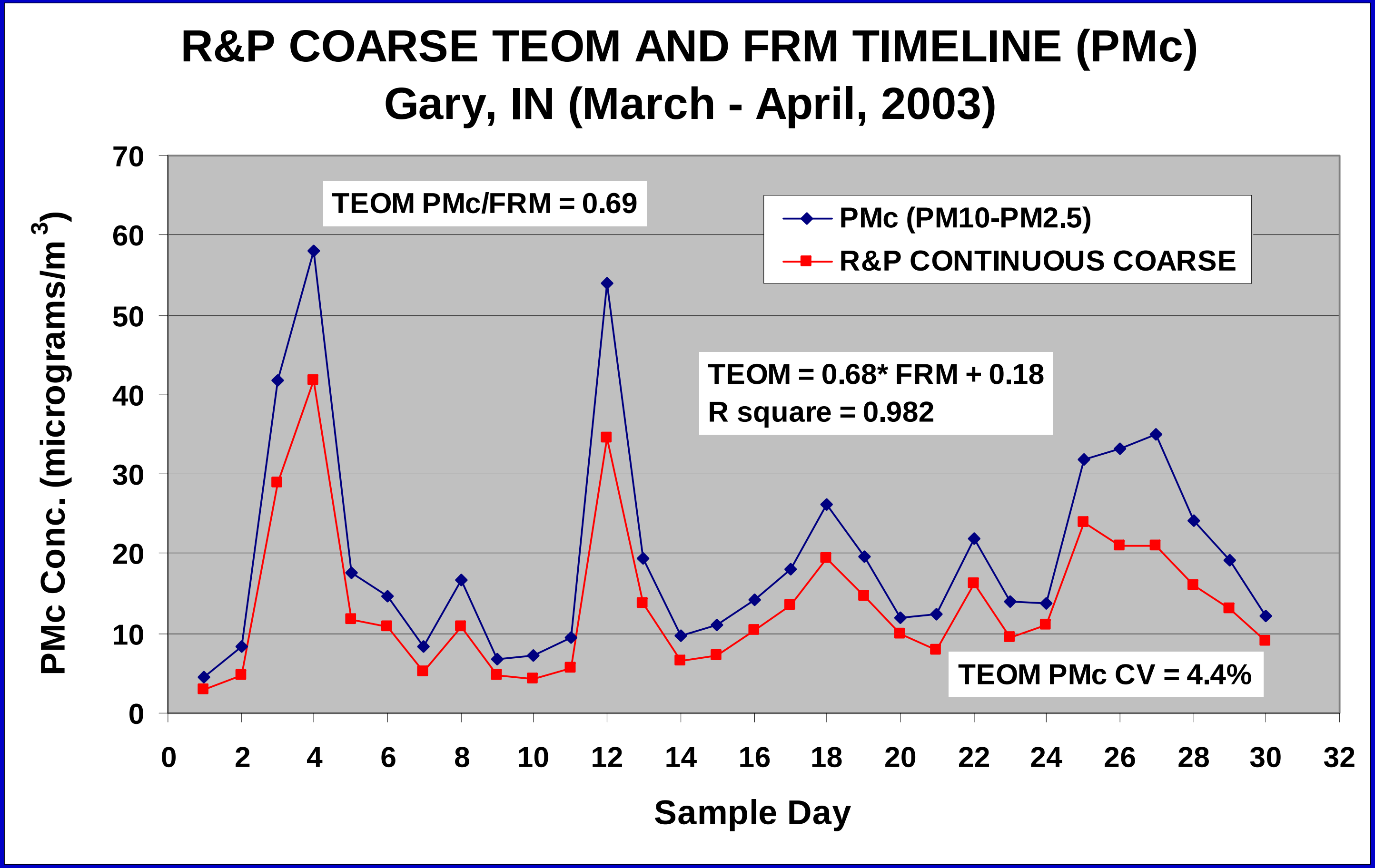
R&P Dichots vs. FRM

Metric	Gary, IN	Phoenix, AZ	Riverside, CA
$PM_{2.5}$	Slope = 0.99 Int. = +0.0 R^2 = 0.998 Ratio to FRM = 0.99	Slope = 1.24 Int. = -1.6 R^2 = 0.97 Ratio to FRM = 1.09	Slope = 0.998 Int. = +0.0 R^2 = 0.995 Ratio to FRM = 1.00
PMc	Slope = 0.87 Int. = +0.39 R^2 = 0.969 Ratio to FRM = 0.89	Slope = 0.70 Int. = +5.0 R^2 = 0.98 Ratio to FRM = 0.79	Slope = 0.95 Int. = +0.25 R^2 = 0.98 Ratio to FRM = 0.96
PM_{10}	Slope = 0.95 Int. = -0.47 R^2 = 0.981 Ratio to FRM = 0.94	Slope = 0.75 Int. = +5.9 R^2 = 0.98 Ratio to FRM = 0.84	Slope = 1.00 Int. = -1.21 R^2 = 0.99 Ratio to FRM = 0.97

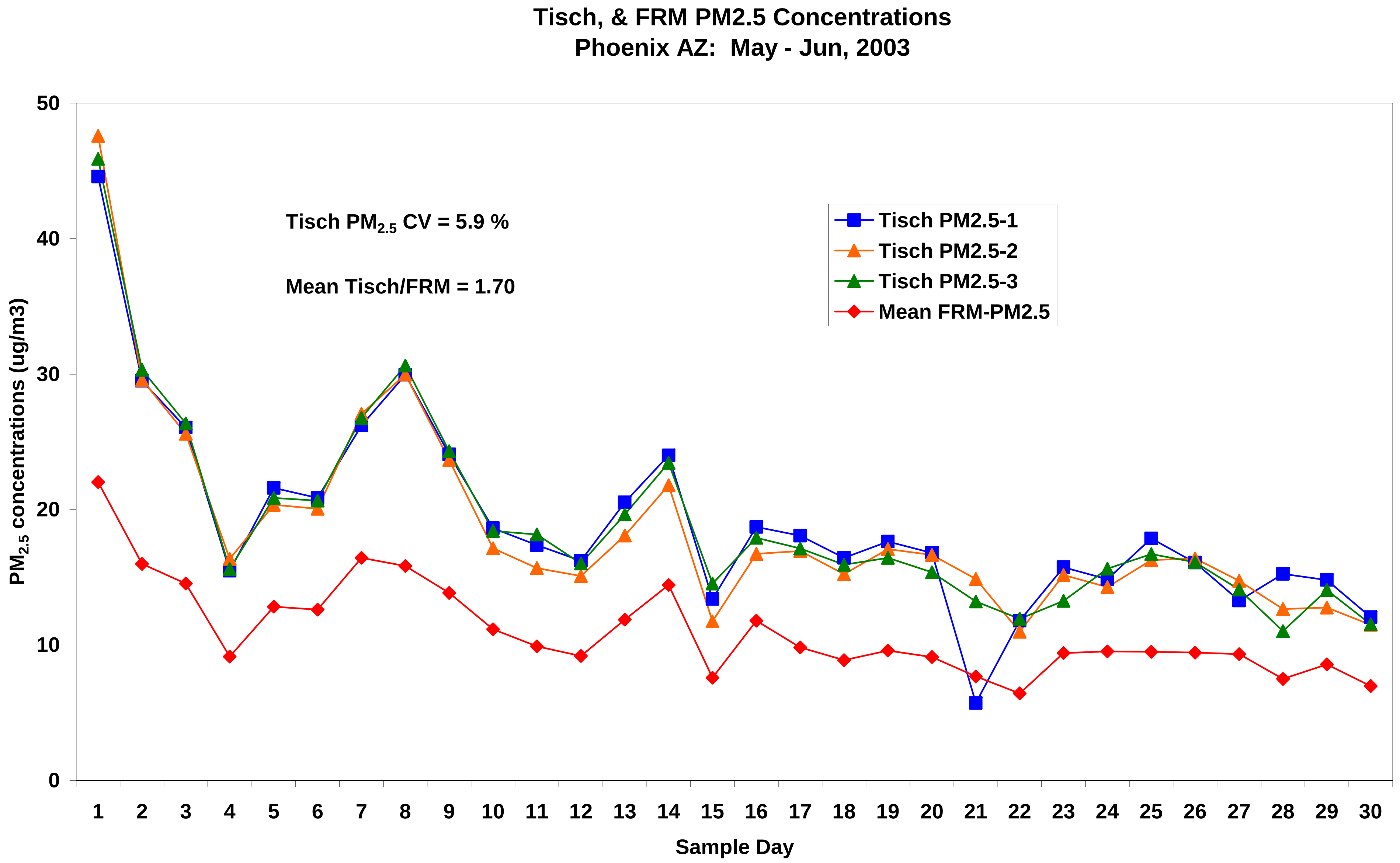
SEQUENTIAL VS. MANUAL DICHOTS
PHOENIX, AZ (JAN 2004)



Metric	Sequential Dichot	Manual Dichot
$PM_{2.5}$	Slope = 1.09 Int. = -0.32 R^2 = 0.982 Ratio to FRM = 1.07	Slope = 1.03 Int. = +0.10 R^2 = 0.982 Ratio to FRM = 1.04
PMc	Slope = 0.84 Int. = +1.5 R^2 = 0.971 Ratio to FRM = 0.90	Slope = 1.02 Int. = -0.08 R^2 = 0.996 Ratio to FRM = 1.00
PM_{10}	Slope = 0.89 Int. = +1.9 R^2 = 0.976 Ratio to FRM = 0.94	Slope = 1.03 Int. = -0.50 R^2 = 0.997 Ratio to FRM = 1.01

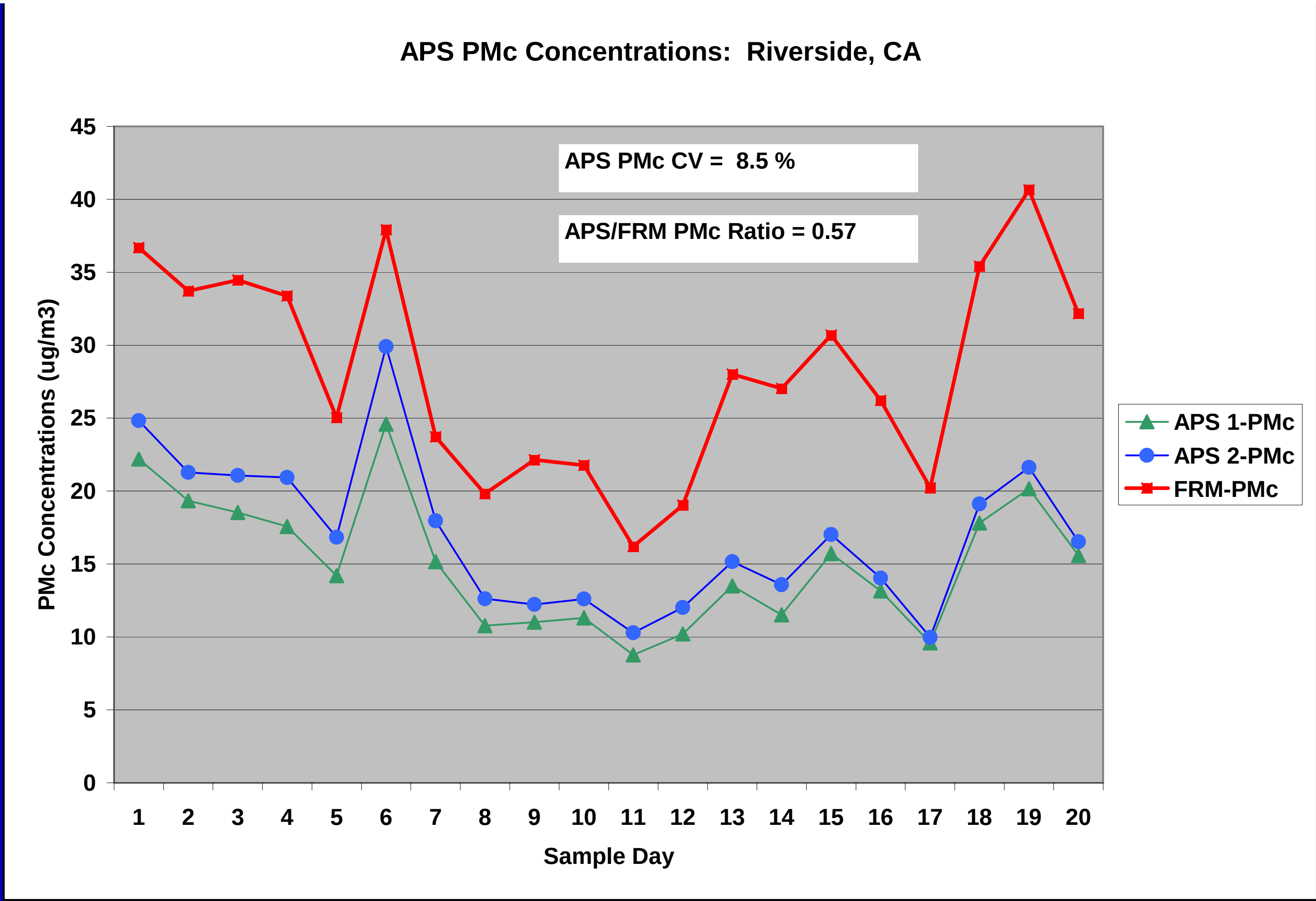


Metric	Gary, IN	Phoenix, AZ (May – June, 2003)	Riverside, CA	Phoenix, AZ (Jan 2004)
PMc	Slope = 0.68 Int. = +0.18 R^2 = 0.982 CV = 4.4% Ratio to FRM = 0.69	Slope = 0.79 Int. = +12.8 R^2 = 0.951 CV = 6.6% Ratio to FRM = 1.05	Slope = 0.74 Int. = -0.64 R^2 = 0.948 CV = 1.7% Ratio to FRM = 0.76	Slope = 0.77 Int. = +0.70 R^2 = 0.995 CV = 2.6% Ratio to FRM = 0.80


Tisch, & FRM PM2.5 Concentrations
Phoenix AZ: May - Jun, 2003
Tisch $PM_{2.5}$ CV = 5.9 %
Mean Tisch/FRM = 1.70
Tisch PM2.5-1
Tisch PM2.5-2
Tisch PM2.5-3
Mean FRM-PM2.5
$PM_{2.5}$ concentrations (ug/m3)
Sample Day
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Tisch Beta Gauge Dichot vs the FRM

Metric	Gary, IN	Phoenix, AZ (May – June, 2003)	Riverside, CA	Phoenix, AZ (Jan 2004)
$PM_{2.5}$	Slope = 1.17 Int. = +1.6 R^2 = 0.945 Ratio to FRM = 1.26	Slope = 2.03 Int. = -3.4 R^2 = 0.946 Ratio to FRM = 1.70	Slope = 2.07 Int. = -6.9 R^2 = 0.904 Ratio to FRM = 1.64	Slope = 1.43 Int. = -0.11 R^2 = 0.939 Ratio to FRM = 1.43
PMc	Slope = 0.885 Int. = +0.34 R^2 = 0.978 Ratio to FRM = 0.91	Slope = 0.92 Int. = +5.9 R^2 = 0.995 Ratio to FRM = 1.04	Slope = 1.17 Int. = -2.7 R^2 = 0.957 Ratio to FRM = 1.08	Slope = 0.99 Int. = +1.66 R^2 = 0.994 Ratio to FRM = 1.05
PM_{10}	Slope = 1.02 Int. = +2.5 R^2 = 0.987 Ratio to FRM = 1.09	Slope = 1.02 Int. = +7.8 R^2 = 0.996 Ratio to FRM = 1.16	Slope = 1.53 Int. = -10.6 R^2 = 0.880 Ratio to FRM = 1.29	Slope = 1.07 Int. = +2.9 R^2 = 0.998 Ratio to FRM = 1.14



Metric	Gary, IN	Phoenix, AZ (May – June, 2003)	Riverside, CA	Phoenix, AZ (Jan 2004)
PMc	Slope = 0.42 Int. = +0.48 R^2 = 0.80 Ratio to FRM = 0.42	Slope = 0.56 Int. = -0.20 R^2 = 0.99 Ratio to FRM = 0.55	Slope = 0.66 Int. = -2.3 R^2 = 0.82 Ratio to FRM = 0.58	Slope = 0.61 Int. = +0.16 R^2 = 0.993 Ratio to FRM = 0.62

Summary of Results

(independent of site)

- **FRMs show strong inter-manufacturer precision (CV<6% for all three metrics) with no tendency for producing negative PMc values**
- **Filter-based dichots show strong precision (CV<5% for all metrics)**
- **Site weighing results agree closely with RTP results**
- **Precision of the semi-continuous samplers ranged from very good to acceptable**
- **Correlation (as R^2) of semi-continuous samplers with the collocated FRMs is usually strong (>0.95)**

R&P 2025 Dichot

- Dichots showed strong inter-sampler precision (CV<4%) at all sites for all three PM metrics.
- Strong correlation ($R^2 > 0.980$) was observed between the dichots and the collocated FRMs at all sites.
- With the exception of Phoenix, $PM_{2.5}$ dichot concentrations agreed well with the $PM_{2.5}$ FRMs.
- Except during the Riverside tests, the dichots underestimated PMc concentrations by >10%. Mass balance calculations showed that 16% of the aspirated PM_{10} aerosol in Phoenix was unaccounted for in the 2025 dichot. January 2004 follow-up tests in Phoenix indicated that particle losses can occur during post-sampling movement of the coarse particle cassette in the sequential sampler.

R&P PMc TEOM

- Excellent inter-sampler precision was observed among the R&P PMc TEOMs at all sites (mean CV = 4%).
- Correlation between the PMc TEOMs and the collocated FRMs was strong ($R^2 \geq 0.95$) at all sites.
- With the exception of Phoenix in 2003, the coarse TEOMs produced PMc concentrations 20% to 30% lower than the FRMs. Depending upon aerosol size distribution, the ~ 9.0 to 9.5 micrometer cutpoint of the TEOM's 50 lpm inlet may account for an appreciable fraction of the observed difference.

Tisch Dichotomous Beta Gauge

- Acceptable inter-sampler precision was observed for the Tisch samplers for all three metrics at all three sites.
- Good correlation (R^2 > 0.880 for all metrics) was observed between the Tisch samplers and the collocated FRMs at all sites.
- The Tisch sampler consistently overestimated (25% to 70%) the $PM_{2.5}$ concentration at all sampling sites. The units provided lower bias (<10%) when measuring ambient PMc concentrations, whereas PM_{10} was overestimated by about 10-30%.

TSI Aerodynamic Particle Sizer

- The two APS units showed acceptable precision at all sampling sites and provided detailed size distribution information not provided by the other samplers involved in the study.
- PMc concentrations measured by the APS units typically “tracked” concentrations measured by the collocated FRM samplers.
- Independent of sampling site, the APS units typically underestimated PMc concentrations by a factor of two. This field behavior is consistent with published performance tests conducted in the laboratory under controlled conditions.

Future Work

- Complete chemical analysis of archived filters; potentially use results to help explain observed sampler performance.
- Conduct detailed analysis of all data, including particle chemistry data and hourly performance of semi-continuous methods.
- Possibly perform laboratory tests with samplers to better understand aerosol fractionation and/or particle loss issues.
- Use study results as guidance during regulatory development of PMc testing requirements and acceptance criteria.

Acknowledgements

- Indiana Department of Environmental Management (Gary site)
- Maricopa County Environmental Services Department (Phoenix site)
- University of California-Riverside, Agricultural Operations (Riverside site)

Disclaimer

- **This work has been funded in part by the United States Environmental Protection Agency under Contract 68-D-00-206 to ManTech Environmental Technology, Inc. It has been subjected to Agency review and approved for publication.**

- **Mention of trade names or commercial products does not constitute endorsement or recommendation for use.**