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Research and Development

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Project Summary

Particle Total Exposure Assessment Methodology (PTEAM): Riverside, California Pilot Study - Volume I

E. D. Pellizzari, K. W. Thomas, C. A. Clayton, R. W. Whitmore, R. C. Shores, H. S. Zelon, and R. L. Peritt

EPA's Atmospheric Research and Exposure Assessment Laboratory (AREAL) and the California Air Resources Board sponsored a study of human exposure to inhalable particles in the Los Angeles Basin. A total of 178 residents of Riverside, CA, wore specially designed personal monitors for a day, and allowed their homes and back yards to be monitored concurrently, in the fall of 1990. Personal exposures averaged 150 μg/m³ during the day, compared to indoor and outdoor concentrations of 94-95 μg/m³. Daytime personal exposures to 14 of 15 elements were also significantly increased compared to indoor and outdoor concentrations. Housework (vacuuming, dusting, cooking) and sharing a home with a smoker were two activities associated with significantly increased exposures to particles and metals.

This Project Summary was developed by EPA's Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In 1986, Congress mandated that the USEPA undertake a study of exposure to particles. EPA's Atmospheric Research and Exposure Assessment Laboratory (AREAL) joined with California's Air Resources Board to sponsor a study in the Los Angeles Basin. Small portable personal monitors were designed to measure inhalable particles (aerodynamic diameter less than 10 μm or PM_{10}). In addition, stationary microenvironmental monitors were designed to sample both PM_{10} and $PM_{2.5}$ (fine particles <2.5 μm in diameter). Following a 9-home study to test the measurement methods in the Azusa, CA, area, a study of 178 residents of Riverside, CA, was carried out in the fall of 1990.

Procedure

Measurement Methods

A personal exposure monitor (PEM) was designed to collect PM_{10} using a sharp-cut impactor with a circular set of holes 1.9 mm in diameter. Particles are collected at a flow rate of 4 Lpm on a 37-mm Teflon filter mounted below a greased impactor plate. The PEM consists of a soft canvas bag containing the pump and battery pack that can be worn on the hip, stomach, lower back, or over the shoulder. A broad shoulder strap supports the sampling head, which can be moved to a comfortable position near the collarbone using a Velcro fastener. When worn on the body, the pump/battery pack slides freely on a belt, allowing it to be shifted to the most comfortable position depending on people's activities or changes of posture. A leather backing for the sampling head was added to prevent it from being accidentally turned toward the body, and a 2-inch guard shaped like a hooded traffic light was added to the top of the sampling head to protect against skin flakes, hairs, or fibers from clothes.

A small quiet monitor for concurrent indoor and outdoor sampling was also created. This monitor is called the Stationary Ambient Monitor (SAM) when used out-

doors and the Stationary Indoor Monitor (SIM) when used indoors. The monitor employs identical sampling heads and flow rates as the PEM to collect PM_{10}, but operates off line current instead of batteries. The sampling head can be replaced with one having holes 1.4 mm in diameter to collect fine particles ($PM_{2.5}$). Laboratory studies indicate that the PEM and the SAM_{10} have a sharp cutpoint at about 11 μm, while the $SAM_{2.5}$ has a sharp cutpoint at 2.5 μm.

Study Design

The City of Riverside, CA, was selected for study because it is known to have highly variable outdoor PM_{10} concentrations and because the socioeconomic characteristics of the community appeared to provide a reasonably representative microcosm of the southern California population. A wide range of outdoor concentrations offers the best chance of determining the contribution of outdoor levels to indoor levels and personal exposures. The fall season was selected since Santa Ana winds occur then; such winds can have strong effects on the outdoor concentrations of particles.

The main goal of the study was to estimate the frequency distribution of exposures to PM_{10} particles for all nonsmoking Riverside residents aged 10 and above, based on a probability sample of 178 residents. A second major objective was to estimate the frequency distribution of concentrations of PM_{10} and $PM_{2.5}$ in residences and nearby outdoor air (e.g., back yards). Other objectives included determining the effect of outdoor air on indoor concentrations, and the contribution of personal activities to exposure.

A three-stage probability sampling procedure was adopted. Thirty-six areas within Riverside were selected for study following socioeconomic stratification. Several homes from each area were sent letters explaining the study. Interviewers then collected information about each household and invited eligible residents to participate. Respondents represented 139,000 ± 16,000 (S.E.) nonsmoking Riverside residents aged 10 and above.

Smokers were excluded from participating, but nonsmoking members of their family were not. Employed persons were slightly oversampled, since employment was thought to be a possible risk factor for exposure to particles.

Each participant wore the PEM for two consecutive 12-hour periods. Concurrent PM_{10} and $PM_{2.5}$ samples were collected by the indoor SIM and outdoor SAM at each home. This resulted in 10 samples per household (day and night samples from the PEM_{10}, SIM_{10}, $SIM_{2.5}$, SAM_{10}, and $SAM_{2.5}$). Air exchange rates were also calculated for each 12-hour period, using the perfluorotracer technique.

Participants were asked to note activities that might involve increased particle levels (nearby smoking, cooking, gardening, etc.). Following each of the two 12-hour monitoring periods, they answered an interviewer-administered recall questionnaire concerning their activities and locations during that time.

Up to four participants per day could be monitored, requiring 48 days in the field. A central outdoor site was maintained over the entire period (Sept. 22-Nov. 9, 1990). The site had two high-volume samplers (Wedding & Assoc.) with 10-μm inlets (actual cutpoint about 9.0 μm), two dichotomous PM_{10} and $PM_{2.5}$ samplers (Sierra-Andersen) (actual cutpoint about 9.5 μm), one PEM and one SAM.

All filters were weighed on-site and then analyzed for elements by x-ray fluorescence (XRF). An additional set of about 600 citric-acid treated filters from personal and indoor samplers was analyzed for nicotine.

Filters were weighed before use and again within 48 hours of collection at an on-site weighing facility with controlled temperature and humidity. Replicate weighings were required to be within 4 μg/filter. Blank filters were weighed, sent out with field samples, and reweighed along with the field samples. Duplicate indoor and outdoor samples were collected at 10% of the homes. Duplicate SAM and PEM samples were also collected at the central site. Duplicate PEM samples were also collected by EPA, RTI, and Harvard scientists while on site.

Results

Of 632 permanent residences contacted, 443 (70%) completed the screening interview. Of these, 257 were asked to participate and 178 (69%) agreed. More than 2750 particle samples were collected, about 96% of those attempted.

Quality of the Data

Blank PEM and SIM/SAM filters (N = 51) showed consistent small increases in mass of 5-10 μg. Blanks (N = 9) placed near ungreased impactor plates had similar increases of 7 μg. Blank dichot filters (N = 41) showed increases averaging 4 μg. Blank SSI filters had increases of about 170 μg. XRF analyses indicated that the increase was not due to aerosol; possibilities include water vapor or electric charge, although stringent efforts were made to control humidity and static charge in the on-site weigh room. The effect of the increase is small (0.4-4 $\mu g/m^3$) and was corrected for by subtracting the mean blank value from all samples. Limits of detection (LODs), based on three times the standard deviation of the blanks, were on the order of 10 $\mu g/m^3$. All field samples exceeded the LOD.

Duplicate samples (N = 363) showed excellent precision for all types of samplers at all locations, with median relative standard deviations ranging from 2-4%.

The collocated samplers at the central site showed good agreement, with correlations ranging from 0.96 to 0.99. As had been noted in the pilot study, the PEM and SAM collected about 12% more mass than the dichotomous samplers (Figure 1), perhaps due to their higher cutpoint (11 μm compared to 9.5 μm) or to a particle "bounce" effect, measured in the laboratory at less than 9%. The Wedding samplers collected about 13% less mass than the dichots at night, but about the same level during the day, reflecting a possible temperature dependency on the part of the Wedding. Although these small differences were significant, they do not affect the main conclusions.

All PEM, SIM, SAM, and dichotomous sampler filters (about 2500) were analyzed by XRF for a suite of 42 elements. The analysis was carried out at EPA's Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, NC. Some filters were analyzed twice under blind conditions. A subset of about 100 filters was analyzed by the Lawrence Berkeley Laboratory (LBL) for quality assurance purposes.

Background levels on laboratory and field blanks were very low for 19 of 20 elements. Blank levels for iron were slightly higher but were 4 to 100 times lower than observed concentrations. Analyses of standard reference materials (SRM 1832 and 1833) were within 7% of the correct values for all 12 elements contained. Median relative standard deviations (RSD) for duplicates analyzed blindly by the principal laboratory were less than 15% for all 15 prevalent (more than 30% of samples with measurable quantities) elements. Median RSDs for duplicates analyzed by the two laboratories were less than 21% for all elements except manganese (76%) and copper (27%). The LBL laboratory reported 10-20% higher average values for 13 of 14 elements. All filters analyzed by LBL had been first analyzed by EPA.

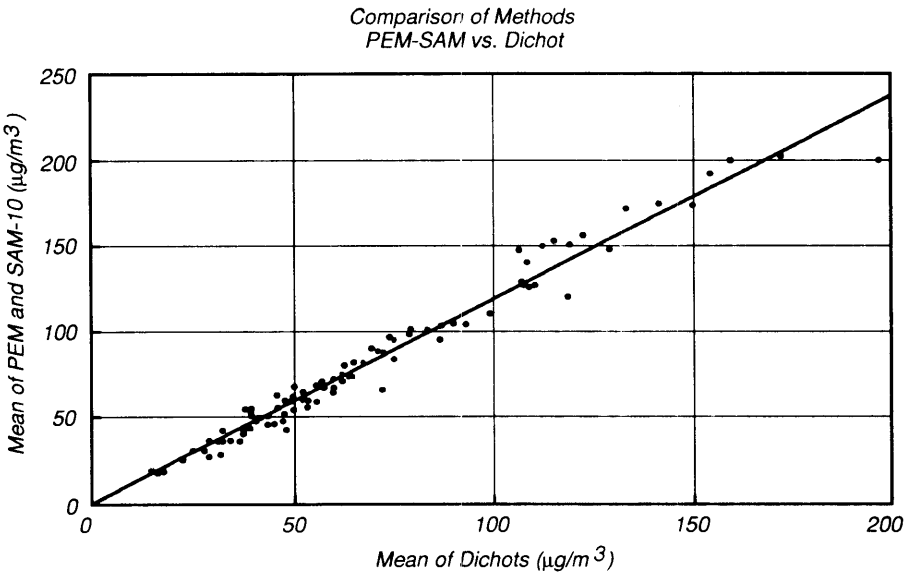

Figure 1. *The collocated PEM and SAM showed good precision but a positive bias with respect to the dichotomous samplers.*

Concentrations

Outdoor 12-h PM_{10} concentrations at the central site ranged from 20-200 µg/m³, with the fine particles accounting for most of the variation (Figure 2). On the six windiest (16-20 mph) days, the coarse particles accounted for most of the PM_{10} mass.

Population-weighted daytime personal PM_{10} concentrations averaged about 150 µg/m³, compared to concurrent indoor and outdoor mean concentrations of about 95 µg/m³ (Table 1; Figure 3). The overnight personal PM_{10} mean was much lower (77 µg/m³) and more similar to the indoor (63 µg/m³) and outdoor (86 µg/m³) means (Figure 4). Approximately 25% of the population was estimated to have exceeded the 24-h National Ambient Air Quality Standard for PM_{10} of 150 µg/m³. Over 90% of the population exceeded the California Ambient Air Quality Standard of 50 µg/m³. Fine ($PM_{2.5}$) particles accounted for about 50% of the total PM_{10} mass both indoors and outdoors.

The measurements at the central site showed good agreement with the outdoor measurements at homes throughout the City of Riverside (Figure 5), indicating that a single central-site PM_{10} monitor can characterize a large urban area adequately. Although the correlations of indoor air concentrations with outdoor air are lower, there is evidence (Figure 6) that outdoor air PM_{10} concentrations can affect indoor air concentrations.

Population-weighted mean elemental concentrations for 15 prevalent elements are provided in Table 2. As with the particle mass, daytime personal exposures were consistently higher than either indoor or outdoor concentrations of all the elements save sulfur. At night, levels were similar in all three types of samples. The weighted mean element/particle mass ratios are provided in Table 3. The personal and indoor PM_{10} samples are depleted in the crustal elements (Si, Al, Fe) compared to the outdoor samples, by amounts ranging from 15 to 25%. The indoor $PM_{2.5}$ samples show no depletion in any elements and may be slightly enriched in Ca, K, Cl, and (night only) S.

Models of Exposure

Questionnaires were analyzed to detect activities associated with increased exposure. Housework (dusting, vacuuming, cooking) was associated with significantly increased personal exposures and indoor air concentrations during the day (Table 4). Sharing a home with one or more smokers also led to increased personal exposures and indoor air concentrations during the night. Persons who commuted to work had significantly *lower* exposures than those who stayed at home, perhaps due to the housework activities of the latter group.

Discussion

Source of Excess Personal Exposure

The source or sources of the roughly 50% increase in daytime personal exposure compared to the indoor and outdoor air concentrations remain unclear. Several possibilities include

1) The apparent increase is due to different sampling characteristics of the personal monitor.
2) The increase is due to skin flakes or clothes fibers accumulating on the personal monitor.
3) The increase is due to increased exposures encountered while participants are out of the house.
4) The increase is due to generation or reentrainment of particles during personal activities.

The first possibility has been tested in several ways. The only difference between the PEM and the SIM is the pump (Casella vs. Medo). Laboratory tests of the two pumps failed to show any difference in sampling characteristics on a test aerosol. Wind speed and direction were also tested and had little effect on either the PEM or the SIM. Particle bounce should affect both the PEM and SIM equally, since the sampling heads are identical. It remains possible that the constant motion of the PEM may somehow affect its sampling characteristics compared to the fixed SIM.

The second possibility was tested by scanning electron microscopy (SEM) on three sets of personal, indoor, and outdoor filters. Although skin flakes were found in large numbers on one personal filter, their mass seemed insufficient to explain the mass difference. Also, if most of the increased mass were due to skin flakes or fibers, increases in elements other than carbon would not be expected; however, 14 of 15 elements were also elevated in the personal samples.

The third possibility has been partially tested by comparing persons who went to work on the day of monitoring with those who did not. Even though their daytime exposures included round-trip commutes in Los Angeles County traffic, their exposures were significantly lower than those of participants who stayed at home.

The fourth possibility seems likely. Persons engaging in activities such as vacuuming, dusting, and cooking had significantly higher exposures than the other participants. House dust is a mixture of airborne outdoor aerosols, tracked-in soil and road dust, and aerosols produced by

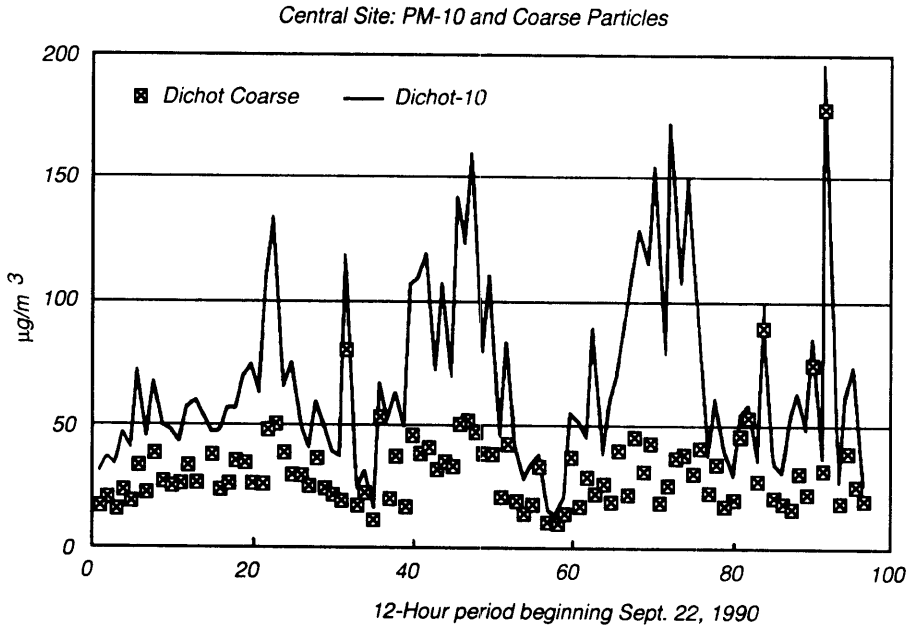

Figure 2. *During the 48-day sampling period, two extended peaks characterized by elevated fine particles (PM-2.5) occurred. Coarse particles were elevated on days with high wind speeds.*

Table 1. *Population-Weighted[a] Concentrations and Standard Errors (µg/m³)*

Sample Type	N	Median	Arithmetic Mean	Percentile 90%	Percentile 98%
Daytime PM_{10}					
Personal	*171*	*130 ± 8*	*150 ± 9*	*260 ± 12*	*380*
Indoor	*169*	*82 ± 8*	*95 ± 6*	*180 ± 11*	*240*
Outdoor	*165*	*83 ± 5*	*94 ± 6*	*160 ± 7*	*240*
Overnight PM_{10}					
Personal	*168*	*66 ± 4*	*77 ± 4*	*140 ± 10*	*190*
Indoor	*163*	*52 ± 4*	*63 ± 3*	*120 ± 5*	*160*
Outdoor	*162*	*74 ± 4*	*87 ± 4*	*170 ± 5*	*210*
Daytime $PM_{2.5}$					
Indoor	*173*	*34 ± 4*	*48 ± 4*	*100 ± 7*	*170*
Outdoor	*167*	*36 ± 4*	*49 ± 3*	*100 ± 6*	*170*
Overnight $PM_{2.5}$					
Indoor	*166*	*26 ± 2*	*36 ± 2*	*83 ± 6*	*120*
Outdoor	*161*	*35 ± 2*	*51 ± 4*	*120 ± 5*	*160*

[a]*Personal samples weighted to represent nonsmoking population of 139,000 Riverside residents aged 10 or above. Indoor-outdoor samples weighted to represent 61,500 homes with at least one nonsmoker aged 10 or above.*

indoor sources. As such, it should contain crustal elements from soil, lead and bromine from automobiles, and other elements from combustion sources. This would be consistent with the observation that nearly all elements were elevated in personal samples. The fact that personal overnight samples showed smaller mass increases than the personal daytime samples is also consistent with the fact that the participants were sleeping for much of the 12-hour overnight monitoring period and were thus not engaging in these particle-generating or reentraining activities. There remains the problem of sulfur, which showed no increase in personal samples compared to indoor or outdoor samples. This may be because sulfate ions have a much smaller mass median diameter and a lower deposition velocity than other ionic constituents of fine particles. Thus, sulfur would not tend to accumulate in house dust as much as other elements. Also, smaller particles may be harder to dislodge from surfaces, due to electrostatic or Van der Waals forces.

Conclusions and Recommendations

The personal and microenvironmental monitors designed especially for this study performed well. About 96% of all samples attempted were collected and median precision was 2-4%. A positive bias of about 12% was noted with respect to the reference dichotomous sampler method.

The major finding of the study was the 50% increase in daytime personal exposures to PM_{10} compared to indoor and outdoor concentrations. The increase appears to be due to personal activities such as dusting, vacuuming, cooking, and sharing a home with a smoker. This suggests that reduction of dust levels in the home could decrease exposure to airborne particles.

Future Publications

Volume II of this three-volume series presents the results of measurements of polyaromatic hydrocarbons (PAH) and phthalates in 120 of the 178 homes in this study. Entitled "PTEAM: Monitoring of Phthalates and PAHs in Indoor and Outdoor Air Samples in Riverside, California—Volume II," it is available from the California Air Resources Board, Sacramento, CA.

Volume III will present the results of additional statistical analyses and physical modeling. It will also contain the results of the nicotine analyses and the air exchange rate measurements. Volume III will be available in 1993 from the National Technical Information Service (NTIS).

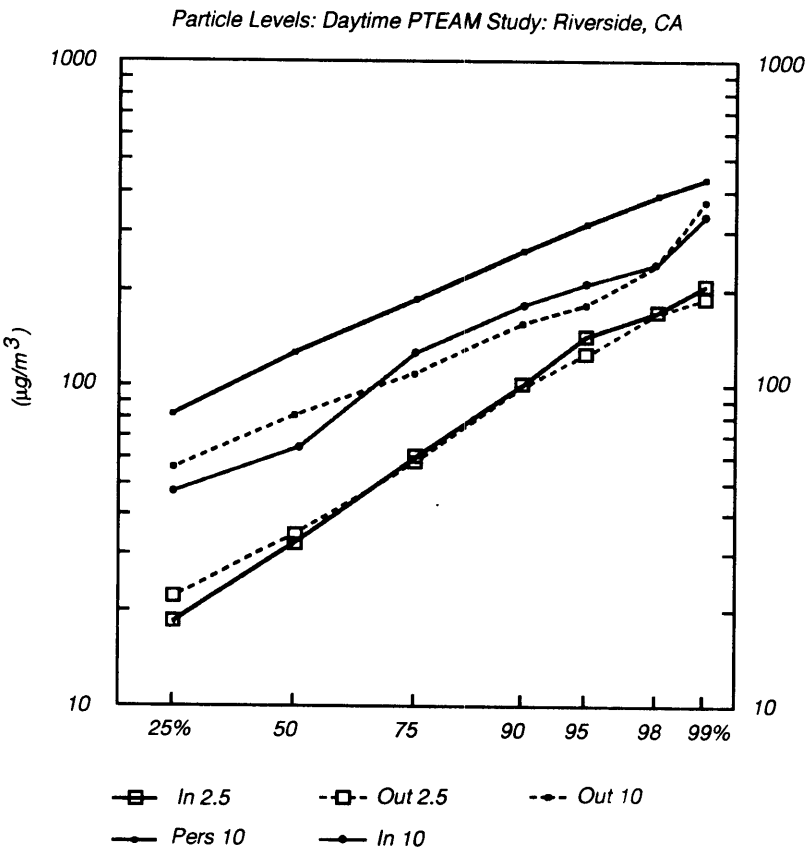

Figure 3. *Population- or household-weighted frequency distributions of 12-h average concentrations of PM-10 and PM-2.5 show a nearly log-normal shape for personal, indoor, and outdoor air. Daytime personal levels are 50% higher than concurrent indoor/outdoor levels.*

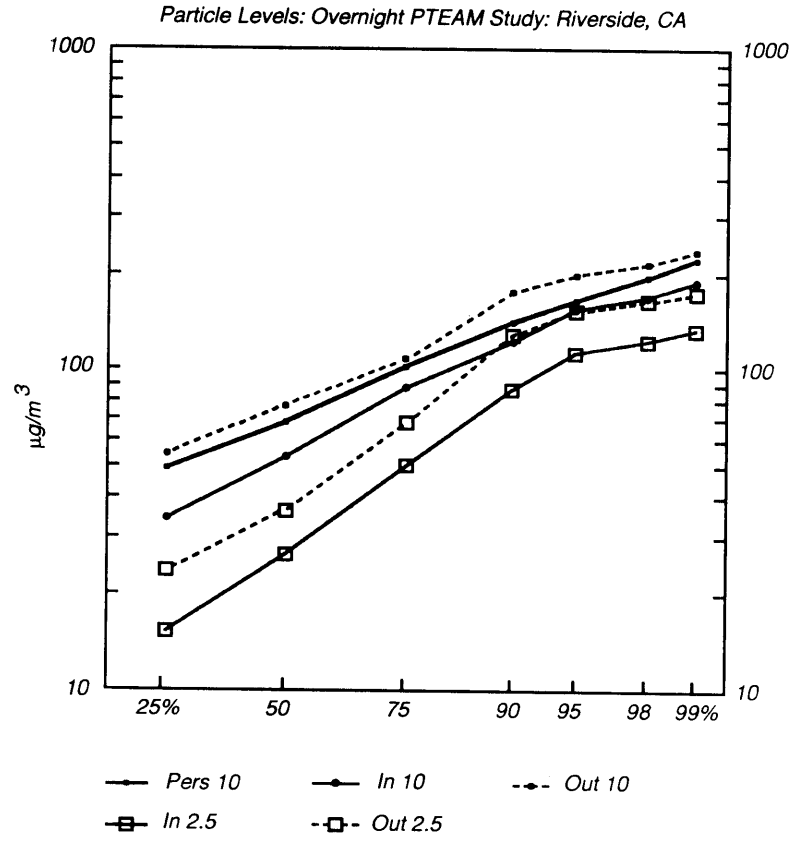

Figure 4. *At night, personal concentrations sink to levels comparable with outdoor air. Indoor levels of both PM-10 and PM-2.5 also fall to 60-70% of outdoor levels.*

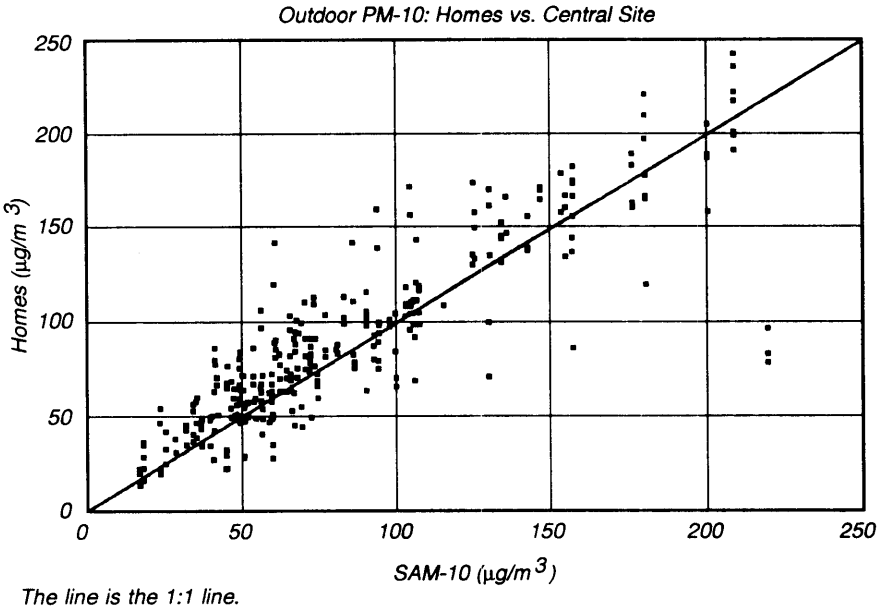

Figure 5. *Outdoor PM-10 levels near homes were also well characterized by the identical monitor at the central site.*

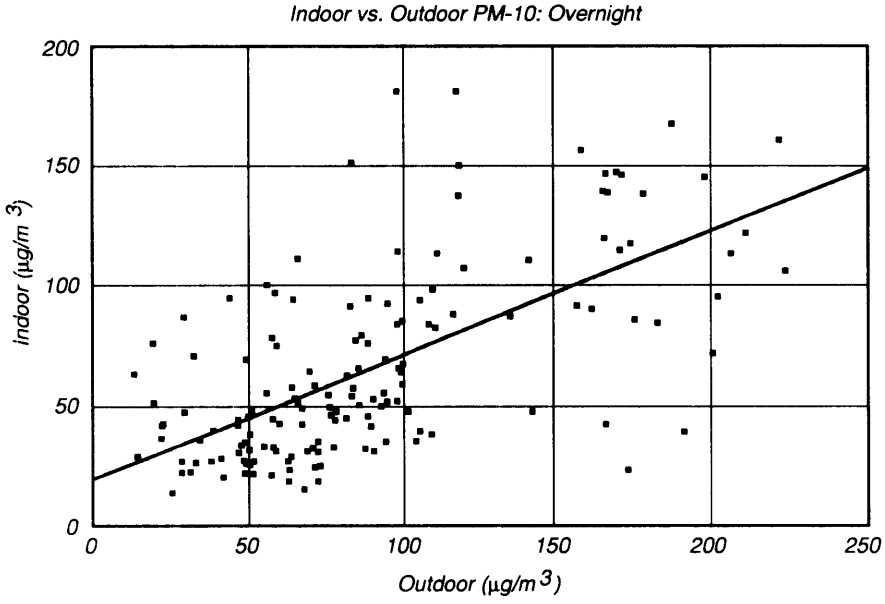

Figure 6. *Although there is considerable scatter due to indoor sources and activities, outdoor concentrations near the home appear to have considerable impact on indoor concentrations.*

Table 2. *Mean Elemental Concentrations (ng/m³) in Personal, Indoor, and Outdoor Samples*[a]

	Daytime					Nighttime				
	$PM_{2.5}$		PM_{10}			$PM_{2.5}$		PM_{10}		
Element	SAM	SIM	SAM	SIM	PEM	SAM	SIM	SAM	SIM	PEM
Si	740.	700.	7700.	6300.	12000.	380.	360.	5000.	3300.	4200.
Al	[b]	-	3100.	2300.	4700.	-	-	2000.	1200.	1400.
Ca	330.	380.	2300.	2300.	4300.	170.	200.	1500.	1200.	1700.
Fe	400.	340.	2300.	1800.	3400.	260.	200.	1700.	990.	1200.
Mn	12.	9.8	51.	38.	69.	9.9	7.5	37.	22.	24.
K	230.	260.	1100.	1100.	1900.	150.	200.	800.	650.	800.
Br	8.8	9.1	10.	13.	25.	11.	8.6	13.	11.	14.
Pb	20.	17.	30.	27.	40.	23.	20.	32.	27.	26.
S	1500.	1300.	1800.	1700.	1800.	1600.	1300.	1900.	1500.	1500.
Zn	41.	42.	65.	86.	150.	38.	34.	56.	60.	67.
Cl	83.	130.	230.	410.	840.	170.	100.	500.	290.	440.
Ti	-	-	210.	190.	390.	-	-	140.	100.	130.
Cu	-	11.	15.	22.	41.	9.6	8.9	17.	15.	19.
Sr	-	-	18.	15.	25.	-	-	14.	9.8	11.
P	-	-	-	-	230.	-	-	-	-	-

[a]*Results are weighted to reflect the target population of individuals (PEM samples) or households (SIM and SAM samples).*
[b]*Fewer than 30% of samples with concentrations greater than the uncertainty limit.*

Table 3. *Mean Ratios of Element/Particle Masses (%) in Personal, Indoor, and Outdoor Samples*[a]

	Daytime					Nighttime				
	$PM_{2.5}$		PM_{10}			$PM_{2.5}$		PM_{10}		
Element	SAM	SIM	SAM	SIM	PEM	SAM	SIM	SAM	SIM	PEM
Si	2.16	2.37	9.04	7.15	7.57	1.39	1.74	7.02	5.97	5.72
Al	[b]	-	3.63	2.56	2.88	-	-	2.78	2.08	1.87
Ca	0.94	1.19	2.70	2.57	2.85	0.58	0.90	2.12	2.14	2.31
Fe	1.17	1.09	2.72	1.99	2.14	0.83	0.85	2.25	1.71	1.56
Mn	0.04	0.03	0.06	0.04	0.04	0.03	0.03	0.05	0.04	0.03
K	0.60	0.69	1.27	1.18	1.22	0.47	0.72	1.09	1.11	1.09
Br	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.02	0.02	0.02
Pb	0.06	0.05	0.03	0.03	0.03	0.06	0.07	0.04	0.04	0.03
S	3.30	3.22	1.92	2.01	1.36	3.62	4.28	2.23	2.73	2.16
Zn	0.13	0.13	0.08	0.11	0.11	0.12	0.15	0.07	0.11	0.10
Cl	0.16	0.27	0.28	0.44	0.58	0.40	0.34	0.68	0.52	0.61
Ti	-	-	0.25	0.21	0.25	-	-	0.19	0.18	0.18
Cu	-	0.04	0.02	0.03	0.03	0.03	0.04	0.02	0.03	0.03
Sr	-	-	0.02	0.02	0.02	-	-	0.02	0.02	0.02
P	-	-	-	-	0.15	-	-	-	-	-

[a]*Results are weighted to reflect the target population of individuals (PEM samples) or households (SIM and SAM samples). Estimated means < 0 are reported as 0.*
[b]*Fewer than 30% of samples with concentrations greater than the uncertainty limit.*

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Table 4. *Effects of Activities on Mean Personal and Indoor Air PM_{10} Concentrations ($\mu g/m^3$)*

Activity and Sample Type	Homes/Persons With Activity			Homes/Persons Without Activity		
	N	Mean	(SE)	N	Mean	(SE)
Housework (Day)						
Personal	110	162*	(11)	61	125	(11)
Indoor	111	106*	(8)	58	71	(6)
Smoking (Night)						
Personal	29	104*	(8)	139	71	(3)
Indoor	30	93*	(9)	131	55	(3)
Work (Day)						
Personal	59	127	(12)	111	162*	(10)

*Both arithmetic mean (shown) and geometric mean significantly ($p<0.05$) higher than corresponding value for other group.

E. D. Pellizzari, K. W. Thomas, C. A. Clayton, R. W. Whitmore, R. C. Shores, H. S. Zelon, and R. L. Peritt are with Research Triangle Institute, Research Triangle Park, NC 27709-2194

***Lance A. Wallace** is the EPA Task Manager (see below).*

The complete report, entitled "Particle Total Exposure Assessment Methodology (PTEAM): Riverside, California Pilot Study--Volume I" (Order No. PB93--166 957/AS; Cost: $44.50, subject to change) will be available only from:

National Technical Information Service
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The EPA Task Manager can be contacted at:

Atmospheric Research and Exposure Assessment Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27701

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