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INDOOR CONCENTRATIONS OF POLYCYCLIC AROMATIC HYDROCARBONS IN
CALIFORNIA RESIDENCES

FINAL REPORT

by

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ABSTRACT

The purpose of this study was to obtain information on indoor and outdoor air concentrations of polynuclear aromatic hydrocarbons (PAHs) and carbon monoxide in California residences. Additional objectives were to investigate the relationship between compounds and different types of indoor combustion sources and to explore relationships among the measured compounds. To meet these objectives, a single season field monitoring study was conducted in 280 homes in northern California. Homes were selected to represent specific combustion source categories including tobacco smoking, fireplaces, woodstoves, and gas heat. For each home, 24-hour indoor and outdoor air samples were collected and analyzed for 13 PAHs and quinoline, a nitrogen substituted PAH. Air exchange measurements were also made. In a subset of ~75% of the homes, indoor and outdoor carbon monoxide measurements were made over the same period. Information was gathered on use of combustion sources and other activities during the monitoring period. Summary statistics were calculated by source categories for indoor air concentration, outdoor air concentration, indoor/outdoor air concentration ratio, and source strength. Statistical models were developed to evaluate the relationship between measured PAH concentrations and source usage.

Results indicate that, in the absence of strong indoor combustion sources, most homes had higher outdoor than indoor air concentrations of PAHs. Among indoor sources, cigarette smoking appeared to have the strongest effect on indoor levels of PAHs. Fireplaces, woodstoves and kerosene heaters also contributed to elevated indoor PAH concentrations. Infiltration of outdoor air into the home was also a major contributor to PAH concentrations in indoor air. Outdoor levels of PAHs correlated highly with each other. However, indoor PAHs behaved differently: correlations were high only for those PAHs of similar volatility. Only a few homes showed elevated levels of carbon monoxide, most were associated with the use of gas heat and fireplaces.

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GLOSSARY OF TERMS, ABBREVIATIONS, AND SYMBOLS

a	- Air Exchange Rate, Air Exchanges per Hour
A	- GC/MS Integrated Peak Area
AC	- Alternating Current
ARB	- Air Resources Board
BaP	- Benzo[a]pyrene
β	- Average Emission Quantity from a Source, Depending on Source Will Be an Emission Factor, Emission Rate, or Emission Strength
CAAQS	- California Ambient Air Quality Standard
CATs	- PFT Collectors
C_i	- Indoor Concentration
CO	- Carbon Monoxide
C_o	- Outdoor Concentration
C_{oi}	- Contribution of Outdoor Pollution to Indoor Concentration
db	- Decibel
°C	- Degree Centigrade
EF	- Emission Factor - Amount of Pollutant Generated per Unit of Source Used
ER	- Emission Rate - Amount of Pollutant Generated per Hour of Source Used
ES	- Emission Strength - Amount of Pollutant Generated Based on Presence of Source
ETS	- Environmental Tobacco Smoke
f	- Fractional Penetration of Outdoor Concentration
FB	- Field Blank
FC	- Field Control
F_{oi}	- Fractional Contribution of Outdoor Pollution to Indoor Concentrations
F_{ii}	- Fractional Contribution of Indoor Pollution to Indoor Concentrations
γ	- Represents Penetration Factor in Source Strength Model
G.S.E.	- Geometric Standard Error
GC/MS	- Gas Chromatography/Mass Spectrometry
g	- Represents Penetration Factor in Indoor Air Model
h	- Hour
k	- Pollutant Decay Rate

Glossary (Continued)

L	-	Liter
m/z	-	Mass-to-Charge Ratio
m	-	Air Mixing Between House Zones
m ³	-	Cubic Meter
mA	-	Milliamp
MB	-	Method Blank
MC	-	Method Control
µg	-	Microgram
µL	-	Microliter
µm	-	Micron
min	-	Minute
mL	-	Milliliter
mm	-	Millimeter
MQL	-	Method Quantifiable Limit
MS	-	Mass Spectrometry
n	-	Number of Observations
ND	-	No Instrumental Signal (Not Detected)
ng	-	Nanogram
NIST	-	National Institute of Standards and Technology
NQ	-	Below the Method Quantifiable Limit (Not Quantifiable)
NRC	-	National Research Council
PAH	-	Polynuclear Aromatic Hydrocarbon
PCA	-	Principal Component Analysis
PFT	-	Perfluorotracer - Chemical Used to Measure Air Exchange Rate
ppm	-	Parts Per Million
POM	-	Polycyclic Organic Matter
QA	-	Quality Assurance
QC	-	Quality Control
QL	-	Quantitation Limits
RRF	-	Relative Response Factor
% RSD	-	Percent Relative Standard Deviation

Glossary (Continued)

RTI	-	Research Triangle Institute
SAS	-	Registered Trademark of SAS Institute, Inc., Cary, NC
S.D.	-	Standard Deviation
S.E.	-	Standard Error
SIM	-	Selected Ion Monitoring
SRM	-	Standard Reference Material
SS	-	Source Strength
Std	-	External Quantitation Standard
$t_{0.99}$	-	Students One-tailed t Statistic at the 99% confidence Level with Seven Degrees of Freedom
TAC	-	Toxic Air Contaminant
u	-	Measure of Average Source Usage over the Monitoring Period
V	-	House Volume
VAC	-	Variable Alternating Current
Ve	-	Extract Volume

SECTION 1

OBJECTIVES AND STUDY DESIGN

1.1 BACKGROUND

Section 39660.5 of the California Health and Safety Codes requires the Air Resources Board (ARB) to assess indoor exposures to substances being considered for identification as toxic air contaminants (TACs). Benzo[a]pyrene (BaP) is a carcinogen. It is within the group of chemicals known as polycyclic organic matter (POM) and, as such, was identified along with other federal hazardous air pollutants, as a toxic air contaminant. Quinoline, a nitrogen substituted PAH, was also identified as a TAC at the same time because of its status as a federal hazardous air pollutant. The other polynuclear aromatic hydrocarbons (PAHs) are considered possible carcinogens and along with quinoline were identified as TACs as part of POMs.

Until recently, methods were not available for monitoring BaP, quinoline and the other PAHs in indoor air, and sufficient data do not exist to make the required exposure assessments. The primary objective of this research study was to obtain indoor concentration data on BaP and the other PAHs listed in Table 1-1 so that reasonable exposure predictions can be made for California residents. Indoor concentration data on quinoline were obtained to evaluate its use as a possible indicator of environmental tobacco smoke (ETS). Data on indoor levels of carbon monoxide were also generated during this study. Simultaneous measurements of outdoor concentrations of the PAHs, quinoline, and CO were obtained. Additional objectives were to investigate emission/air concentration relationships among the compounds and to explore relationships between the compounds and different types of indoor combustion sources. Specific project objectives are outlined in Table 1-2.

The PAHs (other than BaP) were included in the study because

- they have recently been identified as TACs,
- they could be measured using the same methods as BaP, and
- they are generally derived from the same combustion sources which allowed indoor exposure information to be generated using the same study design.

TABLE 1-1. PAHs MEASURED

Structure	Compounds
2 rings	quinoline ^a
3 rings	acenaphthylene, phenanthrene, anthracene
4 rings	chrysene, fluoranthene, pyrene, benzo[a]anthracene
5 rings	benzo[a]pyrene, benzo[fluoranthene], benzo[e]pyrene
6 rings	indeno[1,2,3-cd]pyrene, benzo[ghi]perylene
7 ring	coronene

^a A nitrogen substituted PAH, is referred to as a PAH in this report.

TABLE 1-2. RESEARCH OBJECTIVES FOR THE STUDY

-
-
1. To quantify the distribution of PAH and CO indoor air concentrations, outdoor air concentrations and indoor/outdoor air concentration ratios in selected residences with different combustion sources.
 2. To quantify the distribution of PAH and CO source strengths in selected residences with different combustion sources.
 3. To identify and model factors associated with various combustion sources that influence indoor and outdoor PAH and CO concentrations.
 4. To investigate the relation among PAHs and between PAH species and CO concentrations to identify appropriate marker compounds (surrogates) for
 - BaP air concentrations,
 - environmental tobacco smoke, and
 - total PAH air concentrations.
-
-

In addition, several low molecular weight PAHs (e.g., phenanthrene, pyrene) have relatively high air concentrations and may be useful surrogates for BaP in indoor air. The identification of a higher concentration surrogate might provide an advantage for future studies by allowing lower cost microenvironmental and/or personal monitoring methods to be used.

Carbon monoxide was added to the study for many of the same reasons as the PAHs. It is a toxic chemical and, therefore, Californian's indoor exposures are of concern. Each year a number of cases of serious acute poisonings, including unconsciousness and death, occur in California from accidental exposure to carbon monoxide indoors (Vital Statistics of California, Department of Health Services). Chronic carbon monoxide poisoning may also occur; it is a seldom recognized disorder characterized by a syndrome of headache, fatigue, dizziness, paresthesias, chest pain, palpitations, and visual disturbances (Kirkpatrick, 1987). Indoor concentrations are known to exceed outdoor concentrations when indoor sources are present (NRC, 1986). However, little CO data are available for exposure assessments in California. In addition, simple, cost effective monitoring methods are available for carbon monoxide; it is a combustion product with many of the same sources as BaP; and it may serve as a cost effective surrogate for exposure to BaP or other PAHs.

Polynuclear aromatic hydrocarbons are semivolatile organic chemicals that are formed during the combustion process. Important indoor sources for PAHs include smoking, woodburning, gas heating, and cooking or grilling of foods. Major outdoor sources include automobile exhaust and smoke from woodburning sources. Understanding the factors that contribute to elevated PAH concentrations in air is important since several of the PAHs are carcinogens that pose a relatively high risk to human health (NRR, 1990).

Research performed to date has used two different approaches to study exposures to PAHs. Recent research studies and a summary of their findings are given in Table 1-3. Several studies have evaluated the effect of combustion sources on PAH air levels in a small set of homes under carefully controlled conditions (Offerman et al., 1990; Traynor et al., 1987; Wilson et al., 1990). In contrast, one large field monitoring study measured PAH air concentrations in a statistically representative sample of homes (Sheldon et al., 1992). However, this latter study was performed in Southern California during the fall when participants reported little use of indoor combustion sources; thus results do not provide detailed information on the effect of combustion sources on PAH levels in indoor air. The

TABLE 1-3. RECENT RESEARCH STUDIES TO ASSESS EXPOSURES TO PAHS IN AIR

Study Description	Results	Citation
Total Human Environmental Exposure Study. Field monitoring study, collection of indoor, outdoor, and personal air samples from 20 volunteer participants in Phillipsburg, N.J. BaP associated with coarse particulate measured. Monitoring performed over two winter and one fall seasons. Phillipsburg selected as community with highest ambient BaP air concentrations in N.J.	1. Ambient air concentrations of BaP higher in winter than in fall. - winter, 1987: 0.39 ng/m ³ - winter, 1988: 1.11 ng/m ³ - fall, 1988: 0.14 ng/m ³	Waldman et al.,1991
	2. Foundry and interstate truck traffic had little impact on ambient BaP levels.	
	3. Infiltration of BaP in outdoor air provided a significant contribution to indoor BaP levels.	
	4. Reported mean indoor concentrations of BaP. - winter,1987: 1.16 ng/m ³ - winter,1988: 1.11 ng/m ³ - fall,1988: 0.14 ng/m ³ Highest indoor concentrations were associated with indoor combustion sources such as smoking and cooking.	
	5. Personal air concentrations similar to indoor levels. Highest personal concentration for BaP (100 ng/m ³) was due to archwelding activities.	

(Continued)

TABLE 1-3 (CONTINUED)

Study Description	Results	Citation
Two pilot studies to measure PAHs including quinoline in indoor and outdoor air. In winter 1984, 10 homes in Columbus, Ohio studied. PAH measurements made in kitchen, living room, master bedroom, and outdoors over 8-hour periods. Homes purposely selected with cigarette smoking, fireplace use, gas heating appliances, and gas cooking. In winter 1986, eight homes in Columbus, Ohio studied. PAHs measured in kitchen, living room and outdoors. Homes selected to have the same type of combustion source usage as 1984 study.	<ol style="list-style-type: none"> 1. PAH measurements in kitchen and living room generally similar suggesting good air mixing; measurements in bedroom usually lower. 2. Cigarette smoking and use of gas heating appliances had the greatest effect on indoor PAH concentrations. Typical reported indoor BaP levels for homes with <ul style="list-style-type: none"> - cigarettes: 1.2 ng/m³ - electric heat: 0.28 ng/m³ - gas heat: 0.63 ng/m³ 3. Woodburning only weakly associated with elevated indoor PAH concentrations. 4. Homes with cigarette smoking showed elevated concentrations for quinoline. 5. Mean outdoor BaP concentrations were 0.36 ng/m³ for combined data set. 	<p>Wilson et al., 1990 Mack et al., 1989</p>

(Continued)

TABLE 1-3 (CONTINUED)

Study Description	Results	Citation
Pilot study of three homes in northern California. PAHs measured in air samples collected at one indoor and one outdoor location over 12 hour periods. Monitoring was performed over several time periods in each home. Indoor combustion sources were purposely used during the monitoring periods.	<ol style="list-style-type: none"> 1. Highest air concentrations were reported for the gas phase 3- and 4-ring PAHs. Gas phase PAHs were higher indoors than outdoors regardless of combustion source use. 2. Concentrations of particle phase PAHs were higher indoors than outdoors for homes with tobacco smoking and woodstove use. Gas range use did not appear to elevate indoor PAH levels over outdoor levels. 3. Mean indoor BaP concentration was 0.55 ng/m³; mean outdoor concentration was 0.13 ng/m³. 	Offerman et al., 1990
Study to measure outdoor air concentrations of pollutants in five southern California locations in 1982. Fifteen PAHs quantified in fine particle samples.	Seasonal concentration patterns similar for all PAHs with highest ambient concentrations in the winter and lowest ambient concentrations in the summer. Lower summer concentrations may result from increased atmospheric dilution, more active photochemistry, or lack of heating combustion sources. Highest particle phase concentrations reported for benzo[ghi]perylene, perylene, then coronene. Annual BaP concentrations ranged from <0.01 to 0.44 ng/m ³ .	Rogge et al., 1987

(Continued)

TABLE 1-3 (CONTINUED)

Study Description	Results	Citation
PAH measurements in a test house in California under controlled conditions. Four models of woodstoves were operated under different conditions. Particle phase PAHs monitored in the living room, kitchen, master bedroom, and outdoors.	Air tight stoves emitted only small amounts of PAHs; non-airtight stoves emitted higher amounts. Ratios of indoor to outdoor air concentrations were less than one when airtight stoves were used. Ratios less than one were also reported when no stoves were used. For BaP, outdoor concentrations ranged from 0.18 to 1.9 ng/m ³ . Indoor BaP concentrations ranged from 0.07 to 0.28 ng/m ³ for airtight stoves, 1.9 ng/m ³ for a stove operated as a fireplace, and 11 to 200 ng/m ³ for non-airtight stoves. Calculated BaP source strengths for airtight woodstoves ranged from 10 to 100 ng/hr.	Traynor et al. ,1987
Field study of seven homes in Wisconsin in the winter and spring of 1986. Homes were purposely selected that used woodstoves as a heating source. Indoor air samples collected over 48-hour periods with and without woodburning in the home. Measurements for 8 PAHs reported.	Summed indoor PAH concentrations were elevated during wood burning periods compared to nonwood burning periods. Highest indoor concentrations found in a home when woodstove operated with the door open. Greater proportions of BaP, benzo[ghi]perylene, and indeno[cd]pyrene were present during woodburning periods.	Daisey et al., 1987

(Continued)

TABLE 1-3 (CONTINUED)

Study Description	Results	Citation
Six home field monitoring study. Paired indoor and outdoor samples collected over 24 hour periods. Particle phase PAHs measured. Homes purposely selected that used woodburning as a primary heating source. Study performed in Waterbury, Vt in winter, 1982. Samples were collected for 1 to 4 days at each house.	The mean reported BaP concentration in indoor air was 0.8 ng/m ³ ; the mean reported BaP concentration in outdoor air was 0.8 ng/m ³ . The indoor/outdoor air concentration ratio for BaP was greater than one in 42% of the homes. For the more volatile PAHs such as chrysene and benzo[a]anthracene the indoor/outdoor air concentration ratio was greater than one in <15% of the homes. For the less volatile species (i.e., coronene), the ratio was greater than one in more than 65% of the homes. Fairly large inter and intra house variability in PAH concentrations were reported.	Sexton et al., 1986
Three home field monitoring study. Air samples collected from the kitchen, master bedroom, and living room in each home. Homes purposely selected based on combustion source use. One home had smokers; wood burning was used as a heating source in all three homes. Samples were collected on wood burning and nonwood burning days. BaP was measured in each sample.	Elevated BaP air concentrations were measured on days with wood burning compared to days without wood burning. Air concentrations for BaP were higher indoors than outdoors. Highest indoor BaP concentrations were reported as 7 ng/m ³ during woodstove use and 11.6 ng/m ³ during fireplace use. Highest outdoor air concentration was 4 ng/m ³ .	Moschandreas et al., 1980
Five home field monitoring study. Aerosol mass and PAH concentrations were measured in five typical Northwest homes during a 5-day period of woodstove use. Measurements were repeated during a similar five day period when woodstoves were not in use.	No significant increase in the concentration of aerosol mass or PAH concentration was measured during woodstove use in four of the five homes. Significant increases in mass and PAH levels were found in one home where the woodstove leaked smoke into the home. Measured BaP concentrations in this home were 26 ng/m ³ . Measured BaP concentrations in the other four homes were less than 0.3 ng/m ³ .	Core et.al., 1982

(Continued)

TABLE 1-3 (CONTINUED)

Study Description	Results	Citation
Field monitoring study performed in 125 homes in Riverside, California in the fall of 1990. In each home, two 12-hour indoor air samples collected. In a subset of 65 homes, paired outdoor air samples were also collected. PAH concentrations measured in collected samples. Questionnaire data collected on combustion source use. Homes were randomly selected to represent homes in the Riverside area with at least one nonsmoking resident over the age of 10.	<ol style="list-style-type: none"> 1. Relative air concentrations for the individual PAH species showed highest concentrations for the more volatile three and four ring PAHs. 2. Indoor air samples showed little or not increase in mean or median PAH concentrations compared to outdoor samples. 3. Median indoor concentrations for BaP were 0.14 ng/m³ for daytime samples and 0.20 for nighttime samples. Highest reported indoor BaP concentration was 56 ng/m³; reason for this high level was unknown. 4. Median outdoor concentrations for BaP were 0.09 ng/m³ for daytime samples and 0.19 ng/m³ for nighttime samples. 5. Indoor concentration for most PAHs were higher in homes where smoking took place. Other reported indoor activities did not appear to elevate indoor PAH concentrations, although monitoring was performed during the fall when little use of combustion sources for heating were used. Proximity to heavy traffic appeared to increase outdoor PAH concentrations. 	Sheldon et al.,1992

(Continued)

TABLE 1-3 (CONTINUED)

Study Description	Results	Citation
Pilot study to assess indoor and outdoor PAH concentrations in homes in southern California in spring, 1989. PAH measurements performed in five homes. Samples collected for two 12-hour periods each day for an eight day period.	Highest indoor and outdoor air concentrations found for the vapor phase PAHs. Mean indoor and outdoor BaP concentrations were similar (0.35 ng/m^3). For paired indoor and outdoor samples, outdoor air concentrations for the PAHs were usually higher. Within a home, greater variability in measured PAH concentrations was found for indoor samples compared to outdoor samples. Higher outdoor PAH concentrations were associated with higher indoor concentrations indicating the effect of ambient air intrusion on indoor levels.	Wilson et al., 1990.
Field monitoring study to measure ambient PAH concentrations at seven sites throughout California impacted by different combustion sources. Sites were selected to represent areas with vehicle emissions, agricultural burning, industrial emissions, residential woodburning, and oil product emissions. A total of 118 12-hour daytime and nighttime ambient air samples were collected at these sites. Samples were analyzed for particles, PAHs, nitroarenes, and sulfur heterocycles.	<ol style="list-style-type: none"> 1. Highest mean air concentrations for BaP were reported at the industrial site (4.4 ng/m^3) and the residential woodburning site (6.3 ng/m^3). Mean BaP concentrations at other sites ranged from 0.2 to 0.5 ng/m^3. 2. The emission profile of the PAHs differed from site to site, and no single PAH could be used as a marker compound for the range of PAHs observed in ambient air. 3. None of the PAHs could be used to serve as a tracer for specific combustion sources. 4. Significant differences were observed between sites in ambient PAH concentrations and the amounts of atmospheric transformations that had occurred. 	Atkinson et al., 1988

study reported here extends the available information by evaluating the effects of combustion sources on PAH air concentrations in a large sample in northern California that represents homes with specific combustion source use. This is the first large field monitoring study of its kind and provides valuable information on PAH exposures for California residents and the factors that affect these exposures.

1.2 STUDY DESIGN

To meet the specific project objectives a single season field monitoring program for CO and the PAHs was conducted in the winter of 1992. Monitoring was performed in 280 homes selected from Placerville and Roseville, California. Monitoring was performed in Placerville during the periods from January 7 to January 28 and March 7 to March 23. Monitoring in Roseville took place between January 29 and March 6. Two study areas were used to ensure that a range of building characteristics and source use patterns were included in the study population. Housing units were selected to represent homes in specific source categories based on both the presence and expected use of several combustion sources, including

- fireplaces,
- woodstoves,
- gas heating, and
- environmental tobacco smoke.

Figure 1-1 shows the combustion source categories and the number of homes targeted for monitoring and monitored in each category.

A modified random digit dialing telephone procedure was used to contact potential participants in each of the two study areas. A brief screening interview was administered to obtain information on combustion sources and their use in the home. Homes were then selected and placed into combustion source categories based on these interviews. Indoor combustion source usage rates reported during the screening interview were used for sample selection.

A letter and brochure describing the purpose of the study and the field monitoring activities were sent to each selected household. Follow-up telephone calls were then used to enlist participation and schedule field monitoring visits.

For each household, monitoring was performed over a single 24-hour period. An initial visit 24 hours prior to monitoring was made to install emitters for an air exchange

	No Smoking in House		Smoking in House	
	Gas Heat Not Used	Gas Heat Used	Gas Heat Not Used	Gas Heat Used
Fireplace Used	48 (46)		17 (11)	
Woodstove Used	40 (56)	30 (22)	45 (53)	
Fireplace or Woodstove Not Used	40 (39)	60 (53)		

Figure 1-1. Source Categories and Numbers of Homes Targeted for Monitoring
(number in parenthesis is the number of homes monitored.)

measurement. At each home, indoor and outdoor air samples were collected and analyzed for PAHs. Air exchange measurements were made using a perfluorocarbon tracer (PFT) technique (Dietz et al., 1982). Indoor and outdoor measurements for CO were performed in a subset of ~75% of the study homes. At the end of the 24-hour chemical monitoring period, information was gathered on the use of combustion sources during the monitoring period, the activities of residents that may have affected indoor concentrations of combustion products during the monitoring period, and pertinent building characteristics of the residences.

Statistical analysis was performed on the resulting monitoring and questionnaire data. For each home, measured indoor air concentrations, outdoor air concentrations, and air exchange rates were used to calculate indoor/outdoor concentration ratios and source strengths for each target chemical. These data were also modeled to calculate emission rates (ERs), emission factors (EFs), or emission strengths (ESs) for selected sources. Usage rates reported during field monitoring, not those reported during screening, were used for all statistical analyses. Data analysis included univariate descriptive statistics for each of the measured and calculated variables, correlations among compounds, and the development of models relating pollutant concentrations to one another and to questionnaire data.

Prior to initiating the main study, a pilot study was performed using the survey, sampling and analysis, sample tracking, and data manipulation activities associated with the proposed program. Overall the pilot study proceeded very smoothly, demonstrating that the methods selected to conduct the field study were acceptable with only minor modifications. Results of the pilot study are provided in a separate report (Appendix Q).

The remainder of this report describes in detail the methods that were used for sample selection, household recruitment, field sampling, and sample analyses on the main study. Monitoring results and statistical analyses of the data are then given. Most importantly, we have provided the conclusions from the study that contribute to an understanding of exposures to PAHs and CO in the indoor environment and the factors that effect these exposures.

SECTION 2.0

SUMMARY AND CONCLUSIONS

The purpose of this study was to obtain information on indoor and outdoor air concentrations of polynuclear aromatic hydrocarbons and CO in California residences. Additional objectives were to investigate the relationship between compounds and different types of indoor combustion sources and to explore relationships among the measured compounds. To meet these objectives, a single season field monitoring study was conducted in 280 homes in northern California. Although both PAHs and CO were monitored in the study, data analyses and conclusions in this report focus on the results obtained for the PAHs since they were the primary pollutants of concern for ARB.

Polynuclear aromatic hydrocarbons are semivolatile organic chemicals that are formed during the combustion process. Important indoor sources for PAHs include smoking, woodburning, gas heating, and cooking or grilling of foods. Major outdoor sources include automobile exhaust and smoke from woodburning sources. Understanding the factors that contribute to elevated PAH concentrations in air is important since several of the PAHs are carcinogens that pose a relatively high risk to human health (NCR, 1990). The study reported here was designed to evaluate the effects of combustion sources on PAH air concentrations in a large sample in northern California that represents homes with specific combustion source use. This is the first large field monitoring study of its kind and provides valuable information on PAH exposures for California residents and the factors that affect these exposures.

2.1 METHODS

The field monitoring study was conducted from January to March, 1992. Monitoring was performed in 280 homes located in Placerville and Roseville, California. Two study areas were used to ensure that a range of building characteristics and source use patterns were included in the study population. Homes were selected to represent specific source categories based on the use of several combustion sources, including fireplaces, woodstoves, gas heating, and smoking. Table 2-1 shows the combustion source categories and the number of homes monitored in each category.

TABLE 2-1. COMBUSTION SOURCE CATEGORIES

Combustion Source Category		No. of Homes Monitored
A:	Smokers in house, fireplace not used	53
All:	Smokers in house, fireplace used	11
B:	No smokers, fireplace used	46
C:	No smokers, no gas heat, woodstove used	56
D:	No smokers, with gas heat, woodstove used	22
E:	No smokers, no gas heat, fireplace/woodstove not used	39
F:	No smokers, with gas heat, fireplace/woodstove not used	53

A modified random digit dialing telephone procedure was used to contact potential participants in each of the two study areas. A brief screening interview was administered by telephone to obtain information on combustion sources and their use in the home. Homes were then selected and placed into combustion source categories based on these interviews. A letter and brochure describing the purpose of the study and the field monitoring activities were sent to each selected household. Follow-up phone calls were then used to enlist participation and schedule field monitoring visits.

For each household, monitoring was performed over 24 hours. At each home, indoor and outdoor air samples were collected and analyzed for PAHs. Air exchange measurements were made using a perfluorocarbon tracer technique. CO measurements were taken indoors and outdoors at approximately 75% of the homes using Drager CO monitors/dataloggers. At the end of the monitoring period, information was collected on combustion sources and activities that may have affected indoor PAH concentrations during the monitoring period. A 24-hour study questionnaire administered with computer-assisted personal interviewing techniques was used for this purpose. Data from these questionnaires were used for all statistical analysis.

For PAH monitoring, combined particulate and vapor-phase PAHs were collected using medium-volume constant flow pumps coupled to a sampling cartridge containing a 21 mm quartz fiber filter backed by a 4.5 g bed of XAD-2 resin. PAHs were recovered from the combined cartridge material by sonication extraction with methylene chloride. Concentrated sample extracts were analyzed by gas chromatography/mass spectrometry in the selected ion monitoring mode. Performance of the monitoring method was evaluated using spiked control cartridges, unspiked blanks, surrogate standards spiked into each sample, standard reference materials, and duplicate field samples. Data for BaP are given in Table 2-2 and demonstrate acceptable method performance. Similar results were achieved for the other target PAHs chemicals. Performance results for quinoline, as evaluated by quality control samples, were acceptable. However, quantitation of quinoline in sample extracts was difficult due to matrix interferences. Method modifications will be required to reliably measure quinoline in indoor air samples.

TABLE 2-2. SUMMARY OF METHOD PERFORMANCE RESULTS FOR BENZO[A]PYRENE

Median Method Quantifiable Limit (ng/m ³)	0.04
Precision (Median % RSD for duplicate samples)	4.9
Mean amount (ng) on field blanks (n=30)	ND ^a
Mean % recovery of spiked controls (n=23)	101 ± 21 ^b
Mean % recovery from NIST controls (n=6)	89 ± 20 ^b
Mean % recovery of spiked surrogate (BeP-d ₁₂) (n=417)	97 ± 12 ^b

^a Not detectable - no instrumental signal.

^b % RSD.

The remainder of this section summarizes the data analyses methods, results, and conclusions as they relate to specific study objectives. Discussion focuses on BaP since it is the TAC of concern to the Air Resources Board.

- 2.2 OBJECTIVE 1: TO QUANTIFY THE DISTRIBUTION OF PAH AND CO INDOOR AIR CONCENTRATIONS, OUTDOOR AIR CONCENTRATIONS, AND INDOOR/OUTDOOR AIR CONCENTRATION RATIOS IN SELECTED RESIDENCES WITH DIFFERENT COMBUSTION SOURCES
OBJECTIVE 2: TO QUANTIFY THE DISTRIBUTION OF PAH SOURCE STRENGTHS IN SELECTED RESIDENCES WITH DIFFERENT COMBUSTION SOURCES

Prior to generating summary statistics on air concentration data, the percentage of samples with quantifiable concentrations for each target PAH was calculated for indoor and outdoor air samples. With the exception of quinoline, percent quantifiable values for all PAHs were very high (>80%). For BaP, percent quantifiable values were 99.2% and 98.7% in indoor and outdoor samples, respectively. As shown in Table 2-3, quinoline was only detected in indoor air samples from homes in the two smoking categories. This is consistent with quinoline being a marker for ETS.

Summary statistics were calculated for indoor air concentrations, outdoor air concentrations, and indoor/outdoor air concentration ratios and source strengths by source category. Source strengths in each home were calculated using a simple indoor air model. The indoor air model was also used to determine the relative contribution of indoor and outdoor sources to indoor air concentrations. Summary statistics by combustion source category were then calculated for these latter parameters.

Data on indoor and outdoor air concentrations for BaP are given in Table 2-4 by combustion source category. Indoor/outdoor air concentration ratios, the fractional contribution of indoor and outdoor sources to indoor air concentration, and calculated indoor source strengths are also given in the table. There was a substantial difference between the two study areas in the use of woodstoves and fireplaces as a primary heating source. Since this difference could affect outdoor air BaP concentrations, results for outdoor air concentrations are also reported by study area. Results for indoor air concentration, outdoor air concentration, indoor/outdoor concentration ratios and source strengths are displayed graphically in Figure 2-1.

TABLE 2-3. PERCENT MEASURABLE VALUES FOR QUINOLINE BY COMBUSTION
SOURCE CATEGORY

Combustion Source Category		% Measurable	
		Indoors	Outdoors
A	- Smoking	41.0	0.0
All	- Smoking/Fireplace	58.3	7.1
B	- Fireplace	1.7	0.0
C	- Woodstove/No Gas Heat	0.0	0.0
D	- Woodstove/Gas Heat	0.0	0.0
E	- None	0.0	0.0
F	- Gas Heat	4.8	0.0

TABLE 2-4. SUMMARY DATA FOR BENZO[a]PYRENE REPORTED BY SOURCE CATEGORY

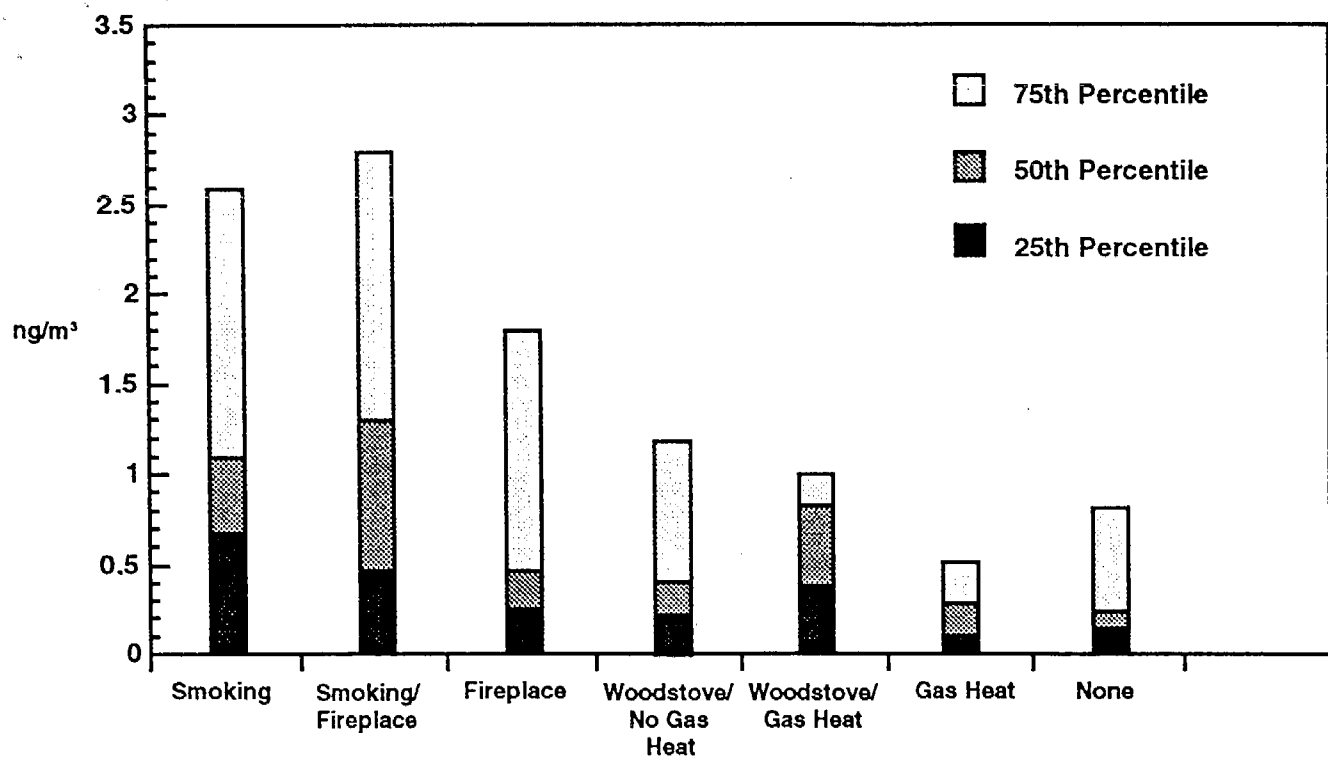
	Category						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove		Gas Heat	None
				No Gas Heat	Gas Heat		
<u>Indoor air concentration (ng/m³)</u>							
Geometric mean	1.2****	1.3***	0.55*	0.55*	0.62*	0.24	0.34
Median	1.1	1.3	0.47	0.41	0.83	0.29	0.25
<u>Outdoor air concentration (ng/m³) - all study homes</u>							
Geometric mean	0.61	0.87	0.61	0.71	1.1	0.44	0.52
Median	0.72	0.91	0.59	0.57	1.2	0.25	0.33
<u>Outdoor air concentration (ng/m³) - Placerville</u>							
Geometric mean	1.1	1.1	1.0	0.85	1.0	1.2	0.99
Median	1.2	1.6	1.3	0.74	1.2	0.80	1.1
<u>Outdoor air concentration (ng/m³) - Roseville</u>							
Geometric mean	0.30	0.73	0.45	0.45	1.2***	0.31	0.32
Median	0.26	0.86	0.43	0.47	1.2	0.23	0.27
<u>Indoor/outdoor air concentration ratio</u>							
Geometric mean	2.2***	1.5***	0.88**	0.76*	0.58	0.56	0.56
Median	1.9	1.4	0.83	0.76	0.52	0.54	0.59
<u>Median fractional contribution to indoor air concentration</u>							
From Outdoors	0.28	0.40	0.65	0.71	1.0	1.0	0.92
From Indoors	0.72	0.60	0.35	0.29	0.0	0.0	0.08
<u>Source Strength (ng/h)^b</u>							
Median	120	240	21	11	0.0	0.0	3.6
Arithmetic mean	210***	360***	140	40	24	0.0	19

^a *** Significantly different than no source category at 0.01 level.

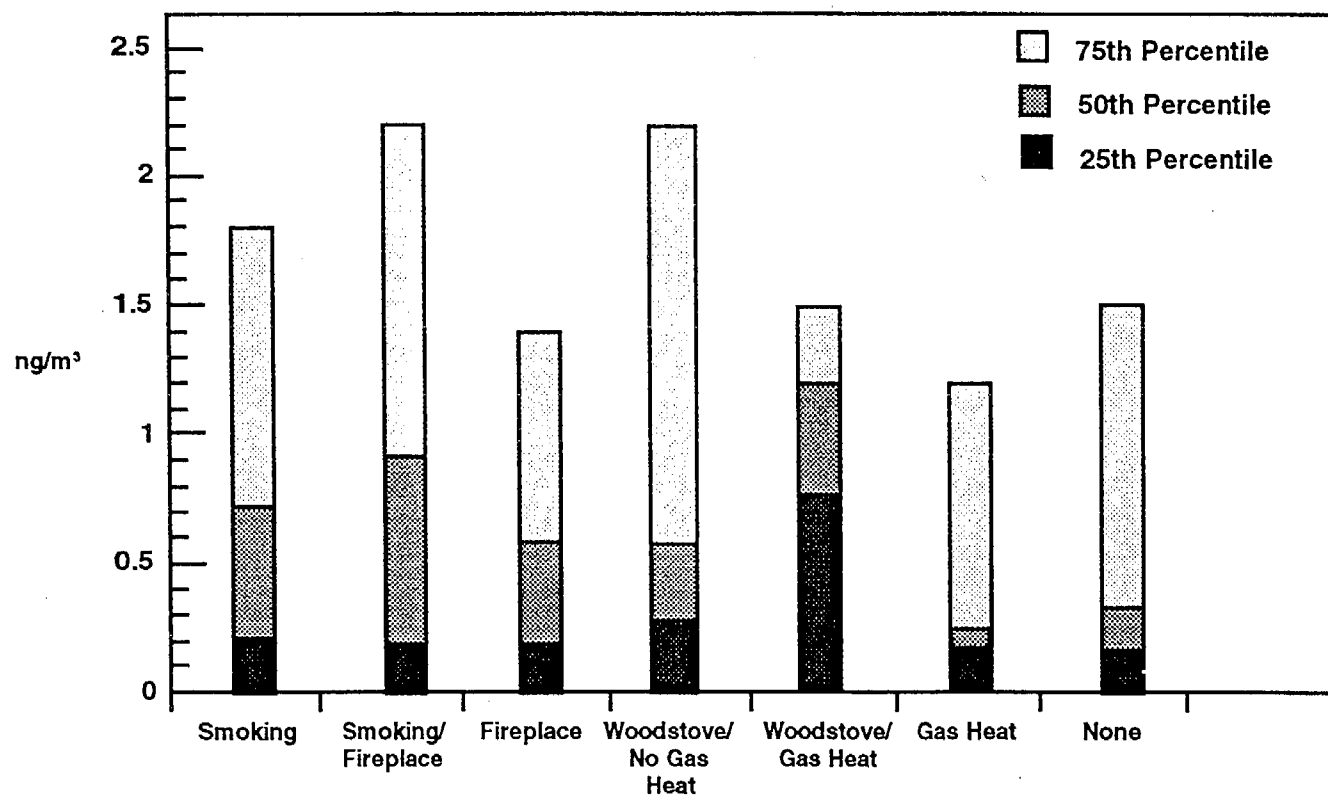
** Significantly different than no source category at 0.05 level.

* Significantly different than no source category at 0.10 level.

^b Tests were only performed on arithmetic means.

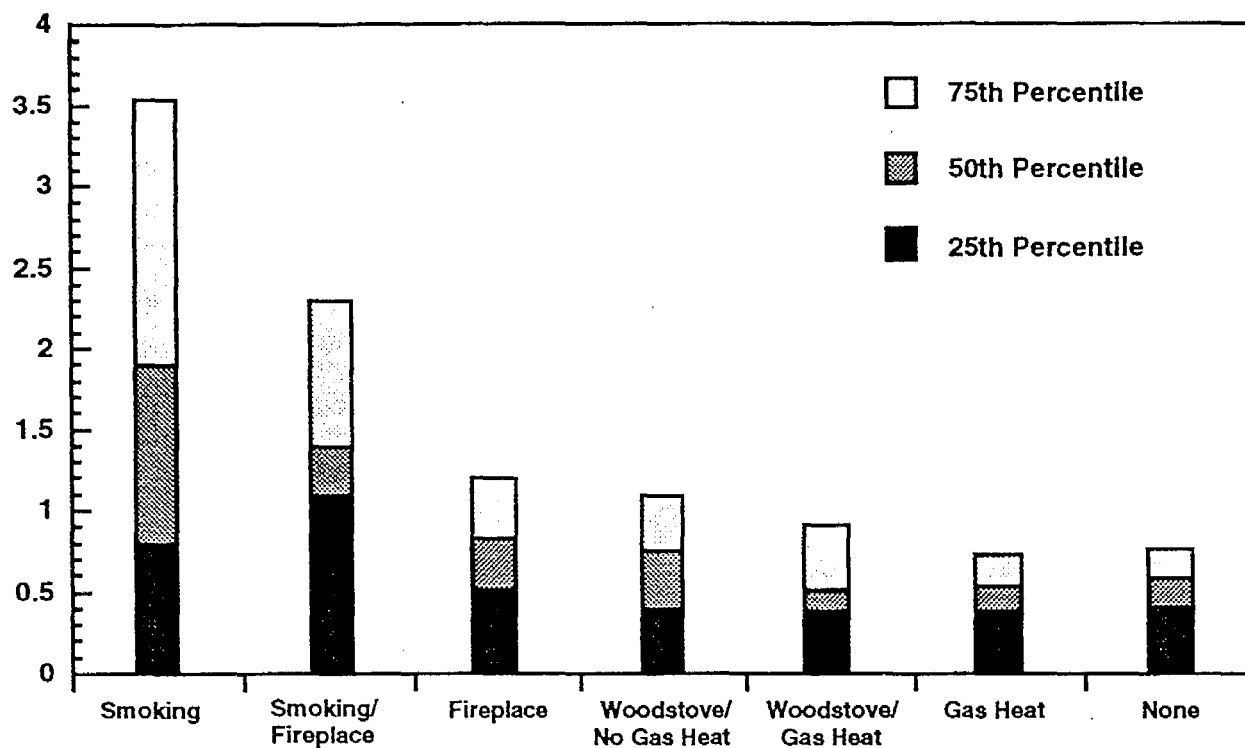


Indoor BaP Concentration (ng/m³) by Combustion Source

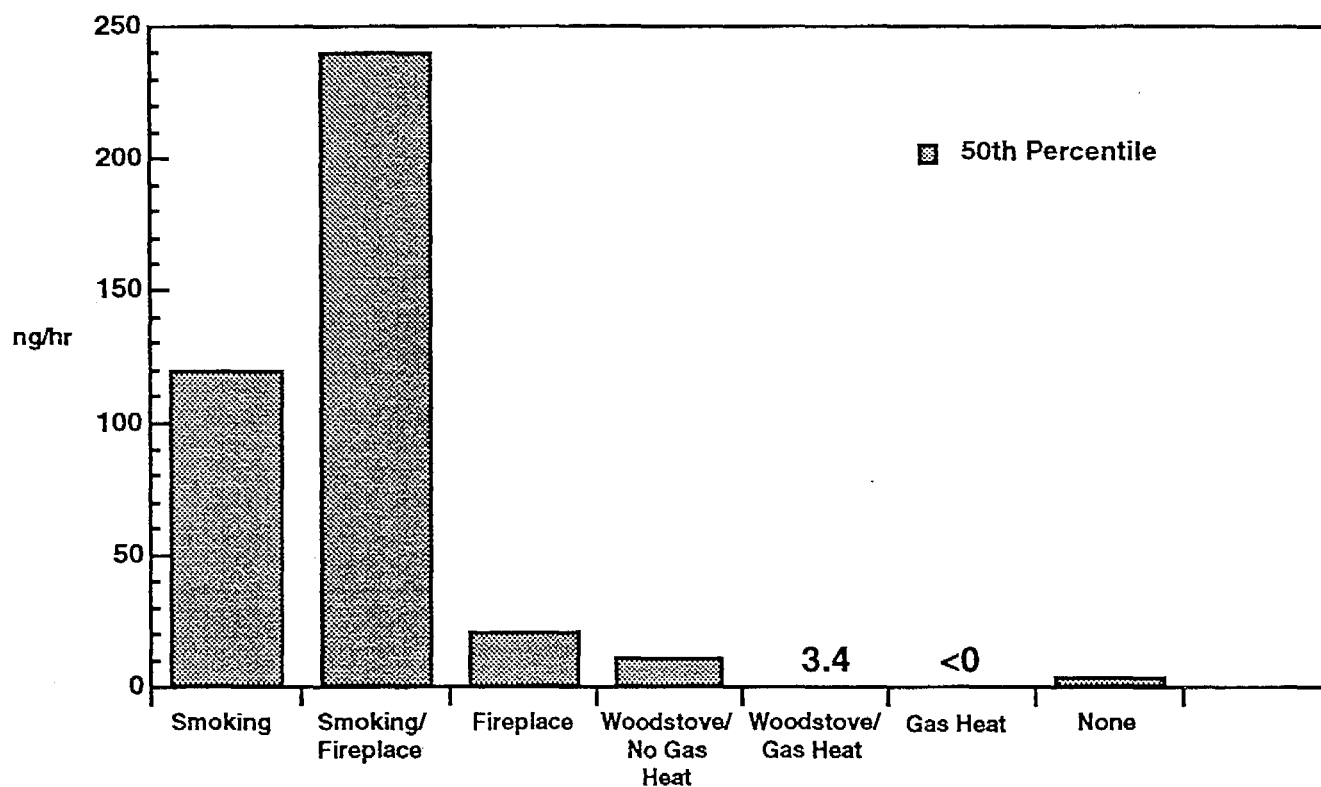


Outdoor BaP Concentrations (ng/m³) by Combustion Source

Figure 2-1. Summary Data for BaP.



Indoor/Outdoor Air Concentration Ratios for BaP



BaP Source Strengths by Combustion Source Category (ng/h)

Figure 2-1 (continued)

To investigate the effect of various combustion sources on PAH air concentrations and air concentration ratios, t-tests were performed between homes in the six source categories and homes in the no source category. Tests were performed only on the means of the logs of the air concentrations which when exponentiated yielded geometric means. The results of the tests that are significantly different than zero at the 0.01, 0.05, and 0.10 level are designated by asterisks on Table 2-4. For source strengths, arithmetic rather than geometric means were calculated, since the latter statistic cannot be calculated for negative or zero values.

The data for BaP show several interesting trends.

- Highest values for indoor air concentrations, indoor/outdoor concentration ratios, and source strengths were seen for homes in the two smoking categories demonstrating the substantial impact smoking has on indoor air exposure.
- Homes with smoking, fireplace use, and woodstove use had higher indoor air concentrations, indoor/outdoor air concentration ratios, and calculated source strengths for BaP than homes placed in the no source category. For homes with smoking, this effect was significant at the 0.01 level. For woodstoves and fireplaces, the effect was significant (at the 0.05 or 0.10 level) for indoor air concentrations and indoor/outdoor air concentration ratios but not for source strength values. It should be noted that homes were placed in the no source category because there was no reported smoking, woodburning or gas heat use; however, other sources of PAHs could be present in the home.
- Homes in the gas heat category did not show elevated BaP concentrations compared to the homes in the no source category.
- For outdoor air, homes in woodburning categories appeared to have elevated outdoor BaP concentrations compared to homes in other categories. This effect is most apparent in Roseville where very few residences used woodburning as a heating source, thus outdoor PAH concentrations at a home should more closely reflect the woodburning activities at that home.

- In homes without very strong sources such as smoking, indoor/outdoor concentration ratios for BaP were less than one. In the same homes, the fractional contribution of outdoor air to indoor air concentrations was high. These results suggest that outdoor air will have a substantial impact on indoor air concentrations. Where woodburning increases outdoor air concentrations of BaP, it should indirectly elevate the indoor levels.

The other PAHs tended to show the same effects as BaP for the indoor air measures (i.e., indoor air concentrations, indoor/outdoor air concentration ratios, and source strengths) estimated on this study. Highest PAH values for all three indoor air measures were reported for homes in the smoking categories. Homes in the woodburning categories tended to show elevated indoor air concentration measures but to a lesser extent than for homes in the smoking categories. The more volatile 3-ringed PAHs including acenaphthylene, phenanthrene, and anthracene showed small increases in the indoor air concentration measures for homes in the gas heat category. Measures of source strength and the fractional contribution from indoor sources to indoor air concentrations indicated a rather substantial unidentified indoor source for phenanthrene, anthracene, fluoranthene, and pyrene. Finally, although not evaluated statistically, homes where smoke was visually observed by the participant or where woodstoves were operated with the stove doors open tended to have very high indoor air concentrations, concentration ratios, and source strength values for the target PAHs.

BaP concentrations were further analyzed to assess their potential health impact. BaP is a carcinogen and was identified by ARB as a toxic air contaminant. It has been estimated that an air concentration of 0.3 ng/m^3 over a 70-year exposure period will result in a 10^{-6} excess cancer risk (Offerman et al., 1990). The California Office of Environmental Health Hazard Assessment has set a preliminary unit risk for BaP as 1.1×10^{-3} per $\mu\text{g/m}^3$. This unit risk value implies that exposure to an air concentration of 0.9 ng/m^3 of BaP over 70 years would give 10^{-6} excess cancer risk. Table 2-5 shows the percentage of indoor and outdoor air samples in each source category that exceeds the 0.3 and 0.9 ng/m^3 concentrations. Percentages of samples that exceed the 2.5 and 5.0 ng/m^3 levels have also been given. Results show that a substantial fraction of the population in this study may be exposed to BaP concentrations above health risk levels (0.3 or 0.9 ng/m^3) especially in homes where smoking occurs.

TABLE 2-5. PERCENT OF AIR SAMPLES WITH BaP CONCENTRATION
EXCEEDING SELECTED LEVELS

Source Category	Percent			
	$\geq 0.3 \text{ ng/m}^3$	$\geq 0.9 \text{ ng/m}^3$	$\geq 2.5 \text{ ng/m}^3$	$\geq 5.0 \text{ ng/m}^3$
INDOOR AIR SAMPLES				
Smoking	95.6	60.0	31.1	4.4
Smoking/Fireplace	92.3	61.5	7.7	0.0
Fireplace	60.3	25.9	13.8	3.4
Woodstove	64.0	34.0	10.0	0.0
Woodstove/Gas Heat	77.3	36.4	9.1	0.0
Gas Heat	51.1	24.4	4.4	0.0
No Source	57.6	27.3	9.1	0.0
OUTDOOR AIR SAMPLES				
Smoking	59.1	40.9	18.2	6.8
Smoking/Fireplace	64.3	57.1	14.3	0.0
Fireplace	52.5	26.2	13.1	1.6
Woodstove	72.5	41.2	15.7	2.0
Woodstove/Gas Heat	100	59.1	18.2	4.5
Gas Heat	53.3	40.0	11.1	2.2
No Source	69.7	42.4	18.2	3.0

For carbon monoxide the method quantifiable limit was estimated as 2 ppm. The percentage of air samples with 24-hour average concentrations equal to or above this concentration are given in Table 2-6 by combustion source category. The maximum 24-hour average CO concentration is also given for each category. The distribution of one-hour average CO concentrations by combustion source category for both indoor and outdoor air samples is given in Table 2-7. For both 24-hour and 1-hour average CO concentrations, the percent measurable values were extremely low. As a result, no additional statistical analysis was performed and no statistical conclusions regarding the effect of combustion sources on indoor and outdoor air concentrations were drawn, although some general results were observed.

The California Ambient Standards for CO are 20 ppm for a 1-hour averaging time and 9 ppm for an 8-hour averaging time. Air measurements in only two homes exceeded these standards. A 1-hour average CO concentration of 24 ppm was measured in one home during fireplace use. In a second home with gas heat, an 8-hour average concentration of 9.5 ppm was measured. These results suggest that combustion sources are generally not responsible for elevating 1-hour or 8-hour average CO concentration in homes.

In many homes, there were short term (1 to 2 minutes) elevated concentrations of CO that did not substantially elevate 24-hour average concentrations. The highest peak indoor air CO concentration (42 ppm) was observed when a gas space heater was turned on in the monitoring area. Elevated peak CO concentration of 22 ppm were observed in a second home that used gas heat as the primary heating source. In most cases, when short-term elevated indoor and/or outdoor CO concentrations were measured, they were associated with fireplace use, gas heat use, or automobile exhausts.

2.3 OBJECTIVE 3: TO IDENTIFY AND MODEL FACTORS ASSOCIATED WITH VARIOUS COMBUSTION SOURCES THAT INFLUENCE INDOOR AND OUTDOOR PAH CONCENTRATIONS

The relationship between combustion sources and indoor PAH air concentrations was further evaluated using an indoor regression model. Essentially, the statistical model was derived by extending the concept of source strength for a single source in a single home to emissions from one or more sources in a group of homes. Using this approach, it was

TABLE 2-6. PERCENT MEASURABLE VALUES FOR CARBON MONOXIDE BY COMBUSTION SOURCE CATEGORY

Combustion Source Category	n	% Measurable ^a		Maximum Indoor Concentration ^b (ppm)
		Indoors	Outdoors	
Smoking	39	7.7	0.0	4
Smoking/Fireplace	9	0.0	0.0	ND ^c
Fireplace	33	12.0	0.0	5
Woodstove	37	10.8	0.0	2
Woodstove/Gas Heat	17	11.7	0.0	4
Gas Heat	36	19.4	0.0	5
No Source	27	14.8	0.0	3.5

^a Percentage of samples with 24-hour average concentrations greater than or equal to 2 ppm.

^b 24-hour average concentrations.

^c Below the MQL.

TABLE 2-7. DISTRIBUTION OF ONE-HOUR AVERAGE CO CONCENTRATIONS IN INDOOR AND OUTDOOR AIR SAMPLES BY COMBUSTION SOURCE CATEGORY

Combustion Source Category	n	Percent of Samples in Concentration Range					
		<2 ppm ^a	2 ppm	>2 to ≤5 ppm	>5 to ≤9 ppm	>9 to ≤20 ppm	>20 ppm
<u>Indoors</u>							
Smoking	864	76.0	14.4	8.9	0.7	0.0	0.0
Smoking/Fireplace	190	79.0	18.4	2.6	0.0	0.0	0.0
Fireplace	744	83.9	8.1	5.5	1.5	0.9	0.1
Woodstove	787	76.6	10.4	9.4	3.6	0.0	0.0
Woodstove/Gas Heat	405	82.5	6.9	10.1	0.5	0.0	0.0
Gas Heat	1002	78.6	7.3	12.6	1.3	0.2	0.0
No Source	603	78.2	10.6	8.5	2.5	0.2	0.0
<u>Outdoors</u>							
Smoking	836	99.5	0.4	0.1	0.0	0.0	0.0
Smoking/Fireplace	211	97.2	1.9	0.9	0.0	0.0	0.0
Fireplace	730	95.1	1.4	3.5	0.0	0.0	0.0
Woodstove	785	98.3	1.3	0.3	0.0	0.1	0.0
Woodstove/Gas Heat	330	97.9	2.1	0.0	0.0	0.0	0.0
Gas Heat	618	97.5	1.7	0.8	0.0	0.0	0.0
No Source	963	94.8	4.2	1.0	0.0	0.0	0.0

^aBelow the estimated method quantifiable limit.

possible to assess the effects of various combustion sources on indoor air PAH concentrations and to estimate emissions for each combustion source.

Table 2-8 shows the combustion sources that were included in the model. The average 24-hour emission estimates for BaP from each source are also given. The combustion sources that have a statistically significant effect on indoor PAH concentrations are highlighted with asterisks. The strongest sources for BaP appear to be tobacco smoke, fireplaces, woodstoves, and kerosene heaters. Although the effect of kerosene heaters appears to be large (280 ng/h), the precision is poor due to the small number of homes with this source.

A summary of the modeling results for all PAHs is given in Table 2-9. For each target PAH, this table shows the effect and statistical significance of each combustion source on indoor air concentrations. If combustion source use was associated with an increase in indoor PAH concentrations, then the sign in the table is positive (+). Conversely, the sign is negative (-) if combustion source use was associated with a decrease in indoor PAH concentrations. The last column in Table 2-9 (% Var) shows how much of the total variability in the indoor concentration was accounted for by the model. For the less volatile PAHs (i.e., benzo[a]anthracene to coronene), the model performed well in describing the variability in indoor air concentrations. For BaP, 78.7% of the variability in the indoor air concentration measured across study homes was accounted for. The patterns for significance for the modeled combustion sources indicate that smoking and number of hours of fireplace use are important indoor sources for all of the PAHs. Number of hours of woodstove use is an important indoor source for the higher molecular weight PAHs. Gas heat use appears to be associated with elevated concentrations of the lower molecular weight PAHs. Although only six homes reported kerosene heater use, this variable was significant at the 0.10 level for the higher molecular weight PAHs.

For phenanthrene, anthracene, fluoranthene, and pyrene, the models did not perform well, as evidenced by the low %Var values reported in Table 2-9. There appears to be a significant unidentified indoor source for these four compounds. Other versions of the models were also not successful in describing the behavior for the four compounds.

Because of the potential importance of outdoor levels on indoor concentrations, the effects of woodburning and other factors on outdoor PAH air concentration were also

TABLE 2-8. COMBUSTION SOURCE VARIABLES EVALUATED BY THE INDOOR PREDICTION MODEL DEFINITIONS AND ESTIMATED EMISSIONS FOR BENZO[a]PYRENE

Combustion Source Variable		Emission Estimates for BaP ^a	
C _o	= outdoor concentration (ng/m ³)	0.54 ^{***b}	-
GH	= gas heat use	0.86	ng/day
FP	= hours of fireplace use/day	89 ^{***}	ng/hr of fireplace use
WS	= hours of woodstove use/day	17 ^{**}	ng/hr of woodstove use
FP/GH	= hours of fireplace use/day for homes with gas heat use	190	ng/hr of fireplace use
GWH	= indoor gas water heater	-1.5	ng/day
CIG	= (no. cigarettes (or equivalent) smoked ^c)/day	130 ^{***}	ng/cigarette
GCD	= gas clothes dryer use in the home including attached garage or attached shed	5.1	ng/day
GSt	= monitoring in kitchen or adjacent open room and constantly burning pilots on gas stove/oven or 10+ min. of burner operation	3.0	ng/day
FOOD	= monitoring in kitchen or adjacent room and grilling or uncovered frying	-4.4	ng/day
KIT	= monitoring in kitchen or adjacent open room	0.80	ng/day
VEH	= vehicles run in an attached garage or underneath parking area	2.5	ng/day
KER	= kerosene heater used in monitoring room	280	ng/day

^a24-h average values.

^b*Statistically significant effect on indoor air BaP concentration at the 0.10 level.

^{**}Statistically significant effect on indoor air BaP concentration at the 0.05 level.

^{***}Statistically significant effect on indoor air BaP concentration at the 0.01 level.

^cOne pipeful of tobacco was equated to 3.33 cigarettes; one cigar to 10 cigarettes.

TABLE 2-9. STATISTICAL SIGNIFICANCE OF INDOOR COMBUSTION SOURCES ON INDOOR AIR PAH CONCENTRATION - INDOOR MODEL PARAMETERS^a

Compound	Statistical Significance ^b												%Var ^c
	GH	FP	WS	FP/GH	GWH	CIG	GCD	GSt	FOOD	KIT	VEH	KER	
Acenaphthylene	+	+	+++	----	-	++++	+	----	+	+	++++	+	52.6
Phenanthrene	++++	+++	+	-	-	++++	--	+	-	++++	+	+	<0.0
Anthracene	++++	+++	+	-	+	++++	-	+	-	++++	+	+	18.3
Fluoranthene	++	++++	++++	-	-	++++	-	+	+	++++	-	+	20.7
Pyrene	++++	++++	++++	--	-	++++	-	-	+	++++	+	+	5.2
Benzo(a)anthracene	++++	++++	+++	-	+	++++	-	----	----	+	----	+	68.8
Chrysene	++++	++++	+	--	+++	++++	+	-	----	+	----	+	71.6
Benzo(a)fluoranthene	-	++++	+	-	+	++++	+	-	----	-	+	++	73.5
Benzo(e)pyrene	+	++++	+	+	-	++++	+++	-	-	----	+	++	75.8
Benzo(a)pyrene	+	++++	+++	+	-	++++	+	+	-	+	+	++	78.7
Indeno[1,2,3-cd]pyrene	++++	++++	+++	+	+	++++	+	----	-	-	+	+	71.0
Benzo(ghi)perylene	+	++++	+++	+	-	++++	+++	-	-	-	++++	+	68.6
Coronene	+	++++	++++	+	-	++++	++	-	-	-	++++	+	61.6

^aParameters are defined in Table 2-8.

^bIf the sign of the parameter estimate is +, then the combustion source increases PAH concentrations; if the sign of the parameter estimate is -, then the combustion source decreases PAH concentrations.

++ or -- denotes that estimate is statistically significant at 0.10 level.

+++ or ---- denotes that estimate is statistically significant at 0.05 level.

++++ or ----- denotes that estimate is statistically significant at 0.01 level.

modeled. The outdoor model was estimated separately for Placerville and Roseville since study area seemed to affect outdoor PAH levels. Modeling results indicate that temperature, rainfall, proximity to a busy roadway and woodburning in the home all affected outdoor PAH concentrations.

The variables generated from the indoor and outdoor models can be used for several purposes. First, the emission estimates shown in Table 2-8 can be used to evaluate the relative importance of various indoor sources. For example, the total mass of BaP emitted into a home by smoking 10 cigarettes in a day would be equal to the number of cigarettes smoked in a day (10) times the emission factor for cigarettes (130 ng/cigarette) or 1300 ng/day of BaP. Similarly the total indoor BaP emission from a fireplace burning in a home for three hours would be equal to hours of fireplace use per day (3) times the emission rate for fireplaces (89 ng/h of fireplace use) or 267 ng/day. Thus, the 24-hour incremental contribution to indoor BaP levels through smoking 10 cigarettes during a day will be about five times greater than the contribution of a fireplace operating for 3 hours during a day.

Another way to use the models is to produce predictions -- either for the purpose of estimating compound concentrations for a given set of conditions (i.e., a given outdoor concentration, air exchange rate, house volume, and combination of indoor source uses), or for comparing two or more sets of conditions (e.g., homes with one combination of sources used at certain rates versus homes with another combination). As an example, five scenarios were selected. In each of the scenarios, the daily temperature was assumed to be 45°F, the rainfall was zero, and the home was assumed to be far from heavy traffic. Fireplace and woodstove usages (in hours) were assumed to be zero for the first, fourth, and fifth scenarios; scenario 2 assumed three hours of fireplace use and scenario 3 assumed 24 hours of woodstove use. The indoor BaP concentrations for each scenario that were estimated using the models are given in Table 2-10.

2.4 OBJECTIVE 4: TO INVESTIGATE THE RELATIONSHIP AMONG COMPOUNDS

The final phase of statistical analysis was aimed at exploring relationships among the various compounds. This was accomplished by generating inter-compound correlations and applying principal component (PCA) analysis to each of the following:

TABLE 2-10. PREDICTIONS OF INDOOR CONCENTRATIONS FOR FIVE SCENARIOS^a

Compound	Area	Predicted Indoor Air Concentration ^b (ng/m ³)				
		1	2	3	4	5
Benzo(a)pyrene	PLACERVILLE	0.66	1.35	1.79	4.07	17.44
	ROSEVILLE	0.58	1.27	1.74	3.99	17.36
Benzo(ghi)perylene	PLACERVILLE	0.61	1.50	2.24	2.87	16.74
	ROSEVILLE	0.88	1.76	2.51	3.14	17.01
Chrysene	PLACERVILLE	0.36	1.07	0.95	4.30	8.99
	ROSEVILLE	0.30	1.02	0.95	4.25	8.94

- ^a Scenario 1 = no indoor sources
 Scenario 2 = 3 hrs of fireplace use
 Scenario 3 = 24 hrs of woodstove use
 Scenario 4 = 10 cigarettes smoked
 Scenario 5 = kerosene heater used

^b 24-h average concentration

- (a) logarithms of the outdoor air PAH concentrations,
- (b) logarithms of the indoor air PAH concentrations, and
- (c) source strengths.

Pearson correlations for outdoor air concentrations were high for all of the PAHs (almost all above 0.75). On the other hand, Pearson correlations for indoor air concentrations tended to be high only for those PAHs with similar volatilities. This disparity between indoor and outdoor correlations could be due to several factors:

- Different PAHs may have different penetration efficiencies into the home which could be a function of volatility. This could be an important effect since PAHs in outdoor air provide a large contribution to indoor air concentrations.
- Different indoor sources may generate different PAHs at different rates. This is probably the reason for the relatively poor correlations between phenanthrene, anthracene, fluorene, and pyrene with the other PAHs.
- Different PAHs may decay indoors at a different rate. Unfortunately, there is little data available to assess this effect.

Relatively good correlations were seen among source strengths for all of the PAHs. The 7-ringed PAH, coronene, was the exception and only correlated well with benzo[ghi]perylene.

The main purpose of the principal component analysis (PCA) was to identify PAHs that showed similar behavior in terms of indoor and outdoor air concentrations and source strengths. The PCA results for outdoor PAH concentrations indicated that air concentration data for a single PAH could adequately be used to describe the concentrations for all of the PAHs since no significant clustering of the PAHs was evident. For the indoor air concentration data, the first component showed all PAHs in a single group indicating similar behavior to the entire group of chemicals in the same relative. This may be due to a single strong source for PAHs such as infiltration from outdoors. Alternatively, it may be due to all indoor combustion sources generating PAHs in the same relative concentrations. For the indoor data, a second component showed PAHs falling into three groups which were generally based on volatility. These groups included

- a cluster containing phenanthrene, anthracene, fluorene and pyrene,
- a cluster containing the 5-, 6-, and 7-ringed particulate phase PAHs, and
- a separate "cluster" containing only one compound, acenaphthylene.

Results for source strengths again showed a first component with all PAHs in a single group. A second component showed compounds as falling into three groups in term of their general behavior which were based on volatility: the 3- and 4- ringed PAHs, the 5- and 6-ringed PAHs, and the 7-ringed PAH, coronene. This type of clustering may be due to the fact that PAHs of similar volatilities behave in a similar manner.

Based on these results, several conclusions can be made about the potential for identifying marker compounds or surrogate measures for BaP concentrations in air, total PAH concentrations in air, and environmental tobacco smoke (ETS).

- For outdoor air, any of the individual PAHs could be used as a marker for BaP.
- For indoor air, only those PAHs, with very similar structures and/or volatilities can be used as a marker for BaP concentrations. These include benzo[fluoro]anthrenes, benzo[e]pyrene, and indeno[1,2,3-cd]pyrene.
- For indoor and outdoor air, any of the individual PAHs can be used as a marker for total PAH concentrations.
- Since CO had very low percent measurable value in all source categories, it is not considered an acceptable marker for BaP air concentrations, total PAH air concentrations, or ETS.
- A definitive marker for ETS was not identified. Although elevated PAH air concentrations were observed in homes where smoking occurred, this effect was also observed for other strong combustion sources. Quinoline was measured only in homes in the smoking categories, which is consistent with quinoline being a marker for ETS. However, substantial matrix interferences were observed during GC/MS analysis of air sample extracts. Monitoring methods must be improved before the utility of quinoline as a marker for ETS can be assessed.

SECTION 3.0

RECOMMENDATIONS

This study has provided important data that can be used by ARB in its exposure and risk assessment process by providing residential indoor air and outdoor air concentration data for selected PAHs in Roseville and Placerville, California. Additional work is recommended that would broaden the scope of the database generated during this study. Recommendations are listed in order of overall priority.

- Methods that were used here should be applicable to personal exposure monitoring. Previous studies for volatile organic compounds and particulates showed elevated air concentrations for personal exposure samples compared to either indoor or outdoor air samples (Sheldon, 1991; Wallace, 1987). A study that incorporates personal exposure monitoring for the PAHs should be performed. Results could then be used to assess actual exposure levels as well as establish the relationship between personal exposure and indoor and outdoor air concentrations. Data could also be used to evaluate the approach that should be taken to model exposure based on measured microenvironmental concentrations.
- Work should be performed to identify and evaluate the indoor sources for phenanthrene, anthracene, pyrene, and fluorene. Results in the study indicated a substantial yet unidentified source for these PAHs in indoor air.
- More detailed information should be obtained on kerosene heaters as a source for PAHs. Results from this study showed very high emission strengths but only 6 out of the 280 homes monitored used kerosene heaters.
- More information should be obtained on the operating conditions for woodstoves that produce high indoor air concentrations for PAHs. Results from this study suggested that high indoor levels occurred when woodstoves were operated with the doors open.
- Studies should be performed to better define the parameters used to model indoor source strengths and pollutant concentrations. The indoor and outdoor pollutant decay rates and the penetration rates for pollutants into buildings need to be better understood.

- Additional monitoring should be performed in other areas of the state and other seasons to demonstrate both spatial and temporal variability. If PAH concentrations are significantly different between seasons or locations, it is essential that these data are generated and used for the required exposure and risk assessments. This is important since results here suggest that a high proportion of the target population may be exposed to BaP above the health risk level.
- Finally, specific chemical markers (i.e., nicotine or quinoline) that identify specific combustion sources (i.e., cigarette smoking) should be refined and applied in future field studies. If quinoline is to be used as a marker for ETS, then method modifications should be made that eliminate problems associated with matrix interferences. Cleanup using solid phase extraction columns and/or use of a nitrogen specific detector are recommended.

SECTION 4

SAMPLING DESIGN/SAMPLE SELECTION

The overall goal of this study was to generate air concentration data on BaP, other PAHs, and CO in indoor environments so that reasonable exposure predictions could be made for California residents. An additional objective was to investigate the relationship between pollutants and different types of indoor combustion sources. Since these objectives were very broad in scope, a study design was developed that focused on the most important factors associated with the overall objectives.

The study was restricted to microenvironmental monitoring in residential units because a large proportion of combustion sources are located in residences and because Californians spend an average of 62% of their time indoors at home (Wiley, 1991). This approach addressed the most likely, as well as the best defined exposures to the targeted pollutants. Two study areas were used to represent homes with different combustion source usage. Roseville was selected to represent an area in the central valley. Placerville was selected to represent an area in the foothills of the Sierra Nevada Mountains.

The study design defined strata for sampling based on the presence and predicted use of selected combustion sources. The study population was randomly selected as groups of homes that represented residential units in each source category in the two study areas. No attempt was made to select homes that represented the general population in the study areas. It should be noted that this approach does not provide population estimates on indoor and/or outdoor air concentrations for the target pollutants for any population in the State of California. Rather, it focuses on the important residential combustion sources and provides reasonably precise distribution estimates on variables that affect indoor exposures for BaP, other PAHs, and CO. This specific combustion source data can then be used by the ARB in conjunction with available information on source use, personal activities, and housing characteristics to make regional or statewide exposure predictions to the targeted pollutants.

For this study, homes were not selected based on their prevalence in the population. Rather, they were selected to obtain a fixed number of homes in each combustion source category. In this type of study, the total number of homes that must be contacted is substantially greater than that for a general population survey. ARB data (Phillips et al., 1990) indicated that woodstoves and fireplaces were used as the primary heating source in

only about 6% of the homes in central and northern California and it was anticipated that finding homes in these two categories would determine the overall effort required to locate study homes.

A modified random digit dialing procedure was selected as the most efficient way to screen the large number of homes needed to find sufficient numbers of homes in all of the combustion source categories. A brief screening interview was administered by telephone to obtain information on combustion sources and their use in the home. Homes were then selected and placed into combustion source categories based on these interviews. Rates of use of indoor combustion sources reported during the screening interview were used for sample selection. A letter and brochure describing the purpose of the study and the field monitoring activities were sent to each selected household. Follow-up telephone calls were then used to enlist participation and schedule field monitoring visits.

The remainder of this section provides details on the study design including the combustion source categories, the number of homes to be monitored in each category, selection of study areas, and methods for selecting study homes.

4.1 COMBUSTION CATEGORIES AND NUMBER OF HOMES TO BE MONITORED

A critical element in the study design was selecting combustion source categories that would account for the highest exposures to PAHs for California residents. Potential indoor combustion sources are shown in Table 4-1. These sources were identified based on information from previous field monitoring or emissions testing studies.

Based on information in the table, combustion source categories for sample stratification were selected as shown in Figure 4-1. Numbers in parentheses are the numbers of residents targeted for monitoring in each category. All homes with smoking (regardless of other sources) were combined into a single category (A). This was considered appropriate since smoking is such a strong source for PAHs in indoor air that it should overwhelm the influence of all other sources (Lioy et al., 1988; Mack et al., 1989). A subcategory (AII) consisting of homes with smoking and fireplace use was created to investigate the effect of these two strong sources in homes. Homes in this category were selected primarily for modeling purposes.

The homes without smoking were then divided into five categories based on the use of woodstoves, fireplaces, or gas heat. Cell B combines all homes with fireplace use

TABLE 4-1. INFORMATION ON POTENTIAL COMBUSTION SOURCES OF INTEREST

Sources	Estimated Emission Rate/ Emission Factor	Estimated Use in 24-hour Period	Estimated Prevalence of Use ^a
Tobacco smoking	high	20-30 cigarettes	high - ~35% of homes
Fireplace use (open wood/coal burning)	high	2-6 hours	low - ~20% of homes
Woodstove	low	3-12 hours	low - ~7% of homes
Use of gas heat	low	2-24 hours	high - ~60% of homes
Use of gas appliance (i.e., stove)	moderate	0.5-2 hours	high - ~40% of homes
Grilling and broiling of foods	high	0.5 hours	high - ~25% of homes

^aBased on results of the New York State combustion source survey (Sheldon, et al., 1989).

	No Smoking in House		Smoking in House	
	Gas Heat Not Used	Gas Heat Used	Gas Heat Not Used	Gas Heat Used
Fireplace Used	B (48)		All (17)	
Woodstove Used	C (40)	D (30)	A (45)	
Fireplace or Woodstove Not Used	E (40)	F (60)		

Figure 4-1. Combustion Source Categories - Categories A through F represent homes with designated combustion sources. Numbers in parentheses are the number of residents targeted for monitoring in each category.

regardless of gas heat use. Fireplaces are generally strong sources for PAHs and with the sample sizes available, their effect should overwhelm any gas heating effects (Affeim et al., 1984; Traynor et al., 1987). On the other hand, since woodstoves and gas heat are considered weak sources for PAHs in indoor air (Mack et al., 1989; Traynor et al., 1987), these sources were evaluated separately (cells C and F) and in combination (cell D) in order to characterize their effects. Homes in cell E were selected to serve as controls (i.e., homes with no sources). Source categories for cooking and broiling food were not specified in the design since this is a highly variable activity that could not be adequately screened for or controlled during field monitoring. As an alternative, information was collected on cooking activities during monitoring. The effect of this activity was modeled over all homes where the activity was present.

Sample sizes in each combustion source category were selected to balance the number of homes (~40 to 50) that were needed for distributional analysis in each category and the total number of homes (280) that could be monitored within the available resources. A sample size of 40 to 50 was regarded as a minimum for estimating distributional characteristics within a combustion source categories. Rather than using an exactly equal distribution of homes in each category, sample sizes were adjusted to optimize information obtained. As shown in Figure 4-1, a slightly larger sample size (60 homes) was proposed for category F (gas heat). This was done to provide sufficient numbers of gas-heated homes both with and without gas appliance use. The lower sample size (30 homes) for category D (woodstove and gas heat) was driven by cost considerations since homes in this category were expected to be present in California at the lowest rate. In addition, it was likely that for homes with these two heating sources, only a single source might be used during a 24-hour monitoring period. The size of the control cell (40 homes) was reduced since a significant number of very low or nondetected values were expected.

To provide useful data in each of the combustion source categories, it was important that homes selected for monitoring were representative of homes with these sources. In other words, source use and general activity patterns during monitoring had to be typical of normal household behavior. For woodstoves and fireplaces, it was anticipated that prevalence would be low and that less than half of the homes would actually use their sources during a 24-hour monitoring period. In order to ensure an adequate sample size for these source categories, selected participants were encouraged to use their woodstoves and

fireplaces during the monitoring period. However, they were also instructed not to deviate substantially from their normal use behavior (e.g., use of fireplace on a warm day, then opening windows to cool the home).

4.2 SELECTION OF SAMPLING LOCATIONS

The study was proposed to be conducted in two separate communities in California to provide a variety of different combustion sources, lifestyles, and housing types. Northern and central California communities were given priority since data for indoor air concentrations for PAHs were available for southern California (Sheldon et al., 1992).

The communities for study were purposely selected in consultation with project personnel from ARB. The most important selection criterion was the availability of homes in the proposed combustion source categories. Homes that used woodstoves and fireplaces as the primary heating source were considered relatively scarce (~6%). Therefore, it was considered essential that one of the study sites have a high use rate (~20%) for these two combustion sources. The second sampling site was then selected to complement the first site, to provide sufficient numbers of homes in all other source categories, and to provide a diversity of building characteristics and household activities. Other criteria for selection included:

- non-resort area,
- urban/suburban area with population > 20,000 (generally less than 25 minutes driving time between homes monitored on the same day),
- adequate prevalence of gas heat/gas appliances,
- adequate diversity in housing types,
- diversity in employment/commuting (e.g., town not dominated by a single industry, low prevalence of long-distance commuters), and
- local government support.

An initial decision was made to choose a study area from the central valley and one study area from either the coastal range or the foothills. Candidate study areas were then selected as follows:

Valley	Coastal Range	Foothills
Lodi	Ukiah	Auburn and vicinity
Roseville	Santa Rosa/Rohnert Park	Placerville and vicinity
Marysville/Linda	Healdsburg	

The two foothill sites were considered preferable over the coastal range sites due to their colder wintertime temperatures. Because of the close proximities of Roseville and Auburn, only one of these two sites would be chosen.

Available information on population, number of homes, and prevalence of combustion source usage was then collected for the potential study areas. A summary of the information is included in Appendix A.

This information was then used to estimate the number of complete telephone screening interviews that would be needed in order to identify sufficient numbers of participants for field monitoring in each of the combustion source categories. The number of completed screening interviews estimated for each combination of candidate study areas is given in Table 4-2. The combination of Placerville and Roseville as study areas was selected based on the relatively low number of screening interviews required and the high level of local government support.

4.3 SELECTION OF PARTICIPANT SAMPLE

The basic sampling approach involved a two-stage process: telephone screening to identify eligible households and to classify them into combustion source categories, and then subsampling of each category (where necessary) to perform monitoring in the targeted numbers of homes for each combustion category. The target population excluded homes without telephones.

4.3.1 Telephone Screening

The goal of the telephone screening was to locate a representative group of homes from each combustion source category in both areas that could serve as study participants. The telephone screening used a "list-assisted" random digit dialing (RDD) telephone sample design, the basic concept of which was developed by A.C. Nielsen Media Research, Inc., to produce their "Total Telephone Frame" (Potter, et al., 1991; Nielsen Media Research, 1988).

TABLE 4-2. ANTICIPATED NUMBERS OF COMPLETED INTERVIEWS OF WILLING PARTICIPANTS REQUIRED TO ACHIEVE DESIRED CELL COUNTS^a

Valley Site	Prevalence of Smoking Homes (%)	Foothills or Coastal Range Site				
		Ukiah	Healdsburg	Santa Rosa	Auburn	Placerville
Lodi	27	2081	2758	4052	2002	1378
	32	2234	2960	4350	2149	1479
	37	2411	3195	4695	2320	1596
Roseville	27	1563	1851	2612	1563	1453
	32	1678	1987	2804	1678	1560
	37	1811	2145	3026	1811	1684
Marysville	27	2007	2640	3860	1933	1453
	32	2155	2834	4144	2076	1560
	37	2326	3059	4473	2240	1684

^aBased on prevalence of source categories in each study area.

This approach began by identifying working exchanges for the areas of interest. The 100-blocks within these exchanges were then matched with information from Donnelley Marketing Information Services (DMIS) to obtain a size measure for each 100-block. A 100-block is defined by the first eight digits of a 10-digit telephone number (each exchange contains 100 of these 100-blocks); the size measure is the number of published residential numbers. The size measure was used to identify those 100-blocks with no known telephones assigned ("no-listing" blocks), and to exclude them from the sampling frame. Based on RTI's prior experience, the exclusion of no-listing blocks will result in the exclusion of a very small proportion of households having telephones. After excluding the "no-listing" blocks, all potential 10-digit numbers were generated to form the sampling frame for each geographic area. These numbers were ordered by the size measure and zones were created. Each zone consisted of N/n numbers, where N and n denote the frame size and the sample size, respectively. A random sequential selection algorithm was then used to select one number per zone. To implement the sample in waves, the sample was randomly partitioned into subsamples consisting of 400 telephone numbers (200 per area).

The following exchanges were identified in local telephone books and subsequently confirmed by the telephone company as the only working exchanges in the two areas of interest: Placerville: 293, 621, 622, 626, 644; Roseville: 721, 722, 723, 725, 726, 728, 729, 771, 773, 781, 782, 783, 784, 786, 791, 797. Of the five hundred 100-blocks in the Placerville area, 176 were determined as "no-listing" blocks, while for Roseville, 530 of the 1600 blocks were "no-listing" blocks. Hence the frame for the Placerville area consisted of 32,400 numbers (324 non-zero blocks of 100 numbers each), while the frame for Roseville contained 107,000 numbers. Early screening results showed that very few of the households with the 721 through 729 exchanges were actually in Roseville; a follow-up call to the telephone company indicated that Roseville residents typically would not have such numbers. A possible exception would occur when a household made a move from a nearby community into Roseville and maintained their number. These exchanges were dropped from the latter portion of the screening and all associated households were considered ineligible.

A tabulation of the screening results is given in Table 4-3.

4.3.2 Sample Stratification

The distributions of the telephone screening results reported for combustion source use were examined and the following definitions for combustion sources were adopted:

TABLE 4-3. TELEPHONE SCREENING RESULTS

Screening Status	Number		
	Placerville Exchanges	Roseville Exchanges	Total
Complete, with address	791	682	1473
Complete, without address	90	109	199
Refused to confirm number	61	91	152
Refusal/eligibility unknown	66	97	163
No adult respondent	1	6	7
Temporary or non-resident	1233	1616	2849
Language barrier (Spanish)	5	6	11
Non-working number	450	1588	2038
Modem/noises/busy/- answer machine/no answer	495	586	1081
Refusal/eligible household	3	10	13
Other	5	9	14
Total	3200	4800	8000

Smoking	= 10 or more cigarettes or any cigar or pipe smoking in the home
Gas heat	= propane or natural gas indicated as primary heating source
Fireplace Use:	Frequent = 3 or more days/week Infrequent = less than 3 days/week
Woodstove Use:	Frequent = 5 or more days/week Infrequent = less than 5 days/week

Combining these definitions gave the combustion source cell designations shown in Table 4-4. The defined combustion strata (Figure 4-1) were then related to the designated combustion source cells, as shown in Table 4-5. The number of eligible respondents falling into various cells is indicated in Table 4-6.

Table 4-7 summarizes information on the estimated numbers of households that were targeted for monitoring in each combustion source category. The first group of columns shows by combustion source category the number of eligible respondents identified during telephone screening. The next set of columns indicates the number of eligibles to be selected for monitoring assuming a 100% participation rate. The actual numbers of participants that would be monitored in each combustion source category are given in the last three columns and takes into account migration between cells but again assumes a 100% response rate. Homes may migrate between combustion source categories if source use on the day of monitoring is different than that indicated during the screening interview. The cell designations in the last three columns then refer to actual source use during monitoring rather than frequent combustion source use as reported during telephone screening. The footnotes to the table indicate the assumptions made in order to arrive at the relationship between the number of homes selected and the anticipated number of homes on the monitoring day. Some switching between reported source use and source use during monitoring (migration) were assumed for fireplace and woodstove use in both study areas. In Roseville, some migration was expected for gas heat usage, as well. The latter assumption was deemed appropriate since the question in the screener asked for primary source of heat, rather than for gas heat use. No migration between smoking/non-smoking categories was assumed.

TABLE 4-4. COMBUSTION SOURCE CELL DESIGNATIONS

	Cell Designation			
	Nonsmoking		Smoking	
	Non-Gas Heat	Gas Heat	Non-Gas Heat	Gas Heat
Frequent Fireplace Use	1	2	7	8
Frequent Woodstove Use	3	4	9	10
Infrequent Fireplace Use	5a	6a	11a	12a
Infrequent Woodstove Use	5b	6b	11b	12b
Fireplace or Woodstove Not Used	5c	6c	11c	12c

TABLE 4-5. COMPOSITION OF COMBUSTION SOURCE CATEGORIES

Category	Cells Included ^a
A	9, 10, 11a-c, 12a-c
AII	7,8
B	1,2
C	3
D	4
E	5a-c
F	6a-c

^a As defined in Table 4-4.

TABLE 4-6. DISTRIBUTION OF ELIGIBLE RESPONDENTS BASED ON SCREENING INTERVIEW

	Nonsmoking		Smoking	
	Non-Gas Heat	Gas Heat	Non-Gas Heat	Gas Heat
PLACERVILLE				
Frequent Fireplace Use	37	11	8	2
Frequent Woodstove Use	290	29	82	7
Infrequent Fireplace Use	21	14	3	2
Infrequent Woodstove Use	51	28	10	5
No Source	81	67	21	22
ROSEVILLE				
Frequent Fireplace Use	43	67	5	18
Frequent Woodstove Use	28	13	9	3
Infrequent Fireplace Use	73	130	12	22
Infrequent Woodstove Use	16	21	0	5
No Source	42	130	17	28

TABLE 4-7. NUMBER OF ELIGIBLE HOMES, NUMBER OF HOMES SELECTED FOR MONITORING, AND ESTIMATED NUMBER OF HOMES MONITORED FOR EACH COMBUSTION SOURCE CATEGORY

Category	Number of Eligibles			Number to be Selected ^a			Estimated Number on Monitoring Day ^b		
	Placerville	Roseville	TOTAL	Placerville	Roseville	TOTAL	Placerville	Roseville	TOTAL
A	152	96	248	20	20	40	22	24	46
All	10	23	33	8	15	23	6	11	17
B	48	110	158	20	45	65	15	33	48
C	290	28	318	30	15	45	28	12	40
D	29	13	42	17	10	27	17	11	28
E	153	131	284	15	15	30	21	19	40
F	109	281	390	25	25	50	26	35	61
Total	791	682	1473	135	145	280	135	145	280

^a Assumes 100% participation.

^b Homes may migrate between combustion source categories if source use on the day of monitoring is different than that indicated during the screening interview. The number of homes in each category were derived based on the following assumed migration rates among cells:

Fireplace:

1 --> 5	30%	5a --> 1	10%
2 --> 6	30%	6a --> 2	10%
7 --> 11	30%	11a --> 7	10%
8 --> 12	30%	12a --> 8	10%

Woodstove Use:

3 --> 5	10%	5b --> 3	20%
4 --> 6	10%	6b --> 4	20%
9 --> 11	10%	11b --> 9	20%
10 --> 12	10%	12b --> 10	20%

Gas Heat Use:
(Roseville Only)

1 --> 2	10%	7 --> 8	10%
3 --> 4	10%	9 --> 10	10%
5 --> 6	10%	11 --> 12	10%

Actual sample sizes for the number of eligibles needed to be larger than those indicated in Table 4-7, since 100% participation was not anticipated. Sampling waves were used during the sample selection procedure to account for the participation rate and allowed adjustments to be made for different participation rates. This approach is described below.

The telephone screening sample consisted of small independent subsamples of random numbers (200 in each). These subsamples were randomly ordered so that a sequential screening would yield a valid sample containing an adequate number of eligible households in all 14 combustion source categories (seven categories for each of the two sites). As expected, a larger number of eligibles than needed were identified in some categories. Another stage of sampling, therefore, was needed to identify households to be contacted for monitoring.

The method of sampling in this final stage was essentially the same as that used for screening. Subsamples from the telephone screening were combined, in order, until a sufficient number of homes in each combustion source category were identified for recruitment into the field monitoring study. Not all homes in the combined subsample were contacted at the same time, rather contact was made with small groups of homes (waves). This approach allowed adjustments to be made for different participation rates and shifts between reported and actual combustion source usage in each source category. Waves were selected that corresponded to participation rates of 100, 75, 60, 50, and 40 percent in each of the 14 categories. The final number of waves for each combustion source category ranged from three to six depending on the source category (rare categories had fewer waves because fewer homes were available for selection).

Throughout recruiting and field monitoring, the response rate and combustion source use in each home during field monitoring were tracked very closely. Waves were then independently released for each combustion source category based on this information to provide the targeted number of homes in each combustion category.

Final response rates and source usage achieved during field monitoring are tabulated by combustion source category in Table 4-8.

TABLE 4-8. RESPONSE RATES AND NUMBER OF HOMES MONITORED IN EACH COMBUSTION SOURCE CATEGORY

Source Category	Number of Homes					
	Selected	Contacted ^a	Eligible	Participated	Monitored ^b	Targeted
A Smoking	104	95	81	47	53	45
AII Smoking/Fireplace	33	32	30	14	11	17
B Fireplace	141	111	102	64	46	48
C Woodstoves	100	91	84	52	56	40
D Woodstoves/Gas Heat	42	37	33	23	22	30
E No Source	85	76	60	33	39	40
F Gas Heat	103	91	84	47	53	60
Total	608	533	474	280	280	280

^aSome of the homes that were selected could not be reached during scheduling.

^bAccounts for migration on monitoring day.

SECTION 5

SURVEY OPERATIONS

Survey activities for this study included administration of telephone screening interviews conducted from RTI's Telephone Survey Unit in North Carolina and in-home data collection activities performed by RTI's field monitoring staff. Telephone calls were used to determine the eligibility of housing units for inclusion in the sampling frame, to establish cooperation with the study participants, and to establish appointments for in-home data collection. Chemists from RTI and our subcontractor, Dynamac, performed all survey activities in the field, including making the initial in-person contacts with the sample households, obtaining informed consent and administering the study questionnaire. Specifically, five sequential survey and data collection activities were performed. These included:

- (1) telephone screening to determine housing characteristics and combustion source usage,
- (2) mailing an information package that described the study to participants at each home selected for participation,
- (3) telephone calling to schedule field monitoring,
- (4) obtaining informed consent during the first field monitoring visit, and
- (5) administering the study questionnaire.

A series of questionnaires and related forms were developed for this study. Table 5-1 lists the documents and the type of information collected on each. A copy of each document is given in the Appendices as indicated in Table 5-1.

The general schedule for completing all survey activities is given in Table 5-2. Procedures for conducting the five survey activities are described in the remainder of this section.

5.1 TELEPHONE SCREENING INTERVIEWS

All telephone screening interviews were performed in RTI's Telephone Survey Unit (TSU) from October 21 to November 18, 1991. Interviews were conducted using Computer Assisted Telephone Interview (CATI) techniques. A copy of the CATI screening questionnaire is included in Appendix B. All interviews were conducted by individuals with extensive telephone interviewing and CATI experience. Training on methods specific to this study was conducted immediately prior to the screening procedures.

TABLE 5-1. STUDY DOCUMENTS

Document	Purpose	Appendix
Screening Questionnaire	Obtain information on combustion source usage in eligible homes; used to select homes in the combustion source categories.	B
Information Package	Provide information to potential participants prior to asking them to participate.	C
Appointment Scheduling Script	Recruit participants into the field monitoring portion of the study; schedule field monitoring visits.	D
Appointment Reminder Script	Remind participants of their field monitoring visits.	E
Participant Consent Form	Obtain informed consent from participants. This is a requirement for all studies that involve human participants.	F
Study Questionnaire	Obtain information on household characteristics and combustion source usage during the monitoring period.	G

TABLE 5-2. SCHEDULE FOR SURVEY ACTIVITIES

Activity	Schedule
Telephone Screening	10/21/91 to 11/18/91
Participant Selection	12/11/91
Mailing Information Package	
Placerville	12/13/91 and 12/28/91
Roseville	1/8/92
Placerville	2/14/92
Scheduling/Reminder Phone Calls	
Placerville	12/18/91 to 12/21/91 and 1/2/92 to 1/27/92
Roseville	1/14/92 to 3/5/92
Placerville	2/24/92 to 3/24/92
Field Monitoring	
Placerville	1/7/92 to 1/28/92
Roseville	1/29/92 to 3/6/92
Placerville	3/7/92 to 3/25/92

Interviewing calls were made from

- 2:00 p.m. to 9:30 p.m., Mondays through Fridays,
- 9:00 a.m. to 5:00 p.m. on Saturdays, and
- 10:30 a.m. to 6:30 p.m. on Sundays.

One telephone interviewer was available earlier during the day to conduct any specific callbacks scheduled for that time.

TSU supervisors and the TSU manager performed quality control review by listening (via "silent monitoring") to interviews and by using a master computer console to view the CATI file as an interview as conducted. RTI's CATI standard procedures were used. Status codes for all attempted phone numbers were recorded. This information was then compiled in a Daily Status Report as shown in Table 5-3. The number of initially untried cases were listed at the top of the Status Report. Every day, as the phone calls were made, cases were assigned to their appropriate codes. The log maintained a 24-hour comparison record of the number of cases completed on one day as compared to the number of cases completed on the previous day. The status of the telephone screening progress was reviewed daily by the Task Leader and the Project Director. All of these quality control and monitoring procedures continued throughout the telephone screening.

Four attempts will be made to resolve the status of each telephone number. After four attempts, unreached numbers were assigned a status of "no answer." The telephone numbers generated for this screening activity were divided into several waves; the first such wave contained approximately 1600 telephone numbers. Telephone screening was performed on one wave at a time. Once the first wave of numbers had been completed (about one week), the telephone screening results were tabulated to produce information on the overall response rate, the prevalence of homes in each combustion category, and the prevalence of contact/respondent difficulties (e.g, those with a language barrier, particularly for Spanish speakers; those ineligible; those refusing to give address information). Additional waves were released in each area in order to obtain sufficient numbers of eligible participants in each category. A total of 8000 numbers were included in the telephone screening.

5.2 MAILING INFORMATION PACKAGES

Information packages were sent to all potential study respondents. Information packages contained three pieces of information:

TABLE 5-3. CARB CATI 1991 DAILY STATUS REPORT

LAST RESULT		CURRENT 15-Oct-91 05:27 pm	PREVIOUS 15-Oct-91 05:06 pm	DIFF
Blank	(Untried cases)	1600	1600	0
502	Answered/phone# Not confirmed	0	0	0
503	Answered/phone# Confirmed/Incomplete	0	0	0
504	Answered/Non Adult/Incomplete	0	0	0
506	Language Barrier/Incomp/Impaired	0	0	0
510	Operator/Non-Working/Disconnected	0	0	0
511	Modem/Noise/Busy/Ans Mach./No Answer	0	0	0
515	Other (Specify)	0	0	0
700	Completed with Address	0	0	0
701	Completed No Address	0	0	0
702	Final-Refused to Confirm Phone #	0	0	0
703	Final-Eligib. Unknown/Refused Bef #7	0	0	0
704	Final-Eligibility Unknown/No Adult	0	0	0
705	Final-Inelig/Non Resid/Temp Location	0	0	0
706	Final-Lang. Barrier (Spanish)	0	0	0
710	Final-Oper/Non-Working/Disconnect	0	0	0
711	Final-Modem/Noise/Busy/No Answer	0	0	0
712	Final-Eligi/Confirmed/Ref After #6	0	0	0
715	Final-Other (Specify)	0	0	0
TOTAL CASES		1600	0	1600

- an introductory letter from John Holmes of the California Air Resources Board,
- a pamphlet that describes the research study, and
- a copy of a local newspaper article that described the study.

All materials for the information packages are included in Appendix C.

Mailing labels for the packages were printed from the computer file generated during telephone screening. Personnel in RTI's Telephone Survey Unit were responsible for assembling and mailing the packages. Informational packages were mailed 1 to 2 weeks prior to making the appointment setting calls.

5.3 APPOINTMENT SETTING/REMINDER CALLS

Appointment setting/reminder activities were performed in RTI's Telephone Survey Unit. All calls were conducted by interviewers who had conducted the telephone screening interviews. Training on methods specific to this activity was conducted immediately prior to starting the appointment setting calls. During training, emphasis was placed on providing background on study objectives and on obtaining a high participation rate, the need to schedule all available time slots for field monitoring, and methods for communicating with the field team during monitoring.

All appointment setting calls were performed with conventional pencil and paper interviewing (PAPI) techniques. Phone calls were made between 5:00 p.m. and 9:00 p.m. PST. Calls were made at other times when potential participants could not be reached during these hours. Calls were continued until an individual was contacted. Record keeping was done using an appointment status form. This form listed the ID number of all participants selected for scheduling calls by wave. At the end of each day, the appointment setting status of each potential participant was entered into the computer and merged with data on the telephone screening files. Daily tabulations were made on the number of households in each combustion source category that had been scheduled for field monitoring, refused to participate, or remained to be contacted.

Only respondents to whom brochures were sent were contacted. When a potential participant was called but had not received the information package, the package was mailed before attempting to schedule a field monitoring appointment. It was found that the information package was critical for explaining the study to potential participants.

Appointments were scheduled by filling in the first available time slot that was mutually convenient for both the respondent and the field staff. If there were any changes to the schedule, either by the participant or at the request of the field staff, TSU attempted to reschedule as soon as possible.

Several days before the initial monitoring visit, reminder telephone calls were made to each study participant. These calls were made by the same telephone interviewers who made the appointment calls. Besides confirming the date and time of the appointments, this activity can serve as a vehicle for early notification of cancellations. Unlike previous phone calling, messages were left on answering machines or with message centers with instructions to call RTI should there be any change. This effort successfully minimized the number of missed appointments once the field monitoring began.

E-mail was used to notify field monitoring staff of scheduled appointments, cancellations, or changes. Interviewers were responsible for filling out the appointment cards and E-mailing the appointment data to the field staff. The appointments that were made during one 24-hour period were sent nightly. The field monitoring team was equipped with lap-top computers with modems and appropriate software for receiving these messages. Messages stayed in queue until received.

The Project Director received all daily progress reports plus all E-mail messages that were sent to and from the field. This assured that she was aware of the status of all activities and could both identify and remedy any problems that arose with scheduling and appointment setting activities.

5.4 SURVEY FIELD MONITORING

Survey activities performed by the field monitoring team included:

- making the initial visit to the household,
- further explaining the study and answering questions,
- obtaining signed participant consent to take part in the study,
- obtaining data requests from participants, and
- administering the study questionnaire.

During the initial monitoring visit, a simple introduction was given to study participants, along with a brief description of the study. Although a script was not developed for this activity, information from the pamphlet (Appendix C) was used.

Participants were then given the participant consent form. After reading this form, they were asked to give written consent. At the same time, participants were asked if they wanted their monitoring results at the end of the study. Affirmative answers were designated on the consent form.

Study questionnaires were administered at the end of the 24-hour field monitoring period using computer-assisted personnel interviewing (CAPI) techniques. Field personnel responsible for the interview were thoroughly trained in the use of the laptop computers. In addition, the Study Questionnaire (Appendix G) and the corresponding training document were reviewed thoroughly.

To assure the quality of questionnaire administration throughout the study period, the site supervisor visited at least 10% of the homes during the interviewing process. He was also available at all other times for additional training, technical assistance, and trouble-shooting activities.

SECTION 6

CHEMICAL SAMPLING AND ANALYSIS

6.1 FIELD MONITORING

Field monitoring was performed from January 7 to March 23, 1992. During that time period, monitoring was performed in a total of 280 homes. One hundred thirty-six of the homes were in the vicinity of Placerville, CA and 144 homes were in the vicinity of Roseville, CA. Monitoring started in Placerville on January 7 and continued through January 27. Monitoring was performed in Roseville from January 28 through March 6. Monitoring was then moved back to Placerville and continued through March 23. Since monitoring was performed through March, study areas were scheduled so that some monitoring would be performed in each study area during the coldest time period (i.e., January and February). Placerville was scheduled during March since it is in the foothills and temperatures should still be cold in March. It was therefore anticipated that residents in this area should still be using combustion sources for heating throughout the entire monitoring period.

Monitoring was performed by RTI and Dynamac Corporation personnel. The field sampling staff generally consisted of three people - the RTI site supervisor and either two RTI chemists or one RTI chemist and one Dynamac technician. The site supervisor was responsible for overseeing all sampling activities. The site supervisor was also responsible for the initial visit to answer participants questions, set out the PFT sources for air exchange measurements, estimate house volume to be used for air exchange rate calculations, and to determine the most suitable locations for placement of the indoor and outdoor air monitoring equipment. A chemist or technician accompanied the site supervisor on the initial visit for safety reasons and to aid in PFT source placement and house measurements. Two chemists/technicians working individually were responsible for subsequent visits to the homes to set-up/take-down sampling equipment, collect samples and administer the 24-h study questionnaire. In 10% of the homes, the site supervisor visited the home to provide a quality control check on monitoring activities. In other cases where it was determined necessary for two persons to visit a home, the site supervisor accompanied the chemist/technician to provide assistance. Table 6-1 summarizes the schedule of activities in each home and Table 6-2 provides an example of the field sampling schedule.

TABLE 6-1. SAMPLE COLLECTION ACTIVITIES FOR EACH HOUSEHOLD

Monitoring Day	Activity
1	RTI site supervisor and one chemist/technician 1) Obtain informed consent 2) Deploy PFT emitters for air exchange measurements 3) Measure house volume for air exchange rate calculations 4) Determine sampling locations 5) Confirm appointment schedule
2	One chemist/technician 1) Set up indoor/outdoor sampling equipment for PAHs 2) Install sampling cartridges 3) Measure sampling flow rate 4) Zero and span CO monitors, record readings 5) Set up indoor and outdoor monitors for CO 6) Set out PFT collectors
3	One chemist/technician 1) Measure flow rates on PAH samplers 2) Remove exposed PAH sampling cartridges 3) Zero and span CO monitors, record readings 4) Disassemble and remove sampling equipment 5) Retrieve and cap PFT collectors 6) Retrieve PFT emitters 8) Download CO data to computer 9) Administer 24-hour study questionnaire 10) Pay \$25 cash incentive

TABLE 6-2. EXAMPLE FIELD MONITORING SCHEDULE

Time (pm)	Day			
	1	2	3	4
3:30 - 4:00	Set up PFT - House 1 (A,B) ^a	Set up PFT - House 5 (A,C)	Set up PFT - House 9 (A,B)	Set up PFT-House 13 (A,C)
4:00 - 4:30	Set up PFT - House 2 (A,C)	Set up PFT - House 6 (A,C)	Set up PFT - House 10 (A,B)	Set up PFT-House 14 (A,C)
4:30 - 5:00	Set up PFT - House 3 (A,B)	Set up PFT - House 7 (A,C)	Set up PFT - House 11 (A,B)	Set up PFT-House 15 (A,C)
5:00 - 5:30	Set up PFT - House 4 (A,B)	Set up PFT - House 8 (A,C)	Set up PFT - House 12 (A,B)	Set up PFT-House (16) (A,C)
5:30 - 6:30		Set up monitors - House 1 (B)	Take down monitors - House 1 (B) Set up monitors - House 5 (C)	Take down monitors - House 5 (C) Set up monitors - House 9 (B)
6:30 - 7:30		Set up monitors - House 2 (C)	Take down monitors - House 2 (C) Set up monitors - House 6 (B)	Take down monitors - House 6 (B) Set up monitors - House 10 (C)
7:30 - 8:30		Set up monitors - House 3 (B)	Take down monitors - House 3 (B) Set up monitors - House 7 (C)	Take down monitors - House 7 (C) Set up monitors - House 11 (B)
8:30 - 9:30		Set up monitors - House 4 (C)	Take down monitors - House 4 (C) Set up monitors - House 8 (B)	Take down monitors - House 8 (B) Set up monitors - House 12 (C)

^a Three persons performed all field monitoring, letter in parenthesis indicates person or persons conducting activity.

A - site supervisor

B - chemist/technician B

C - chemist/technician C

Indoor air samples for PAHs and carbon monoxide (CO) were collected in the primary living area of each home selected for monitoring. For the purposes of this study, the primary living area was defined as the non-bedroom area where individuals spend most of their time, usually the living room or family room. Outdoor air samples were collected at a single outdoor site on the non-roadway side of the home. Where possible, the outdoor sampler was placed at least 15 feet away from the residence or other buildings, any roadways, parking lots, or known sources of PAHs or CO. Indoor and outdoor air samples for PAHs were scheduled for collection at all of the 280 homes monitored. Indoor and outdoor levels of CO were monitored at a subset of 210 homes. Whole house air exchange rates were determined for each house using a perfluorocarbon tracer (PFT) technique. Samples from each home were collected over one 24-hour time period. Monitoring was scheduled for four homes each day. Three of these homes were randomly selected for CO monitoring.

In conjunction with field monitoring, questionnaire data were collected on the use of combustion sources during the monitoring period, the activities of residents that may have affected indoor concentrations of the target chemicals during the monitoring period, and pertinent building characteristics of the residence. This information was collected at the end of the 24-hour monitoring period.

Several types of quality control samples were used throughout the study. For PAH and air exchange rate measurements, field blanks were used to assess contamination and/or interferences on field samples. These samples were unexposed sampling cartridges that traveled to the field site, then were returned to the laboratory and analyzed along with the field samples. Two types of field controls were used to assess PAH analyte recovery - XAD-2 cartridges were spiked with known amounts of the target PAHs and urban dust standard reference material obtained from the National Institute of Standards and Technology (NIST) was embedded in filter samples. Field controls for air exchange measurements were prepared by loading known amounts of the PFT tracer on sampling tubes. As with the field blanks, field controls were shipped to the field, then returned and analyzed along with the samples. Quantitation limit (QL) samples for PAH measurements were prepared by spiking XAD-2 cartridges with low levels of target PAHs. The purpose of these samples was to estimate method quantifiable limits (MQL). Ten percent of the PAH field samples were collected in duplicate and analyzed to evaluate precision.

Since CO was measured using real-time monitoring equipment, different QC procedures were used. In the field, accuracy was checked by analyzing zero and span (11 ppm CO) gas standards at the beginning and end of each 24-hour monitoring period. Precision was evaluated by deploying duplicate monitors at a number of sampling locations. The CO monitors were also calibrated weekly using zero, 2, 10, and 20 ppm CO calibration gases.

Strict sample custody procedures were followed throughout the collection and analysis activities. Each sample was given a unique code to link that sample to the study participant and household, sample type, collection regime, etc. As part of the quality control procedures, a sample log/chain of custody form was prepared. This form was used to track each sample from the time it was collected until the data had been reduced and entered into a computer data base for statistical analysis.

Table 6-3 presents information on the number of samples scheduled, collected and analyzed. These data are provided for both the field and the QC samples.

6.2 PAH MONITORING METHOD

6.2.1 Method Description

For air sampling, combined particulate and vapor phase PAHs were collected using a 115-V AC medium-volume constant flow pump (Esoteric, Model EPASS 20/1-BF or Model SP 25/1), coupled to a sampling cartridge containing a 21 mm quartz fiber filter backed by a 4.5 g bed of XAD-2 resin. Twenty-four hour samples were collected at a flow rate of approximately 12-15 L/min to provide a nominal sample volume of approximately 19 m³. Flow rates at the cartridge inlet were measured before and after sample collection using calibrated rotameters with a fixed-orifice bypass tube.

As PAH samples were collected, they were stored protected from light. All samples were shipped to RTI via Federal Express Overnight Delivery. Immediately upon receipt at RTI, samples were individually inspected for integrity (i.e., broken tubes, loose caps, etc.) and logged-in. The sample log/chain-of-custody form was checked and signed for each sample received. Samples were then stored, sealed in cans in a freezer until extracted and analyzed.

All cartridge materials were rigorously cleaned and checked prior to assembly and field deployment to ensure minimal background contamination. Precleaned, XAD-2 resin (Supelco, INC; Superpak-2) was purchased for use in this study. Additional cleaning procedures were performed to insure the XAD-2 resin was contaminant free. The resin was

TABLE 6-3. FINAL STATUS OF SAMPLE COLLECTION, EXTRACTION AND ANALYSIS

Sample Type	Number				
	Proposed	Scheduled	Collected ^a	Extracted	Analyzed
<u>PAHs</u>					
Indoor Air	280	280	277	275	272
Outdoor Air	280	280	275	273	273
Duplicates	28	28	28	28	28
Field Blanks	28	24	31	31	31
XAD-2 Field Controls	14	24	24	24	24
NIST Field Controls	14	14	14	14	14
MQL Samples ^b	7	8	8	8	8
<u>CO</u>					
Indoor Air	210	210	206	- ^c	-
Outdoor Air	210	210	205	-	-
Duplicates	20	25	25	-	-
MQL Samples	7	31	31	-	-
<u>Air Exchange</u>					
Indoor Samples	280	279	279	-	279
Duplicates	14	13	13	-	13
Field Blanks	14	14	14	-	14
Field Controls	5	5	5	-	5

^a For PAHs, at least a 12 h sample was collected.

^b Method quantitation limits.

^c Monitoring data are generated in the field.

placed in Soxhlet extractors and extracted for 16 hours with methanol. The methanol was drained from the extractor and the resin rinsed with methylene chloride. The resin was then Soxhlet extracted for 16 hours with methylene chloride. After extraction the thimbles containing the resin were removed from the Soxhlet, drained and initially dried in a drying box under a nitrogen atmosphere. Residual methylene chloride was removed by placing the sorbent material in a vacuum oven at 55°C for 16 hours. Quartz fiber filters (Pallflex 2500QAT) were cut to a diameter of 17 mm and treated in a muffle furnace for 4 hours at 400°C to remove organic contaminants. All glassware was washed, heated to 400°C for four hours and rinsed with methylene chloride. All other cartridge materials were rinsed with methylene chloride and dried before assembly. Prior to use in the field, a subset of assembled cartridge materials was extracted and analyzed by GC/MS to assure that background contamination was low.

PAHs were recovered from the combined cartridge material (glass fiber filter and XAD-2 resin) by sonication extraction with methylene chloride for a 30-minute period, soaking overnight, then sonic extraction for an additional 30 minutes. The solvent extract was separated from the cartridge material by filtering through silanized glass wool. The filtered extract was then concentrated to ~1 mL using nitrogen blowdown. The extract was solvent exchanged into toluene and further concentrated to 0.2 mL.

Deuterated surrogate standards were added to samples immediately prior to extraction to monitor overall method performance. External quantitation standards were added to sample extracts immediately prior to final concentration and analysis.

Fluorene-d₁₀, chrysene-d₁₂, and benzo[e]pyrene-d₁₂ were used as the surrogate standards. 9,10-Dichloroanthracene, 1,2,3,4-tetrachloronaphthylene and perylene-d₁₂ were used as external quantitation standards.

Sample extracts were analyzed by direct liquid injection capillary GC/MS. A 1-μL aliquot of the sample extract was injected using a split/splitless injection technique. Analytes separated on the GC column were introduced to a quadrupole mass spectrometer operating with electron ionization in the selected ion monitoring (SIM) mode. Sample constituents were characterized and quantitated by measuring ions characteristic of the target chemicals. Instrumental operating parameters are described in Table 6-4.

Prior to analysis, the GC/MS system was calibrated by analyzing the standards shown in Table 6-5. Concentrations of the target PAHs were chosen to bracket the concentration distributions expected in air samples. Generally, calibrations were performed

TABLE 6-4. GC/MS OPERATING PARAMETERS FOR ANALYSIS OF PAHs

Column Type:	30 m, DB-5, 0.25 mm i.d., 0.1 μ m film
Run Type:	Electron ionization; selected ion monitoring
Injection Type:	Splitless/Split (0.5 min)
Injection Temperature:	300°C
Interface Temperature:	300°C
Source Temperature:	200°C
GC Program:	Initial temperature = 100°C
	Initial program rate = 15°C/min to 130°C
	Program rate = 3°C/min
	Final temperature = 300°C
	Final hold time = 20 minutes
Instrument:	Hewlett Packard 5988A
Multiplier Voltage:	2000 ^a
Emission Current:	~300 mA ^a
Dwell Time:	75-250 msec

^a A typical value.

TABLE 6-5. CALIBRATION STANDARDS FOR PAH ANALYSIS

Compound	Concentration (ng/mL)						
	0.1 X	0.2 X	0.4 X	0.7 X	1 X	2 X	5 X
<u>PAHs</u>							
Acenaphthylene	91.0	182	364	637	910	1,820	4,550
Phenanthrene	224	447	894	1,560	2,240	4,470	11,200
Anthracene	18.5	37.0	74.1	130	185	370	926
Fluoranthene	104	207	414	724	1,040	2,070	5,180
Pyrene	48.3	96.5	193	338	483	965	2,410
Benzo[a]anthracene	8.59	17.2	34.4	60.1	85.9	172	430
Chrysene	8.27	16.5	33.1	57.9	82.7	165	414
Benzo[k]fluoranthene	8.85	17.7	35.4	61.9	88.5	177	443
Benzo[e]pyrene	9.37	18.7	37.5	65.6	93.7	187	468
Benzo[a]pyrene	4.77	9.54	19.1	33.4	47.7	95.4	239
Indeno[1,2,3-cd]pyrene	4.16	8.32	16.6	29.1	41.6	83.2	208
Benzo[ghi]perylene	12.2	24.4	48.8	85.2	122	244	610
Coronene	7.30	14.6	29.2	51.1	73.0	146	365
Quinoline	1,640	3,270	6,540	11,400	16,400	32,700	81,800
<u>Surrogate Standards</u>							
Fluorene-d ₁₀	51	102	204	357	510	1020	2550
Chrysene-d ₁₂	9.05	18.1	36.2	63.4	90.5	181	453
Benzo[e]pyrene-d ₁₂	9.65	19.3	38.6	67.5	96.5	193	483
<u>External Quantitation Standards</u>							
9,10-Dichloroanthracene	193	193	193	193	193	193	193
Perylene-d ₁₂	185	185	185	185	185	185	185
1,2,3,4-Tetrachloronaphthylene	2,020	2,020	2,020	2,020	2,020	2,020	2,020

using the GC/MS peak area of the parent (M^+) and parent-plus-one (M^++1) ions for each analyte. Calibration ions are listed in Table 6-6. For PAHs with no other chemical substituents, the M^+ ion was selected as the primary ion because it is usually the ion with the greatest relative abundance for PAHs. The M^++1 ion was included to verify compound identification.

Results of individual calibration analysis were used to generate relative response factors (RRF) using the following equation:

$$RRF_t = \frac{A_t / C_{std}}{A_{std} / C_t}$$

where:

A	=	system response (integrated peak area)
C	=	concentration in calibration standard (ng/mL)
t	=	analyte
std	=	external quantitation standard.

Average RRFs were then calculated using results from each calibration standard.

Instrumental calibration was considered acceptable if the percent relative standard deviation of the average RRF value was less than 25 for each of the target PAHs.

During sample analysis, two performance checks were made on the analytical system at the start of each day. First, the tune compound, perfluorotributylamine, was introduced into the mass spectrometer ionization source. All characteristic fragment ions were required to be present in the correct relative abundance before proceeding with any further analyses. Second, a mid-level calibration standard (0.4 X standard, Table 6-5) was analyzed and RRF values calculated for each target PAH. Each analyte was considered "in control" if the RRF values calculated for the primary ion were within $\pm 25\%$ of the mean RRF for that analyte. No corrective action was required if benzo[a]pyrene was "in control" and no more than two analytes were "out of control". If acceptable performance was not demonstrated, the appropriate corrective action was taken and the mid-level calibration standard was reanalyzed. If acceptable performance was still not demonstrated, a new calibration curve was generated.

TABLE 6-6. IONS USED FOR QUANTITATION AND VERIFICATION OF PAHs DURING GC/MS ANALYSIS

Chemical	Quantitation Ion (m/z) ^a	Verification Ion (m/z)
Quinoline	129	100
Acenaphthylene	152	151
Phenanthrene	178	179
Anthracene	178	179
Fluoranthene	202	203
Pyrene	202	203
Benzo[a]anthracene	228	229
Chrysene	228	229
Benzo[k]fluoranthene	252	253
Benzo[e]pyrene	252	253
Benzo[a]pyrene	252	253
Indeno[1,2,3-cd]pyrene	276	277
Benzo[ghi]perylene	276	277
Coronene	300	301

^a m/z = Mass-to-charge ratio.

Analyte amounts in sample extracts (T) were calculated as:

$$T(\text{ng}) = \frac{A_t \cdot C_{std} \cdot V_e}{A_{std} \cdot RRF_t}$$

where V_e is the final extract volume (mL). PAH amounts (T_{adj}) in each sample extract were adjusted for the percent recovery of the appropriate surrogate standard (R_s) in that sample extract as

$$T_{adj}(\text{ng}) = \frac{T \times 100}{R_s}$$

Table 6-7 shows which target PAH amounts were adjusted using each of the three surrogates. The rationale for using this approach is outlined in Appendix H. Since the volume of air collected for a given sample was accurately known and the quantity of PAHs per cartridge was determined, the concentration (ng/m^3) in ambient air was then calculated as

$$\text{ng}/\text{m}^3 = \frac{T_{adj} - T_{bkg}}{m^3}$$

where: T_{bkg} = mean background values on the field blank cartridges (ng) adjusted for surrogate recovery

m^3 = sample volume in cubic meters.

Data on the analyte amounts in each sample were transferred to electronic files where all additional calculations were made. These files then became part of the data base for statistical analysis.

Benzo[j]-, benzo[i]-, and benzo[k]fluoranthene in sample extracts coeluted as a single broad peak in the GC/MS chromatogram. These compounds were therefore quantitated as a group (benzofluoranthenes) based on the relative response factor generated for benzo[k]-fluoranthene.

TABLE 6-7. SURROGATE STANDARDS FOR PAH ANALYSIS

Surrogate Standard	Target PAH
Fluorene-d ₁₀	Quinoline, Acenaphthylene, Phenanthrene, Anthracene
Chrysene-d ₁₂	Fluoranthene, Pyrene, Benzo[a]anthracene, Chrysene
Benzo[e]pyrene-d ₁₂	Benzo[k]fluoranthene, Benzo[e]pyrene, Indeno[1,2,3-cd]pyrene, Benzo[ghi]perylene, Coronene

6.2.2 Method Evaluation

6.2.2.1 Field Performance

The pumping systems used to collect the PAH samples were Models SP-25/1 and E-PASS 20/1 BF made by Esoteric Systems, Inc. (Thousand Oaks, CA). These systems were custom designed and built to RTI specifications as compact, very quiet, constant flow pumps. The pumps operated on standard household current of 115 VAC and required less than 1.8 amps of current. Outside case dimensions were 14.6 in. x 14.2 in. x 9.4 in. The cases were weather resistant, making them suitable for use in indoor or outdoor environments. Maximum flow capacity was 25 L/min; however, for this study, the flow rate was adjusted to ~15 L/min. A cartridge with 4.5 g of XAD-2 sorbent created a pressure drop of less than 7 in. Hg. A pressure transducer and electronic circuitry were used to provide constant flow during sample collection. Actual flow rates were measured during field monitoring at the time of sample deployment and collection using a calibrated rotameter. The temperature operating range for the pumps is approximately -10° to +50°C. Sample collection time was indicated by a digital elapsed time display. An automatic low flow shut-off was incorporated as a safety feature to prevent the pumps from overheating which could cause pump damage or a potential fire hazard during monitoring. The shut-off mechanism was activated if the tubing was crimped, if a restriction occurred that caused the flow to drop below a predetermined low flow set-point or if power interruption occurred for a continuous period of more than 3 min. An internal battery back-up system prevented the pump from shutting off during power surges, brown outs or complete power failures up to 3 min. in duration. In the event of an automatic shut-off, the elapsed collection time remained displayed. Noise levels produced by the pump during operation were very low, making it ideal for indoor sampling. Noise levels were measured at less than 50 db at 1 meter during laboratory testing.

During this study, all pumps performed acceptably with >96% of the PAH samples successfully collected (Table 6-8). Only 6 samples were lost due to pump and power failures. An additional 14 samples shut off early due to miscellaneous reasons such as heavy particulate loading, activation of the ground fault interrupter and participants accidentally turning off wall switches. However, these 14 samples were considered valid since the elapsed times exceeded 12 hours duration.

TABLE 6-8. SAMPLE COLLECTION RATE

Samples	Number		Percent ^a	
	Indoor	Outdoor	Indoor	Outdoor
Scheduled	280	280	100	100
Not attempted	0	1	0	0.4
Collected for entire monitoring period (20-24 hours)	273	265	97.5	94.6
Collected for 12 to 20 hours ^b	4	10	1.4	3.6
Collected for 6 to 12 hours	0	0	0	0
Collected for less than 6 hours	2	2	0.7	0.7
Power/pump failure - no displayed time	1	1	0.4	0.4
Not collected for other reason	0	1 ^c	0	0.4

^a Percent of samples scheduled.

^b Samples collected for 12 hrs or more considered valid.

^c Broken cartridge.

6.2.2.2 Instrument Performance

GC/MS system performance was considered acceptable throughout the sample analysis period. During the initial calibration, linearity over the concentration range of the standards was demonstrated for all of the PAHs. The percent relative standard deviation of the average RRF values was less than $\pm 25\%$ for each of the target PAHs. For BaP, linearity down to 9.3 ng/mL (lowest calibration standard) was demonstrated. This is equivalent to a concentration of 0.04 ng/m³ for a 19 m³ air sample volume. This air concentration is well below the 0.3 ng/m³ level that Offerman, et al. (1990) have suggested is required to cause a 10^{-6} excess cancer risk over a 70-year exposure period. All daily performance checks on the GC/MS system indicated "in-control" instrumental performance during the sample analysis period.

6.2.2.3 Method Performance

Several types of quality control (QC) samples were prepared and analyzed.

- Field controls (FC) were sample cartridges spiked with target analytes at known concentrations. Target PAHs were spiked as solutions onto the XAD-2 resin material. Filter controls were filters embedded with a known concentration of NIST urban dust certified for PAH concentrations. These samples were taken to the field and treated exactly as field samples but were not exposed.
- Field blanks (FB) were unspiked cartridges. These samples were taken to the field and treated exactly as field samples, but were not exposed.
- Method controls (MC) were extraction solvent spiked with target analytes then processed and analyzed with field samples.
- Method blanks (MB) were extraction solvent processed and analyzed with field samples.
- Method quantitation limit samples were identical to field controls but were spiked with one-tenth the amount of target analytes compared to the field controls. These samples were used to estimate method quantifiable limits.
- Duplicates were field samples collected at the same time and location, then processed and analyzed separately to assess precision.

Method performance data based on the results of these QC samples are presented below.

Field blanks were used to assess background contamination. Results for these analyses are summarized in Table 6-9. Data show low levels of PAHs for all blanks, indicating that background contamination was not a problem. Highest amounts were found for the low molecular weight PAHs; but these levels were very low compared to the levels expected in air samples and were below the calculated method quantitation limits.

Accuracy of the monitoring method for PAHs was evaluated using XAD-2 cartridges spiked with standard solutions and filters spiked with NIST certified urban dust. Table 6-10 gives results for the control samples analyzed during this study. Results showed recoveries ranging from 84 to 121% for target PAHs spiked onto XAD-2 cartridges. Recoveries of PAHs from controls spiked with NIST urban dust were generally acceptable (>75%), although recoveries for indeno[1,2,3-cd]pyrene were high (164%) and recoveries for pyrene were somewhat low. BaP recoveries were 101% and 89% from field controls and controls spiked with NIST urban dust, respectively.

Accuracy of the monitoring methods was also evaluated by spiking each field and QC sample with deuterated surrogate standards prior to extraction then measuring the amount found in each sample extract. Essentially, these surrogates represent the range of target PAHs and are designed to monitor performance of the extraction and analysis procedure in each sample. Data in Table 6-11 show good recovery (> 90%) and reproducibility for the chrysene-d₁₂ and benzo[e]pyrene-d₁₂. Benzo[e]pyrene-d₁₂ is a 5-ringed PAH that should effectively mimic the behavior of BaP during extraction and analysis. Lower recovery (59%) of fluorene-d₁₀ is presumably due to volatility losses during concentration. As discussed previously, PAH amounts in sample extracts were adjusted for recovery of the surrogate standards in the extract.

Method precision has been estimated based on analytical results for duplicate sample pairs. Data in Table 6-12 show the percent relative standard deviations (% RSD) for measured air concentrations in duplicate samples. Precision between duplicate samples was very good. Median % RSD values for duplicate samples that contained measurable concentrations were less than the mean values for all target chemicals. Mean and median % RSD values for BaP were 9.2 and 4.9%, respectively.

Finally, method quantifiable limits (MQL) were calculated by spiking cartridges with low levels of all target compounds. These cartridges were transported to the field site,

TABLE 6-9. RESULTS OF ANALYSIS OF BLANK SAMPLES

Compound	Mean Amount (ng) \pm S.D.	
	Field Blank (n = 30) ^a	Method Blank (n = 25) ^a
Quinoline	ND ^b	ND
Acenaphthylene	3.6 \pm 3.7	2.6 \pm 3.1
Phenanthrene	4.0 \pm 3.4	1.6 \pm 2.8
Anthracene	0.3 \pm 0.6	0.3 \pm 0.5
Fluoranthene	0.8 \pm 0.7	0.3 \pm 0.7
Pyrene	0.6 \pm 0.5	0.7 \pm 2.6
Benzo[a]anthracene	ND	ND
Chrysene	ND	ND
Benzo[k]fluoranthene	0.1 \pm 0.3	ND
Benzo[e]pyrene	ND	ND
Benzo[a]pyrene	ND	ND
Indeno[1,2,3-cd]pyrene	0.2 \pm 0.4	ND
Benzo[ghi]perylene	ND	ND
Coronene	ND	ND

^a Number of samples.^b All amounts below the calculated MQL.

TABLE 6-10. PAH RECOVERIES IN FIELD CONTROLS AND NIST CONTROL SAMPLES^a

Compound	Field Controls (n = 23)			NIST Controls (n = 16)		
	Spiked (ng)	Spiked ng/m ^{3b}	Recovery (% RSD)	Spiked (ng)	Spiked (ng/m ³)	% Recovery (% RSD)
Quinoline	327	17.2	100 (18)	NA ^c	NA	NA
Acenaphthylene	18	1.0	96 (9.5)	NA	NA	NA
Phenanthrene	45	2.4	98 (8.0)	26	1.4	99 (19)
Anthracene	4	0.2	113 (14)	NA	NA	NA
Fluoranthene	21	1.0	84 (16)	41	2.2	79 (15)
Pyrene	10	0.5	84 (17)	42	2.2	67 (13)
Benzo[a]anthracene	1.7	0.1	96 (18)	NA	NA	NA
Chrysene	1.7	0.1	97 (15)	NA	NA	NA
Benzo[k]fluoranthene	1.8	0.1	115 (15)	48	2.5	126 (14)
Benzo[a]pyrene	1.0	0.05	101 (21)	17	0.9	89 (20)
Benzo[e]pyrene	1.9	0.1	91 (15)	19	1.0	79 (15)
Indeno[1,2,3-cd]pyrene	0.8	0.05	121 (16)	19	1.0	164 (19)
Benzo[ghi]perylene	2.4	0.1	110 (14)	26	1.4	113 (19)
Coronene	1.5	0.08	114 (16)	NA	NA	NA

^a Controls spiked with NIST urban dust.^b Equivalent concentration assuming a 19 m³ sample volume.^c Certified value not given for NIST urban dust.

TABLE 6-11. RECOVERIES OF SURROGATE PAHs FROM FIELD
SAMPLES, CONTROLS AND BLANKS

	Spiked (ng)	% Recovery \pm S.D. (n = ~417)
Fluorene-d ₁₀	87	59 \pm 17
Chrysene-d ₁₂	36	90 \pm 13
Benzo[e]pyrene-d ₁₂	38	97 \pm 12

TABLE 6-12. PERCENT RELATIVE STANDARD DEVIATION (% RSD)
FOR DUPLICATE SAMPLES^a

Compound	n ^b	% RSD	
		Mean	Median
Quinoline	2	10	10
Acenaphthylene	24	9.4	4.9
Phenanthrene	26	5.6	4.1
Anthracene	26	11	8.7
Fluoranthene	24	12	7.2
Pyrene	27	13	9.4
Benzo[a]anthracene	23	11	7.2
Chrysene	25	10	6.9
Benzo[fluoranthenes] ^c	26	12	5.2
Benzo[e]pyrene	26	8.0	5.7
Benzo[a]pyrene	25	9.2	4.9
Indeno[1,2,3-cd]pyrene	27	11	7.9
Benzo[ghi]perylene	27	8.9	5.7
Coronene	25	12	9.4

^a If both quantifiable.

^b Number of sample pairs.

^c Isomers, not resolved, quantitated as a single peak.

returned, and analyzed along with the sample cartridges. MQLs were then calculated using the following equation (EPA, 1983):

$$MQL(ng) = Std. Dev. \times t_{0.99}$$

where Std. Dev. = the standard deviation around the mean for the analysis of the eight fortified cartridges.

$t_{0.99}$ = Student's one-tailed t-statistic at the 99% confidence level with seven degrees of freedom.

Results of MQL determinations are given in Table 6-13. Offerman et al. (1990) have suggested that a monitoring method for PAHs should be sufficiently sensitive to detect BaP at an air concentration of 0.3 ng/m³. This is the concentration for which it has been estimated that the risk of cancer for lifetime exposure is less than 10⁻⁶. For this study, the median MQL for BaP based and collected sample volumes was 0.035 ng/m³ indicating that the method is sufficiently sensitive to obtain data useful for exposure and risk assessments.

Although the method performance data for quinoline was good, there were high levels of interferences in the indoor air sample extracts which made detection and quantitation of quinoline difficult. If quinoline is to be used as a marker for ETS, then method modifications should be made that eliminate problems associated with matrix interference. Cleanup using solid phase extraction columns and/or use of a nitrogen specific detector are recommended.

6.3 CARBON MONOXIDE MONITORING METHOD

6.3.1 Method Description

Carbon monoxide (CO) concentrations were measured indoors and outdoors at approximately 75% of the study homes using portable monitors. The monitors were placed at the same site as the monitors for PAHs. Outdoor CO monitors were placed in "weather tight", temperature controlled, insulated sampling boxes to minimize effects due to ambient outdoor temperatures and moisture. Concentrations of CO were measured continuously, with 1-minute average concentrations stored by a datalogger during the 24-hour sampling period.

The CO monitors used in this study were Draeger Model 190 Toxic Gas Monitor/Dataloggers with extended data logging capability. This monitor utilizes a three-

TABLE 6-13. METHOD QUANTIFIABLE LIMITS (MQL)

Compound	MQL	
	ng/sample	ng/m ^{3a}
Quinoline	472	24.8
Acenaphthylene	23	1.2
Phenanthrene	39	2.1
Anthracene	3.1	0.16
Fluoranthene	10.6	0.56
Pyrene	5.4	0.28
Benzo[a]anthracene	1.5	0.08
Chrysene	1.5	0.08
Benzo[k]fluoranthene	1.7	0.09
Benzo[e]pyrene	1.3	0.07
Benzo[a]pyrene	0.68	0.04
Indeno[1,2,3-cd]pyrene	1.3	0.07
Benzo[ghi]perylene	2.2	0.12
Coronene	2.1	0.11

^aAir concentration assuming a sample volume of 19 m³.

electrode electrochemical sensor for measurement of CO concentrations. Because the air sample is delivered to the sensor by diffusion, the monitor is lightweight and noise-free, and requires minimal battery power for continuous operation. A filter containing Purafil protected the sensor from dust and interferants. The datalogger is designed to update sensor measurements 120 times per minute. These values are averaged and 1-minute averages are stored in the datalogger throughout the measurement period. Stored values are downloaded at the end of the monitoring period using a RS-232 interface to a portable computer.

Prior to initial use in any of the study homes, and approximately once each week during field monitoring, each CO monitor was calibrated using preanalyzed CO in air standards acquired from National Specialty Gases. For calibration, each monitor was attached to scientific grade air (0 ppm) and zeroed by adjusting the zero potentiometer. Since the datalogger will not record negative values, the zero point was adjusted with a + 5 ppm (baseline = 5 ppm) offset in order to minimize data losses that could occur due to negative baseline drift during sampling. Next, the monitor was attached to the 20 ppm CO in air standard and the span potentiometer was adjusted to give a difference of 20 ppm (actual monitor readout was 25 ppm due to 5 ppm offset). Once these two adjustments were made, the monitor was again attached to the 0 ppm cylinder. If the 0 ppm gas reading was not 5 ± 1 ppm, the zero potentiometer was adjusted and the 20 ppm gas was checked again and the monitor adjusted, if necessary. This cycle was repeated until the monitor registered 5 ± 1 with the 0 ppm CO gas standard and 25 ± 1 ppm with the 20 ppm CO gas standard. Once the initial zero and span were adjusted, the monitor was placed in the logging mode and certified gas concentrations of nominally 0, 2, 10 and 20 ppm CO were introduced and concentrations measured.

After the above calibrations were performed, the monitors were considered ready for field use. At each home, the monitor calibration was checked by introducing 0 ppm and 11 ppm CO gas standards at the start of and after the 24-hour monitoring period. Adjustments were made at the start of the monitoring if the zero or span reading had drifted more than 1 ppm. All calibration check data were recorded on the data collection form for each home.

Monitoring results as peak and 24-hour time weighted averages (TWA) were automatically calculated and processed by the datalogger and associated computer software.

6.3.2 Method Evaluation

6.3.2.1 Field Performance

The Draeger Model 190 CO Dataloggers used for the monitoring of carbon monoxide levels generally performed well during the study. The monitors were easy to use and required minimal maintenance. Solutions to problems discovered during the pilot study regarding temperature effects and datalogging limitations were incorporated in the main study with minimal impact on the overall sampling burden. These solutions are discussed in detail in Section 6.3.2.3. Overall, 411 of the scheduled 420 indoor/outdoor CO samples were successfully collected. This represents 98% completion. All nine of the uncollected samples were due to data downloading problems or general monitor failures.

6.3.2.2 Instrument Performance

Instrument performance was evaluated based on the initial calibration for each monitor and the zero and span (11 ppm) gas measurements taken at each home. Results for the initial calibrations are given in Table 6-14. Data for the calibration curves (linear regression analysis) showed slopes of 0.78 to 0.98 for the twelve monitors with a slightly positive intercept of 5.1 to 6.0 (zero was offset to + 5 ppm); all correlation values were greater than 0.990. Except for monitor 6, these calibrations were within the accuracy range specified by the manufacturer (± 2 ppm). Results of the zero and span measurements taken at each home were generally very good. Data for the final zero and span checks showed accuracy within ± 2 ppm with few exceptions. Method quantitation limits were set at 2 ppm based on instrumental drift over the 24-hour monitoring period.

6.3.2.3 Interferences

During the pilot study, two problems that affected the performance of the CO monitors were identified. Solutions to these problems were incorporated in the main study.

The first problem observed was that the monitors were sensitive to temperature. As the temperature decreased, the baseline drifted toward a negative concentration reading; conversely as the temperature increased, the baseline drifted towards a more positive reading. After observing this behavior during the pilot study, laboratory tests were performed at RTI to determine the magnitude of the effect. Table 6-15 shows the effect of temperature on baseline readings. Results showed a -1 ppm shift at low temperatures (7 to 18°C) and a +1 ppm or greater shift at elevated temperatures (> 27°C). The slope of the

TABLE 6-14. INITIAL CALIBRATION OF CO MONITORS

Monitor	Concentration (ppm)				Slope	Intercept	Correlation
	0	2	10	20			
1 (002)	5	8	15	24	0.93	5.6	0.998
2 (003)	5	7	15	23	0.90	5.2	0.998
3 (010)	5	7	15	23	0.90	5.2	0.998
4 (016)	5	6	15	24	0.98	4.7	0.998
5 (038)	5	7	15	23	0.90	5.2	0.998
6 (039)	5	8	15	21	0.78	6.0	0.990
7 (043)	5	7	15	23	0.90	5.2	0.998
8 (046)	5	7	15	24	0.95	5.1	1.00
9 (047)	5	7	15	23	0.90	5.2	0.998
10 (048)	5	7	15	22	0.86	5.4	0.996
11 (057)	5	7	15	23	0.90	5.2	0.998
12 (066)	5	7	15	23	0.90	5.2	0.998

TABLE 6-15. EFFECT OF TEMPERATURE ON BASELINE DRIFT

Average Temperature Range (°C)	Zero Drift (ppm)
7-18	-1
18-27	0
27-34	+1
34-40	+2
40-42	+3

calibration curve, however, remained constant at 7 and 23°C. These observed changes were consistent with the accuracy specified by the manufacturer (± 2 ppm).

In order to minimize temperature effects and allow the monitors to operate in subfreezing outdoor temperatures, special outdoor boxes were constructed. These boxes consisted of weatherproof electrical boxes insulated with aluminum faced rigid foam. Two 7 watt light bulbs attached to a thermostat were electrically wired inside the boxes to act as a gentle, controlled heating source. Holes were provided on the underside of box to allow the monitor's sensor to protrude. This heated box maintained the temperature between approximately 18 and 24°C (65-75°F) and protected the monitors from moisture during sampling.

The second problem noted during field monitoring was associated with the dataloggers. If the monitor reading drifted to a value less than 0 ppm, then the software in the datalogger no longer functioned properly. During the pilot study, the monitors were set up and calibrated in the early evening. As the air temperature cooled at night, the monitor readings became negative and data collection stopped. Monitors at only three of the eight locations continued to operate for the entire 24-hour sample collection period. This was a fairly simple problem that was remedied by offsetting the zero to a slightly positive value (i.e., 5 ppm) and calibrating the instrument using this offset.

6.4 AIR EXCHANGE RATE MEASUREMENTS

6.4.1 Method Description

Air exchange rate measurements were conducted in each study home to determine the integrated air infiltration rate during the monitoring period. Each home was treated as a well-mixed one-compartment model. In each home, permeation devices (emitters) containing a perfluorocarbon tracer (PFT), m-perfluorodimethylcyclohexane (PMCH), were placed throughout the home approximately 24 hours before monitoring began. Six emitters were placed in each home. Three were placed in the bedroom area and three were placed in the kitchen/living room area. Emitters were placed

- 0.5 to 1.5 m above floor,
- at least 1 m from outside walls, and
- at least 1 m from heat or cooling sources (air supply registers, etc.).

The perfluorocarbon tracer was emitted at a known rate (adjusted for temperature) and mixed with the indoor air. Resulting indoor tracer gas concentrations were dependent upon the house volume and the rate of outdoor air infiltration into the home. House volume measurements were made in each home at the time emitters were deployed by measuring the length and width of the foundation and height of each floor. For homes with a very irregular shape or vaulted ceilings, measurement averages were estimated.

The tracer compound was collected by diffusion using capillary adsorbent tube samplers (CAT) placed in the home during the 24-hour monitoring period. One CAT was placed in the same location as the PAH sampling cartridge in the main living area. Sample collection was accomplished by uncapping one end of the adsorbent tube. At the end of the monitoring period, the collectors were simply capped, transported in sealed glass jars at room temperature, then shipped to Brookhaven National Laboratory for analysis. Emitters and collectors were separated during transport and storage to avoid contamination of the CATs.

The amount of adsorbed PFT was determined by gas chromatography with electron capture detection. PFT concentration (C) in parts per trillion (ppt) was derived from the amount of adsorbed PFT (A), the sampling period (t), and the adsorption rate of PFT by the collectors (r):

$$C \text{ (ppt)} = \frac{A}{rt}$$

Air changes per hour (ACH) were calculated from the house volume in m^3 (V), the source emission rate (S) in nL/h (corrected for temperature), the number of sources (N), and the PFT concentration (C) as (Dietz and Cote, 1982):

$$ACH = \frac{NS}{CV}$$

6.4.2 Method Evaluation

No problems were encountered with the deployment or collection of emitters and CATs for air exchange measurements. Overall, 99% of the homes were monitored for air exchange rate. One home was not sampled due to an error by the technician in deploying the collector tube.

Data for QC samples collected as part of this study are summarized in Table 6-16. Results in Table 6-16 show very low background contamination on field blank samples. These results demonstrate acceptable cleanliness of sample materials, but they also show that contamination was not occurring during shipping, deployment, and storage of emitters and CATS during field operations. Acceptable recoveries ($66 \pm 12\%$) of the perfluorocarbon tracer were achieved during analysis of spiked field controls. Finally, precision for duplicate air exchange determinations were generally good with the exception of one pair. If this pair were deleted the average % RSD between duplicate air exchange rate determinations was 4.1 ± 4.3 .

TABLE 6-16. RESULTS OF ANALYSES OF QC SAMPLES FOR AIR EXCHANGE RATE MEASUREMENTS

Sample Type	n	Result
Field Blanks	14	0.003 ± 0.004 pL PFT/CAT
Field Controls	5	$66 \pm 12\%$ recovery
Duplicate Samples ^a	13	$12.2 \pm 29\%$ mean RSD (4.1 ± 4.3) ^b

^a Number of duplicate sample pairs.

^b Result if one duplicate pair with a very high % RSD was deleted from calculation of mean.

SECTION 7

STATISTICAL ANALYSIS

7.1 OVERVIEW OF DATA ANALYSIS

A number of different types of data were available for data analysis from this field monitoring study. These included:

- Indoor and outdoor air concentrations for the target PAHs.
- Indoor and outdoor air concentrations for CO.
- Air exchange rate measurements.
- Results from the 24-hour study questionnaire.
- Meteorological data including temperature and precipitation data from nearby reporting stations.

PAH and air exchange rate measurements were collected at each home. CO monitoring was performed in a subset of approximately 75% of the homes. Monitoring in each home was performed over one 24-hour period. Results from the 24-hour study questionnaire administered at the end of the monitoring period were used to place homes in one of the seven combustion source categories shown in Figure 7-1. A listing of the number of homes with data in each category are given Table 7-1. A hardcopy of other data files (CO measurement results, results from study questionnaires, air exchange rate measurements, meteorological data, PAH results) that were included in the statistical analysis are given in Appendices I to M.

Using these data, various types of statistical analyses were conducted to meet the specific objectives of this study listed in Table 7-2. The types of analyses used to address study objectives for PAHs are also described briefly. Unweighted data were used for all analyses. Because homes in different combustion source categories had different probabilities for selection, different source categories were not combined during analyses. For CO measurements, very few samples gave air concentrations above the estimated method quantitation limits of 2 ppm, therefore, only summary analysis was performed for CO and the specific statistical analysis objectives could not be addressed.

To estimate frequency distributions for residential indoor and outdoor air concentrations of PAHs (Objective 1), univariate statistics were calculated by source category. These statistics included arithmetic and geometric mean concentrations in air samples and their

	No Smoking in House		Smoking in House	
	Gas Heat Not Used	Gas Heat Used	Gas Heat Not Used	Gas Heat Used
Fireplace Used	48 (46) ^a		17 (11)	
Woodstove Used	40 (56)	30 (22)	45 (53)	
Fireplace or Woodstove Not Used	40 (39)	60 (53)		

^a Number of homes targeted for monitoring, number in parenthesis is the number of homes monitored.

Figure 7-1. Source Categories and Numbers of Homes Targeted for Monitoring

TABLE 7-1. OVERVIEW OF AVAILABLE DATA, BY COMBUSTION SOURCE CATEGORY

Combustion Source Category	Number of Houses			
	Questionnaires	Indoor PAH Data	Indoor PAH Data & Air Exchange Rates	Indoor, Outdoor PAH Data & Air Exchange Rates
A Smoking	53	52	52	49
AII Smoking/Fireplace	11	11	11	11
B Fireplace	46	45	44	44
C Woodstove	55	54	54	54
D Woodstove/Gas Heat	22	22	22	22
E No Source	39	36	35	35
F Gas heat	53	51	49	48
TOTAL	279 ^a	271	267	263

^a Monitoring was performed on 280 homes; however, one home in the woodstove category was purposely selected, therefore, results from this home were not included in data analysis.

TABLE 7-2. RELATIONSHIP OF STATISTICAL ANALYSIS TO OBJECTIVES

Analysis Objective	Primary Type of Statistical Analysis
1. To quantify the distribution of PAH and CO indoor air concentrations, outdoor air concentrations, and indoor/outdoor air concentration ratios in selected residences with different combustion sources.	Univariate statistics measured on indoor and outdoor air concentrations by source category. Univariate statistics for calculated indoor/outdoor air concentration ratios by combustion source.
2. To quantify the distribution of PAH and CO source strengths in selected residences with different combustion sources.	Calculate source strength in each home. Univariate statistics on source strengths by combustion source category.
3. To identify and model factors associated with various combustion sources that influence indoor and outdoor PAH and CO concentrations.	Application of statistical models to determine variables that influence indoor and outdoor air concentration. Estimates of emission rates and source factors for indoor sources that effect indoor air concentrations.
4. To investigate the relationship among PAHs and between PAH species and CO concentrations to identify appropriate marker compounds for <ul style="list-style-type: none"> - BaP air concentrations - environmental tobacco smoke - total PAH air concentrations 	Correlations between compound concentrations. Factor analysis to investigate patterns between compounds.

by sample volume. MQL values therefore vary due to differences in collected air volumes. Table 7-3 gives median MQL values by compound for the samples collected and analyzed during this study.

All sample concentrations including those measured below the MQL were calculated, entered into the data file, and used during statistical analysis. However, only when the resulting statistic was above the median MQL value has it been reported. When there was no instrumental signal during analysis, the measured air concentration was reported as zero and this zero value was used for statistical analysis. As a single exception to this approach, one eighth of the MQL value was substituted for zero during calculation of the geometric mean (since the logarithm of zero is undefined).

The percentage of samples with air concentrations above the MQL (percent quantifiable) was calculated by sample type (indoors or outdoors) and compound. Results given in Table 7-3 show very high percent quantifiable values for all compounds except quinoline. Since quinoline was considered a marker for ETS it was not expected to be found outdoors or in homes where tobacco smoking did not occur. Percentage quantifiable values for quinoline by combustion source category show that this compound was primarily measured in homes where smoking occurred.

7.3 CONCENTRATION STATISTICS

Based on the high percent quantifiable values, descriptive statistics for measured air concentrations were calculated for all of the target PAHs by source category. Univariate statistics for measured indoor and outdoor air concentrations are given in Tables 7-4 and 7-5, respectively. These statistics include geometric and arithmetic means, percentiles, and maximum values. Data for BaP are summarized graphically in Figures 7-2 and 7-3. Concentration data that include standard errors for the arithmetic and geometric means are included in Appendix M.

To investigate the effect of various combustion sources on PAH air concentrations, pairwise t-tests were performed between the category of homes with no sources and the six source categories. Tests were performed only on the means of the logs of the air concentrations which when exponentiated yielded geometric means. The results of the tests that were significantly different than zero are reported by showing asterisks in conjunction

TABLE 7-3. MEDIAN METHOD QUANTIFIABLE LIMITS AND % QUANTIFIABLE
VALUES FOR TARGET PAHs IN INDOOR AND OUTDOOR AIR SAMPLES

Compound	Median MQL (ng/m ³)	% Quantifiable	
		Indoors	Outdoors
<u>3-Rings</u>			
Acenaphthylene	1.2	96.7	97.4
Phenanthrene	2.0	100	99.3
Anthracene	0.16	98.9	98.9
<u>4-Rings</u>			
Fluoranthene	0.55	97.8	99.3
Pyrene	0.28	100	99.6
Benzo[a]anthracene	0.078	83.3	97.8
Chrysene	0.078	90.6	99.6
<u>5-Rings</u>			
Benzo[fluoranthenes	0.089	98.9	99.3
Benzo[e]pyrene	0.070	92.2	98.5
Benzo[a]pyrene	0.035	99.2	98.7
<u>6-Rings</u>			
Indeno[1,2,3-cd]pyrene	0.066	99.3	99.6
Benzo[ghi]perylene	0.11	99.3	98.5
<u>7-Rings</u>			
Coronene	0.11	98.1	98.5
<u>2-Rings</u>			
Quinoline	24	10.3	0.4
A Smoking		41.0	0.0
AII Smoking/fireplace		58.3	7.1
B Fireplace		1.7	0.0
C Woodstove/no gas heat		0.0	0.0
D Woodstove/gas heat		0.0	0.0
E No Source		0.0	0.0
F Gas heat		4.8	0.0

TABLE 7-4. SUMMARY STATISTICS FOR INDOOR PAH CONCENTRATIONS BY COMBUSTION SOURCE CATEGORY

Compound	Concentration (ng/m ³)						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
GEOMETRIC MEAN							
Quinoline	NQ ^{***a,b}	23 ^{***}	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	18 ^{***}	23 ^{***}	9.5	7.9	7.5	6.0	7.1
Phenanthrene	30 ^{***}	26 ^{***}	16	17	16	17	17
Anthracene	2.5 ^{***}	2.4 ^{***}	0.80	0.82	0.67	0.80	0.72
Fluoranthene	3.2 ^{***}	2.7 ^{***}	1.4	1.6	1.6	1.2	1.4
Pyrene	3.1 ^{***}	2.7 ^{***}	1.5	1.9	1.7	1.4	1.6
Benzo[a]anthracene	0.69 ^{***}	0.71 ^{***}	0.21	0.24 ^{**}	0.26 ^{**}	0.11	0.14
Chrysene	1.2 ^{***}	1.1 ^{***}	0.29	0.33 [*]	0.35 [*]	0.18	0.21
Benzo[fluoranthenes	2.2 ^{***}	1.7 [*]	0.95	1.0	1.2 [*]	0.51	0.71
Benzo[e]pyrene	0.66 ^{***}	0.70 ^{***}	0.30	0.31	0.34	0.16	0.22
Benzo[a]pyrene	1.2 ^{***}	1.3 ^{***}	0.55 [*]	0.55 [*]	0.62 [*]	0.24	0.34
Indeno[1,2,3-cd]pyrene	1.8 ^{***}	1.9 ^{**}	1.0	1.1	1.1	0.64	0.80
Benzo[ghi]perylene	1.4 ^{***}	1.4 [*]	0.87	0.92	0.87	0.58	0.74
Coronene	0.92 [*]	1.0 [*]	0.67	0.67	0.62	0.48	0.66
ARITHMETIC MEAN							
Quinoline	35	55	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	25	29	15	14	11	8.3	12
Phenanthrene	34	31	19	20	17	19	19
Anthracene	3.2	3.1	1.2	1.2	0.89	1.7	0.87
Fluoranthene	4.5	3.5	1.9	2.3	1.8	1.4	1.6
Pyrene	4.1	3.9	2.0	2.5	1.9	1.6	1.8
Benzo[a]anthracene	1.3	1.1	0.43	0.55	0.32	0.17	0.32
Chrysene	2.0	1.5	0.56	0.61	0.41	0.24	0.40
Benzo[fluoranthenes	3.7	3.7	1.6	2.0	1.5	0.81	1.5
Benzo[e]pyrene	1.1	0.98	0.49	0.55	0.40	0.25	0.42
Benzo[a]pyrene	2.2	2.1	1.0	1.2	0.79	0.41	0.83
Indeno[1,2,3-cd]pyrene	2.8	2.6	1.7	1.9	1.4	0.92	1.4
Benzo[ghi]perylene	2.0	1.9	1.4	1.5	1.1	0.78	1.3
Coronene	1.3	1.3	1.3	1.2	0.86	0.68	1.2
50th PERCENTILE							
Quinoline	NQ	36	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	16	24	10	7.8	6.1	7.8	8.7
Phenanthrene	29	25	13	17	16	15	14
Anthracene	2.3	2.2	0.75	0.75	0.70	0.67	0.67
Fluoranthene	2.8	2.6	1.2	1.6	1.7	1.1	1.2
Pyrene	2.7	2.1	1.3	1.8	1.8	1.4	1.5
Benzo[a]anthracene	0.58	0.68	0.17	0.20	0.26	0.11	0.10
Chrysene	0.96	1.3	0.27	0.28	0.35	0.18	0.18
Benzo[fluoranthenes	2.0	2.8	0.84	0.79	1.3	0.56	0.64
Benzo[e]pyrene	0.61	0.69	0.24	0.27	0.42	0.19	0.23
Benzo[a]pyrene	1.1	1.3	0.47	0.41	0.83	0.29	0.25
Indeno[1,2,3-cd]pyrene	1.7	1.5	1.0	0.83	1.4	0.77	0.80
Benzo[ghi]perylene	1.2	1.2	0.73	0.92	1.0	0.63	0.70
Coronene	0.94	1.2	0.54	0.63	0.65	0.49	0.55

(Cont.)

TABLE 7-4. (CONT.)

Compound	Concentration (ng/m ³)						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
25th PERCENTILE							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	10	13	5.7	3.7	4.4	4.3	3.9
Phenanthrene	21	17	11	12	13	12	13
Anthracene	1.6	1.6	0.47	0.42	0.40	0.45	0.46
Fluoranthene	1.7	1.6	0.88	0.90	1.3	0.79	0.90
Pyrene	1.7	1.5	1.1	1.3	1.5	1.0	1.0
Benzo[a]anthracene	0.29	0.31	0.09	0.11	0.16	0.06	0.05
Chrysene	0.53	0.67	0.10	0.16	0.23	0.09	0.09
Benzo[fluoranthenes	1.0	0.86	0.39	0.51	0.80	0.28	0.31
Benzo[e]pyrene	0.34	0.29	0.16	0.15	0.25	0.08	0.10
Benzo[a]pyrene	0.68	0.47	0.26	0.23	0.39	0.11	0.15
Indeno[1,2,3-cd]pyrene	1.2	1.1	0.57	0.55	0.70	0.36	0.40
Benzo[ghi]perylene	0.86	0.99	0.49	0.41	0.52	0.26	0.32
Coronene	0.56	0.66	0.32	0.25	0.37	0.26	0.33
75th PERCENTILE							
Quinoline	45	100	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	32	31	15	17	14	11	11
Phenanthrene	40	43	20	22	21	20	23
Anthracene	4.3	3.6	1.2	1.4	1.2	1.2	1.1
Fluoranthene	5.0	3.6	1.9	2.3	2.2	1.7	2.2
Pyrene	4.3	3.0	2.1	2.6	2.3	2.1	2.3
Benzo[a]anthracene	2.0	1.5	0.57	0.44	0.37	0.19	0.36
Chrysene	3.1	2.3	0.75	0.60	0.52	0.30	0.50
Benzo[fluoranthenes	4.6	4.3	2.1	1.9	2.0	0.88	1.5
Benzo[e]pyrene	1.4	1.3	0.72	0.59	0.52	0.30	0.47
Benzo[a]pyrene	2.6	2.8	1.8	1.2	1.0	0.51	0.82
Indeno[1,2,3-cd]pyrene	2.8	3.3	2.7	2.2	1.9	1.3	1.6
Benzo[ghi]perylene	2.2	2.4	1.5	1.7	1.6	1.0	1.5
Coronene	1.5	1.7	1.6	1.4	1.1	0.80	1.5
MAXIMUM							
Quinoline	220	160	40	NQ	NQ	28	NQ
Acenaphthylene	120	84	72	110	41	31	84
Phenanthrene	100	76	53	100	33	68	64
Anthracene	10	9.4	6.9	9.4	2.7	28	3.6
Fluoranthene	21	11	10	16	3.8	3.9	5.4
Pyrene	17	13	10	17	3.7	4.1	5.7
Benzo[a]anthracene	11	5.1	2.3	7.8	0.88	0.89	2.0
Chrysene	11	4.3	2.9	7.6	1.1	1.0	2.5
Benzo[fluoranthenes	36	15	6.4	21	4.4	5.9	8.3
Benzo[e]pyrene	11	3.5	1.5	5.1	0.99	1.6	2.1
Benzo[a]pyrene	28	8.6	3.4	16	2.4	3.2	4.8
Indeno[1,2,3-cd]pyrene	32	8.8	5.7	17	3.8	4.9	6.6
Benzo[ghi]perylene	17	6.5	8.4	11	2.7	3.7	7.0
Coronene	8.5	3.2	16	8.6	2.4	4.1	9.2

^a Tests were performed on the difference in means of the ln (concentrations) and results are thus reported in conjunction with the geometric mean.

*** Significantly different than no source category at 0.01 level.

** Significantly different than no source category at 0.05 level.

* Significantly different than no source category at 0.10 level.

Tests were only performed on geometric means.

^b NQ - below the method quantifiable limit.

TABLE 7-5. SUMMARY STATISTICS FOR OUTDOOR PAH CONCENTRATIONS BY COMBUSTION SOURCE CATEGORY

Compound	Concentration (ng/m ³) ^a						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
GEOMETRIC MEAN							
Quinoline	NQ ^b	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	11	14	12	10	14	9.4	13
Phenanthrene	19	20	20	20	21	17	20
Anthracene	1.6	1.7	1.8	1.8	2.0	1.4	1.7
Fluoranthene	3.6	3.7	3.7	4.2	4.0	3.1	3.5
Pyrene	3.3	3.9	3.4	3.7	3.5	2.8	3.3
Benzo[a]anthracene	0.62	0.79	0.62	0.78	0.88	0.46	0.59
Chrysene	0.93	1.2	0.96	1.2	1.3	0.73	0.90
Benzo[fluoranthenes	1.9	2.3	1.8	2.2	2.7	1.4	1.6
Benzo[e]pyrene	0.55	0.66	0.51	0.60	0.73	0.42	0.53
Benzo[a]pyrene	0.61	0.87	0.61	0.71	1.1	0.44	0.52
Indeno[1,2,3-cd]pyrene	1.3	1.6	1.2	1.3	1.7	0.99	1.2
Benzo[ghi]perylene	1.1	1.3	1.0	1.0	1.3	0.88	1.2
Coronene	0.69	0.78	0.66	0.56	0.72	0.61	0.78
ARITHMETIC MEAN							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	18	20	21	19	17	15	22
Phenanthrene	25	22	27	27	24	21	26
Anthracene	2.3	2.2	2.9	3.2	2.4	2.2	2.7
Fluoranthene	5.3	4.5	5.3	7.0	4.6	4.7	5.2
Pyrene	5.3	4.9	5.1	6.5	4.2	4.5	5.0
Benzo[a]anthracene	1.2	1.3	1.3	1.4	1.0	0.93	1.3
Chrysene	1.6	1.7	1.7	1.9	1.5	1.3	1.6
Benzo[fluoranthenes	3.2	3.3	3.2	3.5	3.2	2.5	3.3
Benzo[e]pyrene	0.84	0.90	0.85	0.89	0.82	0.66	0.88
Benzo[a]pyrene	1.3	1.4	1.4	1.4	1.3	0.99	1.3
Indeno[1,2,3-cd]pyrene	2.0	2.1	2.0	2.0	1.9	1.6	2.0
Benzo[ghi]perylene	1.6	1.7	1.7	1.6	1.5	1.4	1.9
Coronene	1.0	1.0	1.1	0.89	0.88	0.89	1.3
50th PERCENTILE							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	11	19	14	10	15	8.4	11
Phenanthrene	19	22	22	18	26	17	19
Anthracene	1.5	1.9	1.9	1.6	2.3	1.2	1.6
Fluoranthene	3.2	4.1	3.4	3.8	4.8	2.9	2.7
Pyrene	2.9	3.6	3.3	3.2	4.2	2.4	2.7
Benzo[a]anthracene	0.56	0.85	0.61	0.65	0.92	0.52	0.39
Chrysene	0.80	1.3	0.95	1.1	1.4	0.68	0.57
Benzo[fluoranthenes	1.7	2.4	1.9	2.0	3.0	1.0	1.3
Benzo[e]pyrene	0.53	0.75	0.50	0.55	0.78	0.35	0.45
Benzo[a]pyrene	0.72	0.91	0.59	0.57	1.2	0.25	0.33
Indeno[1,2,3-cd]pyrene	1.5	1.5	1.3	1.2	1.8	0.79	0.92
Benzo[ghi]perylene	1.1	1.3	0.95	0.92	1.5	0.83	1.2
Coronene	0.70	0.81	0.61	0.52	0.73	0.59	0.65

TABLE 7-5. (Cont.)

Compound	Concentration (ng/m ³) ^a						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
25th PERCENTILE							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	4.0	4.7	6.3	4.1	8.0	4.9	6.1
Phenanthrene	9.5	12	13	12	18	11	12
Anthracene	0.75	0.80	0.94	0.93	1.4	0.80	1.0
Fluoranthene	1.9	1.9	2.4	2.1	3.2	1.9	1.9
Pyrene	1.6	1.9	2.1	1.9	2.9	1.7	1.8
Benzo[a]anthracene	0.23	0.30	0.29	0.37	0.66	0.20	0.24
Chrysene	0.36	0.62	0.49	0.60	0.99	0.34	0.40
Benzo[fluoranthenes	0.82	1.0	0.83	1.0	2.1	0.71	0.78
Benzo[e]pyrene	0.26	0.32	0.26	0.30	0.52	0.22	0.24
Benzo[a]pyrene	0.22	0.20	0.20	0.29	0.77	0.19	0.17
Indeno[1,2,3-cd]pyrene	0.60	0.69	0.60	0.65	1.3	0.55	0.53
Benzo[ghi]perylene	0.50	0.79	0.56	0.48	0.98	0.41	0.57
Coronene	0.35	0.48	0.35	0.25	0.54	0.33	0.31
75th PERCENTILE							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	24	31	35	26	26	19	38
Phenanthrene	34	27	37	36	30	26	35
Anthracene	3.4	3.4	3.7	4.5	3.1	2.5	2.9
Fluoranthene	5.6	5.9	6.5	7.9	5.9	4.5	6.2
Pyrene	5.7	7.8	6.3	7.3	5.2	4.6	6.2
Benzo[a]anthracene	1.1	2.1	1.4	1.9	1.5	1.0	1.4
Chrysene	1.6	2.8	1.8	2.6	2.0	1.4	2.1
Benzo[fluoranthenes	4.3	6.2	4.0	4.9	5.2	3.2	3.7
Benzo[e]pyrene	1.2	1.4	1.1	1.3	0.98	0.87	1.2
Benzo[a]pyrene	1.8	2.2	1.9	2.2	1.5	1.2	1.5
Indeno[1,2,3-cd]pyrene	2.9	3.3	3.0	3.1	2.3	2.1	3.2
Benzo[ghi]perylene	2.1	2.6	2.6	2.4	1.8	1.7	3.2
Coronene	1.3	1.6	1.4	1.4	1.0	1.0	1.8
MAXIMUM							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	110	56	110	72	41	110	110
Phenanthrene	99	44	100	110	50	110	120
Anthracene	16	5.2	15	21	4.8	16	21
Fluoranthene	33	8.6	29	43	8.7	54	28
Pyrene	35	13	29	40	8.9	58	28
Benzo[a]anthracene	7.9	3.9	11	7.3	2.1	12	8.7
Chrysene	8.7	4.3	12	8.2	2.6	14	9.8
Benzo[fluoranthenes	18	7.6	21	16	6.7	23	22
Benzo[e]pyrene	4.2	2.3	4.9	3.7	1.6	4.9	4.8
Benzo[a]pyrene	8.6	4.0	9.9	6.3	2.6	11	9.5
Indeno[1,2,3-cd]pyrene	9.7	5.3	9.9	8.8	4.3	12	11
Benzo[ghi]perylene	7.8	4.0	8.2	8.3	3.3	8.8	9.4
Coronene	3.8	2.8	4.9	5.1	2.2	4.6	5.2

^a Statistical tests were performed in the same manner as in Table 7-4; however, none of the source categories had geometric mean outdoor concentrations that were significantly different than outdoor concentrations for the no source category at the 0.10 level.

^b Below the method quantifiable limit.

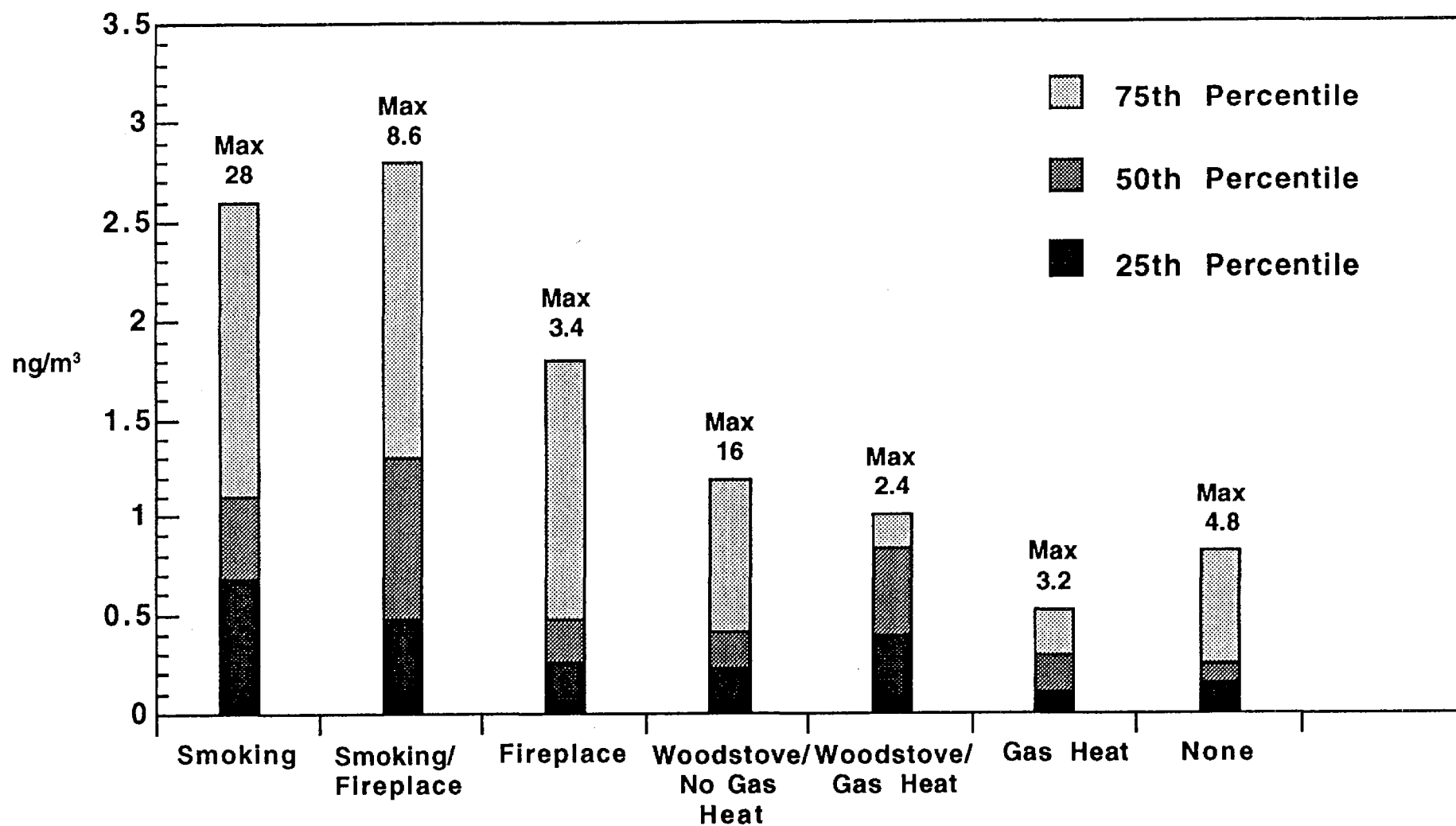


Figure 7-2. Indoor BaP Concentration (ng/m³) by Combustion Source

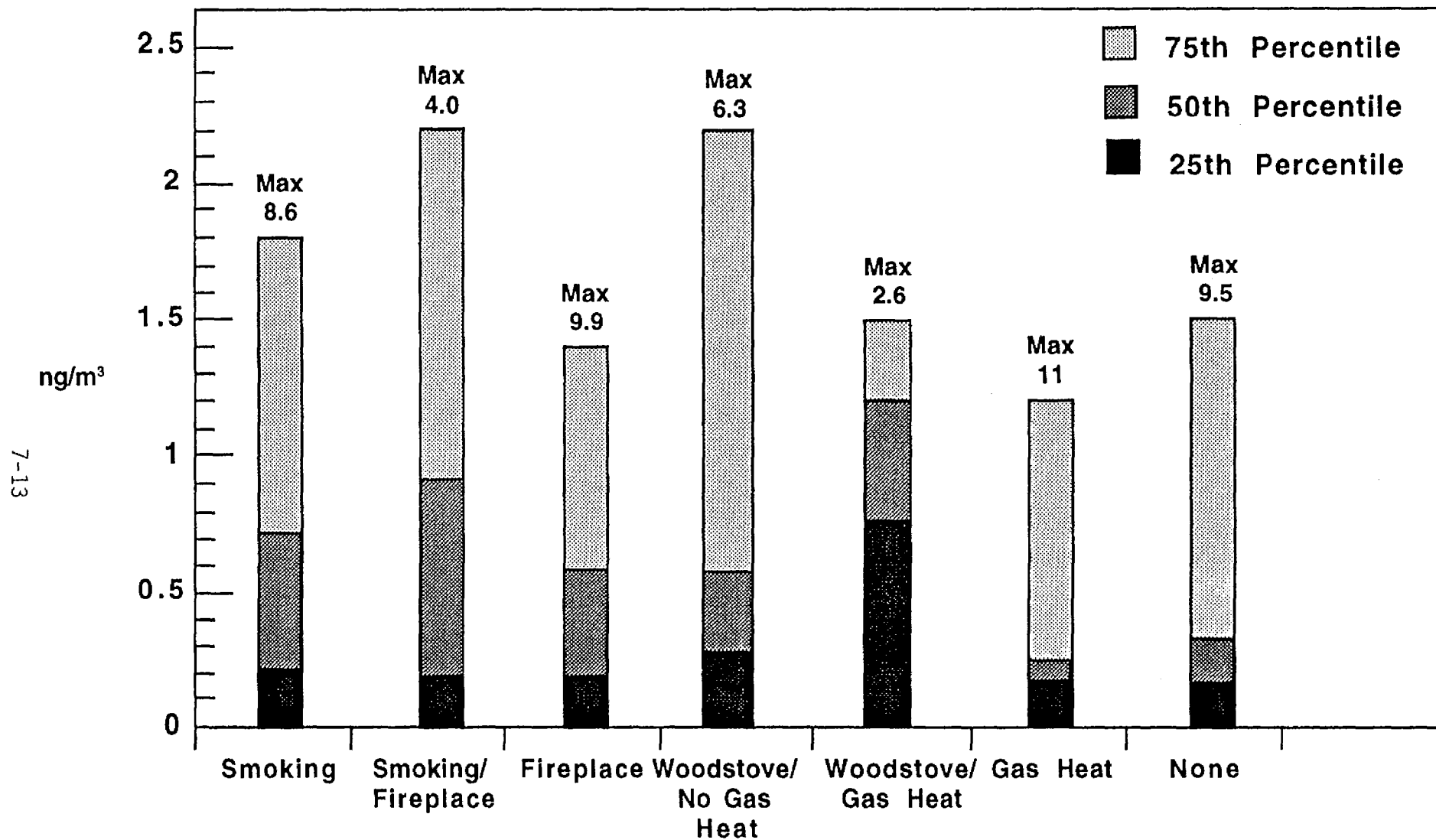


Figure 7-3. Outdoor BaP Concentrations (ng/m³) by Combustion Source

with the corresponding geometric means. T-tests were not performed on the arithmetic mean values, due to the tendency of the concentration distributions to be skewed (and hence non-normal). All tests should be regarded as approximate.

Data for both indoor and outdoor air samples show the trend of highest relative air concentrations for the more volatile 3- and 4-ringed species and lowest concentrations for the particulate phase 5-, 6-, and 7-ringed species. Quinoline concentrations were below the MQL in most outdoor samples. For outdoor air samples, the highest geometric mean concentrations were reported for phenanthrene; the lowest geometric mean concentrations were reported for benzo[e]pyrene. This is generally the distribution in which the target PAHs are formed during combustion processes (Li et al., 1992; Offerman et al., 1990). For indoor air samples, the highest geometric mean concentrations were again reported for phenanthrene; whereas the lowest geometric mean air concentrations were seen for benzo[e]pyrene, as well as benzo[a]anthracene and chrysene. The relatively low indoor air concentrations for these latter two compounds have been reported previously (Sexton et al., 1986; Traynor et al., 1987) and may be due to either differences in indoor combustion processes that have lower indoor source strengths, more rapid decay of the PAHs indoors, or reduced penetration from outdoors.

Comparison of air concentrations between source categories showed several interesting trends. Homes in the smoking categories had higher indoor PAH concentrations than homes in other categories. This was true for all of the target PAHs and all of the statistics except maximum values.

Although maximum concentration values are reported in the tables, any conclusions drawn from these data on combustion source effects should be viewed with caution. Combustion source categories were not exclusive, and homes with other strong combustion sources (e.g., kerosene heaters) could have been placed into any category. Thus, high reported air concentrations in a category may not be due to the designated combustion source but may reflect other sources or activities.

For most of the target PAHs, geometric mean indoor air concentrations for homes in the smoking categories were significantly greater at the 0.01 level than concentrations for homes in the no source category. Coronene is an exception to this, where indoor concentrations between homes with and without smoking were only significantly greater

than zero at the 0.10 level. Measured air concentrations in homes in the smoking and in the smoking/fireplace category showed only small differences between the two groups.

Indoor air concentrations for homes in the fireplace and woodstove categories tended to be slightly elevated compared to homes in the no source category. For benzo[a]anthracene and chrysene, geometric mean indoor air concentrations were significantly higher at the 0.05 level for the two woodstove categories. For BaP, homes in the fireplace and woodstove categories had significantly higher geometric mean indoor air concentrations (0.10 level) than homes in the no source categories. Homes in the gas heat category tended to have lower indoor air concentrations than homes in the no source category although this difference was not significant.

To further evaluate air concentration differences between categories, the air concentration ratio for source homes to no source homes was calculated for each target PAH and each category. The magnitude of these ratios is illustrated in Table 7-6 for the geometric mean, arithmetic mean, and median indoor air concentrations. The indoor air concentration ratio patterns in the table show many of the same trends discussed above:

- Homes in the two smoking categories showed mean and median indoor air concentration ratios greater than two for most chemicals. For phenanthrene, pyrene, benzo[ghi]perylene, and coronene the ratio was smaller although still positive.
- For homes in the fireplace and woodstove categories, the 4- and 5-ringed PAHs including benzo[a]anthracene, chrysene, benzo[a]fluoranthene, benzo[e]pyrene, and benzo[a]pyrene tended to show elevated concentrations compared to the no source homes.
- For homes in the woodstove/gas heat category, only the geometric mean and median indoor air concentrations showed elevated concentrations compared to the no source category. Again, it was the 4- and 5-ringed species that showed this effect.

Although not statistically evaluated, homes where smoke was visually observed by the participant or where woodstoves were operated with the stove door open tended to have very high indoor air concentrations for all target PAHs. This finding is consistent with results reported by other researchers. (Affheim et al., 1986; Traynor et al., 1987; Sexton et al., 1986; and Daisey et al., 1987)

TABLE 7-6. RELATIVE RATIOS OF INDOOR PAH CONCENTRATIONS OF HOMES WITH INDOOR SOURCES TO HOMES IN THE NO SOURCE CATEGORY

Compound	Relative Concentration Ratio ^a					
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat
GEOMETRIC MEAN						
Quinoline	NC ^b	NC	NC	NC	NC	NC
Acenaphthylene	XXX	XXX	X			
Phenanthrene	XX	XX				
Anthracene	XXX	XXX				
Fluoranthene	XXX	XX				
Pyrene	XX					
Benzo[a]anthracene	XXX	XXX	XX	XX	XX	
Chrysene	XXX	XXX	X	XX	XX	
Benzo[fluoranthenes	XXX	XXX	X	X	XX	
Benzo[e]pyrene	XXX	XXX	X	X	XX	
Benzo[a]pyrene	XXX	XXX	XX	XX	XX	
Indeno[1,2,3-cd]pyrene	XXX	XXX		X	X	
Benzo[ghi]perylene	XX	XX				
Coronene	X	XX				
ARITHMETIC MEAN						
Quinoline	NC	NC	NC	NC	NC	NC
Acenaphthylene	XXX	XXX				
Phenanthrene	XX	XX				
Anthracene	XXX	XXX	XX	XX		XX
Fluoranthene	XXX	XXX		X		
Pyrene	XXX	XXX		X		
Benzo[a]anthracene	XXX	XXX	X	XX		
Chrysene	XXX	XXX	X	XX		
Benzo[fluoranthenes	XXX	XXX		X		
Benzo[e]pyrene	XXX	XXX				
Benzo[a]pyrene	XXX	XXX		X		
Indeno[1,2,3-cd]pyrene	XXX	XX		X		
Benzo[ghi]perylene	XX	X				
Coronene						
50th PERCENTILE						
Quinoline	NC	NC	NC	NC	NC	NC
Acenaphthylene	XX	XXX				
Phenanthrene	XXX	XX				
Anthracene	XXX	XXX				
Fluoranthene	XXX	XXX		X	X	
Pyrene	XX	X				
Benzo[a]anthracene	XXX	XXX	X	XXX	XXX	
Chrysene	XXX	XXX	XX	XX	XX	
Benzo[fluoranthenes	XXX	XXX				
Benzo[e]pyrene	XXX	XXX			XX	
Benzo[a]pyrene	XXX	XXX	XX	XX	XXX	
Indeno[1,2,3-cd]pyrene	XXX	XX			XX	
Benzo[ghi]perylene	XX	XX				
Coronene	XX	XXX				

^a Concentration in source category relative to no source category.

XXXX - Source $\geq 10X$ greater than no source.
 XXX - Source 2X to 10X greater than no source.
 XX - Source 1.5X to 2X greater than no source.
 X - Source 1.33X to 1.5X greater than no source.

^b Not calculated; air concentration in the no source category was below the method quantifiable limit.

Mean outdoor PAH air concentrations (Table 7-5) tended to be relatively constant for homes in all source categories. Geometric mean air concentrations for homes in the source categories compared to those in the no source category showed no significant difference at the 0.10 level (based on a t-test applied to \ln (concentrations)). A comparison of outdoor concentration ratios for homes in each source category relative to homes in the no source category (Table 7-7) indicates elevated geometric mean and median concentrations for many of the target PAHs in homes with woodstoves and fireplaces. These results suggest that smoke from woodburning sources increased outdoor air PAH concentrations in the vicinity of the home. The effect is most pronounced for the 4- and 5-ringed PAHs (benzo[a]anthracene, chrysene, benzo[fluoranthene], and benzo[a]pyrene) when comparing median (50th percentile) outdoor air concentrations.

To further evaluate this effect, outdoor PAH concentration statistics were calculated separately for the two study areas. These data for geometric mean and median outdoor air concentrations are presented in Table 7-8. Patterns for concentration ratios of homes in source categories relative to homes in the no source category are given in Table 7-9. Results in these tables show higher overall outdoor PAH concentrations for Placerville; whereas Roseville showed greater increases in outdoor air concentrations for homes with woodburning sources compared to homes with no sources. These results are consistent with woodburning activities in the two areas. In Placerville, more than 50% of homes used woodburning as a primary source of heat. Under these conditions, it would be anticipated that most of the homes in the study area, regardless of source category, should be in near proximity to woodburning sources. Thus homes in the non-woodburning categories would still be impacted by woodburning in the community. In Roseville, very few residences used woodburning as a heating source; thus outdoor PAH air concentrations at a home are more likely to reflect the woodburning activities at that home.

A comparison between outdoor air concentrations in Roseville and Placerville (Table 7-8) for the no source category provides additional information on the effects of woodburning in the two areas. In Placerville, the 4- and 5-ringed PAHs (benzo[a]anthracene, pyrene, benzo[fluoranthene], benzo[e]pyrene, and benzo[a]pyrene) have elevated outdoor air concentrations compared to the PAH distributions reported for Roseville. As suggested previously, and as reported in the literature, these species tend to be elevated for wood

TABLE 7-7. RELATIVE RATIOS OF OUTDOOR PAH CONCENTRATIONS OF HOMES WITH
INDOOR SOURCES TO HOMES IN THE NO SOURCE CATEGORY

Compound	Relative Concentration Ratio ^a					
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat
GEOMETRIC MEAN						
Quinoline	NC	NC ^b	NC	NC	NC	NC
Acenaphthylene						
Phenanthrene						
Anthracene						
Fluoranthene						
Pyrene						
Benzo[a]anthracene		X		X	X	
Chrysene		X		X	X	
Benzo[fluoranthenes		X		X	X	
Benzo[e]pyrene					X	
Benzo[a]pyrene		X			X	
Indeno[1,2,3-cd]pyrene		X			X	
Benzo[ghi]perylene						
Coronene						
ARITHMETIC MEAN						
Quinoline	NC	NC	NC	NC	NC	NC
Acenaphthylene						
Phenanthrene						
Anthracene						
Fluoranthene					X	
Pyrene						
Benzo[a]anthracene						
Chrysene						
Benzo[fluoranthenes						
Benzo[e]pyrene						
Benzo[a]pyrene						
Indeno[1,2,3-cd]pyrene						
Benzo[ghi]perylene						
Coronene						
50th PERCENTILE						
Quinoline	NC	NC	NC	NC	NC	NC
Acenaphthylene		XX			X	
Phenanthrene					X	
Anthracene					X	
Fluoranthene		XX		X	XX	
Pyrene		X			XX	
Benzo[a]anthracene	X	XXX	XX	XX	XXX	X
Chrysene	X	XXX	XX	XX	XXX	
Benzo[fluoranthenes		XX	X	XX	XXX	
Benzo[e]pyrene		XX			XX	
Benzo[a]pyrene	XXX	XXX	XX	XX	XXX	
Indeno[1,2,3-cd]pyrene	XX	XX	X	X	XX	
Benzo[ghi]perylene						
Coronene						

^a Concentration in the source category relative to the no source category.

XXXX - Source $\geq 10X$ greater than no source.
 XXX - Source 2X to 10X greater than no source.
 XX - Source 1.5X to 2X greater than no source.
 X - Source 1.33X to 1.5X greater than no source.

^b Not calculated; air concentration in the no source category was below the method quantifiable limit.

TABLE 7-8. SUMMARY STATISTICS FOR OUTDOOR PAH CONCENTRATIONS BY COMBUSTION SOURCE CATEGORY AND STUDY AREA

Compound	Concentration (ng/m ³) ^a						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
PLACERVILLE							
GEOMETRIC MEAN							
Quinoline	NQ ^b	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	12	12	13	9.3	11	11	11
Phenanthrene	21	19	22	19	19	21	25
Anthracene	1.9	1.7	2.1	1.8	1.8	2.0	2.3
Fluoranthene	4.6	4.6	5.1	4.4	4.1	5.0	5.7
Pyrene	4.2	4.9	4.5	3.9	3.6	4.6	5.1
Benzo[a]anthracene	0.94	1.0	0.94	0.87	0.88	0.9	1.2
Chrysene	1.3	1.6	1.5	1.3	1.3	1.4	1.8
Benzo[fluoranthenes	3.1	3.1	3.1	2.7	3.0	3.0	3.7
Benzo[e]pyrene	0.78	0.80	0.74	0.69	0.70	0.73	0.94
Benzo[a]pyrene	1.1	1.1	1.0	0.85	1.0	1.2	0.99
Indeno[1,2,3-cd]pyrene	1.8	1.8	1.5	1.4	1.5	1.6	1.9
Benzo[ghi]perylene	1.4	1.4	1.2	1.1	1.2	1.3	1.6
Coronene	0.74	0.70	0.68	0.56*	0.58	0.74	0.96
50th PERCENTILE							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	13	21	25	8.1	13	8.5	11
Phenanthrene	20	27	27	17	21	19	25
Anthracene	1.7	2.5	3.3	1.4	2.1	1.6	2.2
Fluoranthene	3.6	5.4	6.7	3.8	5.3	3.5	5.4
Pyrene	3.2	5.4	6.1	3.2	4.8	3.4	4.7
Benzo[a]anthracene	0.95	1.4	1.3	0.65	1.1	0.77	0.93
Chrysene	1.3	2.1	1.9	1.1	1.6	1.1	1.6
Benzo[fluoranthenes	3.4	4.4	3.7	2.1	3.7	24	3.3
Benzo[e]pyrene	0.75	1.0	0.90	0.59	0.82	0.58	0.80
Benzo[a]pyrene	1.2	1.6	1.3	0.74	1.2	0.80	1.1
Indeno[1,2,3-cd]pyrene	1.8	2.2	2.2	1.3	1.7	1.2	1.8
Benzo[ghi]perylene	1.4	1.8	1.8	0.92	1.3	1.1	1.5
Coronene	0.74	0.88	0.88	0.44	0.63	0.86	0.66
ROSEVILLE							
GEOMETRIC MEAN							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	9.5	16	12	13	21	8.8	12
Phenanthrene	17	20	19	20	27 **	15	17
Anthracene	1.3	1.7	1.7	2.0	2.4 *	1.8	1.4
Fluoranthene	2.6	3.2	3.1	3.7*	3.8 *	2.5	2.6
Pyrene	2.5	3.1	3.0	3.4	3.4	2.3	2.5
Benzo[a]anthracene	0.36	0.63	0.50	0.59	0.90**	0.33	0.37
Chrysene	0.59	0.92	0.76	0.88	1.3 **	0.55	0.60
Benzo[fluoranthenes	0.98	1.8	1.3	1.3	2.3 *	0.98	1.0
Benzo[e]pyrene	0.35	0.56	0.42	0.42	0.78**	0.33	0.38
Benzo[a]pyrene	0.30	0.73	0.45	0.45	1.2 ***	0.31	0.32
Indeno[1,2,3-cd]pyrene	0.81	1.4	1.0	1.0	2.0 **	0.80	0.84
Benzo[ghi]perylene	0.86	1.23	0.91	0.86	1.6	0.72	0.96
Coronene	0.63	0.85	0.65	0.57	1.2	0.56	0.70

TABLE 7-8. (Cont.)

Compound	Concentration (ng/m ³) ^a						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
50th PERCENTILE							
Quinoline	NQ	NQ	NQ	NQ	NQ	NQ	NQ
Acenaphthylene	8.6	17	12	15	27	7.8	11
Phenanthrene	15	20	20	23	30	17	15
Anthracene	1.3	1.5	1.7	2.0	2.5	1.1	1.5
Fluoranthene	2.3	3.3	3.1	3.7	3.6	2.5	2.5
Pyrene	2.3	2.8	3.0	3.4	3.2	2.3	2.3
Benzo[a]anthracene	0.35	0.78	0.49	0.67	0.89	0.28	0.34
Chrysene	0.58	1.2	0.69	0.94	1.4	0.48	0.49
Benzofluoranthenes	0.92	2.2	1.3	1.4	2.2	0.90	0.97
Benzo[e]pyrene	0.32	0.68	0.44	0.45	0.74	0.28	0.34
Benzo[a]pyrene	0.26	0.86	0.43	0.47	1.2	0.23	0.27
Indeno[1,2,3-cd]pyrene	0.89	1.5	0.97	0.90	1.8	0.61	0.64
Benzo[ghi]perylene	0.82	1.3	0.85	0.97	1.7	0.60	0.86
Coronene	0.59	0.75	0.55	0.76	1.40	0.46	0.58

^a Tests were performed on the difference in means of the ln (concentrations) and results are thus reported in conjunction with the geometric mean.

*** Significantly different than no source category at 0.01 level.

** Significantly different than no source category at 0.05 level.

* Significantly different than no source category at 0.10 level.

^b NQ - below the method quantifiable limit.

TABLE 7-9. RELATIVE RATIOS OF OUTDOOR PAH CONCENTRATIONS OF HOMES WITH INDOOR COMBUSTION SOURCES TO HOMES IN THE NO SOURCE CATEGORY BY STUDY AREA

Compound	Relative Concentration Ratio ^a					
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat
PLACERVILLE ^{a,b}						
ROSEVILLE ^b						
GEOMETRIC MEAN						
Quinoline	NC ^{b,c}	NC	NC	NC	NC	NC
Acenaphthylene		X			XX	
Phenanthrene					XX	
Anthracene				XXX	XX	
Fluoranthene				X	X	
Pyrene				X	X	
Benzo[a]anthracene		XX	X	XX	XXX	
Chrysene		XX		X	XXX	
Benzo[fluoranthene]		XX	X	X	XXX	
Benzo[e]pyrene		X			XXX	
Benzo[a]pyrene		XX	XX	XX	XXX	
Indeno[1,2,3-cd]pyrene		XX			XXX	
Benzo[ghi]perylene					XX	
Coronene					XX	
50th PERCENTILE						
Quinoline	NC	NC	NC	NC	NC	NC
Acenaphthylene		XX		X	XXX	
Phenanthrene		X	X	XX	XXX	
Anthracene				X	XX	
Fluoranthene		X	X	X	X	
Pyrene			X	X	X	
Benzo[a]anthracene		XXX	X	XXX	XXX	
Chrysene		XXX	X	XX	XXX	
Benzo[fluoranthene]		XXX	X	X	XXX	
Benzo[e]pyrene		XXX	X	X	XXX	
Benzo[a]pyrene		XXX	X	X	XXX	
Indeno[1,2,3-cd]pyrene		XXX	X	X	XXX	
Benzo[ghi]perylene		XX			XX	
Coronene					XXX	

^a Concentration in the source category relative to the no source category.

XXXX - Source $\geq 10X$ greater than no source.

XXX - Source 2X to 10X greater than no source.

XX - Source 1.5X to 2X greater than no source.

X - Source 1.33X to 1.5X greater than no source.

^b In Placerville outdoor PAH concentrations in none of the source categories were more than 1.33X greater than outdoor concentrations for the no source category.

^c Not calculated; air concentration in the no source category was below the method quantifiable limit.

combustion processes (Li, 1993). In Roseville, the higher molecular weight PAHs, (most notably coronene) had relatively higher outdoor air concentrations compared to Placerville which is consistent with higher reported concentrations of these chemicals as a result of gasoline combustion processes.

A comparison of the indoor to outdoor PAH air concentrations given in Tables 7-4 and 7-5 shows generally higher outdoor concentrations for homes in all source categories except the two smoking categories. This relationship is evaluated more closely by calculating indoor/outdoor air concentration ratios for the target PAHs at each home. Univariate summary statistics for this variable are given in Table 7-10 by source category. Results are displayed graphically for BaP in Figure 7-4. T-tests were performed between geometric mean indoor/outdoor concentration ratios for homes in each source category and homes in the no source category. T-tests were performed only on the means of the log of the air concentration ratios which when exponentiated yield geometric means. T-test were not performed on the arithmetic mean values, due to the tendency of the concentration distributions to be skewed and hence nonnormal. Results from this analysis are also included in the table. Table 7-11 shows patterns for indoor/outdoor air ratios for homes in source categories relative to homes in the no source categories.

Mean and median results in the table show several interesting trends:

- (1) Except for the smoking categories, indoor/outdoor air concentration ratios are generally less than one. This suggests that PAHs from the outdoors do not penetrate into a home with 100% efficiency. It also suggests that even for homes with combustion sources, penetration of air from outdoors may provide a substantial contribution to indoor PAH concentrations.
- (2) For homes in the smoking categories, mean and median indoor/outdoor air concentration ratios are generally greater than one. For homes in the smoking only category, BaP gave the highest indoor/outdoor air concentration ratios of all the target PAHs.
- (3) Indoor/outdoor air concentration ratios for homes in the smoking only category were generally higher than for homes in the smoking and fireplace category. For several 4- and 5-ringed PAHs, indoor/outdoor air concentration ratios were less than one in the latter category. This effect for homes in the

TABLE 7-10. SUMMARY STATISTICS FOR INDOOR/OUTDOOR PAH CONCENTRATION RATIOS BY COMBUSTION SOURCE CATEGORY

Compound	Indoor/Outdoor Concentration Ratio						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
GEOMETRIC MEAN							
Quinoline	NC ^a	NC	NC	NC	NC	NC	NC
Acenaphthylene	1.7 ^{***b}	1.7 ^{***}	0.78	0.76	0.50	0.71	0.53
Phenanthrene	1.6 ^{***}	1.3 ^{***}	0.84	0.85	0.71	1.02	0.84
Anthracene	1.5 ^{***}	1.4 ^{***}	0.46	0.45	0.32	0.64 [*]	0.41
Fluoranthene	0.91 ^{***}	0.72 ^{***}	0.38	0.39	0.40	0.39	0.37
Pyrene	0.94 ^{***}	0.71 [*]	0.46	0.49	0.49	0.52	0.47
Benzo[a]anthracene	1.1 ^{***}	0.89 ^{***}	0.35 ^{***}	0.30 [*]	0.29 [*]	0.26	0.22
Chrysene	1.3 ^{***}	0.93 ^{***}	0.31 ^{**}	0.27	0.27	0.24	0.22
Benzo[fluoranthenes	1.2 ^{***}	0.65 [*]	0.54 ^{**}	0.47	0.44	0.36	0.38
Benzo[e]pyrene	1.3 ^{***}	1.1 ^{***}	0.59 ^{***}	0.52 ^{**}	0.46 [*]	0.40	0.40
Benzo[a]pyrene	2.2 ^{***}	1.5 ^{***}	0.88 ^{**}	0.76 [*]	0.58	0.56	0.56
Indeno[1,2,3-cd]pyrene	1.6 ^{***}	1.2 ^{***}	0.89 ^{**}	0.82 [*]	0.68	0.67	0.63
Benzo[ghi]perylene	1.3 ^{***}	1.1 ^{***}	0.87 ^{***}	0.87 ^{***}	0.67	0.67	0.59
Coronene	1.4 ^{***}	1.3 ^{**}	1.0 [*]	1.2 ^{**}	0.87	0.82	0.77
ARITHMETIC MEAN							
Quinoline	NC	NC	NC	NC	NC	NC	NC
Acenaphthylene	3.4	2.2	1.5	1.7	0.64	1.2	0.91
Phenanthrene	2.2	1.6	1.1	2.4	0.89	1.3	1.0
Anthracene	2.6	1.7	0.71	1.1	0.56	1.9	0.62
Fluoranthene	1.5	0.84	0.53	1.1	0.45	0.5	0.43
Pyrene	1.5	0.90	0.65	0.96	0.57	0.70	0.57
Benzo[a]anthracene	2.9	1.2	0.54	1.3	0.34	0.35	0.25
Chrysene	2.6	1.2	0.43	0.86	0.30	0.31	0.25
Benzo[fluoranthenes	2.2	0.99	0.67	1.6	0.52	0.44	0.58
Benzo[e]pyrene	2.3	1.3	0.74	1.3	0.51	0.48	0.41
Benzo[a]pyrene	5.8	2.1	1.2	2.6	0.67	0.63	0.61
Indeno[1,2,3-cd]pyrene	3.0	1.3	1.3	1.6	0.78	0.96	0.75
Benzo[ghi]perylene	2.0	1.2	1.2	1.7	0.75	1.3	0.68
Coronene	2.2	1.4	1.6	2.1	0.97	1.4	1.1
50th PERCENTILE							
Quinoline	NC	NC	NC	NC	NC	NC	NC
Acenaphthylene	1.3	1.2	0.87	0.64	0.58	0.67	0.50
Phenanthrene	1.7	1.2	0.76	0.87	0.64	1.0	0.76
Anthracene	1.3	1.6	0.48	0.38	0.30	0.67	0.41
Fluoranthene	0.95	0.68	0.32	0.37	0.41	0.41	0.42
Pyrene	1.1	0.81	0.42	0.49	0.50	0.58	0.54
Benzo[a]anthracene	0.85	0.71	0.28	0.31	0.28	0.23	0.25
Chrysene	1.2	0.97	0.25	0.28	0.25	0.21	0.24
Benzo[fluoranthenes	1.1	0.79	0.41	0.46	0.46	0.36	0.37
Benzo[e]pyrene	1.0	0.92	0.46	0.52	0.43	0.36	0.38
Benzo[a]pyrene	1.9	1.4	0.83	0.76	0.52	0.54	0.59
Indeno[1,2,3-cd]pyrene	1.5	1.1	0.75	0.74	0.59	0.59	0.66
Benzo[ghi]perylene	1.1	1.1	0.74	0.74	0.57	0.61	0.56
Coronene	1.1	1.3	0.87	0.98	0.84	0.74	0.68

(Cont.)

TABLE 7-10. (Cont.)

Compound	Indoor/Outdoor Concentration Ratio						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
25th PERCENTILE							
Quinoline	NC	NC	NC	NC	NC	NC	NC
Acenaphthylene	0.75	0.93	0.48	0.39	0.36	0.42	0.32
Phenanthrene	0.75	0.98	0.52	0.43	0.48	0.61	0.57
Anthracene	0.67	1.0	0.22	0.22	0.15	0.25	0.26
Fluoranthene	0.37	0.44	0.24	0.20	0.29	0.27	0.22
Pyrene	0.44	0.38	0.27	0.30	0.33	0.32	0.31
Benzo[a]anthracene	0.44	0.47	0.20	0.17	0.20	0.16	0.15
Chrysene	0.56	0.53	0.19	0.15	0.21	0.16	0.18
Benzo[fluoranthenes	0.66	0.57	0.35	0.27	0.27	0.28	0.28
Benzo[e]pyrene	0.76	0.75	0.39	0.32	0.33	0.29	0.28
Benzo[a]pyrene	0.79	1.1	0.52	0.40	0.38	0.40	0.41
Indeno[1,2,3-cd]pyrene	0.82	1.0	0.59	0.52	0.47	0.41	0.41
Benzo[ghi]perylene	0.80	0.85	0.60	0.51	0.48	0.49	0.41
Coronene	0.84	1.0	0.66	0.75	0.65	0.55	0.46
75th PERCENTILE							
Quinoline	NC	NC	NC	NC	NC	NC	NC
Acenaphthylene	4.3	3.54	1.3	1.4	0.81	1.2	1.1
Phenanthrene	3.6	2.1	1.4	1.2	0.90	1.3	1.3
Anthracene	3.9	2.8	0.89	0.79	0.54	1.4	0.71
Fluoranthene	1.7	1.3	0.57	0.58	0.52	0.58	0.60
Pyrene	1.9	1.3	0.71	0.68	0.63	0.80	0.77
Benzo[a]anthracene	2.9	2.1	0.73	0.48	0.42	0.38	0.34
Chrysene	2.8	1.5	0.45	0.42	0.37	0.34	0.32
Benzo[fluoranthenes	2.1	1.5	0.78	0.65	0.67	0.48	0.50
Benzo[e]pyrene	2.2	1.6	0.80	0.67	0.63	0.48	0.54
Benzo[a]pyrene	3.5	2.3	1.2	1.1	0.92	0.73	0.77
Indeno[1,2,3-cd]pyrene	2.5	1.5	1.1	1.1	0.87	0.79	0.86
Benzo[ghi]perylene	2.0	1.3	0.98	1.3	0.94	0.76	0.73
Coronene	2.1	1.6	1.2	1.5	1.1	0.94	0.93
MAXIMUM							
Quinoline	NC	NC	NC	NC	NC	NC	NC
Acenaphthylene	20	5.1	16	31	1.9	9.2	3.7
Phenanthrene	7.8	3.5	6.7	63	4.3	4.1	2.6
Anthracene	13	3.3	2.6	16	2.2	37	2.8
Fluoranthene	8.3	1.6	3.0	23	1.1	2.9	0.84
Pyrene	11	2.4	5.7	11	2.0	5.4	1.5
Benzo[a]anthracene	31	2.8	3.2	52	0.92	1.9	0.59
Chrysene	21	3.6	2.7	30	0.57	1.4	0.48
Benzo[fluoranthenes	20	2.3	2.3	62	1.4	2.2	6.9
Benzo[e]pyrene	24	3.0	3.2	43	1.0	3.3	0.77
Benzo[a]pyrene	81	8.1	4.9	94	1.7	2.1	1.1
Indeno[1,2,3-cd]pyrene	29	2.5	8.0	38	1.8	6.1	3.7
Benzo[ghi]perylene	24	2.1	11	39	1.7	28	2.9
Coronene	27	2.1	21	37	3.1	26	7.0

^a Not calculated, quinoline was below the method quantifiable limit in the outdoor samples.

^b Tests were performed on the difference in means of the ln (concentration ratios) and results are reported in conjunction with geometric means.

*** Significantly different than no source category at 0.01 level.

** Significantly different than no source category at 0.05 level.

* Significantly different than no source category at 0.10 level.

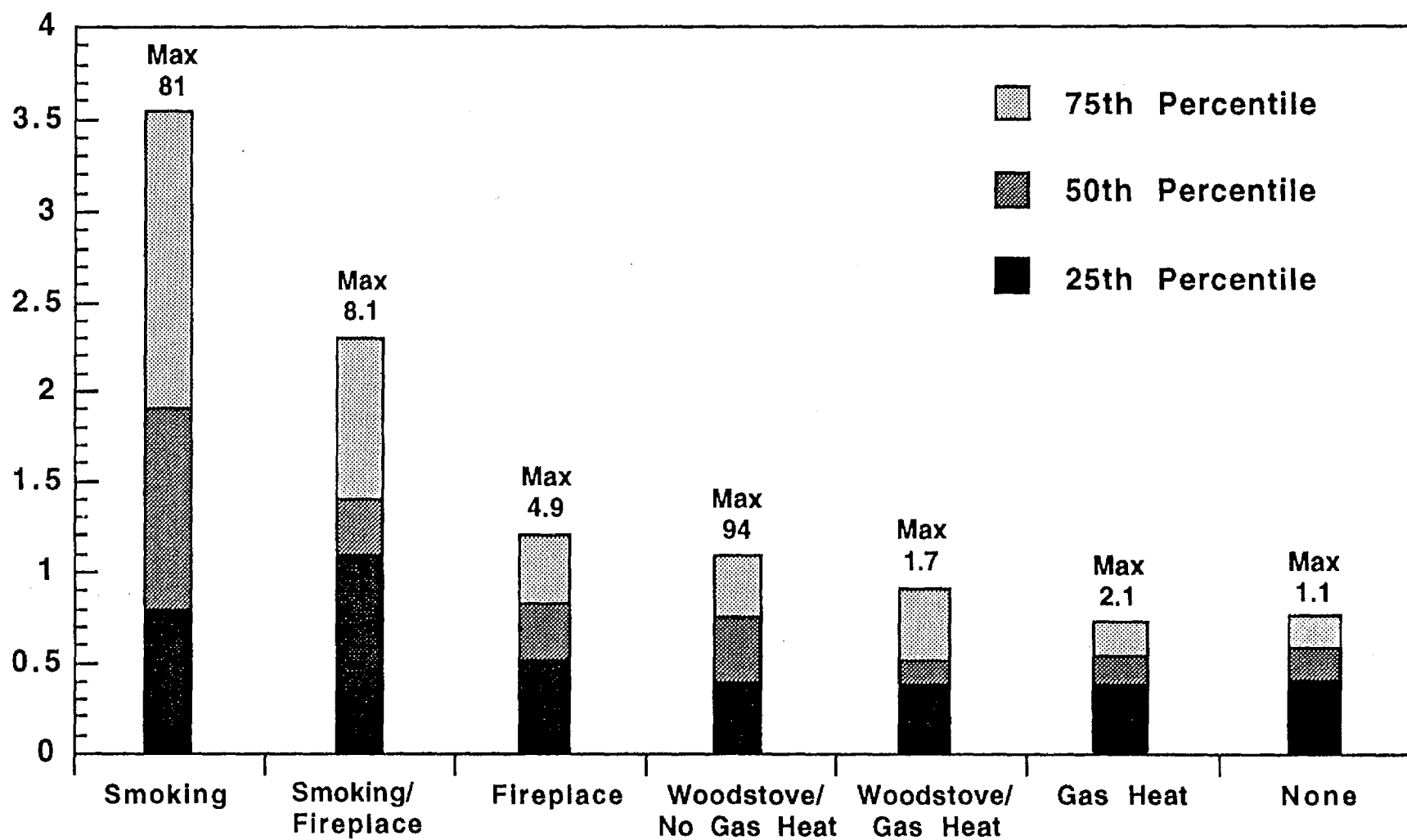


Figure 7-4. Indoor/Outdoor Air Concentration Ratios for BaP

TABLE 7-11. RELATIVE RATIOS OF INDOOR/OUTDOOR PAH CONCENTRATION RATIOS OF HOMES WITH INDOOR COMBUSTION SOURCES TO HOMES IN THE NO SOURCE CATEGORY

Compound	Relative Ratio ^a					
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat
GEOMETRIC MEAN						
Quinoline	NC ^b	NC	NC	NC	NC	NC
Acenaphthylene	XXXX	XXXX	X	X		
Phenanthrene	XX	XX				
Anthracene	XXX	XXX				XX
Fluoranthene	XXX	XX				
Pyrene	XXX	XX				
Benzo[a]anthracene	XXX	XXX	XX	X	X	
Chrysene	XXX	XXX	X			
Benzo[fluoranthenes	XXX	XX	X			
Benzo[e]pyrene	XXX	XXX	X			
Benzo[a]pyrene	XXX	XXX	XX	X		
Indeno[1,2,3-cd]pyrene	XXX	XX	X			
Benzo[ghi]perylene	XXX	XX	X	X		
Coronene	XX	XX	X	XX		
ARITHMETIC MEAN						
Quinoline	NC	NC	NC	NC	NC	NC
Acenaphthylene	XXX	XXX	XX	XX		X
Phenanthrene	XXX	XX		XXX		
Anthracene	XXX	XXX		XX		XXX
Fluoranthene	XXX	XX		XXX		
Pyrene	XXX	XX		XX		
Benzo[a]anthracene	XXXX	XXX	XXX	XXX	X	X
Chrysene	XXXX	XXX	XX	XXX		
Benzo[fluoranthenes	XXX	XX		XXX		
Benzo[e]pyrene	XXX	XXX	XX	XXX		
Benzo[a]pyrene	XXX	XXX	XXX	XXX		
Indeno[1,2,3-cd]pyrene	XXX	XX	XX	XXX		
Benzo[ghi]perylene	XXX	XX	XX	XXX		XX
Coronene	XXX		XX	XX		
50th PERCENTILE						
Quinoline	NC	NC	NC	NC	NC	NC
Acenaphthylene	XXX	XXX	XX			
Phenanthrene	XXX	XX				
Anthracene	XXX	XXX				XX
Fluoranthene	XXX	XX				
Pyrene	XXX	XX				
Benzo[a]anthracene	XXX	XXX				
Chrysene	XXX	XXX				
Benzo[fluoranthenes	XXX	XXX				
Benzo[e]pyrene	XXX	XXX		X		
Benzo[a]pyrene	XXX	XXX	X			
Indeno[1,2,3-cd]pyrene	XXX	XX				
Benzo[ghi]perylene	XXX	XX				
Coronene	XX	XX		X		

^a Indoor/outdoor concentration ratio in the source category relative to the no source category.

XXXX - Source $\geq 10X$ greater than no source.

XXX - Source 2X to 10X greater than no source.

XX - Source 1.5X to 2X greater than no source.

X - Source 1.33X to 1.5X greater than no source.

^b Not calculated; air concentration in the no source category was below the method quantifiable limit.

smoking/fireplace category may be due to the higher outdoor air concentrations (Table 7-7) due to woodburning in the home.

- (4) All target PAHs in the homes in the smoking category had significantly higher (0.01 confidence level) indoor/outdoor air concentration ratios compared to homes in the no source category. The same was true for homes in the smoking/fireplace category, except for phenanthrene, pyrene, benzo[fluoranthene], and coronene. All of these compounds showed significant differences in indoor/outdoor air concentration ratios but at a lower confidence level.
- (5) For homes in the fireplace and woodstove categories, the 4- and 5-ringed PAHs tended to show elevated indoor/outdoor air concentration ratios relative to the no source category. This effect was most pronounced for homes in the fireplace category and was not observed for homes in the woodstove/gas heat category. Again this may be due to the higher outdoor air concentration reported in this latter category (Table 7-7). It should be kept in mind that other indoor and outdoor activities could be occurring in homes in these categories that could effect the PAH concentrations and thus results are only suggesting trends caused by combustion source use.
- (6) For homes in the gas heat category, only anthracene showed significantly elevated indoor/outdoor air concentration ratios compared to homes in the no source category. For the geometric mean indoor/outdoor concentration ratios, this difference was significant at the 0.10 level.

As with indoor air concentrations, high indoor/outdoor air concentration ratios were found in homes where woodstoves were operated with the doors open or where smoke was visually observed in the home.

As mentioned above, indoor/outdoor air concentration ratios less than one suggest that PAHs in outdoor air could provide a substantial contribution to indoor air concentration even for homes with indoor combustion sources. To evaluate this effect, analyses were performed to determine the relative contribution of indoor and outdoor sources to indoor air concentrations. These relative contributions can be described by a simple mass balance (Nagda et al., 1987) equation where

$$\text{Indoor Air Concentration} = \frac{\text{Contribution of Indoor Sources}}{\text{Indoor Sources}} + \frac{\text{Contribution of Outdoor Source}}{\text{Outdoor Source}}$$

(7-1)

$$\text{that is, } C_i = \frac{SS}{Va} + fC_o$$

where

C_i is the indoor air concentration, ng/m³

SS is the source strength for indoor source, ng/h

V is the house volume, m³

a is the air exchange rate, h⁻¹

f is the fractional penetration of the outdoor air concentration

C_o is the outdoor air concentration, ng/m³

Using this equation, fC_o is equal to the contribution of outdoor sources to the indoor air concentration. Thus the fractional contribution of outdoor pollution to indoor air concentration (F_{oi}) may be calculated as

$$F_{oi} = \frac{fC_o}{C_i} \quad (7-2)$$

For each home, indoor and outdoor air concentrations were measured. Average f values were calculated for each PAH using the regression models described in Section 7.5.

The fractional contribution of indoor sources (F_{ii}) was then calculated as

$$F_{ii} = 1 - F_{io}$$

Median values for F_{io} and F_{ii} are given by source category in Table 7-12. The values for the penetration factor used for the calculations are also given. The results in this table again demonstrate the important impact of smoking on indoor PAH concentrations. For all PAHs, homes in the two smoking categories showed relatively high values for F_{ii} with highest median values (0.86) calculated for anthracene and lowest values calculated for coronene (0.30).

Further inspection of the results suggests that the PAHs can be divided into two groups. For phenanthrene, anthracene, fluoranthene, and pyrene, a substantial fraction (0.40 to 0.60) of the indoor air levels results from indoor sources. This is true even for homes in

TABLE 7-12. MEDIAN OUTDOOR AND INDOOR FRACTIONAL CONTRIBUTIONS TO INDOOR PAH CONCENTRATIONS BY COMBUSTION SOURCE CATEGORY

Compound	Fractional Contribution to Indoor Air ^b							
	F ^a	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat	No Source
FROM OUTDOORS								
Acenaphthylene	0.50	0.40	0.40	0.58	0.78	0.87	0.74	1
Phenanthrene	0.46	0.27	0.39	0.60	0.53	0.72	0.46	0.60
Anthracene	0.18	0.13	0.12	0.38	0.49	0.59	0.26	0.44
Fluoranthene	0.22	0.23	0.32	0.68	0.59	0.54	0.53	0.52
Pyrene	0.24	0.22	0.29	0.57	0.49	0.48	0.41	0.44
Benzo[a]anthracene	0.23	0.27	0.32	0.82	0.74	0.83	1	0.93
Chrysene	0.22	0.19	0.22	0.87	0.77	0.87	1	0.92
Benzo[fluoranthenes	0.39	0.36	0.49	0.94	0.85	0.85	1	1
Benzo[e]pyrene	0.45	0.43	0.48	0.98	0.87	1	1	1
Benzo[a]pyrene	0.54	0.28	0.40	0.65	0.71	1	1	0.92
Indeno[1,2,3-cd]pyrene	0.64	0.44	0.58	0.86	0.87	1	1	1
Benzo[ghi]perylene	0.61	0.54	0.54	0.83	0.83	1	1	1
Coronene	0.76	0.70	0.69	0.57	0.77	0.90	1	1
FROM INDOOR SOURCES								
Acenaphthylene	0.50	0.60	0.60	0.42	0.22	0.13	0.26	0
Phenanthrene	0.46	0.73	0.61	0.40	0.47	0.28	0.54	0.40
Anthracene	0.18	0.87	0.88	0.62	0.51	0.41	0.74	0.56
Fluoranthene	0.22	0.77	0.68	0.32	0.41	0.46	0.47	0.48
Pyrene	0.24	0.78	0.71	0.43	0.51	0.52	0.59	0.56
Benzo[a]anthracene	0.23	0.73	0.68	0.18	0.26	0.17	0	0.07
Chrysene	0.22	0.81	0.78	0.13	0.23	0.13	0	0.08
Benzo[fluoranthenes	0.39	0.64	0.51	0.06	0.15	0.15	0	0
Benzo[e]pyrene	0.45	0.57	0.52	0.02	0.13	0	0	0
Benzo[a]pyrene	0.54	0.72	0.60	0.35	0.29	0	0	0.08
Indeno[1,2,3-cd]pyrene	0.64	0.56	0.42	0.14	0.13	0	0	0
Benzo[ghi]perylene	0.61	0.46	0.46	0.17	0.17	0	0	0
Coronene	0.76	0.30	0.41	0.43	0.23	0.10	0	0

^a Calculated from the regression models.

^b Calculated F_{io} values greater than 1.0 have been reported as 1. Calculated negative F_{ii} values have been reported as zero.

the no source category. This result implies that there is an unidentified indoor source for these 3- and 4-ringed PAHs. Similar findings for these gas phase PAHs were reported by Offerman et al. (1990). F_{ii} values for these compounds in homes in the woodburning and fireplace categories show little elevation compared to F_{ii} values in the no source categories. For anthracene, there was an increase in the median F_{ii} values for homes in the gas heat category compared to homes in the no source category. It should be noted that the regression models did not work well for these four compounds and, therefore, the f values used in the calculation may not be correct.

Results for the remaining PAHs show high F_{io} values indicating that the largest source for PAHs in the homes is infiltration of air from outdoors. This is true for homes in the no source, gas heat, fireplace, and woodstove categories. Among these homes, the woodstove category showed the highest fractional contribution from indoor sources with BaP giving the highest F_{ii} value. The F_{ii} value for acenaphthylene was 0.25 in gas heat homes indicating some contribution to indoor air concentrations from this source.

BaP concentrations were further analyzed to assess potential health impact. BaP is a carcinogen and is currently under consideration by ARB as a toxic air contaminant. It has been estimated that an air concentration of 0.3 ng/m^3 over a 70-year exposure period will result in a 10^{-6} excess cancer risk (Offerman et al., 1990). The California Office of Environmental Health Hazard Assessment has set a preliminary unit risk for BaP as 1.1×10^{-3} per $\mu\text{g/m}^3$. This unit risk value implies that exposure to an air concentration of 0.9 ng/m^3 over 70 years would give 10^{-6} excess cancer risk.

Table 7-13 shows the percentage of indoor and outdoor air samples of each source category that exceeds the 0.3 and 0.9 ng/m^3 concentrations. Percentages of samples that exceed the 2.5 and 5.0 ng/m^3 levels have also been given. Results show that a substantial fraction of the population in this study may be exposed to BaP concentrations above the 0.3 or 0.9 ng/m^3 level especially in homes where smoking occurs.

7.4 SOURCE STRENGTH STATISTICS

Although indoor air concentration should be a useful variable for assessing the effect of combustion sources on PAH exposure data, other variables such as source strength may provide more precise data for exposure estimates. The relationship between indoor and outdoor air concentrations is defined as (Nagda et al., 1987)

TABLE 7-13. PERCENT OF AIR SAMPLES WITH BaP CONCENTRATION
EXCEEDING SELECTED LEVELS

Source Category	Percent			
	$\geq 0.3 \text{ ng/m}^3$	$\geq 0.9 \text{ ng/m}^3$	$\geq 2.5 \text{ ng/m}^3$	$\geq 5.0 \text{ ng/m}^3$
INDOOR AIR SAMPLES				
Smoking	95.6	60.0	31.1	4.4
Smoking/Fireplace	92.3	61.5	7.7	0.0
Fireplace	60.3	25.9	13.8	3.4
Woodstove	64.0	34.0	10.0	0.0
Woodstove/Gas Heat	77.3	36.4	9.1	0.0
Gas Heat	51.1	24.4	4.4	0.0
No Source	57.6	27.3	9.1	0.0
OUTDOOR AIR SAMPLES				
Smoking	59.1	40.9	18.2	6.8
Smoking/Fireplace	64.3	57.1	14.3	0.0
Fireplace	52.5	26.2	13.1	1.6
Woodstove	72.5	41.2	15.7	2.0
Woodstove/Gas Heat	100	59.1	18.2	4.5
Gas Heat	53.3	40.0	11.1	2.2
No Source	69.7	42.4	18.2	3.0

$$SS = mV (a + k) C_i - mVfaC_o \quad (7-3)$$

where:

SS	=	source strength, ng/h
V	=	house volume, m ³
m	=	air mixing between zones
a	=	air exchange rate, h ⁻¹
k	=	pollutant decay rate, h ⁻¹
C _i	=	indoor concentration, ng/m ³
f	=	fractional penetration of outdoor concentration
C _o	=	outdoor concentration, ng/m ³

For this analysis, 24-hour time-weighted source strength values were computed for each pollutant in each home by using the 24-hour time-weighted measurement values C_i, C_o, and a. However, these calculations require that assumptions be made about m, k, and f. In the simplest case, m is set equal to one (complete mixing) and k is set equal to zero (no pollutant decay). Under these conditions equation 7-3 becomes

$$SS = Va(C_i - f VaC_o), \text{ or}$$

$$SS = Va(C_i - f C_o) \quad (7-4)$$

Average f values generated during modeling (Section 7.5) were used for the source strength calculations here. Univariate statistics for calculated source strengths are given in Table 7-14 by combustion source category. Median source strengths values generated for BaP are summarized graphically in Figure 7-5. Since the calculated source strength for some homes was zero or a negative value, geometric means for the source strength term could not be calculated.

It should be understood that the simplifying assumptions used here (i.e., m = 1 and k = 0) may result in inaccuracies to the source strength calculations for each home. For example, if mixing is not uniform throughout the home (m≠0), then the calculation of source strengths from measured PAHs concentrations in a home will depend upon the mixing pattern as well as the location of the combustion source and the indoor air monitor. The

TABLE 7-14. SUMMARY STATISTICS FOR INDOOR PAH SOURCE STRENGTHS
BY COMBUSTION SOURCE CATEGORY

Compound	Source Strength (ng/h)						
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove /Gas Heat	Gas Heat	No Source
ARITHMETIC MEAN							
Acenaphthylene	3300 ^{***a}	5200 ^{***}	2400	670	430	330	150
Phenanthrene	5200 ^{***}	6100 ^{***}	3900	1400	1400	1800	1200
Anthracene	570 ^{***}	770 ^{***}	430	120	93	61 [*]	171
Fluoranthene	730 ^{***}	700 ^{***}	510	120	170 [*]	83	82
Pyrene	630 ^{***}	840 ^{***}	510	140	190	120	100
Benzo[a]anthracene	180 ^{***}	230 ^{***}	100	19	16	0.0	6.8
Chrysene	280 ^{***}	310 ^{***}	140	19	21	0.0	10
Benzo[fluoranthenes	380 ^{***}	720 ^{***}	280	66	62	0.0	39
Benzo[e]pyrene	100 ^{***}	160 ^{***}	65	16	7.5	0.0	4.7
Benzo[a]pyrene	210 ^{***}	360 ^{***}	140	40	24	0.0	19
Indeno[1,2,3-cd]pyrene	230 ^{***}	330 ^{***}	160 [*]	51	33	0.0	21
Benzo[ghi]perylene	160 ^{***}	240 ^{***}	140 [*]	52	31	0.0	20
Coronene	98 ^{***}	140 ^{***}	120	52	45	5.8	34
50th PERCENTILE							
Acenaphthylene	2100	3900	650	320	79	300	14
Phenanthrene	3200	4300	1100	900	640	920	1600
Anthracene	404	680	78	52	94	110	46
Fluoranthene	320	450	67	78	100	78	70
Pyrene	340	340	120	120	140	130	96
Benzo[a]anthracene	68	160	6.2	4.5	8.0	0.0	0.35
Chrysene	150	310	7.4	6.9	7.4	0.0	1.1
Benzo[fluoranthenes	200	430	11	10	27	0.0	0.0
Benzo[e]pyrene	60	120	2.4	1.8	0.0	0.0	0.0
Benzo[a]pyrene	120	240	21	11	0.0	0.0	3.6
Indeno[1,2,3-cd]pyrene	151	220	23	13	0.0	0.0	0.0
Benzo[ghi]perylene	100	120	29	23	0.0	0.0	0.0
Coronene	40	81	23	19	13	0.0	0.0
MAXIMUM							
Acenaphthylene	26000	18000	45000	12000	6600	3700	6000
Phenanthrene	28000	24000	55000	16000	7400	9800	6900
Anthracene	3100	2300	8400	1500	520	1900	470
Fluoranthene	4600	2300	13000	2800	590	610	610
Pyrene	4200	4200	12000	2300	530	440	880
Benzo[a]anthracene	1300	1200	2900	630	150	60	170
Chrysene	2000	940	4200	700	230	83	250
Benzo[fluoranthenes	2300	3200	7000	1400	510	860	880
Benzo[e]pyrene	560	740	1500	410	78	42	193
Benzo[a]pyrene	990	1800	2500	990	230	50	440
Indeno[1,2,3-cd]pyrene	910	1700	2800	1200	340	450	370
Benzo[ghi]perylene	670	1200	2200	660	330	310	460
Coronene	800	510	2200	530	360	670	730

^a Tests were only performed on the arithmetic mean.

^{***} Significantly different than no source category at 0.01 level.

^{**} Significantly different than no source category at 0.05 level.

^{*} Significantly different than no source category at 0.10 level.

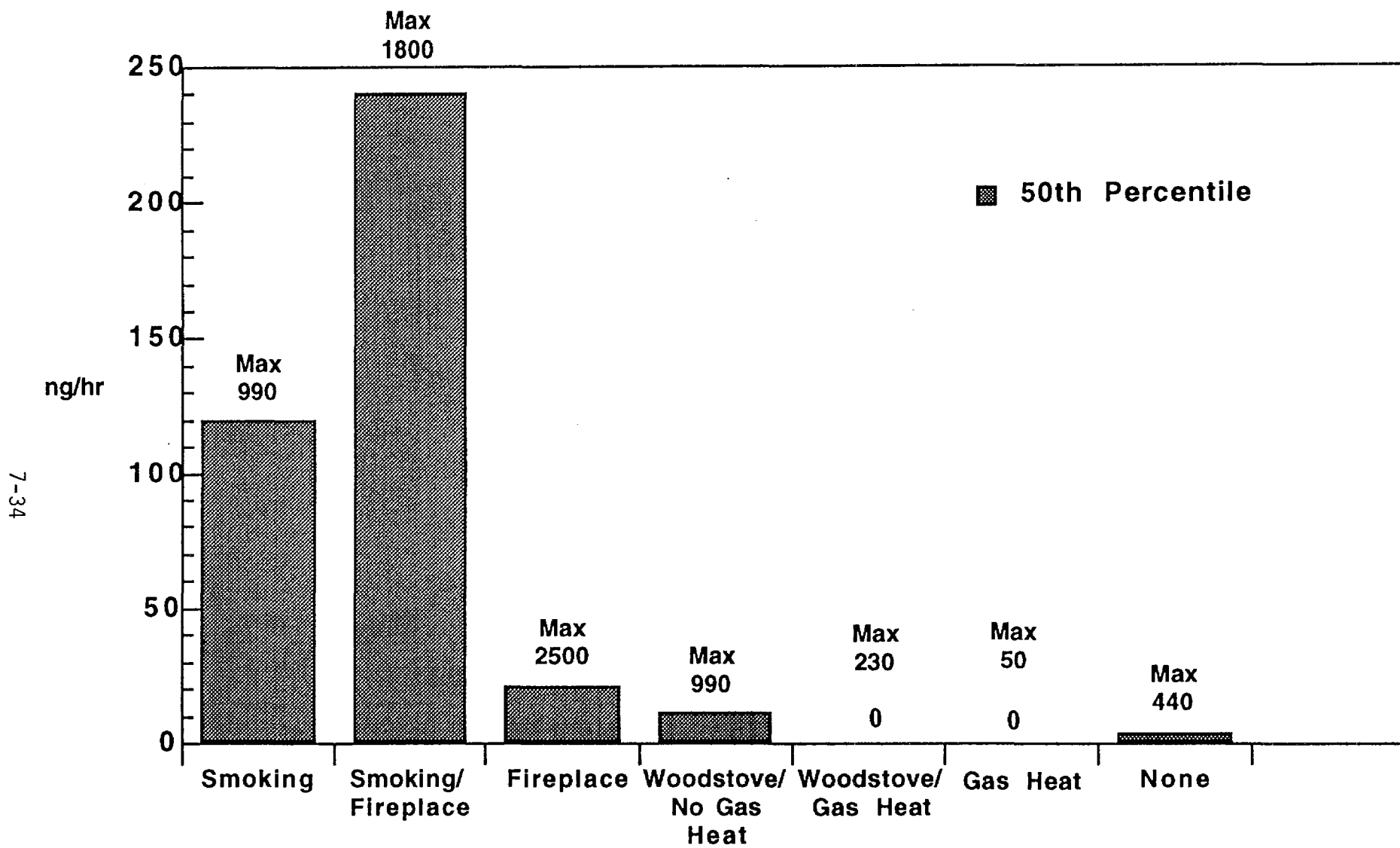


Figure 7-5. BaP Source Strengths by Combustion Source Category (ng/h)

magnitude of the calculated source strengths will be directly proportional to the magnitude of the mixing term. If mixing is actually 0.5 (rather than 1, as assumed), then the calculated source strength would be doubled. As a second source of error, a decay rate of zero ($k=0$) may underestimate the calculated source strength values if indoor pollutant decay actually occurs. The relative magnitude of this error will depend upon the ratio of the actual decay rate to the air exchange as well as the outdoor concentration and assumptions about penetration factors. Finally, estimates for penetration factors could add uncertainty to the calculated source strength term. For example, penetration factors that are larger than those estimated here would result in smaller source strength values. The penetration factors estimated from the regression modeling are similar to penetration factors estimated previously by Sheldon et al. (1992) and Traynor et al. (1987). As a result of these potential inaccuracies in the source strength calculation, negative values may occur for some homes. The use of the average estimated penetration factors (f) in each home may also result in negative source strength values due to the fact that f values in individual homes will vary and should be distributed around the average value.

To investigate the effect of various combustion sources on PAH source strengths, t-tests were performed between the category of homes with no sources and the six source categories. Tests were performed using arithmetic mean air concentrations. Differences in source strengths that are significantly different than zero at the 0.01, 0.05, and 0.10 level are shown on Table 7-14. To further evaluate source strength differences between categories, the ratio of the source strength term for homes in the source and no source categories was calculated for each target PAH. The magnitude of these ratios is shown in Table 7-15 for the arithmetic and median values.

The results for source strengths show many of the same trends as reported for the air concentration data.

- (1) Highest source strengths among PAHs were calculated for the more volatile PAHs, especially acenaphthylene and phenanthrene.
- (2) For acenaphthylene, phenanthrene, anthracene, fluoranthene, and pyrene, relatively high source strength values were calculated for homes in the no source category, again suggesting that there is a relatively important unidentified indoor source for these volatile PAHs.

TABLE 7-15. RELATIVE RATIOS OF INDOOR SOURCE STRENGTHS TO NO SOURCE
CATEGORY SOURCE STRENGTHS

Compound	Relative Source Strength Ratio ^a					
	Smoking	Smoking/ Fireplace	Fireplace	Woodstove	Woodstove/ Gas Heat	Gas Heat
ARITHMETIC MEAN						
Acenaphthylene	XXXX	XXXX	XXXX	XXX	XXX	XXX
Phenanthrene	XXX	XXX	XXX			XX
Anthracene	XXX	XXX	XXX			
Fluoranthene	XXX	XXX	XXX	X	XXX	
Pyrene	XXX	XXX	XXX	X	XX	
Benzo[a]anthracene	XXX	XXX	XXX	XXX	XXX	
Chrysene	XXXX	XXXX	XXXX	XX	XXX	
Benzofluoranthenes	XXX	XXXX	XXX	XX	XX	
Benzo[e]pyrene	XXX	XXX	XXX	XXX	XX	
Benzo[a]pyrene	XXXX	XXXX	XXX	XXX		
Indeno[1,2,3-cd]pyrene	XXXX	XXXX	XXX	XXX	XX	
Benzo[ghi]perylene	XXX	XXXX	XXX	XXX	XX	
Coronene	XXX	XXX	XXX	X		
50th PERCENTILE						
Acenaphthylene	XXXX	XXXX	XXXX	XXXX	XXX	XXXX
Phenanthrene	XXX	XXX				
Anthracene	XXX	XXXX	XX		XXX	XXX
Fluoranthene	XXX	XXX			X	
Pyrene	XXX	XXX	X	X	X	X
Benzo[a]anthracene	XXXX	XXXX	XXXX	XXXX	XXXX	
Chrysene	XXXX	XXXX	XXX	XXX	XXX	
Benzofluoranthenes	NC ^b	NC	NC	NC	NC	NC
Benzo[e]pyrene	NC	NC	NC	NC	NC	NC
Benzo[a]pyrene	XXXX	XXXX	XXX	XXX		
Indeno[1,2,3-cd]pyrene	NC	NC	NC	NC	NC	NC
Benzo[ghi]perylene	NC	NC	NC	NC	NC	NC
Coronene	NC	NC	NC	NC	NC	NC

^a Source strength of source category relative to no source category.

XXXX - Source $\geq 10X$ greater than no source.

XXX - Source $2X$ to $10X$ greater than no source.

XX - Source $1.5X$ to $2X$ greater than no source.

X - Source $1.33X$ to $1.5X$ greater than no source.

^b Not calculated since source strength value of the no source category was zero.

- (3) Homes in the smoking category showed very high source strengths for all of the PAHs. The arithmetic mean source strengths for homes in the two smoking categories were significantly greater than those for homes in the no source category at the 0.01 level. As shown in Table 7-15, the PAH source strengths for homes in the smoking categories were two to ten times higher than for homes in the no source category. Source strengths calculated for coronene in homes in the two smoking categories were lower than for the other PAHs suggesting that tobacco smoking is a weaker source for this pollutant than the other PAHs.
- (4) Homes in the fireplace and woodstove categories had substantially elevated source strengths compared to homes in the no source category although this difference was only significant (0.10 level) for indeno[1,2,3-cd]pyrene and benzo[ghi]perylene in homes with fireplaces.
- (5) For homes in the gas heat category, only acenaphthylene showed both elevated mean and median source strengths compared to homes in the no source category.

7.5 MODELS FOR FACTORS THAT AFFECT AIR CONCENTRATIONS

7.5.1 Statistical Model

The overall objective of the statistical modeling was to identify and quantify the factors associated with various combustion sources that influence indoor PAH air concentrations. One approach for modeling concentration data is to perform an analysis of variance using source categories like those shown above. Such an approach would allow average effects due to the source categories to be estimated. However, like the t-tests described in the prior subsections, it would ignore the fact that combustion sources may be used at differing rates by different households within the same source category and also that other combustion sources may be present (kerosene heaters, gas water heaters, cooking-related activities). An alternative statistical modeling approach was therefore adopted that allowed us to evaluate the impact of individual combustion sources on indoor PAH air concentrations and to estimate emissions from the most important sources.

The underlying statistical model was derived by extending the concept of source strength (SS) for a single source in a single home to emissions from one or more sources in a group of homes. In these models, source strengths provide information on the rate

pollutants are generated in a home regardless of the source. Emissions, on the other hand, are linked to sources and provide information on the rate pollutants are generated for a specific pollutant source. Depending upon the combustion source, three types of emission terms can be described. These include emission rates (ER), emission factors (EF), and emission strengths (ES). Emission rates are calculated based on time of use of a combustion source and are applied to sources such as woodstoves, fireplaces, and combustion appliances where use is usually defined by hours used per day. Emission factors are calculated based on unit consumed and are generally applied to cigarettes and other tobacco products. Emission strengths are used when the presence or absence of a source is indicated but not the rate of use.

For a set of houses known to have a single source of PAHs, the relationship between source strength and an "average" emission parameter (β) for a given combustion source is equal to:

$$SS_i = \beta U_i + \epsilon_i \quad (7-5)$$

where SS_i is the source strength for the i^{th} house, U_i is a measure of the average usage of the combustion source over the monitoring period, and ϵ_i is a random deviation for the i^{th} house. The deviation (ϵ_i) occurs as a result of house-to-house variability, day-to-day variability, and measurement error. The best way to estimate the emission parameter (β) depends on the distributional structure of the errors (ϵ_i). It should also be noted that the precision with which β can be estimated is a function of both the magnitude and structure of the error variances and the distribution of combustion source usage (U_i) occurring in homes on the day of monitoring.

Conceptually, model (7-5) can be extended to homes with multiple combustion sources as:

$$SS_i = \beta_1 U_{1i} + \beta_2 U_{2i} + \dots + \beta_p U_{pi} + \epsilon_i \quad (7-6)$$

where SS_i is the source strength for the i^{th} house, U_{ji} is a measure of combustion source usage for the j^{th} combustion source ($j=1,2,\dots,p$) and i^{th} house, and β_j is the "average" emission parameter associated with the j^{th} combustion source. The precision with which the model parameters can be estimated depends on the error variability (ϵ_i) and on the joint distribution of the various combustion source usages (U) that occur on the day of monitoring.

A statistical model for relating indoor PAH concentrations to outdoor PAH concentrations and indoor combustion sources can then be derived by replacing the source strength term (SS) in equation 7-1 with the right hand side of equation 7-6 to give

$$C_{li} = \gamma C_{Oi} + (V_i a_i)^{-1} (\beta_1 U_{1i} + \beta_2 U_{2i} + \dots + \beta_p U_{pi}) + \delta_i \quad (7-7)$$

The subscript i denotes house i and C_{li} and C_{Oi} are the indoor and outdoor air concentrations at house i. γ plays the role of the penetration factor (f) in the prior source strength equation (7-1). V_i is volume of house i, a_i is air exchange rate for house i, and δ_i is an error term. An advantage of equation 7-7 is that γ does not have to be assigned a value a priori but can be estimated from the regression model and will represent an average (over homes) penetration factor.

Estimation of models like model (7-7) via least squares is appropriate if the variability of the errors can be assumed to be constant. Usually this is not the case, and some transformation of the concentration data is needed. The magnitude of the analytical errors in measured PAH concentrations was assumed to be approximately proportional to the concentration level (i.e., errors would tend to exhibit a constant relative standard deviation). This implies that a logarithmic transformation is needed, and results in the following transformed model:

$$\ln[C_{li}] = \ln[\gamma C_{Oi} + (V_i a_i)^{-1} (\beta_1 U_{1i} + \beta_2 U_{2i} + \dots + \beta_p U_{pi})] + \delta_i \quad (7-8)$$

where the δ_i now represent the errors on a logarithmic scale. This is the basic statistical model used for analysis. During modeling, measured PAH air concentrations, air exchange rate data, measured house volumes, and questionnaire responses on source usage were used to estimate "average" emissions for various combustion sources. The model was also used to estimate an "average" penetration factor (g) for each PAH. Nonlinear least squares methods were used for estimating the penetration and emission parameters in the models. This was done by applying the SAS¹ procedure NLIN to fit the statistical models.

In developing the statistical model, it was assumed that indoor PAH decay rates were zero ($k = 0$) and air mixing was uniform ($m = 1$) in each home. Obviously, different assumptions could have been made. For example, it would have been possible to assume (rather than calculate) a penetration factor for each PAH, then to generate a model to estimate indoor PAH decay rates and source emissions. Dockerty and Spengler (1981)

¹SAS is the registered trademark of SAS Institute, Inc., Cary, NC.

calculated penetration factors for fine particle sulfate to be 0.64. Koutrakis et al. (1992) calculated penetration factors for fine particle lead to be 0.84. If all of the target PAHs were bound to the fine particulate, it might be reasonable to use similar penetration factors during model development. However, the target PAHs have a broad range of volatilities and, should partition between the vapor and particulate phases differently with correspondingly different penetration factors. Under these conditions, it was felt that there could be too much uncertainty in assuming a single penetration factor during modeling.

In the analysis of the PTEAM PAH data, Xue et al. (1993) assumed a single penetration factor for all PAHs, then estimated indoor PAH decay rates and combustion source emissions. The model used for this analysis, as well as a summary of the results, are given in Appendix R. As discussed previously, the introduction of a decay rate term, as done by Xue, will increase the calculated emission value for a combustion source. The magnitude of this increase is expected to be 50 to 100% and will depend upon the calculated decay rate, the air exchange rate, and the estimated penetration factor.

The source usage variables (U) applied in the statistical model could have been defined in a number of ways; some of these possibilities are given in Table 7-16. The right hand column of Table 7-16 defines the source usage variables in terms of the participant's responses to the 24-hour questionnaire (Appendix J). A number of statistical models using various combinations of source usage variables were tried. Performance of each of the candidate models was evaluated by examining the degree to which it accounted for the variability in measured indoor air PAH concentrations across homes. The final model selected was judged "best" in the sense that it provided a uniformly good fit (relative to the other candidate models) across the set of target PAHs. This final model form consisted of 12 source usage variables, one of which was an interaction-type term. The variables used in the final model and their definitions are listed in Table 7-17. Each of the major sources comprising the six source categories for household selection (gas heat, fireplaces, woodstoves, and tobacco smoking) are included in the final model. Usage variables associated with other combustion sources (gas water heaters gas clothes dryers kerosene heaters vehicles in a garage, and three variables associated with kitchen appliances and activities) are also included.

The units for the model emission parameters (β s) or their estimates (bs) are given in Table 7-17. The derivation of these units can be determined from equation (7-6) where the

TABLE 7-16. CANDIDATE SOURCE USAGE VARIABLES (U) FOR INDOOR PREDICTION MODEL

Variable Name and Description	Definition in Terms of Questionnaire Items ^a
GAS HEAT:	
U_1 = 1 if gas heat used; = 0 otherwise.	$I(Q8A=1)$
U_{1A} = 1 if indoor gas heat used; = 0 otherwise.	$I(Q8A=1 \text{ and } Q10F=1 \text{ or } 2)$
U_{1B} = 1 if gas heat used and system over 10 yrs old; = 0 otherwise.	$I(Q8A=1 \text{ and } Q10B>10)$
U_{1C} = 1 if gas heat used and system has pilot light; = 0 otherwise.	$I(Q8A=1 \text{ and } Q10E=1)$
FIREPLACE USE:	
U_2 = hours of fireplace use/day.	$\max(0, Q11B)$
U_{2A} = 1 if fireplace was used; = 0 otherwise.	$I(Q11B>0)$
U_{2B} = 1 if fireplace in monitoring room was used; = 0 otherwise.	$I(Q11H=1 \text{ and } Q11B>0)$
U_{2C} = 1 if a high efficiency type fireplace was used; = 0 otherwise.	$I(Q11L=1 \text{ and } Q11B>0)$
U_{2D} = hours of fireplace use in monitoring room/day.	$I(Q11H=1) * \max(0, Q11B)$
U_{2E} = hours of use of a high efficiency type fireplace/day.	$I(Q11L=1) * \max(0, Q11B)$
WOODSTOVE USE:	
U_3 = hours of woodstove use/day.	$\max(0, Q13B)$
U_{3A} = 1 if woodstove was used; = 0 otherwise.	$I(Q13B>0)$
U_{3B} = 1 if woodstove in monitoring room was used; = 0 otherwise.	$I(Q13H=1 \text{ and } Q13B>0)$
U_{3C} = hours of woodstove use in monitoring room/day.	$I(Q13H=1) * \max(0, Q13B)$
U_{3D} = estimated hours of woodstove use with open doors/day.	$\max(0, Q11B) * [0.05 * I(Q13I=1) + 0.375 * I(Q13I=2) + 0.625 * I(Q13I=3) + I(Q13I=4)]$
U_{3E} = 1 if smoke from woodstove observed; = 0 otherwise.	$I(\text{woodstove mentioned in } Q35D)$
INTERACTIONS OF GAS HEAT WITH FIREPLACE AND WOODSTOVE USE:	
$U_4 = U_1 * U_2$ = hours of fireplace use/day for homes with gas heat.	
$U4A = U1 * U3$ = hours of woodstove use/day for homes with gas heat.	

(continued)

TABLE 7-16. (continued)

Variable Name and Description	Definition in Terms of Questionnaire Items ^a
GAS WATER HEATER:	
$U_5 = 1$ if indoor gas water heater; = 0 otherwise.	$I(Q19A=1 \text{ and } Q19D=1 \text{ or } 2)$
$U_{5A} = 1$ if gas water heater; = 0 otherwise.	$I(Q19A=1)$
TOBACCO SMOKING:	
$U_6 =$ number of cigarettes (or equivalent) smoked/day. (1 pipeful = 3.33 cigarettes; 1 cigar = 10 cigarettes)	$+3.333 * \max(0, Q32)$
$U_{6A} = 1$ if tobacco smoked; = 0 otherwise.	$I(\max(Q30, Q31, Q32) > 0)$
GAS CLOTHES DRYER:	
$U_7 = 1$ if gas clothes dryer used in the home including in an attached garage or an attached shed; = 0 otherwise.	$I(Q17=1 \text{ or } 2)$
KITCHEN:	
$U_8 = 1$ if monitoring in kitchen or adjacent open room and constantly burning pilots on gas stove/oven or 10+ minutes of burner operation; = 0 otherwise.	$I(Q41=1 \text{ or } 2 \text{ and } (Q21C=3 \text{ or } Q22D=3 \text{ or } Q21D+Q22F \geq 10))$
$U_9 = 1$ if monitoring in kitchen or adjacent open room and grilling or uncovered frying; = 0 otherwise.	$I(Q41=1 \text{ or } 2 \text{ and } (Q28C > 0 \text{ or } Q28D > 0 \text{ or } Q28G > 0))$
$U_{10} = 1$ if monitoring in kitchen or adjacent open room; = 0 otherwise.	$I(Q41=1 \text{ or } 2)$
$U_{8A} =$ time grill on (minutes) with monitoring in kitchen or adjacent open room.	$I(Q41=1 \text{ or } 2) * \max(0, Q28C)$
$U_{9A} =$ time of grilling or uncovered frying (minutes) with monitoring in kitchen or adjacent open room.	$I(Q41=1 \text{ or } 2) * (\max(0, Q28D) + \max(0, Q28G))$
VEHICLES:	
$U_{11} = 1$ if vehicles run in an attached garage or underneath parking area; = 0 otherwise.	$I(Q5=1)$
KEROSENE HEATER:	
$U_{12} = 1$ if kerosene heater used in monitoring room; = 0 otherwise.	$I(Q14A=1 \text{ and } Q14C=1)$

^a The function $I(\text{statement})$ has a value of 1 if the statement is true and a value of 0 if it is false.

TABLE 7-17. SOURCE USAGE VARIABLES (U) USED IN INDOOR PREDICTION MODEL

Source Use Variable (U) and Description	Estimated Model Parameter	
	Designation	Units
C_o = outdoor concentration (ng/m^3)	g	-
U_1 = 1 if gas heat used; = 0 otherwise	b1	ng/h
U_2 = hours of fireplace use/day	b2	(ng/h)/(h FP use/day)
U_3 = hours of woodstove use/day	b3	(ng/h)/(h WS use/day)
U_4 = $U_1 \cdot U_2$ = hours of fireplace use/day for homes with gas heat use; = 0 otherwise	b4	(ng/h)/(h FP use/day)
U_5 = 1 if indoor gas water heater; = 0 otherwise	b5	ng/h
U_6 = no. cigarettes (or equivalent) ^a smoked/day	b6	(ng/h)/(cigarette/day)
U_7 = 1 if gas clothes dryer used; = 0 otherwise	b7	ng/h
U_8 = 1 if monitoring in kitchen or adjacent open room and constantly burning pilots on gas stove/oven or 10+ min. of burner operation; = 0 otherwise	b8	ng/h
U_9 = 1 if monitoring in kitchen or adjacent room and grilling or uncovered frying; = 0 otherwise	b9	ng/h
U_{10} = 1 if monitoring in kitchen or adjacent open room; = 0 otherwise	b10	ng/h
U_{11} = 1 if vehicles run in an attached garage or underneath parking area; = 0 otherwise	b11	ng/h
U_{12} = 1 if kerosene heater used in monitoring room; = 0 otherwise	b12	ng/h

^aOne pipeful of tobacco was equated to 3.33 cigarettes; one cigar to 10 cigarettes.

units associated with a given emission estimate (b_j) are the source strength units (i.e., ng/h) divided by the units associated with the corresponding usage variable:

$$b_j = \frac{SS(ng/h)}{U_j(units)} \quad (7-9)$$

When the combustion source usage variable (U_j) is an indicator variable (i.e., present or absent in the home), the corresponding emission estimate (b_j) has units equal to ng/h. As shown in Table 7-17, this is the case for most of the emission estimates in the final model. These emission estimates are directly equal to emission strengths for the combustion source.

The usage variable for woodstoves (U_3) is the number of hours of woodstove use (during the day of monitoring), therefore, the units for the corresponding emission parameter (b_3) are ng/h per h of woodstove use/day. This emission parameter is proportional to an emission rate (ER) for woodstoves which may be calculated as:

$$\text{Woodstove ER} = 24(\text{h/day}) * b_3[(\text{ng/hr})/(\text{hr of woodstove use/day})]$$

or

$$= 24 * b_3 \text{ ng/hr of woodstove use}$$

For fireplaces, the emission parameters are b_2 and b_4 . At least for cases in which b_4 is non-negligible, the model implies that homes using and not using gas heat will have different fireplace (FP) emission rates that can be calculated as:

$$\text{Fireplace ER for homes not using gas heat} = 24 * b_2 \text{ ng/hr of FP use}$$

and

$$\text{Fireplace ER for homes using gas heat} = 24 * (b_2 + b_4) \text{ ng/hr of FP use.}$$

For tobacco smoking, the emission parameter is b_6 , which has units of ng/hr per cigarette (or equivalent) per day. This emission parameter is proportional to an emission factor (EF) for cigarettes that can be calculated as:

$$\text{Tobacco smoking EF} = 24 (\text{hrs/day}) * b_6[(\text{ng/hr})/(\text{cigarette/day})]$$

$$= 24 * b_6 \text{ ng/cigarette}$$

7.5.2 Estimates of Indoor Model Parameters

The emission parameters (b) and penetration factors (g) estimated by the final statistical model are given in Appendix N for each PAH. Asymptotic standard errors (column 4 of Table N-1) and 95% confidence limits are also included for each estimate. These

modeling results are summarized in Tables 7-18 to 7-20. Table 7-18 gives the average emissions for each combustion source reported as emission strengths, emission factors or emission rates. These emission estimates were calculated from the corresponding emission parameters (Table N-1)

as described above. Table 7-19 indicates, by compound, the total variability in the logarithms of the indoor concentrations (total uncorrected and total corrected sums of squares), and indicates the amount of residual variation (model residual) and the amount of variability in indoor air concentration accounted for by the final model (%Var). Table 7-20 shows the value of the estimated penetration factor. It also shows the effect and statistical significance of each combustion source on indoor air concentrations. If combustion source use was associated with an increase in indoor PAH concentrations, then the sign in the table is positive (+). Conversely, the sign is negative (-) if combustion source use was associated with a decrease in indoor PAH concentrations. The last column in Table 7-20 (% VAR) shows how much of the total variability in the indoor concentration was accounted for by the model. For the less volatile PAHs (benzo[a]anthracene to coronene), the model performed well in describing the variability in indoor air concentrations. For BaP, 78.7% of the variability was accounted for.

Results from the model shows that the estimated penetration factor is statistically significant for every compound. This confirms that PAHs from the outdoors provide a substantial contribution to indoor air concentrations. The patterns for significance for the modeled combustion sources indicate that the number of cigarettes smoked and the number of hours of fireplace use are important parameters that are associated with elevated indoor air concentrations for all of the PAHs. Number of hours of woodstove use is an important parameter that is associated with elevated indoor air concentrations for the higher molecular weight PAHs. Gas heat use appeared to be associated with elevated concentrations of the lower molecular weight PAHs. The effect of kerosene heaters on indoor air concentrations appears to be large (emission strength = 280 ng/h for BaP); however, due to the small number of homes with this source (six homes, all in Placerville), the precision of this emission estimate is poor. These modeling results are generally consistent with the air concentration and source strength data discussed previously that show a very strong impact of cigarette smoking on indoor air PAH concentrations with weaker effects for fireplaces and woodstoves.

TABLE 7-18. AVERAGE EMISSION ESTIMATES RESULTING FROM THE INDOOR MODEL

Compound	Emission Source ^a											
	GH	FP	WS	FP&GH	GWH	CIG	GCD	GSt	FOOD	KIT	VEH	KER
	Emission Term ^b :	ES	ER	ER	ER	ES	EF	ES	ES	ES	ES	ES
	Units:	ng/h	ng/h of FP use	ng/h of WS use	ng/h of FP use	ng/h	ng/cigarette	ng/h	ng/h	ng/h	ng/h	ng/h
Acenaphthylene	13	1200	420	-4400	-110	1900	300	-280	150	18	700	5500
Phenanthrene	590	3600	790	-890	-110	2300	-730	610	-110	810	360	2200
Anthracene	46	290	40	-8.3	8.2	350	-33	1.4	-19	52	0.50	54
Fluoranthene	35	390	130	-18	-5.3	290	-12	11	17	52	-2.0	500
Pyrene	49	500	150	16	-2.1	240	-13	-3.5	8.6	75	13	430
Benzo[a]anthracene	5.2	82	8.6	29	2.5	83	-0.4	-3.6	-5.8	0.71	-3.7	130
Chrysene	7.6	94	8.4	16	4.2	160	1.5	-1.2	-7.8	0.21	-6.3	140
Benzo[fluoranthenes	-3.8	270	6.2	160	3.4	200	19	-0.08	-18	-3.6	10	580
Benzo[e]pyrene	2.0	51	3.6	77	-2.0	65	8.1	-1.0	-3.4	-2.6	1.2	130
Benzo[a]pyrene	0.86	89	17	190	-1.6	130	5.1	3.0	-4.4	0.79	2.5	280
Indeno[1,2,3-cd]pyrene	19	150	33	400	8.1	150	1.0	-30	-11	-5.3	0.23	360
Benzo[ghi]perylene	4.3	120	24	230	-0.64	90	43	-1.3	-12	-3.5	15	270
Coronene	1.1	99	22	200	-0.95	48	36	-6.0	-7.2	-1.2	14	150

^a GH-gas heat, FP-fireplace, WS-woodstove, FP&GH - gas heat and fireplace, GWH=gas water heater, CIG - cigarettes, GCD - gas clothes dryer, GSt - gas stove, FOOD-food grilled or fried uncovered, KIT - monitoring in kitchen; VEH - vehicle running in garage; KER - kerosene heater.

^b ES - emission strength, ER - emission rate, EF - emission factor.

TABLE 7-19. INDOOR MODEL ESTIMATION SUMMARY

Compound	n ^a	Mean of Indoor ln(conc)	Sums of Squares			%Var ^b	Residual Standard Deviation
			Total Uncorrected	Total Corrected	Model Residual		
Acenaphthylene	229	2.2078	1485.16	368.88	174.78	52.6	0.8995
Phenanthrene	243	2.9318	2164.38	75.69	94.41	-24.7	0.6407
Anthracene	243	0.0129	214.25	214.21	174.91	18.3	0.8721
Fluoranthene	257	0.5110	207.44	140.33	111.25	20.7	0.6752
Pyrene	255	0.6138	200.79	104.72	99.29	5.2	0.6405
Benzo[a]anthracene	256	-1.4404	927.45	396.32	123.80	68.8	0.7138
Chrysene	255	-1.0410	640.29	363.94	103.46	71.6	0.6539
Benzo[fluoranthene]	249	0.0132	304.41	304.37	80.76	73.5	0.5850
Benzo[e]pyrene	255	-1.1595	620.43	277.57	67.05	75.8	0.5264
Benzo[a]pyrene	252	-0.6176	455.53	359.40	76.51	78.7	0.5658
Indeno[1,2,3-cd]pyrene	253	0.0433	281.47	280.99	81.52	71.0	0.5828
Benzo(ghi)perylene	257	-0.1278	216.03	211.83	66.46	68.6	0.5219
Coronene	256	-0.4008	271.33	230.22	88.33	61.6	0.6029

^a Number of homes.

^b %Var = (1-residual sum of squares (model)/total corrected sum of squares)x100%
= percentage of total variation of indoor ln(conc) accounted for by the model.

TABLE 7-20. STATISTICAL SIGNIFICANCE OF INDOOR COMBUSTION SOURCES ON INDOOR AIR PAH CONCENTRATION -
INDOOR MODEL PARAMETERS^a

Compound	g ^c	Statistical Significance ^b												%Var ^d
		b1 (GH)	b2 (FP)	b3 (WS)	b4 (FP&GH)	b5 (GWH)	b6 (CIG)	b7 (GCD)	b8 (GSt)	b9 (FOOD)	b10 (KIT)	b11 (VEH)	b12 (KER)	
Acenaphthylene	0.50	+	+	+++	----	-	++++	+	----	+	+	++++	+	52.6
Phenanthrene	0.46	++++	+++	+	-	-	++++	--	+	-	++++	+	+	<0.0
Anthracene	0.18	++++	+++	+	-	+	++++	-	+	-	++++	+	+	18.3
Fluoranthene	0.22	++	++++	++++	-	-	++++	-	+	+	++++	-	+	20.7
Pyrene	0.24	++++	++++	++++	--	-	++++	-	-	+	++++	+	+	5.2
Benzo(a)anthracene	0.23	++++	++++	+++	-	+	++++	-	----	----	+	----	+	68.8
Chrysene	0.22	++++	++++	+	--	+++	++++	+	-	----	+	----	+	71.6
Benzofluoranthenes	0.39	-	++++	+	-	+	++++	+	-	----	-	+	++	73.5
Benzo(e)pyrene	0.45	+	++++	+	+	-	++++	+++	-	-	----	+	++	75.8
Benzo(a)pyrene	0.54	+	++++	+++	+	-	++++	+	+	-	+	+	++	78.7
Indeno[1,2,3-cd]pyrene	0.64	++++	++++	+++	+	+	++++	+	----	-	-	+	+	71.0
Benzo(ghi)perylene	0.61	+	++++	+++	+	-	++++	+++	-	-	-	++++	+	68.6
Coronene	0.76	+	++++	++++	+	-	++++	++	-	-	-	++++	+	61.6

^aParameters are defined in Table 7-17; GH-gas heat; FP-fireplace; WS-woodstove; GWH-gas water heater; CIG-cigarettes; GCD-gas clothes dryer; GSt-gas stove; FOOD-food grilled or fried uncovered; KIT-monitoring in kitchen, VEH-vehicle running in garage; KER-kerosene heater.

^bIf the sign of the parameter estimate is +, then the combustion source increases PAH concentrations; if the sign of the parameter estimate is -, then the combustion source decreases PAH concentrations.

++ or -- denotes that estimate is statistically significant at 0.10 level.

+++ or --- denotes that estimate is statistically significant at 0.05 level.

++++ or ---- denotes that estimate is statistically significant at 0.01 level.

^cEstimated penetration factors are all statistically significant at the 0.01 level.

^d%Var = percentage of total variance of ln(concentrations) accounted for by the model.

For phenanthrene, anthracene, fluoranthene, and pyrene, the models did not perform well, as evidenced by the %Var values (Appendix N), and by plots of the model residuals. As mentioned previously, there appears to be an important unidentified indoor source for these four compounds. The effect is most pronounced for phenanthrene although the reason for this is unknown. Other versions of the models [e.g., different combustion source usage variables (Us), inclusion of a constant term] were also not successful in describing the behavior for the four compounds. For most of the compounds, the fit did appear adequate, and for the major sources mentioned above, the results were quite consistent.

7.5.3 Indoor Model Performance

Two methods were used to evaluate model performance:

- For each compound, the model parameters were re-estimated using data from a randomly selected subsample of about 75% of the observations. Predictions for the remaining observations were produced, and the distribution of the deviations between observed and predicted values for this complementary subset were then summarized. (When initially attempted, the nonlinear modeling procedure failed to converge for benzo[fluoranthene]; an alternative random subset was selected for this case for which convergence was achieved.)
- For each compound, the model parameters were re-estimated separately for each of the two areas. The results were examined by comparing the estimated parameters. Also, predictions for Placerville using the estimated model from Roseville were generated (and vice versa), and compared to the observed concentrations. (The model estimation procedure failed to converge for a number of cases; although different starting values were tried, no further attempt to achieve convergence was made.)

The results of these evaluations are summarized in Table 7-21 and Table 7-22. Table 7-21 indicates the statistical significance of each emission parameter estimate on indoor air PAH concentrations, along with the direction of the effect (+ or -). The estimated value of the penetration factor is also given. The results are shown by compound and for each of the four datasets used to estimate the parameters – namely, the entire dataset (ALL), the Placerville (PLAC) subset, the Roseville subset (ROSE), and the random subset (SUBS). Note that the emission parameter for kerosene heaters (b12), is set to zero for Roseville, since none of the

TABLE 7-21. STATISTICAL SIGNIFICANCE OF INDOOR COMBUSTION SOURCES ON INDOOR AIR PAH CONCENTRATIONS - INDOOR MODEL RESULTS BY DATA SUBSETS USED FOR MODEL VALIDATION

Compound	Data Used for Estimation	g ^c	Statistical Significance											
			b1 (GH)	b2 (FP)	b3 (WS)	b4 (FP&GH)	b5 (GWH)	b6 (CIG)	b7 (GCD)	b8 (GSt)	b9 (FOOD)	b10 (KIT)	b11 (VEH)	b12 (KER)
Acenaphthylene	ALL	0.50	+ ^d	+	+++	-	-	++++	+	-	+	+	++++	+
	PLAC	0.39	+	+	+	-	-	++++	+	+	+	+	+	+
	SUBS	0.43	+	++	++	-	+	++++	-	-	-	-	+	+
Phenanthrene	ALL	0.46	++++	+++	+	-	-	++++	-	+	-	++++	+	+
	ROSE	0.55	++	+	-	-	+	++++	-	+	-	+++	+	0 ^e
	SUBS	0.47	+++	++	+	-	-	++++	-	+	-	++++	+	+
Anthracene	ALL	0.18	++++	+++	+	-	+	++++	-	+	-	++++	+	+
	SUBS	0.17	+++	+++	+	-	+	++++	-	-	-	++++	+	+
Fluoranthene	ALL	0.22	++	+++	++++	-	-	++++	-	+	+	++++	-	+
	ROSE	0.27	+	+	+	-	-	++++	+	-	-	++++	-	0
	SUBS	0.22	+	+++	++++	-	-	++++	-	-	+	++	+	+
Pyrene	ALL	0.24	++++	++++	++++	-	-	++++	-	-	+	++++	+	+
	PLAC	0.22	+	+++	++++	-	-	++++	-	+	+	++++	+	+
	ROSE	0.28	++	-	+	+	+	++++	-	-	-	++++	+	0
	SUBS	0.23	+++	++++	++++	-	-	++++	-	-	+	++++	+	+
Benzo[a]anthracene	ALL	0.23	++++	++++	+++	-	+	++++	-	-	-	+	-	+
	PLAC	0.25	+	++	-	-	-	++++	+	+	+	+	+	+
	ROSE	0.20	+++	+	+	+	+++	++++	-	-	-	+	-	0
	SUBS	0.23	++++	++++	+++	-	+	++++	-	-	-	+	-	+

(continued)

TABLE 7-21. STATISTICAL SIGNIFICANCE OF INDOOR COMBUSTION SOURCES ON INDOOR AIR PAH CONCENTRATIONS - INDOOR MODEL
RESULTS FOR BY DATA SUBSETS USED FOR MODEL VALIDATION

Compound	Data Used for Estimation	g ^c	Statistical Significance											
			b1 (GH)	b2 (FP)	b3 (WS)	b4 (FP&GH)	b5 (GWH)	b6 (CIG)	b7 (GCD)	b8 (GSt)	b9 (FOOD)	b10 (KIT)	b11 (VEH)	b12 (KER)
Chrysene	ALL	0.22	++++	++++	+	-	+++	++++	+	-	-	+	-	+
	ROSE	0.19	+++	+	+	-	++++	++++	+	+	-	+	-	0
	SUBS	0.23	++++	++++	+++	-	+++	++++	+	-	-	-	-	+
Benzo[fluoranthenes	ALL	0.39	-	++++	+	-	+	++++	+	-	-	-	+	++
	ROSE	0.32	-	+	+	+	+	++++	+	+	-	-	+	0
	SUBS	0.37	-	++++	++	-	+	++++	+	+	-	-	+	++
Benzo[e]pyrene	ALL	0.45	+	++++	+	+	-	++++	+++	-	-	-	+	++
	ROSE	0.38	+	+	+	+	-	++++	++	-	-	-	+	0
	SUBS	0.46	+	++++	+	-	.	++++	++++	-	-	-	+	+
Benzo[a]pyrene	ALL	0.54	+	++++	+++	+	-	++++	+	+	-	+	+	+
	ROSE	0.49	+	+	+++	+	-	++++	+	+	-	+	+	0
	SUBS	0.56	+	++++	+	-	-	++++	+	-	-	+	+	+
Indeno[1,2,3-cd]pyrene	ALL	0.64	++++	++++	+++	+	+	++++	+	-	-	-	+	+
	ROSE	0.63	++++	+	+	+	+	++++	+	-	-	-	+	0
	SUBS	0.65	+++	++++	++	-	+	++++	-	-	.	-	+	+
Benzo[ghi]perylene	ALL	0.61	+	++++	+++	+	-	++++	+++	-	-	-	+++	++
	PLAC	0.68	-	+	+	-	-	++++	-	-	-	-	+++	+
	ROSE	0.57	+	+	+	+	+	++++	+++	-	-	-	+	0
	SUBS	0.65	+	++++	+	-	-	++++	++++	-	.	-	+++	+

(continued)

TABLE 7-21. STATISTICAL SIGNIFICANCE OF INDOOR COMBUSTION SOURCES ON INDOOR AIR PAH CONCENTRATIONS - INDOOR MODEL RESULTS FOR BY DATA SUBSETS USED FOR MODEL VALIDATION

Compound	Data Used for Estimation	g ^c	Statistical Significance											
			b1 (GH)	b2 (FP)	b3 (WS)	b4 (FP&GH)	b5 (GWH)	b6 (CIG)	b7 (GCD)	b8 (GSt)	b9 (FOOD)	b10 (KIT)	b11 (VEH)	b12 (KER)
Coronene	SUBS	0.65	+	++++	+	-	-	++++	++++	-	.	-	+++	+
	ALL	0.76	+	++++	++++	+	-	++++	++	-	-	-	++++	+
	PLAC	0.76	-	+++	++++	-	-	++++	-	-	-	-	+++	+
	ROSE	0.77	-	+	+	+	+	++++	+++	-	-	-	+	0
	SUBS	0.78	+	+++	++	-	-	++++	++	-	-	-	+++	+

^a Parameters are defined in Table 7-17; GH-gas heat; FP-fireplace; WS-woodstove; FP/GH-FP and GH; GWH-gas water heater; CIG-cigarettes; GCD-gas cloths dryer; GSt-gas stove; FOOD-food grilled or fried uncovered; KIT-monitoring in kitchen, VEH-vehicle running in garage; KER-kerosene heater.

^b ALL=all data, PLAC=Placerville, ROSE=Roseville, SUBS=random 75% subset.

^c Estimated penetration factors, g, are all statistically significant at the 0.01 level.

^d If the sign of the parameter estimate is +, then the combustion source increases PAH concentrations; if the sign of the parameter estimate is -, then the combustion source decreases PAH concentrations.

++ or -- denotes that estimate is statistically significant at 0.10 level.

+++ or --- denotes that estimate is statistically significant at 0.05 level.

++++ or ---- denotes that estimate is statistically significant at 0.01 level.

^e No reported kerosene heater use in Roseville.

TABLE 7-22. ROOT MEAN SQUARED ERRORS (RMSEs) OF RESIDUALS [ln(ng/m³)]
BY DATA SUBSETS USED FOR MODEL VALIDATION

Compound	Percent of Variation Accounted for by the Models					RMSE x 100, By Data Used for Estimation and Data Subsets									
						E =	ALL	ALL	ALL	PLAC	PLAC	ROSE	ROSE	SUBS	SUBS
	E ^a =	ALL	PLAC	ROSE	SUBS	D =	ALL	PLAC	ROSE	PLAC	ROSE	PLAC	ROSE	SUBS	COMPL
Acenaphthylene	53	61			51		87	94	79	85	203			81	135
Phenanthrene	<0			<0	<0		62	70	54			78	52	64	58
Anthracene	18				12		85	93	76					86	85
Fluoranthene	21			23	12		66	76	54			81	52	67	65
Pyrene	5	<0	<0	<0	<0		62	72	52	71	55	85	50	64	62
Benzo[a]anthracene	69	62	69	71			70	72	67	69	84	80	66	66	80
Chrysene	72			74	75		64	67	60			73	59	60	80
Benzo[fluoranthene]	74			66	72 ^b		57	54	59			64	58	58	59
Benzo[e]pyrene	76			72	76		51	50	52			55	51	50	65
Benzo[a]pyrene	79			78	79		55	56	54			59	54	53	63
Indeno[1,2,3-cd]pyrene	71			68	72		57	51	62			55	61	54	66
Benzo(ghi)perylene	69	74	63	69			51	49	52	47	63	55	51	48	62
Coronene	62	67	60	61			59	55	62	54	67	66	60	54	72

^a E = the portion of data upon which model estimation was based. D = the portion of data over which the RMSEs of the errors (observed - predicted) were calculated. A blank indicates that convergence was not achieved. SUBS = random subset of approximately 75% of the observations; COMPL = the complementary subset.

^b An alternative random subset was used to achieve convergence.

six homes using kerosene heaters during the monitoring period were in Roseville. Table 7-22 gives, for each convergent case, the following:

- The percentage of variation in the log(indoor concentrations) accounted for by the model, which is analogous to the R^2 statistic for linear statistical models and which is defined as $100\% \times (1 - \text{SSE}/\text{CSS})$, where SSE denotes the error or residual sum of squares, and CSS denotes the corrected total sum of squares.
- The root mean squared error (RMSE), which is defined as the square root of the sum of squares of the residuals (over the particular data subset) divided by the number of such residuals. (The tabular values have been multiplied by 100 for convenience.)

Note that the RMSEs are calculated for various combinations of models and datasets. The data subset used to estimate the model parameters is denoted by E, and the subset over which the RMSE is calculated is denoted by D. When $D = E$, then $\text{RMSE} = \text{the square root of } \text{SSE}/n$, where n is the number of observations used in the estimation. When D and E are different, the RMSE is an overall measure of error incorporating both a variance (precision) component and a (squared) bias component.

In our judgment, the results of these tables provide adequate support for using the model (7-8) as a prediction model for indoor air PAH concentrations for at least eight of the thirteen PAHs -- namely, those listed last in the tables.

7.5.4 Use of the Models

The emission estimates shown in Table 7-18 and Appendix N may be of direct interest for assessing the relative importance of various indoor sources. For example, the total BaP emitted into a home by smoking 10 cigarettes in a day would be equal to the number of cigarettes smoked in a day (10) times the emission factor for cigarettes (130 ng/cigarette) or 1300 ng/day of BaP would be generated per day. Similarly the total indoor BaP emission from a fireplace burning in a home for 3 hours would be equal to hours of fireplace use per day (3) times the emission rate for fireplaces (89 ng/hr of fireplace use) or 267 ng/day. Thus, the 24-hour incremental contribution to BaP levels through smoking 10 cigarettes during a day will be about five times more than the contribution of a fireplace operating for 3 hours during a day. Such a comparison assumes that all other influences are equal, including both other indoor sources and the outdoor air concentration. This assumption may

not be valid in the case of fireplaces and woodstoves, since these may contribute to higher outdoor levels as well as higher indoor levels.

Another way to use the models is to produce predictions -- either for the purpose of estimating an indoor air concentration for a given set of circumstances (i.e., a given outdoor concentration, air exchange rate, house volume, and combination of indoor combustion source uses), or for comparing two or more sets of circumstances (e.g., homes with one combination of combustion sources used at certain rates versus homes with another combination). This approach can obviously be used to perform simulations in which input values for the model are generated according to some assumed distributions, and the model is then used to produce the resulting distribution of predicted indoor concentrations. Input variables can include outdoor air concentration (C_o), house volume (V), air exchange rate (a), mixing (m), and/or the combustion source variables (U_{ji} s) appearing in eq. (7-8). Table 7-23 furnishes information on the distributions of the combustion source usage variables (U) and on the house characteristic variables (a and V) that were observed in the study (these are unweighted statistics and are not population estimates).

To use the models to produce predictions, an outdoor concentration level must be provided. Such a value may be assigned arbitrarily; however, to provide a meaningful value requires consideration of a number of possible factors that may influence outdoor PAH concentrations. These include the home's location (town, proximity to traffic), weather conditions, amount of woodburning by both the resident and his/her neighbors, etc. As an aid in understanding such influences on outdoor air concentrations (C_o), the following model was considered:

$$\ln[C_{oi}] = \ln[c_0 + c_1Z_{1i} + c_2Z_{2i} + c_3Z_{3i} + c_4Z_{4i}] + e_i \quad (7-10)$$

where the c_j s are unknown parameters to be estimated, and where

c_0 = a constant

Z_{1i} = "average" daily outdoor temperature ($^{\circ}\text{F}$), where "average" is the mean of the minimum and maximum reported temperature at a nearby weather station;

Z_{2i} = rainfall indicator: = 1, if daily rainfall reported at a nearby weather station exceeds 0.04 inches; = 0, otherwise;

Z_{3i} = a road proximity index (derived from questionnaire item Q39):
= 0, if home is > 0.5 mile from a roadway with heavy traffic,

TABLE 7-23. SUMMARY STATISTICS FOR VARIABLES THAT CAN BE USED TO PRODUCE PAH AIR CONCENTRATION PREDICTIONS FROM MODELS

Variable Name	PLACERVILLE					ROSEVILLE				
	n	Min	Max	Arithmetic Mean	S.D.	n	Min	Max	Arithmetic Mean	S.D.
MEASURES ASSOCIATED WITH INDOOR SOURCES:										
U ₁ =I(gas heat use)	131	0	1	0.31	0.47	140	0	1	0.58	0.50
U ₂ =fireplace use hours	131	0	24	1.56	4.58	140	0	12	1.12	2.28
U ₃ =woodstove use hours	131	0	24	7.22	8.81	140	0	24	1.95	5.25
U ₄ =U ₁ *U ₂	131	0	18	0.26	1.80	140	0	12	0.80	2.06
U ₅ =I(indoor gas water heater)	131	0	1	0.23	0.42	140	0	1	0.76	0.43
U ₆ =no. cigarettes smoked	131	0	130	7.55	18.50	140	0	63	5.04	10.76
U ₇ =I(gas clothes dryer use)	131	0	1	0.06	0.24	140	0	1	0.06	0.25
U ₈ =I(kitchen gas appliances)	131	0	1	0.13	0.34	140	0	1	0.19	0.40
U ₉ =I(kitchen grilling/frying)	131	0	1	0.37	0.49	140	0	1	0.41	0.49
U ₁₀ =I(kitchen monitoring)	131	0	1	0.69	0.47	140	0	1	0.84	0.37
U ₁₁ =I(vehicles run in garage)	131	0	1	0.26	0.44	140	0	1	0.63	0.48
U ₁₂ =I(kerosene heater use)	131	0	1	0.05	0.21	140	0	0	0	-
HOUSE CHARACTERISTICS:										
House Volume (m ³)	131	92	1180	372	173	139	96	966	406	174
Air Exchange (h ⁻¹) x 10 ³	130	93	2253	652	411	137	169	2376	630	365
MEASURES ASSOCIATED WITH OUTDOOR CONCENTRATIONS:										
Z ₁ =outdoor temperature ^a (°F) (avg. of daily min & max)	35	38.5	56.5	47.7	4.7	38	43.5	60.5	53.8	4.1
Z ₂ =1(rain>0.04") ^a	35	0	1	0.14	0.36	38	0	1	0.52	0.51
Z ₃ =road proximity index ^b	132	0	3	0.45	0.74	139	0	3	0.45	0.62
Z ₄ =fireplace+woodstove hours	132	0	24	8.59	8.66	139	0	24	3.09	5.34

^a Statistics are based on the number of monitoring days, rather than on the number of homes monitored.

^b Z₃ = 0, if more than 0.5 mi to heavily trafficked area; = 1, if 100 yards to 0.5 mi;
= 2, if 100 ft. to 100 yards; = 3, if less than 100 ft.

- = 1, if home is between 100 yd and 0.5 mi from such a roadway,
- = 2, if home is between 100 ft and 100 yd from such a roadway,
- = 3, if home is within 100 ft of such a roadway; and

Z_{4i} = number of hours of fireplace and/or woodstove use (0 to 24 hrs) by the participating home. (Note that the Z_1 variable serves as a surrogate for the likelihood of fireplace and woodstove use by neighbors, as well as by the participant.)

e_i = error variability.

Table 7-23 also shows estimates for these Z variables. Distributional information on the Z variables (designated as C0 to C4) is given in Appendix O. Since a home's general location may also affect typical outdoor air levels of the PAHs, model (7-11) was estimated separately for Placerville and Roseville. The SAS procedure NLIN was used to produce the parameter estimates.

The results of this outdoor air modeling are given in Tables 7-24 to 7-26. The specific parameter estimates are given for Placerville in Table 7-24 and for Roseville in Table 7-25. Preliminary statistical tests indicated that separate models for the two areas were indeed needed for about half of the compounds. (Tests of other candidate models were also made. This included a check of a quadratic term for Z_{3i} .) Table 7-26 provides statistics that summarize how the models fit. The Placerville outdoor air concentration data generally exhibited more inherent variability than did the Roseville data, and the Placerville models accounted for about 20 to 28 percent of the total variability in the $\ln(\text{outdoor concentrations})$. The models for Roseville usually accounted for somewhat more of the variability in those levels (from about 22 to 35%). As a result, the residual standard deviations for Placerville were generally larger than the comparable ones for Roseville. The overall patterns and significance of the parameter estimates are summarized in Table 7-26. For all compounds the temperature and rainfall variables (c_1 and c_2) were always associated with lower outdoor air concentrations (negative coefficients), while outdoor air concentrations always showed an increase associated with the road proximity index (c_3) and the amount of woodburning (c_4). It should be emphasized that these models furnish rough approximations of the influences of the Z variables on the outdoor levels. The intent is simply to provide reasonable inputs for C_o in the indoor models.

TABLE 7-24. MODEL ESTIMATION RESULTS FOR OUTDOOR PAH CONCENTRATION: PLACERVILLE

Compound	Parameter		Estimate			
	Description		c_0	c_1	c_2	c_3
	Units		Constant	Outdoor Temperature	Rainfall	Proximity to Roadway
			ng/m ³	ng/m ³ /°F	ng/m ³	ng/m ³ /road proximity index
Acenaphthylene			46	-0.77	-2.6	5.9
Phenanthrene			70	-1.1	-5.5	6.8
Anthracene			7.8	-0.13	-0.32	0.90
Fluoranthene			21	-0.34	-0.97	1.6
Pyrene			20	-0.33	-1.0	1.4
Benzo[a]anthracene			4.4	-0.07	-0.26	0.32
Chrysene			6.2	-0.10	-0.41	0.42
Benzo[fluoranthene]			12	-0.19	-1.1	0.73
Benzo[e]pyrene			2.2	-0.03	-0.29	0.24
Benzo[a]pyrene			4.3	-0.07	-0.35	0.24
Indeno[1,2,3-cd]pyrene			4.8	-0.07	-0.73	0.52
Benzo[ghi]perylene			3.7	-0.05	-0.58	0.41
Coronene			4.7	-0.02	-0.33	0.29

TABLE 7-25. MODEL ESTIMATION RESULTS FOR OUTDOOR PAH CONCENTRATION: ROSEVILLE

Parameter	Estimate				
	c_0	c_1	c_2	c_3	c_4
Description	Constant	Outdoor Temperature	Rainfall	Proximity to Roadway	Woodburning
Units	ng/m ³	ng/m ³ /°F	ng/m ³	ng/m ³ /road proximity constant	ng/m ³ /hr of WS or FP use
Acenaphthylene	76	-1.2	-3.8	2.6	0.31
Phenanthrene	70	-0.99	-1.8	3.1	0.36
Anthracene	70	-0.10	-0.20	0.28	0.06
Fluoranthene	12	-0.17	-0.29	0.30	0.07
Pyrene	12	-0.18	-0.31	0.41	0.06
Benzo[a]anthracene	3.2	-0.05	-0.11	0.06	0.02
Chrysene	4.4	-0.07	-0.12	0.07	0.03
Benzofluoranthenes	7.4	-0.11	-0.49	0.20	0.04
Benzo[e]pyrene	2.6	-0.04	-0.15	0.05	0.009
Benzo[a]pyrene	3.6	-0.06	-0.15	0.07	0.01
Indeno[1,2,3-cd]pyrene	6.7	-0.11	-0.24	0.07	0.02
Benzo[ghi]perylene	5.2	-0.08	-0.41	0.16	0.009
Coronene	3.9	-0.06	-0.33	0.09	0.002

TABLE 7-26. STATISTICAL SIGNIFICANCE OF OUTDOOR MODEL PARAMETERS ON OUTDOOR PAH CONCENTRATIONS

Compound	Town	Statistical Significance					%Var ^b
		c ₀	c ₁	c ₂	c ₃	c ₄	
Acenaphthylene	PLAC	++++ ^c	----	-	++++	+	22.4
	ROSE	++++	----	----	+++	++	30.7
Phenanthrene	PLAC	++++	----	---	++++	+	24.1
	ROSE	++++	----	-	+++	++	22.1
Anthracene	PLAC	++++	----	-	++++	+	21.6
	ROSE	++++	----	-	++	++++	26.1
Fluoranthene	PLAC	++++	----	--	++++	+	26.7
	ROSE	++++	----	-	+	+++	23.6
Pyrene	PLAC	++++	----	--	++++	+	27.8
	ROSE	++++	----	-	++	+++	26.9
Benzo(a)anthracene	PLAC	++++	----	---	+++	+	24.2
	ROSE	++++	----	---	+	++++	34.2
Chrysene	PLAC	++++	----	---	+++	+	27.6
	ROSE	++++	----	--	+	++++	35.1
Benzo(k)fluoranthene	PLAC	++++	----	----	++	+	26.1
	ROSE	++++	----	----	+	++	26.0
Benzo(e)pyrene	PLAC	++++	----	----	++++	+	21.7
	ROSE	++++	----	----	+	+	30.4
Benzo(a)pyrene	PLAC	++++	----	----	++	+	22.4
	ROSE	++++	----	----	++	++	34.9
Indeno[1,2,3-cd]pyrene	PLAC	++++	----	----	+++	+	21.6
	ROSE	++++	----	---	+	+	29.3
Benzo(ghi)perylene	PLAC	++++	----	----	+++	+	21.8
	ROSE	++++	----	---	+	+	26.2
Coronene	PLAC	++++	--	----	++++	+	20.8
	ROSE	++++	----	----	+	+	26.8

^a Parameters are defined in eq. 7-10 in the text. If the sign of the parameter estimate is +, then the variable increases outdoor PAH concentration; if the sign of the parameter is - then the variable decreases outdoor PAH concentrations.

^b %Var = percent of total variance of ln(outdoor concentrations) accounted for by the model.

^c ++ or -- denotes that estimate is statistically significant at 0.10 level.

+++ or ---- denotes that estimate is statistically significant at 0.05 level.

++++ or ----- denotes that estimate is statistically significant at 0.01 level.

Exhibit 7-1 provides a set of calculations that illustrate how the estimates of Tables 7-18, 7-24, and 7-25 can be used to produce predictions of indoor concentrations for using five scenarios. The example spreadsheet is for BaP. The top portion of the exhibit involves estimating the outdoor concentrations, which make use of the parameter estimates from Tables 7-24 and 7-25, along with the specified values for the Z variables. In each of the scenarios, the daily temperature is assumed to be 45°F, the rainfall is zero, and the home is assumed to be far from heavy traffic. Fireplace and woodstove usages (in hours) are assumed to be zero for the first, fourth, and fifth scenarios; scenario 2 assumes three hours of fireplace use and scenario 3 assumes 24 hours of woodstove use. The outdoor concentrations predicted under these conditions are given in Table 7-27.

These predictions were then used (in the lower portion of the spreadsheet for each scenario) as inputs to the indoor model, along with the source emission estimates from Table 7-18 and the specific assumed values for the characteristic house (W) and source usage (U_j) variables. The fourth scenario differs from the first only in that 10 cigarettes were assumed to be smoked in the home during the 24-hr period. The fifth differs from the first only in that a kerosene heater was assumed to be in use. The resultant indoor concentration predictions are summarized in Table 7-28, which also provides estimates for benzo[ghi]perylene and chrysene for comparison.

7.6 RELATIONSHIPS AMONG COMPOUNDS

The final phase of statistical analysis was aimed at exploring relationships among the various compounds. This entailed generation of inter-compound correlations and application of factor analysis (i.e., principal component analysis (PCA) plus a varimax rotation) to each of the following:

- logarithms of the outdoor air PAH concentrations,
- logarithms of the indoor air PAH concentrations, and
- source strengths.

The primary purpose of these analyses was to investigate the relationship among PAHs and between PAH species and CO to identify appropriate marker compounds for

- BaP air concentrations,
- environmental tobacco smoke, and
- total PAH air concentrations.

EXHIBIT 7-1. ILLUSTRATIVE SPREADSHEET CALCULATIONS FOR PREDICTING
BENZO[A]PYRENE CONCENTRATIONS FOR FIVE SCENARIOS

SCENARIO 1:		OUTDOOR PARMS				
		PLAC	ROSE			
CONST		4.3069	3.5849			
TEMP	45	-0.0705	-0.0579			
RAIN IND	0	-0.3526	-0.1450			
ROAD PRX	0	0.2464	0.0709			
FP HRS	0					
WS HRS	0					
FP+WS HR	0	0.0107	0.0128			
EST. OUTDR CONC		1.1334	0.9784	0.541	0.61271	0.52886
W	0.06					
GAS HEAT IND.	0			0.8596	0	0
FP HRS #	0			3.7176	0	0
WS HRS #	0			0.6895	0	0
FP HRS*GH IND. #	0			4.1537	0	0
INDOOR GAS WH	0			-1.589	0	0
NO. CIGARETTES	0			5.6894	0	0
GAS CLOTHES DRYER	0			5.1166	0	0
KITCHEN GAS APPLIANCES	0			2.9892	0	0
KITCHEN GRILL/FRY	0			-4.4221	0	0
KITCHEN MONITORING	1			0.794	0.04764	0.04764
CAR RUN IN GARAGE	0			2.471	0	0
KEROSENE HEATER	0			279.7	0	0
TOTAL FOR INDOOR SOURCES:					0.04764	0.04764
ESTIMATED INDOOR CONCENTRATIONS:					0.66035	0.57650

SCENARIO 2:		OUTDOOR PARMS				
		PLAC	ROSE			
CONST		4.3069	3.5849			
TEMP	45	-0.0705	-0.0579			
RAIN IND	0	-0.3526	-0.1450			
ROAD PRX	0	0.2464	0.0709			
FP HRS	3					
WS HRS	0					
FP+WS HR	3	0.0107	0.0128			
EST. OUTDR CONC		1.1655	1.0168	0.541	0.63008	0.54963
W	0.06					
GAS HEAT IND.	0			0.8596	0	0
FP HRS #	3			3.7176	0.66917	0.66917
WS HRS #	0			0.6895	0	0
FP HRS*GH IND. #	0			4.1537	0	0
INDOOR GAS WH	0			-1.589	0	0
NO. CIGARETTES	0			5.6894	0	0
GAS CLOTHES DRYER	0			5.1166	0	0
KITCHEN GAS APPLIANCES	0			2.9892	0	0
KITCHEN GRILL/FRY	0			-4.4221	0	0
KITCHEN MONITORING	1			0.794	0.04764	0.04764
CAR RUN IN GARAGE	0			2.471	0	0
KEROSENE HEATER	0			279.7	0	0
TOTAL FOR INDOOR SOURCES:					0.71681	0.71681
ESTIMATED INDOOR CONCENTRATIONS:					1.34688	1.26644

EXHIBIT 7-1. (continued)

SCENARIO 3:		OUTDOOR PARMS				
		PLAC	ROSE			
CONST		4.3069	3.5849			
TEMP	45	-0.0705	-0.0579			
RAIN IND	0	-0.3526	-0.1450			
ROAD PRX	0	0.2464	0.0709			
FP HRS	0			CONTRIBUTION TO		
WS HRS	24			INDOOR	INDOOR CONC.	
FP+WS HR	24	0.0107	0.0128	PARMS	PLAC	ROSE
EST. OUTDR CONC		1.3902	1.2856	0.541	0.75164	0.69505
W	0.06					
GAS HEAT IND.	0			0.8596	0	0
FP HRS #	0			3.7176	0	0
WS HRS #	24			0.6895	0.99288	0.99288
FP HRS*GH IND. #	0			4.1537	0	0
INDOOR GAS WH	0			-1.589	0	0
NO. CIGARETTES	0			5.6894	0	0
GAS CLOTHES DRYER	0			5.1166	0	0
KITCHEN GAS APPLIANCES	0			2.9892	0	0
KITCHEN GRILL/FRY	0			-4.4221	0	0
KITCHEN MONITORING	1			0.794	0.04764	0.04764
CAR RUN IN GARAGE	0			2.471	0	0
KEROSENE HEATER	0			279.7	0	0
TOTAL FOR INDOOR SOURCES:					1.04052	1.04052
ESTIMATED INDOOR CONCENTRATIONS:					1.79216	1.73557

SCENARIO 4:		OUTDOOR PARMS				
		PLAC	ROSE			
CONST		4.3069	3.5849			
TEMP	45	-0.0705	-0.0579			
RAIN IND	0	-0.3526	-0.1450			
ROAD PRX	0	0.2464	0.0709			
FP HRS	0			CONTRIBUTION TO		
WS HRS	0			INDOOR	INDOOR CONC.	
FP+WS HR	0	0.0107	0.0128	PARMS	PLAC	ROSE
EST. OUTDR CONC		1.1334	0.9784	0.541	0.61271	0.52886
W	0.06					
GAS HEAT IND.	0			0.8596	0	0
FP HRS #	0			3.7176	0	0
WS HRS #	0			0.6895	0	0
FP HRS*GH IND. #	0			4.1537	0	0
INDOOR GAS WH	0			-1.589	0	0
NO. CIGARETTES	10			5.6894	3.41364	3.41364
GAS CLOTHES DRYER	0			5.1166	0	0
KITCHEN GAS APPLIANCES	0			2.9892	0	0
KITCHEN GRILL/FRY	0			-4.4221	0	0
KITCHEN MONITORING	1			0.794	0.04764	0.04764
CAR RUN IN GARAGE	0			2.471	0	0
KEROSENE HEATER	0			279.7	0	0
TOTAL FOR INDOOR SOURCES:					3.46128	3.46128
ESTIMATED INDOOR CONCENTRATIONS:					4.07399	3.99014

EXHIBIT 7-1. (continued)

SCENARIO 5:		OUTDOOR PARMS				
		PLAC	ROSE			
CONST		4.3069	3.5849			
TEMP	45	-0.0705	-0.0579			
RAIN IND	0	-0.3526	-0.1450			
ROAD PRX	0	0.2464	0.0709			
FP HRS	0			CONTRIBUTION TO		
WS HRS	0			INDOOR	INDOOR CONC.	
FP+WS HR	0	0.0107	0.0128	PARMS	PLAC	ROSE
EST. OUTDR CONC		1.1334	0.9784	0.541	0.61271	0.52886
W	0.06					
GAS HEAT IND.	0			0.8596	0	0
FP HRS #	0			3.7176	0	0
WS HRS #	0			0.6895	0	0
FP HRS*GH IND. #	0			4.1537	0	0
INDOOR GAS WH	0			-1.589	0	0
NO. CIGARETTES	0			5.6894	0	0
GAS CLOTHES DRYER	0			5.1166	0	0
KITCHEN GAS APPLIANCES	0			2.9892	0	0
KITCHEN GRILL/FRY	0			-4.4221	0	0
KITCHEN MONITORING	1			0.794	0.04764	0.04764
CAR RUN IN GARAGE	0			2.471	0	0
KEROSENE HEATER	1			279.7	16.782	16.782
TOTAL FOR INDOOR SOURCES:					16.8296	16.8296
ESTIMATED INDOOR CONCENTRATIONS:					17.4424	17.3585

= calculated value from a prior entry

TABLE 7-27. PREDICTED OUTDOOR AIR CONCENTRATIONS FOR BaP FOR
SELECTED SOURCES

Scenario	Fireplace Hrs	Woodstove Hrs	Predicted Outdoor BaP Concentration (ng/m ³) ^a	
			Placerville	Roseville
1,4,5	0	0	1.13	0.98
2	3	0	1.17	1.02
3	0	24	1.39	1.29

^a Average 24 hours.

TABLE 7-28. PREDICTIONS OF INDOOR AND OUTDOOR AIR
CONCENTRATIONS FOR FIVE SCENARIOS^a

Compound	Area	Predicted Indoor Air Concentration ^b (ng/m ³)				
		1	2	3	4	5
Benzo(a)pyrene	PLACERVILLE	0.66	1.3	1.8	4.1	17
	ROSEVILLE	0.58	1.3	1.7	4.0	17
Benzo(ghi)perylene	PLACERVILLE	0.61	1.5	2.2	2.9	17
	ROSEVILLE	0.88	1.8	2.5	3.1	17
Chrysene	PLACERVILLE	0.36	1.1	0.95	4.3	9.0
	ROSEVILLE	0.30	1.0	0.95	4.3	8.9

^a Scenario 1 = no indoor sources
 Scenario 2 = 3 hrs of fireplace use
 Scenario 3 = 24 hrs of woodstove use
 Scenario 4 = 10 cigarettes smoked
 Scenario 5 = kerosene heater used

^b Average 24 hours

Analyses were performed for the 13 PAHs and the sum of the 13 PAHs to represent total PAH. Statistical analyses were not performed for CO or quinoline because of the low % detected values for these two chemicals.

7.6.1 Pearson Correlations

The Pearson correlations are presented in Tables 7-29, 7-30 and 7-31 for outdoor air concentrations, indoor air concentrations, and source strengths, respectively. Also shown are the correlations of the $\ln(\text{concentration})$ for each compound with the $\ln(\text{total PAH concentration})$, where the total is over the 13 compounds in the list. All analyses reported in this subsection are based upon those 212 observations for which indoor and outdoor concentration data were available for all 13 compounds and for which air exchange rate data were available. The obvious feature from these correlation matrices is that while the outdoor air correlations are high for all PAHs (almost all above 0.75), the indoor air correlations tend to be high only for those PAHs with similar volatilities (i.e., near the diagonal of the matrix). Also, for the indoor air concentrations, acenaphthylene did not appear to be highly correlated with any of the other compounds. This effect for indoor correlations could be due to several factors:

- Different PAHs have different penetration efficiencies into homes which tend to be a function of volatilities. This could be an important effect since PAHs in outdoor air provide a large contribution to indoor air concentrations.
- Different indoor sources may generate different PAHs at different rates. This is probably the reason for the relatively poor correlations between phenanthrene, anthracene, fluorene, and pyrene with the other PAHs.
- Different PAHs may decay indoors at different rates. Unfortunately, there is little data available to assess this effect.

All compounds tended to give relatively high correlations (>0.75) with total PAHs in both indoor and outdoor samples, although outdoor correlations were higher than the indoor correlations. Relatively good correlations are seen among source strengths for all of the PAHs. Coronene is the exception, which only correlated well with benzo[ghi]perylene.

7.6.2 Factor Analysis

As used here, the factor analysis consisted of two steps: application of a principal components analysis (PCA) to the correlation matrices, and varimax rotation of the principal components. The factor analysis was applied to the correlation matrices involving the 13

TABLE 7-29. INTER-COMPOUND ASSOCIATIONS FOR LOGARITHMS OF OUTDOOR AIR CONCENTRATIONS (n=212)

Compound	Arithmetic Mean	S.D.	Correlations ^a x 100 With:												
			B	C	D	E	F	G	H	I	J	K	L	M	T
A=Acenaphthylene	2.50	1.06	94	94	86	88	91	89	77	90	88	90	93	91	97
B=Phenanthrene	3.01	0.71		96	92	92	91	90	78	88	86	87	88	84	98
C=Anthracene	0.60	0.95			94	94	93	92	78	88	87	87	87	81	97
D=Fluoranthene	1.37	0.83				98	93	94	79	87	86	84	84	76	94
E=Pyrene	1.29	0.88					93	93	79	87	87	85	86	78	95
F=Benzo(a)anthracene	-0.31	1.11						99	88	97	96	94	92	83	96
G=Chrysene	0.088	0.97							88	96	95	94	91	81	95
H=Benzo(a)fluoranthene	0.73	1.14								89	88	85	84	73	83
I=Benzo(e)pyrene	-0.49	0.92									97	97	97	88	94
J=Benzo(a)pyrene	-0.32	1.23										96	94	85	93
K=Indeno[1,2,3-cd]pyrene	0.31	1.01											95	90	93
L=Benzo(ghi)perylene	0.16	0.93												95	94
M=Coronene	-0.35	1.00													89
T=total PAHs (13 compounds)	3.96	0.83													

^a Pearson correlations.

TABLE 7-30. INTER-COMPOUND ASSOCIATIONS FOR LOGARITHMS OF INDOOR AIR CONCENTRATIONS (n=212)

Compound	Arithmetic Mean	S.D.	Correlations ^a x 100 With:												
			B	C	D	E	F	G	H	I	J	K	L	M	T
A=Acenaphthylene	2.26	1.14	52	56	54	53	56	56	51	55	57	56	57	54	75
B=Phenanthrene	2.95	0.57		77	80	72	50	53	42	45	44	44	42	37	88
C=Anthracene	0.037	0.96			74	71	58	61	48	49	48	43	43	35	81
D=Fluoranthene	0.57	0.75				95	77	79	69	68	65	61	59	48	87
E=Pyrene	0.66	0.66					76	78	70	68	65	61	60	49	83
F=Benzo[a]anthracene	-1.30	1.18						99	95	95	93	84	82	68	76
G=Chrysene	-0.94	1.12							94	93	91	82	80	65	77
H=Benzo[fluoranthenes	0.12	1.08								98	96	89	87	71	69
I=Benzo[e]pyrene	-1.07	1.03									98	93	93	79	73
J=Benzo[a]pyrene	-0.52	1.17										93	92	79	73
K=Indeno[1,2,3-cd]pyrene	0.14	0.95											94	86	71
L=Benzo(ghi)perylene	-0.070	0.90												94	71
M=Coronene	-0.37	0.94													65
T=total PAHs (13 compounds)	3.77	0.64													

^a Pearson correlations.

TABLE 7-31. INTER-COMPOUND ASSOCIATIONS FOR SOURCE STRENGTHS (n=212)

Compound	Arithmetic Mean	S.D.	Correlations ^a x 100 With:											
			B	C	D	E	F	G	H	I	J	K	L	M
A=Acenaphthylene	1581	4669	83	87	86	82	83	82	79	81	76	73	73	44
B=Phenanthrene	2933	5772		87	87	86	73	74	70	70	65	66	67	42
C=Anthracene	302	741			93	90	87	88	83	83	77	72	71	41
D=Fluoranthene	360	1105				97	92	93	87	86	78	74	73	41
E=Pyrene	353	1058					89	90	85	84	77	74	73	42
F=Benzo(a)anthracene	76	266						98	95	96	91	84	78	43
G=Chrysene	107	368							92	93	87	80	75	41
H=Benzo(k)fluoranthene	188	625								98	95	91	86	48
I=Benzo(e)pyrene	46	147									97	93	88	52
J=Benzo(a)pyrene	97	280										95	88	54
K=Indeno[1,2,3-cd]pyrene	102	312											94	66
L=Benzo(ghi)perylene	84	237												82
M=Coronene	66	219												

^a Pearson correlations.

PAHs (Tables 7-29, 7-30, 7-31) but excluding the total PAHs. The main purpose of the analysis was to determine which PAHs had similar behavior in terms of indoor air concentration, outdoor air concentration, and source strength. PCA is "a statistical technique that linearly transforms an original set of variables into a substantially smaller set of uncorrelated variables that represents most of the information in the original set of variables" (Dunteman, 1989). Through the reduction in dimension, some of the basic relationships among the variables may be discerned. For instance, if two principal components are used, then a two-dimensional plot (component 1 vs. 2) may reveal which compounds tend to behave alike and which do not. The varimax rotation procedure consists of a rotation of the (hyper)plane defined by the (two or more) principal component axes to produce a new set of perpendicular axes. The new set of axes is unique and is chosen to optimize a particular criterion (the varimax criterion); plots in the rotated factor space may yield further insight into which compounds tend to behave similarly.

The results for the PCA on logarithms of outdoor air concentrations (see Appendix P) indicated that data for a single compound would adequately describe the outdoor air concentration data for all of the PAHs: the first component accounted for 90% of the variability while the second accounted for only an additional 3.7%. The respective eigenvalues were 11.69 and 0.48. (A general rule of thumb is to consider relevant only those components associated with eigen values that exceed 1). The elements in the eigenvector associated with the first component were almost identical, ranging from 0.262 to 0.287. The elements of the eigenvectors are the coefficients in a linear combination that apply to the original variables [here, logs of outdoor concentrations] after suitable scaling and standardization. Hence, the eigenvector associated with the first [largest] eigenvalue identifies the linear combination of such variables that will account for the most variability. The second eigenvector identifies another linear combination that is uncorrelated with the first and that accounts for the most variability that remains. Variables having similar eigenvector elements are considered "close" and their data tend to exhibit similar behavior; thus examination of the elements of the eigenvectors can aid in identifying which PAHs [compounds] tend to behave similarly. In some cases the varimax rotation procedure may shed further light on such groupings; this was not true in this case, however. Thus no significant clustering of the compounds was evident for the outdoor data, although the second component's loadings tended to separate phenanthrene , anthracene, fluoroanthene

and pyrene as one group; 5-, 6-, and 7- ringed particulate phase PAHs as a second group, and perhaps the compounds acenaphthylene, benzo[a]anthracene, and chrysene as a third group.

For the indoor air concentration data, the first two principal components accounted for over 85 percent of the total variability (72.6% for the first component and 13% for the second), and only those two eigenvalues (9.44 and 1.69, respectively) exceeded one (see Appendix P). The eigenvector associated with the first component contained elements that were all positive and of approximately equal value, suggesting a single large source with approximately equal influence on all of the compounds (i.e., outdoor concentrations or similar PAH emissions from all combustion sources). As noted directly from the correlation matrix, the PAHs most closely aligned with one another were generally those with similar volatilities. The plots of the factor patterns (Appendix P) showed phenanthrene, anthracene, fluorene and pyrene as one group (with phenanthrene and anthracene perhaps as one subgroup, and fluorene and pyrene as another); a cluster containing the 5-, 6-, and 7-ring ed particulate phase PAHs (with perhaps benzo[a]anthracene and chrysene); and a separate "cluster" containing only acenaphthylene.

Factor analysis results for source strengths, also reported in Appendix P, showed that two of the eigenvalues of the correlation matrix exceeded one: component 1 had a value of 10.54 (81%) and component 2, a value of 1.14 (8.8%). Loadings for the first component were about equal for all compounds except for coronene; the loadings for the second were negative for the first seven compounds, and were positive with increasing values for the remaining six. The factor pattern plot showed compounds as falling into three groups: the 3- and 4- ring ed PAHs, the 5- and 6-ring ed PAHs, and the 7-ring ed PAH, coronene.

7.6.3 Marker Compounds

The correlations and PCA results suggest that any one of three compounds might serve as a marker for indoor levels of benzo(a)pyrene, as shown by the estimated regression models below:

$$\text{BaP} = 0.027 + 0.546[\text{benzofluoranthenes}] \quad (\text{correlation} = 0.96)$$

$$\text{BaP} = -0.091 + 2.116[\text{benzo(e)pyrene}] \quad (\text{correlation} = 0.98)$$

$$\text{BaP} = -0.256 + 0.788[\text{indeno[1,2,3-cd]pyrene}] \quad (\text{correlation} = 0.93)$$

Based on these results, several conclusions can be made about the potential for identifying marker compounds or surrogate measures for BaP concentrations in air, total PAH concentrations in air, and environmental tobacco smoke (ETS).

- For outdoor air, any of the individual PAHs could be used as a marker for BaP or total PAH concentrations.
- For indoor air, only those PAHs with very similar structures and/or volatilities can be used as a marker for BaP concentrations. These include benzo[a]fluoranthene, benzo[e]pyrene, and indeno[1,2,3-cd]pyrene.
- For indoor and outdoor air, any of the individual PAHs can be used as a marker for total PAH concentrations
- Since CO had a very low percent measurable value in all source categories, it is not considered an acceptable marker for BaP air concentrations, total PAH air concentrations or ETS.
- A definitive marker for ETS was not identified. Although elevated PAH air concentrations were observed in homes where smoking occurs, this effect was also observed for other strong combustion sources. Quinoline was measured only in homes in the smoking categories, this is consistent with quinoline being a marker for ETS. However, substantial matrix interferences were observed during GC/MS analysis of air sample extracts. Monitoring methods must be improved before the utility of quinoline as a marker for ETS can be assessed.

7.7 SUMMARY OF CARBON MONOXIDE RESULTS

For carbon monoxide the method quantifiable limit was estimated as 2 ppm. The percentage of air samples with 24-hour average concentrations equal to or above this concentration is given in Table 7-32 by combustion source category. The maximum 24-hour average CO concentration for each combustion source category is also given in Table 7-32. A summary of 24-hour average CO results by combustion source category is given in Appendix I. The distribution of one-hour average CO concentrations by combustion source category for both indoor and outdoor air samples is given in Table 7-33. For both 24-hour and 1-hour average CO concentrations, % measurable values were low, thus no statistical analysis was performed on the data and no statistical conclusions regarding the effect of combustion

TABLE 7-32. PERCENT MEASURABLE VALUES FOR CARBON MONOXIDE BY COMBUSTION SOURCE CATEGORY

Combustion Source Category	n	% Measurable ^a		Maximum Indoor Concentration ^b (ppm)
		Indoors	Outdoors	
A - Smoking	39	7.7	0.0	4
All - Smoking/Fireplace	9	0	0.0	1
B - Fireplace	33	12.0	0.0	5
C - Woodstove	37	10.8	0.0	2
D - Woodstove/Gas Heat	17	11.7	0.0	4
E - No Source	27	14.8	0.0	3.5
F - Gas Heat	36	19.4	0.0	5

^a Percentage of samples with 24-hour average concentrations greater than or equal to 2 ppm.

^b 24-Hour average concentrations.

TABLE 7-33. DISTRIBUTION OF ONE-HOUR AVERAGE CO CONCENTRATIONS IN INDOOR AND OUTDOOR AIR SAMPLES BY COMBUSTION SOURCE CATEGORY

Combustion Source Category	n	Percent of Samples in Concentration Range					
		<2 ppm ^a	2 ppm	>2 ppm to ≤5 ppm	>5 ppm to ≤9 ppm	>9 ppm to ≤20 ppm	>20 ppm
<u>Indoors</u>							
Smoking	864	76.0	14.4	8.9	0.7	0.0	0.0
Smoking/Fireplace	190	79.0	18.4	2.6	0.0	0.0	0.0
Fireplace	744	83.9	8.1	5.5	1.5	0.9	0.1
Woodstove	787	76.6	10.4	9.4	3.6	0.0	0.0
Woodstove/Gas Heat	405	82.5	6.9	10.1	0.5	0.0	0.0
Gas Heat	1002	78.6	7.3	12.6	1.3	0.2	0.0
No Source	603	78.2	10.6	8.5	2.5	0.2	0.0
<u>Outdoors</u>							
Smoking	836	99.5	0.4	0.1	0.0	0.0	0.0
Smoking/Fireplace	211	97.2	1.9	0.9	0.0	0.0	0.0
Fireplace	730	95.1	1.4	3.5	0.0	0.0	0.0
Woodstove	785	98.3	1.3	0.3	0.0	0.1	0.0
Woodstove/Gas Heat	330	97.9	2.1	0.0	0.0	0.0	0.0
Gas Heat	618	97.5	1.7	0.8	0.0	0.0	0.0
No Source	963	94.8	4.2	1.0	0.0	0.0	0.0

^aBelow the MQL.

sources on indoor and outdoor air concentrations were drawn. A brief discussion of results is provided here.

The California Ambient Air Quality Standards for CO are 20 ppm for a 1-hour averaging time and 9 ppm for an 8-hour averaging time. Air measurements in only two homes exceeded these standards. A 1-hour average CO concentration of 24 ppm was measured in one home during fireplace use. In a second home with gas heat, an 8-hour average concentration of 9.5 ppm was measured. These results suggest that combustion sources are generally not responsible for substantially elevated CO 1-hour or 8-hour average concentration in homes.

In many homes, there were short term (1 to 2 minutes) elevated concentrations of CO that did not substantially elevate 24-hour average concentrations. The highest peak concentration for CO (42 ppm) was observed when a gas space heater was turned on in the monitoring area. An elevated peak CO concentration of 22 ppm was observed in a second home that used gas heat as the primary heating source. In most cases, when elevated indoor and/or outdoor CO concentrations were measured, they were associated with fireplace use, gas heat use, or automobile exhausts.

SECTION 8

QUALITY CONTROL/QUALITY ASSURANCE

A Quality Assurance Project Plan (QAPP) was prepared for this study; a copy of the QAPP is included in Appendix S. The QA activities specific to this study included:

- Meeting with project management to discuss QA matters,
- Conducting systems audits of major project components,
- Monitoring situations requiring corrective action,
- Monitoring analysis of QC samples, and
- Submitting reports.

Results for analysis of quality control samples and a discussion of performance for the monitoring methods used on this study are given in Section 6. Tables 8-1 to 8-3 provides information on the quality assurance objectives set forth in the QAPP for completeness, accuracy, and precision. Results achieved during this field monitoring study are also given.

A Quality Assurance Statement which summarizes audits, reviews, and inspections is included in Appendix T.

TABLE 8-1. SUMMARY OF DATA COLLECTION COMPLETENESS

Parameter	% Completeness	
	Objective	Achieved
Quinoline	90	92.8
Acenaphthylene	90	91.6
Phenanthrene	90	94.3
Anthracene	90	94.3
Fluoranthene	90	96.7
Pyrene	90	96.4
Benzo[a]anthracene	90	96.4
Chrysene	90	96.1
Benzo[k]fluoranthene	90	95.4
Benzo[e]pyrene	90	96.3
Benzo[a]pyrene	90	95.7
Indeno[1,2,3-cd]pyrene	90	95.7
Benzo[ghi]perylene	90	96.7
Coronene	90	96.6
CO	90	94.3
Air Exchange	95	99.3
Questionnaire Data	95	99.7

^a% valid data relative to that proposed

TABLE 8-2. SUMMARY OF MEASUREMENT ACCURACY

Parameter	% Recovery ^a		
	QA Objective	Field Controls	NIST Controls
Quinoline	>70	100(18) ^b	NA ^c
Acenaphthylene	>70	96(9.5)	NA
Phenanthrene	>70	98(8.0)	99(19)
Anthracene	>70	113(14)	NA
Fluoranthene	>70	84(16)	79(15)
Pyrene	>70	84(17)	67(13)
Benzo[a]anthracene	>70	96(18)	NA
Chrysene	>70	97(15)	NA
Benzo[k]fluoranthene	>70	115(15)	126(14)
Benzo[a]pyrene	>70	101(21)	89(20)
Benzo[e]pyrene	>70	91(15)	79(15)
Indeno[1,2,3-cd]pyrene	>70	121(16)	164(19)
Benzo[ghi]perylene	>70	110(14)	113(19)
Coronene	>70	114(16)	NA
Air Exchange	>90	66(12)	NA

^a% recovery from spiked control samples.^b% RSD in parentheses.^cCertified value not given for NIST standard.

TABLE 8-3. SUMMARY OF MEASUREMENT PRECISION

Parameter	% RSD ^a	
	QA Objective	Mean
Quinoline	<25	10
Acenaphthylene	<25	9.4
Phenanthrene	<25	5.6
Anthracene	<25	11
Fluoranthene	<25	12
Pyrene	<25	13
Benzo[a]anthracene	<25	11
Chrysene	<25	10
Benzo[k]fluoranthene	<25	12
Benzo[e]pyrene	<25	8.0
Benzo[a]pyrene	<25	9.2
Indeno[1,2,3-cd]pyrene	<25	11
Benzo[ghi]perylene	<25	8.9
Coronene	<25	12
CO	≤25	20
Air Exchange	≤10	12.2(4.1) ^b

^a % relative standard deviation between (duplicate) samples.

^b Result of one duplicate pair with a high % RSD was deleted from calculation of the mean.

SECTION 9

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