SELECTED DATA ANALYSES RELATING TO STUDIES OF PERSONAL CARBON MONOXIDE EXPOSURE IN DENVER AND WASHINGTON, D.C.

PEI ASSOCIATES

SELECTED DATA ANALYSES RELATING TO STUDIES OF PERSONAL CARBON MONOXIDE EXPOSURE IN DENVER AND WASHINGTON, D.C.

by

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FOREWORD

Measurement and monitoring research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has the responsibility for assessment of environmental monitoring technology and systems; implementation of agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency including the Office of Air, Noise and Radiation, the Office of Toxic Substances, and the Office of Enforcement.

This document is a report of selected analyses of personal carbon monoxide (CO) exposure data obtained in a human exposure study performed in Denver, Colorado, and Washington, DC, during the winter of 1982-83. This report discusses relationships between personal exposure to CO and human activity patterns, ambient aerometric variables, indoor sources, and other factors.

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ABSTRACT

Under EPA Contract 68-02-3496, PEI Associates, Inc. conducted a study of personal exposure to carbon monoxide (CO) in Denver, Colorado. The target population for the study included all noninstitutionalized, nonsmoking residents of the urbanized portion of the metropolitan area who were between 18 and 70 years of age at the time of the study. A total of 454 study participants were obtained through the use of a screening questionnaire administered to several thousand households in the study area. Each participant was asked to carry a personal exposure monitor (PEM) and an activity diary for two consecutive 24-hour sampling periods and to provide a breath sample at the end of each sampling period. Each participant also completed a detailed background questionnaire. A similar study was conducted in Washington, D.C., by Research Triangle Institute. Analyses of the Denver fixed-site data suggest that ambient CO levels decrease with increasing windspeed. Five monitors reported daily maximum 8-hour concentrations exceeding 15; all were located in the central business district. Linear regression analyses relating PEM values to Washington fixed-site readings yielded R^2 values exceeding 0.15 for eight microenvironments: indoors-hospital (0.66), indoors-church (0.60), indoors-garage (0.19), outdoors-park (0.15), train/subway (0.61), jogging (0.30), truck (0.27), and bicycle (0.16). Daily maximum 8-hour exposures in Denver were found to be higher on days when fixed-site daily maximum 8-hour values exceeded 9 ppm. Microenvironments found to be associated with daily maximum 8-hour exposure above 9 ppm include service stations, public garages, restaurants, outdoor locations within 10 yards of roads in areas of high ambient CO, and trucks when the trip begins or ends in an area of high ambient CO. Occupations involving proximity to running motor vehicles or internal combustion engines in a closed space are strongly associated with high daily maximum 8-hour exposures. Analyses of Denver in-transit exposures suggest exposures are higher when inside motor vehicles than when walking. In-vehicle exposures are higher during rush-hour periods. Smoking does not significantly increase invehicle exposure. Analyses of indoor exposure data for Denver identified 10 factors which significantly affected exposure. Exposures were higher in homes with gas cooking stoves, with gas clothes dryers, with unvented gas furnaces, with unvented space heaters, and with storm windows, storm doors, or special dampers. A model was developed which explained 34 percent of the variation in Denver PEM values. The daily maximum 8-hour exposure values reported on consecutive days by Denver subjects were not highly correlated (R^2 = 0.16). The PEM's used in the Denver study were found to experience zero-span problems more frequently on cold days and to experience lock-up more frequently on warm days.

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FREQUENTLY-USED ABBREVIATIONS[a]

ABBREVIATIONS

λ	-- coefficient for Box-Cox transformation
A	-- Section 6 only: first of two consecutive sampling periods
ANOVA	-- analysis of variance
b	-- blank
B	-- location code from activity diary (Section 3)
B	-- Section 6 only: second of two consecutive sampling periods
BG	-- block group
BMDP	-- package of computer programs for statistical analysis
c	-- mean CO concentration, ppm, measured during occupancy period (Section 4.1)
c_{PEM} or C_{PEM}	-- PEM CO reading, ppm
C	-- Section 6 only: C = B value - A value
CMR	-- Colorado Market Research
CO	-- carbon monoxide
d	-- mean duration of occupancy period (Section 4.1)
D	-- Section 6 only: D = ln (B value) - ln (A value)
D3	-- transit mode code from activity diary
D.F.	-- degrees of freedom
DQC	-- data quality code
DR	-- duration, minutes (Section 4.2)
EMSL	-- Environmental Monitoring Systems Laboratory
EPA	-- U.S. Environmental Protection Agency
EV	-- explanatory variable (Section 8.3)
EWA	-- enclosed work area
FSU	-- first-stage sampling unit
GE	-- General Electric
H	-- differing definitions of Group H can be found in Sections 3.5 and 4.1
H_o	-- null hypothesis
HU	-- housing unit
L	-- differing definitions of Group L can be found in Sections 3.5 and 4.1
LCD	-- liquid crystal display
LRM	-- logistic regression model (Section 8.3)
MAGUS	-- Magus Group, Incorporated
MDTR	-- mode of transit (Section 4.2)
n	-- number of values or entries
N	-- number of pairwise comparisons (Section 5.3) or number of positive values (Section (6.4)
NAAQS	-- National Ambient Air Quality Standard
n.e.c.	-- not elsewhere coded
NEM	-- NAAQS Exposure Model
NU	-- not used (Section 4.3)
OER	-- observed-to-expected ratio (Section 4.1)
p	-- probability
PEI	-- PEI Associates, Inc.

ABBREVIATIONS

PEM	-- personal exposure monitor
PID	-- personal identification number
ppm	-- parts per million
PREC	-- total precipitation for day, inches (Sections 2.2 and 8.3)
PROPN	-- proportion of PEM's associated with a given temperature and a given failure mode (Section 8.3)
R^2	-- coefficient of determination
RDEN	-- residential density (Section 2)
ROM	-- read-only memory
RTI	-- Research Triangle Institute
SAMPLE-DATA	-- computer file containing personal exposure data
SAROAD	-- Storage and Retrieval of Aerometric Data (EPA data bank)
SASD	-- Strategies and Air Standards Division
s.d.	-- standard deviation
s.e.	-- standard error
SM	-- smoking (Section 4.2)
SSU	-- second-stage sampling unit
std. dev.	-- standard deviation
TAVG	-- daily mean temperature, ^{o}F (Sections 2.2 and 8.3)
TDEN	-- trip density (Section 2)
TM	-- time of day (Section 4.2)
TMAX	-- daily maximum temperature, ^{o}F (Sections 2.2 and 8.3)
TMIN	-- daily maximum temperature, ^{o}F (Sections 2.2 and 8.3)
UNV	-- used and not vented (Section 4.3)
UV	-- used and vented (Section 4.3)
WIND	-- mean windspeed for day, mi/h (Sections 2.2 and 8.3)

[a]Additional abbreviations are listed in Tables 3-1, 3-4, 5-1, 5-6, and 8-1.

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The analyses described in this report were performed by Ted Johnson, Jim Capel, and Luke Wijnberg of PEI Associates, Inc. Luke Wijnberg is the primary author of Sections 4.2 and 8; Ted Johnson wrote the remaining sections. Jim Capel and Luke Wijnberg created most of the data files used in these analyses and contributed all necessary computer programs. Dave Dunbar was the Project Director for PEI, and Ted Johnson served as the Project Manager.

The Project Officer for the U.S. Environmental Protection Agency (EPA) was Gerry Akland. Dave Mage served as Assistant Project Officer. Tom Lawless supplied data files containing the carbon monoxide values reported by the fixed sites operating in Denver and Washington during the study period. This work was supported by the Environmental Monitoring Systems Laboratory of EPA through Contract No. 68-02-3496 and Contract No. 68-02-3755.

The majority of data analyzed in this report were obtained by PEI from a study of human exposure to carbon monoxide conducted in Denver, Colorado. The following persons contributed to the success of that study.

PEI Associates, Inc.

- Dave Dunbar - Project Director
- Ted Johnson - Project Manager, data validation, and statistical analysis
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- Luke Wijnberg - statistical analysis and nonresponse adjustments to sample weights

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- Gary Graff - solicitation of participants and administration of telephone questionnaires
- Evan Cole - instrument calibration and data reduction
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- Jeff Kicig - coding
- Frank Kunc - field screening, interviewer
- Mike Dulacki - field screening
- Bob Devita - field screening
- Brenda Harris - interviewer

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William Kalsbeek - evaluation of sampling protocol and proposed sample stratification

SECTION 1

INTRODUCTION

The National Ambient Air Quality Standard (NAAQS) for carbon monoxide (CO) states that 1-hour CO concentrations shall not exceed 35 ppm more than once per year and that 8-hour CO concentrations shall not exceed 9 ppm more than once per year. Compliance with these standards is usually determined by fixed-site monitoring data. However, fixed-site monitoring data may not provide an accurate indication of personal exposure within an urban population, which is a function of both geographic location (e.g., downtown versus suburbia) and immediate physical surroundings (e.g., indoors versus outdoors). Better estimates of personal exposure can be developed by equipping a large number of subjects with portable monitors and activity diaries. If the subjects are properly selected, their exposures can be extrapolated to a larger "target" population.

Two such studies were conducted during the winter of 1982-83 in Denver, Colorado, and Washington, D.C. Both studies were sponsored by the Environmental Monitoring Systems Laboratory (EMSL) of the U.S. Environmental Protection Agency (EPA). In the Denver study, PEI Associates, Inc. (PEI), asked each of 454 subjects to carry a personal exposure monitor (PEM) and an activity diary for two consecutive 24-hour sampling periods and to provide a breath sample at the end of each sampling period. Each participant also completed a detailed background questionnaire. The questionnaire results and approximately 900 subject-days of PEM and activity diary data collected between November 1, 1982, and February 28, 1983, were analyzed to determine if factors such as microenvironment and the presence of indoor CO sources significantly affect personal CO exposure. In addition, the exposure of a defined target population was extrapolated from exposures recorded by the study participants. PEI also compared CO levels recorded by fixed-site monitors to levels recorded simultaneously by PEM's. Detailed descriptions of the Denver study design and data collection procedures, together with results of initial data analyses, are available in a report by Johnson.[1]

The Washington study, which was performed by Research Triangle Institute, has been described in detail by Hartwell et al.,[2] Settergren et al.,[3] and Clayton et al.[4] It differs from the Denver study in that 1) twice as many subjects were used in the Washington study and 2) each subject carried a PEM and a diary for a single 24-hour period.

The present report describes various statistical analyses related to the Denver and Washington studies which were performed by PEI subsequent to the reports by Johnson and Hartwell et al. Most of the analyses are exploratory in nature with the general goal being the development of a model for predicting CO exposure (as indicated by PEM's) using data recorded at the fixed monitoring sites, in the activity diaries, and in the background questionnaires. Some of the analyses were performed to answer specific questions posed by EMSL and the Strategies and Air Standards Division (SASD) of EPA. As noted in the text, the results of many of the analyses suggested new questions and the need for additional analysis.

1.1 ORGANIZATION OF REPORT

This report is organized as follows. Section 2 provides summary statistics for data reported by the fixed-site monitors operating during the Denver and Washington studies and discusses relationships between the Denver fixed-site data and selected meteorological parameters. Sections 3 and 4 discuss relationships between CO exposures as measured by PEM's and selected explanatory variables based on fixed-site data, activity diary entries, and background questionnaire responses. In Section 5, candidate models for predicting CO exposure are constructed using the most promising explanatory variables and are then optimized using stepwise regression techniques. Section 5 also discusses how microenvironments with similar exposure characteristics can be grouped into aggregate microenvironments. Section 6 describes analyses performed to determine if daily maximum exposures experienced by participants on consecutive days were statistically related. Data concerning the average time spent by participants in various microenvironments and aggregate microenvironments are provided in Section 7. Factors associated with the failure of PEM's in the field are discussed in Section 8. Section 9 presents a summary of analytical results and major conclusions. Note that all analyses are based on Denver data unless otherwise indicated.

Appendix A provides an overview of the Denver study and summarizes the statistical analyses described in the earlier report by Johnson.[1] It is recommended that the reader review Appendix A before proceeding to Section 2. Site descriptions and summary statistics for the fixed-site CO monitors operating during the Washington study are provided in Appendix B. Other background information concerning the Washington study will be provided in the text where necessary.

1.2 REFERENCES

1. Johnson, T. A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/54-84-014, March 1983.

2. Hartwell, T. D., C. A. Clayton, R. M. Michie, R. W. Whitmore, H. S. Zelon, S. M. Jones, and D. A. Whitehurst. Study of Carbon Monoxide Exposure of Residents of Washington, D. C. and Denver, Colorado. Prepared for the U.S. Environmental Protection Agency. Research Triangle Institute, Research Triangle Park, North Carolina. 1984.

3. Settergren, S. K., T. D. Hartwell, and C. A. Clayton. Study of Carbon Monoxide Exposure of Residents of Washington, D. C.--Additional Analyses. Prepared for the U.S. Environmental Protection Agency. Research Triangle Institute, Research Triangle Park, North Carolina. 1984.

4. Clayton, C. A., S. B. White, and S. K. Settergren. Carbon Monoxide Exposure of Residents of Washington, D. C.: Comparative Analysis. Prepared for the U.S. Environmental Protection Agency. Research Triangle Institute, Research Triangle Park, North Carolina. 1984.

SECTION 2

FIXED-SITE MONITORS

Fifteen fixed-site CO monitors operated in Denver during the period of the study. Figure 3 in Appendix A shows the locations of these 15 monitors; Table 2-1 provides the corresponding site characteristics. Nine monitors were temporary and were discontinued at the conclusion of the study. All of the monitors reported hourly average CO data and operated continuously.

The quantities RDEN and TDEN relate to the average residential and traffic densities of the census tract containing each monitor and are explained in Section 5.1 of Reference 1. The land use designation pertains to the neighborhood in the immediate vicinity of each monitor. Appendix G of Reference 1 contains more detailed descriptions of the area surrounding each site. Site selection, data acquisition, and quality assurance activities are described in Reference 2.

2.1 SUMMARY STATISTICS FOR DENVER SITES

A computer file was created which provides the hourly average values reported by all 15 fixed-sites between November 1, 1982, and February 28, 1983, on an hour-by-hour basis. From these data an additional variable was created--the hour-by-hour arithmetic mean of the values reported by the 15 sites. This synthethic data set is denoted by the three-digit code "AVG" and is referred to as the "composite" data set in the discussion that follows.

Table 2-2 summarizes the results of analyzing the hourly average values using BMDP program P2D.[3] Table 2-3 lists the date and time of the maximum value reported by each site. Ten of the 15 maximum values occurred during either the morning or the evening high traffic periods (8:00, 17:00, or 18:00). Four of the 15 maximum values occurred on January 27, 1983. The maximum value in the composite data set was 15.8 ppm and occurred at 8:00 on December 17, 1982.

A supplementary file was created that contained daily maximum 1-hour and 8-hour values for all 16 data sets on a day-by-day basis. Daily maximum

TABLE 2-1. FIXED-SITE MONITORS OPERATING IN THE DENVER METROPOLITAN AREA DURING STUDY

Map code	District or town	Address	SAROAD code	Building	Land use	Census tract	RDEN	TDEN	1981 violations
A	Denver	2105 Broadway	060580002F01	Special	Central business, high traffic	a	b	c	33
B	Denver	2325 Irving	060580014F01	Special	Residential	5.02	18.35	5.91	16
C	Denver	14th & Albion	060580013F01	Special	Strip commercial, high traffic	43.01	23.34	35.27	d
D	Denver	208 Grant St.	062080821F05	School	Downtown residential	28.02	30.77	19.03	e
E	Denver	1821 S. Yates	062080822F05	School	Residential, near commercial	46.01	11.79	5.72	e
F	Denver	3635 Quivas St.	062080820F05	School	Residential, near expressway	11.02	27.95	7.90	e
G	Denver	3509 S. Glencoe	062080823F05	School	Residential, on suburban artery	40.04	8.51	5.53	e
H	Greenwood Village	6060 South Quebec	062080825F05	Trailer	Office, light business	67.02	7.97	2.78	e
I	Denver	3620 Franklin St.	062080818F05	School	Residential	36.01	26.75	5.06	e
J	Denver	Speer & Lawrence	062080819F05	School	Campus near high traffic	19.00	67.64	8.56	e
K	Aurora	50 S. Peoria	060140002F01	Special	Suburban golf course	77.02	8.51	4.96	0
L	Arvada	5701 Garrison	060120002F01	Trailer	Residential near shopping district	103.08	8.89	6.19	3
M	Highlands	8100 S. University	060080002F01	Trailer	Vacant land at edge of residential area	56.15	9.12	2.59	0
N	Englewood	3600 S. Elati	062080824F05	Municipal building	Light commercial near major shopping center	60.00	13.43	6.23	e
O	Montbello	4845 Oakland	062080817F05	School	Offices and small warehouses (suburban commercial)	41.05	0.0	3.60	e

[a]16.00 or 25.00. [b]65.13 or 56.09. [c]9.97 or 13.51. [d]Permanent site with no 1981 data. [e]Temporary site with no 1981 data.

TABLE 2-2. SUMMARY STATISTICS FOR HOURLY AVERAGE CARBON MONOXIDE VALUES REPORTED BY DENVER MONITORING SITES BETWEEN NOVEMBER 1, 1982, AND FEBRUARY 28, 1983

Map code	SAROAD code	Number of hourly values	Hourly average carbon monoxide concentration, ppm								
			Minimum	Maximum	Mean	Std. dev.	Percentiles				
							10	25	50	75	90
A	060580002F01	2865	0.0	44.1	4.75	4.40	1.0	1.8	3.5	6.2	9.8
B	060580014F01	2621	0.0	26.5	3.38	3.75	0.4	0.9	2.0	4.5	8.4
C	060580013F01	2579	0.0	25.6	3.87	3.54	0.9	1.4	2.6	5.1	8.8
D	062080821F05	2693	0.0	26.7	2.97	3.06	0.5	1.0	2.0	3.8	6.6
E	062080822F05	2788	0.0	21.0	2.28	2.69	0.3	0.6	1.3	2.9	5.6
F	062080820F05	2777	0.0	29.4	2.94	3.07	0.5	1.0	1.9	3.8	6.9
G	062080823F05	2708	0.2	13.9	1.94	1.69	0.5	0.8	1.3	2.3	4.1
H	062080825F05	2744	0.0	14.0	1.53	1.54	0.2	0.5	1.0	2.0	3.5
I	062080818F05	2724	0.0	24.7	2.86	3.03	0.5	1.0	1.8	3.8	6.6
J	062080819F05	2618	0.0	26.8	2.94	3.13	0.5	1.0	2.0	3.9	6.6
K	060140002F01	2842	0.0	16.2	1.83	1.63	0.4	0.8	1.4	2.3	3.8
L	060120002F01	2846	0.0	23.8	3.04	2.85	0.7	1.1	2.1	4.0	6.6
M	060080002F01	2827	0.0	9.6	0.93	1.05	0.0	0.3	0.6	1.2	2.2
N	062080824F05	2724	0.0	24.7	2.86	3.04	0.5	0.9	1.8	3.8	14.6
O	062080817F05	2716	0.0	15.9	1.72	1.76	0.3	0.5	1.1	2.2	4.1
	Composite	2880	0.2	15.8	2.64	2.24	0.7	1.1	1.9	3.4	5.6

TABLE 2-3. DATE AND TIME OF MAXIMUM HOURLY AVERAGE CARBON MONOXIDE VALUE

Map code	SAROAD code	Maximum hourly avg., ppm	Date	Time
A	060580002F01	44.1	12-16-82	17:00
B	060580014F01	26.5	1-27-83	19:00
C	060580013F01	25.6	1-27-83	17:00
D	062080821F05	26.7	12-26-82	17:00
E	062080822F05	21.0	1-15-83	21:00
F	062080820F05	29.4	1-27-83	19:00
G	062080823F05	13.9	11-05-82	10:00
H	062080825F05	14.0	1-03-83	17:00
I	062080818F05	23.8	12-17-82	8:00
J	062080819F05	26.8	1-27-83	18:00
K	060140002F01	16.2	11-10-82	8:00
L	060120002F01	23.8	1-03-83	8:00
M	060080002F01	9.6	12-09-82	13:00
N	062080824F05	24.7	12-17-82	8:00
O	062080817F05	15.9	1-11-83	17:00

values were not determined for days with less than 18 hours out of the possible 24. Table 2-4 summarizes the results of analyzing the daily maximum 1-hour values using BMDP program P2D. Table 2-5 provides similar results for daily maximum 8-hour values. These tables supersede Tables 6-15 and 6-16, respectively, in Reference 1.

2.2 RELATIONSHIP BETWEEN DENVER FIXED-SITE READINGS AND SELECTED METEOROLOGICAL PARAMETERS

Two of the permanent monitors (Map Codes A and B) and three of the temporary monitors (Map Codes D, F, and J) reported daily maximum 8-hour

TABLE 2-4. SUMMARY STATISTICS FOR DAILY MAXIMUM 1-HOUR CARBON MONOXIDE VALUES REPORTED BY DENVER MONITORING SITES BETWEEN NOVEMBER 1, 1982, AND FEBRUARY 28, 1983

Map code	SAROAD code	Number of daily max. values	Daily maximum 1-hour carbon monoxide concentration, ppm								
			Minimum	Maximum	Mean	Std. dev.	Percentiles 10	25	50	75	90
A	060580002F01	120	1.5	44.1	12.87	7.41	5.6	8.0	10.5	16.1	23.7
B	060580014F01	108	0.6	26.5	10.33	5.58	2.8	5.9	9.9	14.2	17.3
C	060580013F01	108	2.0	25.6	11.22	5.26	4.4	7.4	10.6	14.3	19.1
D	062080821F05	113	1.0	26.7	8.89	5.11	3.6	5.6	7.9	10.7	16.8
E	062080822F05	120	0.5	21.0	7.92	4.60	2.6	4.7	7.1	10.5	14.1
F	062080820F05	118	0.8	29.4	8.71	4.75	3.2	5.6	8.0	11.1	15.0
G	062080823F05	115	0.8	13.9	5.30	2.71	2.3	3.3	4.8	7.0	9.5
H	062080825F05	118	0.7	14.0	4.53	2.47	2.0	2.5	4.0	6.2	7.9
I	062080818F05	114	0.8	23.8[a]	8.64	5.12	3.4	5.0	7.3	12.3	15.6
J	062080819F05	110	0.8	26.8	8.72	5.21	3.5	5.0	7.4	10.8	16.1
K	060140002F01	118	1.3	16.2	5.09	2.81	2.0	3.1	4.5	6.3	9.2
L	060120002F01	119	0.9	23.8	8.42	4.69	2.5	5.0	7.5	11.1	14.8
M	060080002F01	116	0.4	9.6	2.98	1.57	1.3	1.9	2.8	3.9	5.3
N	062080824F05	118	0.8	24.7	8.80	5.16	3.0	5.0	7.8	12.1	15.1
O	062080817F05	114	0.2	15.9	5.23	2.69	1.7	3.4	5.1	6.6	8.3
	Composite	120	0.7	15.8	6.62	3.16	2.8	4.5	6.0	8.2	10.6

[a]The maximum 1-hour value of 24.7 listed in Table 6-13 is not listed here because it occurred on a day which did not meet data completeness criteria discussed in Section 6.6.

TABLE 2-5. SUMMARY STATISTICS FOR DAILY MAXIMUM 8-HOUR CARBON MONOXIDE VALUES REPORTED BY DENVER MONITORING SITES BETWEEN NOVEMBER 1, 1982, AND FEBRUARY 28, 1983

Map code	SAROAD code	Number of daily max. values	Daily maximum 8-hour carbon monoxide concentration, ppm								
			Minimum	Maximum	Mean	Std. dev.	Percentiles				
							10	25	50	75	90
A	060580002F01	120	1.3	20.7	7.66	3.97	3.4	4.9	6.8	9.6	13.8
B	060580014F01	108	0.4	18.5	6.11	3.60	1.9	3.3	5.9	7.9	10.9
C	060580013F01	107	1.4	13.1	6.31	2.86	2.5	3.9	5.7	8.5	10.3
D	062080821F05	113	0.8	15.2	5.13	2.85	1.9	3.1	4.5	6.2	9.5
E	062080822F05	118	0.4	14.1	4.14	2.45	1.5	2.4	3.4	5.6	7.5
F	062080820F05	118	0.5	15.1	5.16	2.84	1.9	3.0	4.9	6.6	9.0
G	062080823F05	114	0.7	7.8	3.05	1.51	1.6	2.0	2.6	4.0	5.1
H	062080825F05	113	0.6	7.2	2.48	1.40	1.1	1.4	2.1	3.2	4.1
I	062080818F05	112	0.7	13.6	4.97	2.93	1.8	2.8	4.2	6.4	9.3
J	062080819F05	108	0.5	15.2	5.00	2.96	2.1	3.1	4.2	6.2	8.9
K	060140002F01	118	1.0	9.3	2.98	1.51	1.5	1.9	2.7	3.7	5.0
L	060120002F01	118	0.7	13.2	4.86	2.40	2.0	2.8	4.5	6.5	8.1
M	060080002F01	116	0.2	5.8	1.57	1.08	0.5	0.9	1.3	1.8	3.3
N	062080824F05	116	1.2	13.5	5.01	2.79	2.2	2.7	4.4	6.4	9.5
O	062080817F05	114	0.1	8.6	3.01	1.58	1.3	1.9	2.7	3.8	5.2
	Composite	120	0.6	10.3	4.16	2.01	1.7	2.9	3.7	5.3	7.0

values exceeding 15 ppm. These five monitors were all located in the central business district of Denver, an area of high traffic density. A detailed analysis of fixed-site data and associated meteorological conditions by the State of Colorado concluded that the critical meteorological conditions producing 8-hour CO concentrations in excess of 15 ppm were 1) wind speed < 6 mph, 2) morning temperature inversion > $4^{o}C/100$ m, 3) inversion depth between 1000 and 1500 feet, and 4) high pressure with light winds at 700 mb and 500 mb levels.[2]

In a supplemental analysis, PEI attempted to relate fixed-site readings with the following meteorological variables as reported at Stapleton International Airport:

TMAX = daily maximum temperature, ^{o}F

TMIN = daily minimum temperature, ^{o}F

TAVG = daily mean temperature, ^{o}F

PREC = total precipitation for day, inches

WIND = mean windspeed for day, mi/h.

Note that there is only one value per day for each of the variables. At the time of this analysis, meteorological data reported at 3-hour intervals (the standard interval for the National Weather Service) were unavailable for analysis. Figure 3 in Appendix A shows the location of Stapleton International Airport with respect to the 15 fixed-site monitors operating during the study.

PEI conducted stepwise linear regression analyses using the general model

$$\hat{c}_{FS} = \alpha + (\beta_1)(TMAX) + (\beta_2)(TMIN) + (\beta_3)(TAVG) + (\beta_4)(PREC) + (\beta_5)(WIND) + (\beta_6)(WIND)^{-1} + (\beta_7)(WIND)^{-2} + (\beta_8)[\ln(WIND)] \quad (2\text{-}1)$$

where $\hat{c}_{FS}$ = estimated hourly average fixed-site CO concentration, ppm.

Table 2-6 lists the overall R^2 value of each "best-fit" model suggested by the stepwise regression analyses and the F-to-remove value associated with

TABLE 2-6. COEFFICIENTS OF DETERMINATION AND F-TO-REMOVE VALUES FOR BEST-FIT MODELS DETERMINED BY STEPWISE LINEAR REGRESSION

Map code	SAROAD code	R^2	F to remove[a]							
			TMAX	TMIN	TAVG	PREC	WIND	$WIND^{-1}$	$WIND^{-2}$	ln(WIND)
A	060580002F01	0.072	88	b	b	b	b	b	b	<u>176</u>
B	060580014F01	0.133	199	b	144	b	b	b	<u>238</u>	b
C	060580013F01	0.071	<u>133</u>	b	b	b	b	127	b	b
D	062080821F05	0.072	115	b	b	b	b	b	b	<u>141</u>
E	062080822F05	0.077	b	b	b	b	b	b	b	<u>232</u>
F	062080820F05	0.114	153	b	91	b	b	<u>231</u>	b	b
G	062080823F05	0.093	b	b	b	b	b	<u>276</u>	b	b
H	062080825F05	0.089	b	b	b	b	b	b	<u>268</u>	b
I	062080818F05	0.110	<u>219</u>	b	137	b	b	131	b	b
J	062080819F05	0.087	134	b	b	b	b	b	b	<u>174</u>
K	060140002F01	0.068	b	b	b	b	b	<u>208</u>	b	b
L	060120002F01	0.097	87	126	b	b	b	b	b	<u>151</u>
M	060080002F01	0.100	b	b	b	b	b	b	<u>313</u>	b
N	062080824F05	0.063	70	b	b	b	b	<u>158</u>	b	b
O	062080817F05	0.098	70	82	b	b	b	b	b	<u>181</u>
	Composite	0.122	163	78	b	b	b	<u>285</u>	b	b

[a]Largest F value is underlined.

[b]Variable not retained in model.

each variable retained by the best-fit model. The relative contribution a variable makes to the best-fit model increases with the F-to-remove value. Note that the largest F-to-remove value for each best-fit model is underlined in Table 2-6. In most cases, the largest F-to-remove value is associated with $WIND^{-1}$, $WIND^{-2}$, or ln(WIND). Although TMAX has the largest F-to-remove value in only two cases, it is retained in most of the best-fit models. TMIN and TAVE are retained in less than half of the best-fit models; PREC and WIND do not appear in any of the best-fit models. The best-fit model for the composite site is

$$\hat{c}_{FS} = -1.041 + (0.060)(TMAX) - (0.051)(TMIN) + (13.8)(WIND)^{-1}; \quad (2\text{-}2)$$

$R^2 = 0.122$. Note that the estimated CO concentration increases with maximum daily temperature, decreases with minimum daily temperature, and decreases with windspeed.

None of the R^2 values in Table 2-6 exceeds 0.133. Consequently, the meteorological variables included in the general model (Equation 2-1) appear to be poor predictors of the 1-hour values measured by the fixed-site monitors. The two best predictors are the natural logarithm of windspeed and the reciprocal of wind speed. TMAX is the best temperature-related predictor.

To determine if WIND raised to a power could provide a better fit than any of the variables considered in Equation 2-1, PEI evaluated the model

$$\hat{c}_{FS} = (a)(WIND)^{b} \quad (2\text{-}3)$$

by conducting linear regression analysis using the equivalent expression

$$\ln(\hat{c}_{FS}) = \ln(a) + b[\ln(WIND)] \quad (2\text{-}4)$$

where c_{FS} was the 1-hour CO value at the composite site. The regression analysis yields ln(a) = 2.293, b = -0.835, and a slightly larger R^2 (0.138). The best-fit model is thus

$$\hat{c}_{FS} = (9.908)(WIND)^{-0.835}. \quad (2\text{-}5)$$

As would be expected, CO concentration decreases as windspeed increases.

As previously indicated, the meteorological variables considered in the general models represented by Equations 2-1 and 2-3 consist of daily values. Higher R^2 values for best-fit models may have resulted if three-hour meteorological variables had been included in the general model.

2.3 COMPARISON OF DENVER AND WASHINGTON COMPOSITE SITE SUMMARY STATISTICS

Site descriptions and summary statistics for the 11 fixed-site monitors operating in Washington are presented in Appendix B. PEI prepared a data set for a "composite" monitor, the data set consisting of the hour-by-hour arithmetic means of the values reported by the 11 Washington sites. Table 2-7 presents daily maximum summary statistics for the Washington composite site together with those of the Denver composite site discussed in Section 2.1. Comparison of the summary statistics for the two composite sites reveals that Denver experienced much higher ambient CO levels during the study period than did Washington. With respect to composite daily maximum 1-hour CO concentrations, Denver has a mean of 6.6 ppm--more than twice Washington's mean of 3.2 ppm.

2.4 REFERENCES

1. Johnson, T. A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/54-84-014, March 1983.

2. The Denver Carbon Monoxide Study: Fixed Station Siting, Data Acquisition, and Quality Assurance. Air Pollution Control Division, Department of Health, State of Colorado. September 1983.

3. Dixon, W. J., ed. BMDP Statistical Software 1981. University of California Press, Berkeley, California. 1981.

TABLE 2-7. SUMMARY STATISTICS FOR DAILY MAXIMUM 1-HOUR AND 8-HOUR CARBON MONOXIDE CONCENTRATIONS REPORTED BY THE COMPOSITE SITES IN DENVER AND WASHINGTON

Statistic	Daily maximum CO concentration, ppm			
	Denver[a]		Washington[b]	
	1-h values	8-h values	1-h values	8-h values
Minimum	0.7	0.6	0.8	0.7
Maximum	15.8	10.3	8.6	6.4
Mean	6.6	4.2	3.2	2.3
Standard deviation	3.2	2.0	1.8	1.2
10th percentile	2.8	1.7	1.4	1.1
25th percentile	4.5	2.9	1.9	1.4
50th percentile	6.0	3.7	2.8	1.9
75th percentile	8.2	5.3	4.1	2.7
90th percentile	10.6	7.0	5.9	4.1
95th percentile	13.0	8.2	6.9	4.8
98th percentile	14.7	9.2	7.9	5.4
99th percentile	15.3	9.4	8.4	5.5

[a]120 values.

[b]110 values.

SECTION 3

RELATIONSHIPS BETWEEN EXPOSURES AND FIXED-SITE READINGS

PEI has performed a series of regression analyses to test whether any strong, linear relationships exist between personal exposures, as indicated by PEM readings, and CO levels reported simultaneously by fixed-site monitors. The analyses are described here in the order in which they were performed. Section 3.1 reviews linear regression analyses of Denver data preciously reported by Johnson[1] and summarized in Appendix A. In these analyses, the dependent variable is PEM value (grouped by microenvironment) and the independent variable is hourly-average CO value reported simultaneously by the nearest fixed site or by the "composite" site. Section 3.2 describes stepwise linear regression analyses in which PEM value is the dependent variable and the simultaneous values reported by all 15 Denver fixed sites and the composite site are 16 independent variables. PEM values are not grouped by microenvironment in the Section 3.2 analyses. Section 3.3 describes linear regression analyses performed by PEI using Washington data. The analyses are similar to those described in Section 3.1 in that the dependent variable is PEM value grouped by microenvironment and the independent variable is simultaneous value reported by the nearest fixed site or by the composite site. Section 3.4 repeats the analyses described in Section 3.1 using "adjusted" PEM values from the Denver study as the dependent variable. Section 3.5 compares daily maximum 1-h and 8-h exposures determined from PEM data with daily maximum 1-h and 8-h CO values reported by the Denver fixed-site monitors.

3.1 REVIEW OF PREVIOUS ANALYSES USING DENVER DATA

In the absence of personal monitoring data, estimates of population exposure are often based on fixed-site monitoring data. In some applications of the NAAQS Exposure Model (NEM),[1] for example, the air quality in a particular microenvironment is estimated using the equation

$$x_{m,t} = a_m + (b_m)\,(x_{mon,t}) \qquad (3\text{-}1)$$

where $x_{m,t}$ is the estimated pollutant concentration in microenvironment m at time t; a_m is an additive factor related to pollutant sources in the microenvironment (e.g., gas stoves in the residential microenvironment); b_m is a multiplicative factor; and $x_{mon,t}$ is the air pollutant concentration reported by a particular fixed-site monitor at time t. Equation 3-1 implies that a strong, linear relationship exists between pollutant levels in certain microenvironments and simultaneous pollutant levels measured at fixed-site monitors. This assumption can be examined in the case of CO by performing linear regression analyses that use PEM values grouped by microenvironment as the dependent variable and simultaneously-recorded fixed-site values as the independent varialbe.

To perform these analyses, each PEM value must be paired with a value reported by a single fixed-site monitor. Since the census tract of each nontransit PEM value is known, it seems reasonable to assign a single fixed-site monitor to each census tract in the study area. Whenever a PEM value is reported for a given census tract, it is paired with the simultaneous value of the fixed-site monitor assigned to that census tract. -

One possible method of assigning fixed-site monitors to census tracts is to use the monitor located nearest to the geographic centroid of the census tract. An implicit assumption of this method is that the correlation between ambient CO measurements taken at two locations increases as the separation distance decreases. As a test of this assumption, the correlations between all pairs of fixed-site monitors in Denver were calculated using BMDP program P8D. As discussed in Section 6.9 of Reference 2, correlation was found to decrease as separation distance increased.

This analysis suggested that a linear regression analysis that pairs each nontransit PEM value with the simultaneous value reported at the nearest fixed site might be appropriate for the Denver study data. A computer program was written that determined the fixed-site monitor nearest to each census tract centroid. Weighted linear regression analyses were then performed with the data grouped by selected microenvironment codes (i.e., B + D3). Results for nontransit microenvironments for which $n \geq 10$ are listed in Table V of Appendix A in order of R^2 value. Values of R^2 range from 0.00 to 0.46. As might be expected, many of the microenvironments with small R^2 values are associated with local CO sources that tend to reduce the correlation between PEM value and nearest fixed-site value; however, other microenvironments associated with local CO sources have relatively large R^2 values.

Table V does not list any in-transit microenvironments because of the difficulty in pairing in-transit PEM values with a "nearest" fixed-site monitor value. In the SAMPLE-DATA file, each in-transit PEM value has two census tract listings, one associated with the start address and the other with the end address. Neither may be a good indicator of the CO conditions encountered during the trip. One alternative procedure is to pair the intransit PEM values with simultaneous values from the composite data set described in Section 2.1. As discussed in Section 6.9 of Reference 2, the composite data set shows relatively high correlations with most of the fixed-site data sets. It also provides an indication of the average CO level in the study area. Table VI in Appendix A lists the results of linear regression analyses pairing in-transit PEM values with simultaneous values from the composite data set. Values of R^2 range from 0.04 (car) to 0.58 (motorcycle).

3.2 PEM VALUES VERSUS VALUES REPORTED BY OPTIMIZED GROUP OF DENVER FIXED-SITE MONITORS

The analyses described in Section 3.1 suggest that the correlation between PEM values and nearest fixed-site (or composite-site) 1-hour CO values is weak for most microenvironments. PEI also investigated whether the 1-hour CO values reported by a particular fixed-site monitor or "optimized" group of fixed-site monitors were better correlated with PEM values. In an exploratory analysis, PEI performed weighted linear regression analyses with PEM value as dependent variable and simultaneous fixed-site value at a particular monitor as the independent variable. Table 3-1 lists the results for each of the 15 Denver monitors and for the "composite" site. Note that R^2 values are quite low; they range from 0.010 to 0.049. Site 4 (2105 Broadway) has the largest R^2 value. Other sites with $R^2 \geq 0.037$ include Site 16 (Composite), Site 9, Site 10, and Site 11.

PEI also performed step-wise multiple linear regression analyses with PEM value (c_{PEM}) as dependent variable and the simultaneous values reported by all 15 fixed-site monitors and by the "composite site" as 16 independent variables

TABLE 3-1. DENVER FIXED-SITE MONITORS AND RESULTS OF WEIGHTED LINEAR REGRESSION ANALYSES WITH PEM VALUE AS DEPENDENT VARIABLE AND SIMULTANEOUS FIXED-SITE VALUE AS INDEPENDENT VARIABLE

	Site code			Linear regression		
Site	3-digit	Map[a]	SAROAD	Intercept	Slope	R^2
1	HIG	M	060080002F01	2.66	0.624	0.010
2	ARV	L	060120002F01	2.19	0.364	0.026
3	AUR	K	060140002F01	2.02	0.632	0.026
4	002	A	060580002F01	1.71	0.322	0.049
5	013	C	060580013F01	2.02	0.321	0.032
6	014	B	060580014F01	2.43	0.263	0.022
7	817	O	062080817F05	2.20	0.631	0.028
8	818	I	062080818F05	2.35	0.355	0.028
9	819	J	062080819F05	2.05	0.385	0.039
10	820	F	062080820F05	2.11	0.382	0.037
11	821	D	062080821F05	2.05	0.381	0.037
12	822	E	062080822F05	2.40	0.367	0.025
13	823	G	062080823F05	1.97	0.621	0.028
14	824	N	062080824F05	2.22	0.355	0.029
15	825	H	062080825F05	2.07	0.711	0.027
16	AVE		Composite	1.73	0.589	0.044

[a]See Figure 3 of Appendix A.

(c_i, i = 1,2,...,16). The step-wise regression was performed by adding or subtracting one site at a time and testing for an improvement in model fit. The results are summarized in Table 3-2 for the weighted analysis and in Table 3-3 for the unweighted analysis. Note that in each table the R^2 value for the best fit is small (<0.07) and that the R^2 value for Site 16 (the composite site) by itself is almost as large as the multiple R^2 value for the best fit. The regression equation corresponding to the best fit is

$$\hat{c}_{PEM} = 0.781 + (0.257)(c_1) + (0.155)(c_2) + (0.135)(c_4) + (0.047)(c_5) - (0.077)(c_6) + (0.142)(c_{10}) - (0.075)(c_{12}) + (0.312)(c_{13}) \quad (3\text{-}2)$$

for the weighted analysis (Table 3-2) and

$$\hat{c}_{PEM} = 0.777 + (0.252)(c_1) + (0.057)(c_4) - (0.154)(c_8) - (0.138)(c_{12}) + (0.175)(c_{13}) + (0.764)(c_{16}) \quad (3\text{-}3)$$

for the unweighted analysis (Table 3-3). For a discussion of sample weights, see Section 2.4 of Reference 2.

Overall, these analyses suggest that one-hour values reported by a particular fixed-site monitor or "optimized" group of fixed-site monitors do not provide a good means of predicting simultaneous PEM values.

3.3 PEM VALUES VERSUS VALUES REPORTED BY NEAREST WASHINGTON FIXED-SITE MONITOR

As previously indicated, Research Triangle Institute conducted a study of personal exposure to carbon monoxide (CO) in Washington, D.C., during the period November 8, 1982 - February 25, 1983. Appendix B provides summary statistics for 1-hour and 8-hour CO values reported by the Washington fixed-site monitors for this period. This section contains the results of linear regression analyses conducted by PEI which relate PEM values provided by RTI to 1-hour CO concentrations recorded simultaneously at the fixed sites. Statistical analyses performed by RTI on the Washington data have been described by Hartwell et al.,[3] by Settergren et al.,[4] and by Clayton et al.[5]

TABLE 3-2. RESULTS OF STEP-WISE MULTIPLE LINEAR REGRESSION ANALYSIS (WEIGHTED)

Step	Operation	Resulting R^2	Change in R^2
1	Add Site 16	0.0515	0.0515
2	Add Site 13	0.0544	0.0030
3	Add Site 4	0.0562	0.0018
4	Add Site 2	0.0572	0.0010
5	Remove Site 16	0.0571	-0.0001
6	Add Site 1	0.0577	0.0007
7	Add Site 10	0.0582	0.0003
8	Add Site 6	0.0585	0.0003
9	Add Site 12	0.0587	0.0002
10	Add Site 5	0.0589	0.0003

TABLE 3-3. RESULTS OF STEP-WISE MULTIPLE LINEAR REGRESSION ANALYSIS (UNWEIGHTED)

Step	Operation	Resulting R^2	Change in R^2
1	Add Site 16	0.0606	0.0606
2	Add Site 1	0.0638	0.0032
3	Add Site 8	0.0647	0.0009
4	Add Site 12	0.0656	0.0009
5	Add Site 13	0.0663	0.0007
6	Add Site 4	0.0667	0.0003

Table 3-4 presents the format of two files developed by PEI which combine PEM, activity diary, and fixed-site data. For purposes of this analysis, PEI identified the microenvironment associated with each PEM value through the four-digit variable LOC (columns 12-15). In-transit microenvironments were further differentiated through the four-digit variable MODETRAV (columns 16-19), given LOC = 0100 (i.e., in transit). In developing these files, PEI edited some of the RTI data to ensure that the LOC and MODETRAV codes were consistent.

In the file, a single census tract (TRACT1) is listed for each nontransit PEM value. Two census tracts are listed for each in-transit PEM value: TRACT2 corresponds to the "start" address, and TRACT3 corresponds to the "end" address. Based on the census tract code TRACT1, each nontransit PEM value is paired with the value (COLEV1) reported by the nearest fixed-site monitor for the hour during which the PEM value was measured. Three fixed-site values are assigned to each in-transit PEM value. COLEV1 is the value for the "composite" fixed site; COLEV2 is the value for the fixed site nearest TRACT2; and COLEV3 is the value for the fixed site nearest TRACT3.

Weighted linear regression analyses were performed with the data grouped by selected microenvironment codes. Results for microenvironments for which $n \geq 10$ are listed in Tables 3-5 through 3-8 in order of R^2 value. Table 3-5 provides the nontransit results where the independent variable is the fixed-site value and the dependent variable is the PEM value. Tables 3-6, 3-7, and 3-8 provide in-transit regression results where the independent variables are the composite, start, and end fixed-site values, respectively. Values of R^2 range from 0.00 to 0.66. As might be expected, many of the microenvironments with small R^2 values are associated with local CO sources that tend to reduce the correlation between PEM value and nearest fixed-site value.

Only two nontransit microenvironments have R^2 values exceeding 0.20: hospital (R^2 = 0.66) and church (R^2 = 0.60). The R^2 value for office is 0.06; the R^2 value for residence is 0.02. Excluding the subcategories "multiple response" and "missing," the in-transit microenvironments which have an R^2 value exceeding 0.20 in Table 3-6, 3-7, or 3-8 are train/subway, jogging, and truck. The R^2 values for car range from 0.06 to 0.08 in the three tables. It is interesting to note that for a given in-transit microenvironment, Tables 3-6 and 3-8 generally contain larger R^2 values than Table 3-7. This suggests that in-transit PEM values are better paired to fixed-site values reported by

TABLE 3-4. FORMAT OF FILES (WASHINGTON ONLY) LISTING PEM, ACTIVITY DIARY, AND FIXED-SITE DATA FOR NONTRANSIT AND IN-TRANSIT MICROENVIRONMENTS

Variable	Length	Columns	Description
PID	7	1 - 7	Person ID number
ACTNO	2	8 - 9	Activity sequence number
ACT	2	10 - 11	Activity code
LOC	4	12 - 15	Location of activity
MODETRAV	4	16 - 19	Mode of travel
GARAGE	2	20 - 21	Garage attached to building?
GASSTOVE	2	22 - 23	Gas stove in use?
SMOKERS	2	24 - 25	Smokers present?
BEGTIM	7.4	26 - 32	CO interval start time (hours)
SAMPDATE	6	33 - 38	Date of sample (MMDDYY)
DUR	7	39 - 45	Duration of activity (minutes)
COLEV	8	46 - 53	CO level from field data (PPM)
LCAT	2	57 - 58	Major environment
CLA	2	59 - 60	Minor environment
TRACT1	6	61 - 66	Census tract for address 1
TRACT2	6	67 - 72	Census tract for address 2 (start)
TRACT3	6	73 - 78	Census tract for address 3 (end)
DWEIGHT	12	79 - 90	Diary analysis weight
SITE1	6	91 - 96	Site code for address 1
COLEV1	5	97 - 101	CO concentration at nearest site for nontransit microenvironment, at composite site for in-transit microenvironment
SITE2[a]	6	102 - 107	Site code for address 2
COLEV2[a]	5	108 - 112	Concentration at SITE2
SITE3[a]	6	113 - 118	Site code for address 3
COLEV3[a]	5	119 - 123	Concentration at SITE3

[a]Appears only in in-transit file.

TABLE 3-5. RESULTS OF WEIGHTED LINEAR REGRESSION ANALYSIS (WASHINGTON ONLY) WITH NONTRANSIT PEM VALUE AS DEPENDENT VARIABLE AND SIMULTANEOUS VALUE AT NEAREST FIXED SITE AS INDEPENDENT VARIABLE

Code	Microenvironment[a]		Linear regression				
	Category	Subcategory	n	Intercept	Slope	R^2	p
0660	Indoors	Hospital	46	-0.05	0.63	0.66	0.000
0663	Indoors	Church	44	-0.04	0.58	0.60	0.000
0661	Indoors	Garage	70	4.02	3.43	0.19	0.000
0884	Outdoors	Park, sports arena, playground	11	0.06	-0.01	0.15	0.239
0667	Indoors	Laboratories	23	0.30	0.26	0.11	0.132
0883	Outdoors	Residential area	82	0.53	0.52	0.10	0.003
0300	Indoors	Office	1741	0.94	0.45	0.06	0.000
0700	Outdoors	Within 10 yards of road or street	224	1.33	0.50	0.04	0.002
0400	Indoors	Store	178	1.25	-0.33	0.02	0.047
0200	Indoors	Residence	14962	1.21	0.18	0.02	0.000
0881	Outdoors	Garage, parking lot	38	5.05	-0.42	0.00	0.709
0668	Indoors	Not specified	57	3.52	-0.16	0.00	0.751
0665	Indoors	School, school gym	239	1.01	0.06	0.00	0.555
0500	Indoors	Restaurant	120	2.88	-0.03	0.00	0.848
0669	Indoors	Other indoor location	129	5.07	0.09	0.00	0.900

[a]Listed in order of R^2 value.

[p]Probability that slope = 0.

TABLE 3-6. RESULTS OF WEIGHTED LINEAR REGRESSION ANALYSES (WASHINGTON ONLY) WITH IN-TRANSIT PEM VALUE AS DEPENDENT VARIABLE AND SIMULTANEOUS VALUE FROM COMPOSITE DATA SET AS INDEPENDENT VARIABLE

Code	In-transit subcategory[a]	Linear regression				
		n	Intercept	Slope	R^2	p
0500	Train/subway	38	0.05	1.09	0.61	0.000
0661	Jogging	11	0.43	0.67	0.25	0.118
9600	Multiple response	20	-0.98	2.58	0.20	0.050
9800	Missing	22	-0.21	1.83	0.13	0.100
0200	Car	2646	1.51	1.74	0.08	0.000
0400	Truck	85	2.16	2.00	0.07	0.014
0300	Bus	67	1.01	2.45	0.05	0.066
0100	Walking	510	1.21	-0.94	0.03	0.000
0664	Van	21	1.91	0.33	0.03	0.478
0662	Bicycle	16	3.62	-0.08	0.01	0.721

[a]Listed in order of R^2 value.

[p]Probability that slope = 0.

TABLE 3-7. RESULTS OF WEIGHTED LINEAR REGRESSION ANALYSES (WASHINGTON ONLY) WITH IN-TRANSIT PEM VALUE AS DEPENDENT VARIABLE AND SIMULTANEOUS VALUE AT FIXED SITE NEAREST START ADDRESS AS INDEPENDENT VARIABLE

Code	In-transit subcategory[a]	Linear regression				
		n	Intercept	Slope	R^2	p
0500	Train/subway	23	0.67	0.49	0.47	0.000
9800	Missing	21	0.30	2.29	0.31	0.009
0661	Jogging	11	1.13	0.41	0.30	0.081
0400	Truck	63	0.48	3.94	0.27	0.000
9600	Multiple response	14	0.26	1.28	0.21	0.099
0200	Car	1748	2.98	0.97	0.07	0.000
0100	Walking	355	1.50	0.46	0.07	0.000
0662	Bicycle	11	3.97	-0.06	0.01	0.737
0664	Van	16	2.39	-0.62	0.01	0.695
0300	Bus	36	8.90	-0.65	0.01	0.600

[a]Listed in order of R^2 value.

[p]Probability that slope = 0.

TABLE 3-8. RESULTS OF WEIGHTED LINEAR REGRESSION ANALYSES (WASHINGTON ONLY) WITH IN-TRANSIT PEM VALUE AS DEPENDENT VARIABLE AND SIMULTANEOUS VALUE AT FIXED SITE NEAREST END ADDRESS AS INDEPENDENT VARIABLE

Code	In-transit subcategory[a]	Linear regression				
		n	Intercept	Slope	R^2	p
9800	Missing	12	0.01	1.73	0.53	0.007
0661	Jogging	11	1.13	0.41	0.30	0.081
0662	Bicycle	11	4.28	-0.18	0.16	0.231
0400	Truck	48	0.96	3.10	0.11	0.024
0200	Car	1708	3.12	0.83	0.06	0.000
9600	Multiple response	11	4.06	-0.41	0.01	0.727
0500	Train/subway	13	2.61	0.16	0.01	0.729
0100	Walking	323	2.33	0.22	0.00	0.235
0664	Van	16	2.54	0.03	0.00	0.920
0300	Bus	45	5.18	0.05	0.00	0.946

[a]Listed in order of R^2 value.
[p]Probability that slope = 0.

the composite site or site nearest the end address than to those reported by the site nearest the start address.

It is also worth noting that for a given in-transit microenvironment, n will be larger in Table 3-6 than in Table 3-7 or Table 3-8. This is because in-transit PEM values could always be paired with a composite fixed-site value but not always with a "start" or "end" fixed-site value. In many cases, no start or end census tract code was provided for a PEM value.

The potential for high CO exposures in indoor garages is evidenced by the large slope (3.43) and intercept (4.02) values listed for this microenvironment in Table 3-5. No other nontransit microenvironment has a slope >1. Two microenvironments have intercepts larger than 4.02: outdoors - garage/parking lot (5.05) and indoors - other location (5.07). The finding that both of these microenvironments have R^2 values of 0.00 suggests that local sources (e.g., automobiles in the garage) may mask the traffic-oriented ambient levels measured by the nearest fixed-site monitor.

3.4 ADJUSTED PEM VALUES VERSUS VALUES REPORTED BY NEAREST DENVER FIXED-SITE MONITOR

Table III of Appendix A lists weighted means and standard deviations for the PEM values recorded in various microenvironments during the Denver study. At the request of EMSL, PEI developed a similar table based on "adjusted" PEM values. Each adjusted PEM value is the reported PEM value minus the simultaneously reported CO value at the nearest fixed site (nontransit microenvironments) or at the composite site (in-transit microenvironments). Table 3-9 lists these results. Note that indoors - public garage, motorcycle, indoors - service station, and bus are the microenvironments with the largest means in Table III and in Table 3-9. The adjustment process does not appear to nullify the differences between the microenvironments.

Tables 3-10 and 3-11 are similar to Tables V and VI in Appendix A except that adjusted PEM values were used as the dependent variables in the regression analyses. For 13 of the 32 microenvironments, the adjustment process yields larger R^2 values. These microenvironments include -

79 bb	outdoors	- park or golf course
78 bb	outdoors	- sports arena
61 bb	indoors	- other public building
59 bb	indoors	- health care facility
02 bb	indoors	- residence
60 bb	indoors	- school
03 bb	indoors	- office
76 bb	outdoors	- residential grounds
72 e	outdoors	- public garage
56 bb	indoors	- auditorium
53 bb	indoors	- manufacturing facility
51 bb	indoors	- residential garage
62 bb	indoors	- other location

Adjustment yields only reduced R^2 values among the in-transit microenvironments.

These results are consistent with our expectations. The microenvironments which yield higher R^2 values after adjustment are those with low average CO levels before adjustment. Thus the adjustment process subtracts relatively large fixed-site values from relatively small PEM values to yield adjusted values nearly equal to the fixed-site values but opposite in sign. Linear

TABLE 3-9. WEIGHTED MEAN ADJUSTED PEM CONCENTRATION (MICROENVIRONMENTS ORDERED ACCORDING TO TABLE V LISTING)

Code		Microenvironment			CO concentration, ppm	
B	D3	Category	Subcategory	n	Mean	Std. dev.
52	a	Indoors	Public garage	110	8.24	18.21
01	93	In transit	Motorcycle	22	7.32	6.22
54	bb	Indoors	Service station or motor vehicle repair facility	112	6.23	8.56
01	03	In transit	Bus	76	5.88	6.05
72	a	Outdoors	Public garage	29	1.70	3.66
01	02	In transit	Car	3631	5.44	9.72
71	bb	Outdoors	Residential garage or carport	22	4.47	8.79
62	bb	Indoors	Other location	381	4.87	19.33
01	04	In transit	Truck	405	4.58	9.39
55	bb	Indoors	Other repair shop	46	3.35	7.20
58	bb	Indoors	Shopping mall	55	2.18	5.52
51	bb	Indoors	Residential garage	66	1.65	7.44
07	c	Outdoors	Within 10 yards of road	468	1.28	4.82
01	01	In transit	Walking	619	1.28	5.90
bb	bb	Not specified	Not specified	583	1.05	6.47
05	bb	Indoors	Restaurant	486	1.06	3.85
74	bb	Outdoors	Service station or motor vehicle repair facility	11	2.00	3.48
03	c	Indoors	Office	2090	0.39	4.45
73	d	Outdoors	Parking lot	51	1.13	4.21
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	94	0.51	5.01
04	bb	Indoors	Store	675	0.49	5.38
80	bb	Outdoors	Other location	115	0.65	4.13
59	bb	Indoors	Health care facility	336	-0.51	4.39
61	bb	Indoors	Other public building	111	-1.02	3.29
53	bb	Indoors	Manufacturing facility	41	-1.42	3.27
02	bb	Indoors	Residence	20953	-0.41	4.19
77	bb	Outdoors	School grounds	15	-0.11	2.61
60	bb	Indoors	School	342	-0.92	3.18
57	bb	Indoors	Church	178	-0.53	3.05
76	bb	Outdoors	Residential grounds	70	-0.45	2.47
01	92	In transit	Bicycle	9	0.19	3.39
78	bb	Outdoors	Sports arena, amphitheater, etc.	16	-0.12	3.85
79	bb	Outdoors	Park or golf course	18	-1.55	1.35

[a]Includes D3 = bb, 01, and 02.

[b]Blank.

[c]Includes D3 = bb and 01.

[d]Includes D3 = bb, 01, 02, and 03.

TABLE 3-10. RESULTS OF WEIGHTED LINEAR REGRESSION ANALYSES WITH NONTRANSIT ADJUSTED PEM VALUE AS DEPENDENT VARIABLE AND SIMULTANEOUS VALUE AT NEAREST FIXED SITE AS INDEPENDENT VARIABLE

Code		Microenvironment[a]			Linear regression			
B	D3	Category	Subcategory	n	Intercept	Slope	R^2	p
80	bb	Outdoors	Other location	115	0.35	0.11	0.01	0.325
79	bb	Outdoors	Park or golf course	18	-0.09	-0.61	0.65	0.000
77	bb	Outdoors	School grounds	15	-0.37	0.15	0.01	0.780
54	bb	Indoors	Service station or motor vehicle repair facility	112	4.18	0.68	0.06	0.012
05	bb	Indoors	Restaurant	486	1.69	-0.24	0.03	0.000
74	bb	Outdoors	Service station or motor vehicle repair facility	11	1.61	0.21	0.01	0.780
07	c	Outdoors	Within 10 yards of road	468	1.58	-0.11	0.00	0.166
57	bb	Indoors	Church	178	0.09	-0.30	0.05	0.004
73	d	Outdoors	Parking lot	51	2.26	-0.40	0.11	0.019
55	bb	Indoors	Other repair shop	46	3.69	-0.12	0.00	0.659
78	bb	Outdoors	Sports arena, amphitheater, etc.	16	3.05	-2.76	0.31	0.024
61	bb	Indoors	Other public building	111	0.74	-0.58	0.24	0.000
58	bb	Indoors	Shopping mall	55	1.24	0.43	0.01	0.389
04	bb	Indoors	Store	675	1.67	-0.44	0.06	0.000
59	bb	Indoors	Health care facility	336	0.97	-0.55	0.12	0.000
02	bb	Indoors	Residence	20953	1.00	-0.57	0.13	0.000
60	bb	Indoors	School	342	0.97	-0.68	0.26	0.000
03	bb	Indoors	Office	2090	2.53	-0.66	0.18	0.000
71	bb	Outdoors	Residential garage or carport	22	5.67	-0.39	0.02	0.504
bb	bb	Not specified	Not specified	583	2.07	-0.37	0.02	0.001
76	bb	Outdoors	Residential grounds	70	0.84	-0.70	0.18	0.000
72	e	Outdoors	Public garage	29	3.02	-0.20	0.08	0.143
52	e	Indoors	Public garage	110	9.41	-0.22	0.00	0.567
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	94	2.25	-0.62	0.10	0.002
53	bb	Indoors	Manufacturing facility	41	1.41	-0.82	0.41	0.000
51	bb	Indoors	Residential garage	66	3.98	-0.86	0.10	0.009
62	bb	Indoors	Other location	381	7.94	-0.93	0.03	0.000

[a]Listed in order of Table V.

[b]Blank.

[c]Includes D3 = bb and 01.

[d]Includes D3 = bb, 01, 02, and 03.

[e]Includes D3 = bb, 01, and 02.

[p]Probability that slope = 0.

TABLE 3-11. RESULTS OF WEIGHTED LINEAR REGRESSION ANALYSES WITH IN-TRANSIT ADJUSTED PEM VALUE AS DEPENDENT VARIABLE AND SIMULTANEOUS VALUE FROM COMPOSITE DATA SET AS INDEPENDENT VARIABLE

Code		In-transit subcategory	Linear regression				
B	D3		n	Intercept	Slope	R^2	p
01	93	Motorcycle	22	4.50	1.14	0.28	0.011
01	03	Bus	76	3.17	1.02	0.13	0.002
01	01	Walking	619	0.06	0.47	0.03	0.000
01	04	Truck	405	3.27	0.54	0.02	0.013
01	02	Car	3631	6.01	-0.21	0.00	0.002
01	a	All	4762	5.15	-0.08	0.00	0.186

[a]Includes D3 codes 01, 02, 03, 04, 92, and 93.

[p]Probability that slope = 0.

regression analysis yields high R^2 values with negative slope coefficients in such cases. All 13 of the microenvironments listed above have negative slopes in Table 3-10.

The rationale for adjusting indoor PEM values is that indoor PEM values should nearly equal simultaneous outdoor CO levels in the absence of indoor sources. An adjusted value thus provides a measure of CO from indoor sources if the fixed-site value subtracted from the PEM value equals the CO level <u>immediately</u> <u>outside</u> <u>the</u> <u>building</u>. The fixed-site monitors in Denver tend to be traffic-oriented and thus generally overestimate typical outdoor CO levels near most indoor locations in Denver. For this reason, adjustment of PEM values does not appear to be a promising approach to characterizing indoor sources of CO.

3.5 DAILY MAXIMUM EXPOSURES VERSUS VALUES REPORTED BY DENVER FIXED-SITE MONITORS

The analyses discussed in Sections 3.1 through 3.4 suggest that individual PEM readings are not highly correlated with simultaneous fixed-site readings. In a supplemental analysis, PEI investigated whether daily maximum 1-hour and

8-hour exposures reported by PEM's in the Denver study were correlated with daily maximum 1-hour and 8-hour CO concentration reported by fixed sites. PEI developed a file which lists the daily maximum 1-h and 8-h CO exposures for each person-day of the Denver study. Paired with these values are the daily maximum 1-h and 8-h composite fixed-site values which occurred during the midnight-to-midnight period containing the daily maximum 1-h exposure or the first hour of the daily maximum 8-h exposure. The composite fixed-site data were used because of the difficulty in pairing daily maximum exposures which spanned two or more census tracts with a single fixed-site monitor.

Weighted linear regression analysis using the daily maximum 1-h exposure as the dependent variable and the daily maximum 1-h composite fixed-site value as the independent variable yields the regression equation

$$\hat{c}_{exp,1h} = 8.32 + (0.317)(c_{comp,1h}) \quad (3\text{-}4)$$

with $R^2 = 0.0067$. Weighted linear regression analysis using the daily maximum 8-h exposure as the dependent variable and the daily maximum 8-h composite fixed-site value as the independent variable yields the regression equation

$$\hat{c}_{exp,8h} = 2.24 + (0.693)(c_{comp,8h}) \quad (3\text{-}5)$$

with $R^2 = 0.057$. Repeating the linear regression analyses without weighting yields

$$\hat{c}_{exp,1h} = 8.47 + (0.313)(c_{comp,1h}) \quad (3\text{-}6)$$

with $R^2 = 0.0075$ and

$$\hat{c}_{exp,8h} = 2.38 + (0.612)(c_{comp,8h}) \quad (3\text{-}7)$$

with $R^2 = 0.058$. The small R^2 values suggest that composite fixed-site daily maximum values are poor predictors of daily maximum exposures.

In a related task assignment for EMSL, PEI was directed to investigate the magnitude of exposures among the Denver study participants on days when violations of the National Ambient Air Quality Standard (NAAQS) for carbon monoxide (CO) occurred. For purposes of this analysis, PEI defined a violation as the occurrence of a daily maximum 8-hour CO value at any one of the 15 fixed-site monitors operating in Denver during the study. Daily maximum 1-hour data were not considered because only one site (Map Code A) reported daily maximum 1-hour values exceeding 35 ppm during the study period; whereas, 11 of the 15 fixed-site monitors reported daily maximum 8-hour values exceeding 9 ppm (Table 3-12). These results suggest that fixed-site monitors operating in the Denver area are much more likely to report violations of the current 8-hour National Ambient Air Quality Standard (NAAQS) than the current 1-hour NAAQS.

Table 3-13 lists the days during the study period for which one or more fixed-site monitors reported daily maximum 8-hour values exceeding 9 ppm. If the daily maximum 8-hour exposure calculated for a person-day of PEM data started on one of these days, the person-day was included in Group H; otherwise, it was included in Group L. BMDP program P2D was used to analyze the daily maximum 8-hour exposure values in Group H, in Group L, and in the combined group (i.e., all values). Only values for person-days with valid overall data quality codes were analyzed. Table 3-14 lists summary statistics taken from the BMDP runs. The mean of Group H is 6.69 ppm; the mean of Group L is 4.13 ppm. Figure 3-1 presents histograms for the two groups. Because both distributions are skewed and have large kurtosis values (Table 3-14), PEI investigated taking the natural logarithms of the exposure values as a means of obtaining more normal distributions. Table 3-15 lists summary statistics for the transformed data; Figure 3-2 provides histograms. The values for skewness and kurtosis are much smaller in Table 3-15 than in Table 3-14, but are still significant. For this reason, PEI performed both parametric and nonparametric tests on the grouped data. Table 3-16 lists the results of these tests.

The Levene test is a test for homogeneity of variance. The small p value (0.0001) suggests the variances of the logarithms of Groups L and H are not equal. Consequently, the t (separate) test is more appropriate than the t (pooled) test for determining if the means of the two groups are equal under the assumption of normality. Since $p < 0.0001$ for the t (separate) test, one can conclude the means of the logarithms are not equal.

TABLE 3-12. PERCENTAGE OF DAILY MAXIMUM 8-HOUR VALUES REPORTED BY DENVER MONITORING SITES EXCEEDING SELECTED CARBON MONOXIDE CONCENTRATIONS BETWEEN NOVEMBER 1, 1982, AND FEBRUARY 28, 1983

Map code	SAROAD code	Percentage of daily maximum 8-hour values			
		> 7 ppm	> 9 ppm	> 12 ppm	> 15 ppm
A	060580002F01	49.2	28.3	13.3	7.5
B	060580014F01	35.2	15.7	7.4	1.9
C	060580013F01	33.6	18.7	3.7	0
D	062080821F05	22.1	13.3	1.8	0.9
E	062080822F05	13.6	4.2	1.7	0
F	062080820F05	18.6	8.5	2.5	0.8
G	062080823F05	1.8	0	0	0
H	062080825F05	0.9	0	0	0
I	062080818F05	20.5	10.7	1.8	0
J	062080819F05	22.2	8.3	4.6	0.9
K	060140002F01	3.4	0.8	0	0
L	060120002F01	20.3	4.2	0.8	0
M	060080002F01	0	0	0	0
N	062080824F05	20.7	11.2	1.7	0
O	062080817F05	2.6	0	0	0

TABLE 3-13. DAYS FOR WHICH ONE OR MORE DENVER FIXED-SITE MONITORS REPORTED DAILY MAXIMUM 8-HOUR VALUES EXCEEDING 9 PPM

Date	Number of sites reporting values > 9 ppm	Composite site value[a]	Date	Number of sites reporting values > 9 ppm	Composite site value[a]
11-05	6	7.4	12-13	7	8.6
11-06	6	7.1	12-16	8	9.1
11-10	6	7.2	12-17	5	7.1
11-12	1	5.3	12-20	2	6.1
11-13	4	5.0	12-21	3	4.7
11-15	1	5.8	12-26	1	5.6
11-16	2	6.1	12-29	5	8.4
11-17	2	5.3	12-31	2	4.6
11-18	2	5.8	1-01	1	5.2
11-19	1	4.7	1-03	3	6.1
11-24	9	9.4	1-04	1	5.3
11-25	1	3.1	1-06	2	4.5
11-27	6	8.2	1-07	4	5.6
11-29	1	4.5	1-11	1	3.9
11-30	1	4.5	1-12	4	7.0
12-03	1	5.6	1-15	10	10.3
12-04	1	6.2	1-17	2	5.5
12-06	1	5.3	1-19	4	6.9
12-09	9	9.2	1-20	2	6.0
12-12	3	6.3	1-27	8	8.1

[a]Daily maximum 8-hour concentration (ppm).

TABLE 3-14. SUMMARY STATISTICS FOR DAILY MAXIMUM 8-HOUR CARBON MONOXIDE EXPOSURES

Statistic	Group H	Group L	All
Number of cases	227	493	770
Minimum, ppm	0.0	0.0	0.0
Maximum, ppm	44.0	34.8	44.0
Mean, ppm	6.69	4.13	5.05
Mode, ppm	6.7	1.4	a
Standard deviation, ppm	5.68	3.82	4.73
Skewness/std. error	22.06	24.28	36.48
Kurtosis/std. error	50.15	54.91	95.76
10th percentile, ppm	2.1	0.7	1.0
25th percentile, ppm	3.5	1.7	2.2
50th percentile, ppm	5.6	3.2	3.9
75th percentile, ppm	8.2	5.2	6.6
90th percentile, ppm	11.3	8.3	9.7
95th percentile, ppm	15.0	10.4	12.8
98th percentile, ppm	25.4	16.1	17.6
99th percentile, ppm	36.8	17.6	25.0

[a]Not unique.

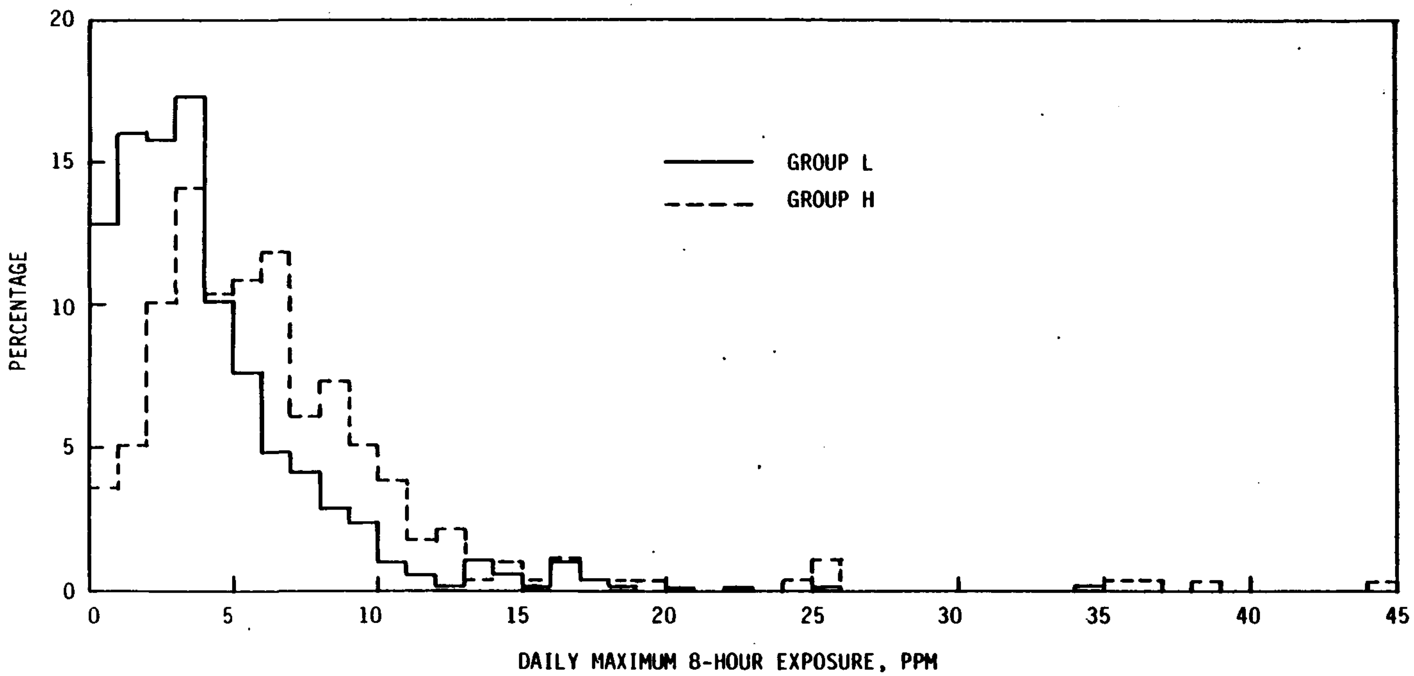

Figure 3-1. Histograms of daily maximum 8-hour exposures to carbon monoxide.

TABLE 3-15. SUMMARY STATISTICS FOR LOGARITHMS OF DAILY MAXIMUM 8-HOUR CARBON MONOXIDE EXPOSURES

Statistic	Group H	Group L	All
Number of cases	277	493	770
Minimum, ln(ppm)	-3.69	-3.69	-3.69
Maximum, ln(ppm)	3.78	3.55	3.78
Mean, ln(ppm)	1.62	1.00	1.22
Mode, ln(ppm)	1.90	0.34	a
Standard deviation, ln(ppm)	0.81	1.08	1.04
Skewness/std. error	-9.04	-12.49	-15.99
Kurtosis/std. error	22.41	16.34	23.84
10th percentile, ln(ppm)	0.74	-0.36	0.00
25th percentile, ln(ppm)	1.25	0.53	0.79
50th percentile, ln(ppm)	1.72	1.16	1.36
75th percentile, ln(ppm)	2.10	1.65	1.89
90th percentile, ln(ppm)	2.42	2.12	2.27
95th percentile, ln(ppm)	2.71	2.34	2.55
98th percentile, ln(ppm)	3.23	2.78	2.87
99th percentile, ln(ppm)	3.61	2.87	3.22

[a]Not unique.

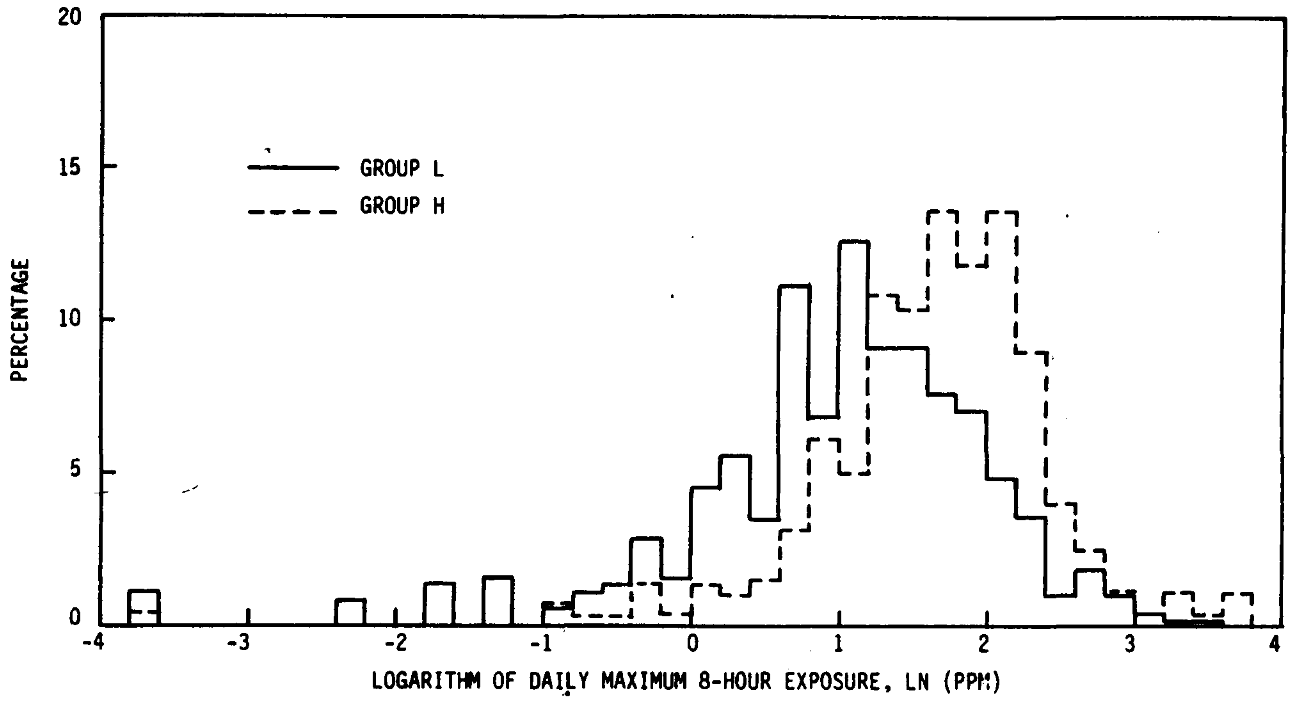

Figure 3-2. Histograms of logarithms of daily maximum 8-hour exposures to carbon monoxide.

TABLE 3-16. RESULTS OF STATISTICAL TESTS COMPARING THE LOGARITHMS OF GROUP L AND GROUP H

Test	Assumed distributions	Test statistic	D.F.	p
t (separate)	Normal, unequal variances	-9.09	705	0.0000
t (pooled)	Normal, equal variances	-8.41	768	0.0000
Levene	Normal	14.80	1, 768	0.0001
Mann-Whitney[a]	None	41554.50	-	0.0000
Kruskal-Wallis[a]	None	81.42	1	0.0000

[a]Results are independent of log transformation.

The two nonparametric tests (Mann-Whitney and Kruskal-Wallis) also yielded p values less than 0.0001. These results suggest that the null hypothesis that the two groups have the same distributions be rejected. Usually when the null hypothesis is rejected, the assumption is made that one group has a higher median.

The general conclusion from these analyses is that the median concentrations of Group L and Group H differ significantly at the p = 0.0001 level. The median for Group H is 5.6 ppm--an increase of 2.4 ppm (75%) over the Group L median of 3.2 ppm. Because both distributions are nonnormal, it is difficult to determine if the means of the two distributions are significantly different.

3.6 REFERENCES

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SECTION 4

RELATIONSHIPS BETWEEN EXPOSURES AND SELECTED EXPLANATORY VARIABLES

A major goal in analyzing data from the Denver study is the identification of factors associated with high CO exposure among the study subjects. This section begins with an exploratory analysis which considered the relationships between high daily maximum exposures and a variety of candidate factors, including the frequency that a subject occupies a microenvironment, the duration of exposure in the microenvironment, the subject's occupation, traffic density, mode of transportation, and fixed-site reading. Also included in this section are analyses of factors which affect in-transit and indoor exposures.

4.1 HIGH DAILY MAXIMUM 8-HOUR EXPOSURES

EMSL directed PEI to identify factors associated with person-days of data for which the daily maximum 8-hour exposure exceeds 9 ppm. To facilitate this investigation, PEI divided the person-days into two exposure groups. Group H (high exposures) contains person-days with daily maximum 8-hour values exceeding 9 ppm; Group L (low exposures) contains the remaining person-days. Note that these definitions differ from those used in Section 3.5.

PEI began an exploratory analysis by comparing the microenvironment listings of Group H person-days with those of Group L. The basic unit of analysis was the occupancy period. As described in Section 6.7 of Reference 1, an occupancy period begins when a subject enters a microenvironment and ends when the subject leaves the microenvironment. Table 4-1 lists by exposure group the number of occupancy periods reported for each microenvironment (n), the mean duration of the occupancy periods, and the mean CO concentration measured during the occupancy periods. It should be noted that mean occupancy periods for the indoor residential microenvironment are likely to be inaccurate because subjects were usually occupying residences before the first diary entry and after the last diary entry. The microenvironments are

TABLE 4-1. OCCUPANCY PERIOD STATISTICS BY MICROENVIRONMENT AND EXPOSURE GROUP

Code		Microenvironment		Occupancy periods						OER	t statistic	
				Group H			Group L					
B	D3	Category	Subcategory	Sample size (n_H)	Mean duration, min	Mean conc., ppm	Sample size (n_L)	Mean duration, min	Mean conc., ppm	(n_H/m_H)	Duration means	Conc. means
52	a	Indoors	Public garage	29	26.9	14.3	45	26.2	6.6	2.66[e]	0.03	1.34
01	93	In transit	Motorcycle	5	19.2	6.4	10	28.4	15.5	2.26	-1.76	-2.88[f]
54	bb	Indoors	Service station or motor vehicle repair facility	38	59.4	11.9	14	114.7	5.4	4.96[e]	-1.60	1.29
01	03	In transit	Bus	9	13.5	15.4	49	30.3	7.5	1.05	-4.06[f]	2.02
72	a	Outdoors	Public garage	13	5.7	9.8	11	18.1	7.1	3.68[e]	-1.04	1.23
01	02	In transit	Car	304	27.7	13.1	1998	25.2	7.1	0.90	0.99	6.56[f]
71	bb	Outdoors	Residential garage or carport	6	2.2	9.8	13	12.2	1.7	2.14	-1.72	1.72
62	bb	Indoors	Other location	16	144.5	36.2	148	83.5	2.8	0.66	2.16[f]	4.27[f]
01	04	In transit	Truck	53	29.1	14.5	196	32.6	5.2	1.45[e]	-0.63	7.60[f]
55	bb	Indoors	Other repair shop	3	138.5	18.4	8	203.4	3.2	1.85	-0.71	4.46
58	bb	Indoors	Shopping mall	6	71.0	8.1	18	80.4	4.4	1.70	-0.23	1.14
51	bb	Indoors	Residential garage	5	3.5	5.3	42	25.2	2.4	0.72	-3.44[f]	0.95
07	c	Outdoors	Within 10 yards of road	74	28.0	5.9	244	33.3	2.5	1.58[e]	-0.82	3.30[f]
01	01	In transit	Walking	49	14.9	7.5	400	21.7	2.4	0.74[e]	-2.20[f]	3.06[f]
bb	bb	Not specified	Not specified	41	49.5	4.9	218	40.1	3.1	1.07	0.99	1.80
05	bb	Indoors	Restaurant	42	149.2	3.6	194	65.4	3.5	1.21	2.69[f]	0.13
74	bb	Outdoors	Service station or motor vehicle repair facility	3	11.0	5.7	7	6.5	3.6	2.04	6.61[f]	1.23
03	c	Indoors	Office	73	163.2	7.5	457	213.2	2.8	0.94	-2.73[f]	5.59[f]
73	d	Outdoors	Parking lot	9	33.2	5.9	42	16.2	3.2	1.20	1.40	1.66
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	9	93.6	10.4	23	126.1	2.2	1.91	-1.23	2.99[f]
04	bb	Indoors	Store	47	69.5	6.7	307	45.2	2.3	0.90	1.39	4.73[f]
80	bb	Outdoors	Other location	16	21.8	7.6	37	93.3	1.0	2.05[e]	-2.24[f]	2.74[f]
59	bb	Indoors	Health care facility	5	182.9	3.5	78	161.0	2.1	0.41	0.31	0.33
61	bb	Indoors	Other public building	3	43.4	7.7	49	78.7	2.0	0.39	-2.88[f]	1.53
53	bb	Indoors	Manufacturing facility	0			6	373.9	1.9	0.00		
02	bb	Indoors	Residence	293	322.5	6.4	2055	342.0	1.2	0.85[e]	-0.90	13.01[f]
77	bb	Outdoors	School grounds	6	16.3	1.2	8	13.9	3.8	2.91[e]	0.73	-1.36
60	bb	Indoors	School	10	138.9	7.7	82	162.4	1.3	0.74	-0.56	2.76[f]
57	bb	Indoors	Church	8	80.4	3.4	47	119.7	0.9	0.99	-2.98[f]	1.13
76	bb	Outdoors	Residential grounds	6	29.6	1.6	39	32.8	0.6	0.91	-0.53	0.67
01	92	In transit	Bicycle	4	14.0	1.6	5	13.4	1.8	3.02	0.16	-0.09
78	bb	Outdoors	Sports arena, amphitheater, etc.	0			6	192.2	0.7	0.00		
79	bb	Outdoors	Park or golf course	1	89.0	0.0	10	57.0	0.6	0.62		
			Total	1186			6866					

[a]Includes D3 = bb, 01, and 02. [b]Blank. [c]Includes D3 = bb and 01. [d]Includes D3 = bb, 01, 02, and 03.

[e]Ratio is significantly different from 1.0 at p = 0.05 level. [f]Significant at p = 0.05 level.

listed in the same order as they appear in Table 6-20 of Reference 1 (i.e., in descending order of weighted mean CO concentration as discussed in Section 6.7).

If there were no differences between Group H person-days and Group L person-days with respect to the number of times a particular microenvironment was occupied, then n_H would be expected to equal m_H, where

$$m_H = (n_H + n_L)(N_H)/(N_H + N_L). \qquad (4\text{-}1)$$

In this expression, N_H equals 1189, the number of occupancy periods associated with Group H person-days, and N_L equals 6866, the number of occupancy periods associated with Group L person-days. The ratio of n_H to m_H is thus the ratio of the number of observed events to the number of expected events. In the discussion that follows, such ratios are referred to as observed-to-expected ratios (OER's) and are calculated using the general expression

$$OER = x/m \qquad (4\text{-}2)$$

where x is the number of events observed and m is the number expected. Bailer and Ederer[2] provide tables for determining if an OER differs significantly from unity for a given x.

Values for OER = n_H/m_H are presented in Table 4-1 under the column heading "OER (n_H/m_H)." Nine of the OER's are flagged as significant at the $p = 0.05$ level. The four largest flagged values correspond to the microenvironments labeled indoors-service station (4.96), outdoors-public garage (3.68), outdoors-school grounds (2.91), and indoors-public garage (2.66). Other microenvironments with flagged OER's greater than 1.0 are outdoors-other location (2.05), outdoors-within 10 yards of road (1.58), and in transit-truck (1.45). All of these microenvironments are associated with outdoor locations and/or motor vehicles.

Table 4-1 also lists t statistics by microenvironment for tests that Group H and Group L duration means are equal and that Group H and Group L concentration means are equal. The statistics were calculated assuming unequal variances; flagged t values indicate that the probability that the associated means are equal is 0.05 or less. A positive t value indicates that the Group H mean exceeds the Group L mean. With respect to duration, the only flagged positive t values are associated with outdoors-service station (6.61), indoors-restaurant (2.69), and indoors-other location (2.16). With respect to concentration, there are 11 flagged positive t values in Table 4-1. The seven largest flagged t values are associated with indoors-residence (13.01), in transit-truck (7.60), in transit-car (6.56), indoors-office (5.59), indoors-store (4.73), indoors-other location (4.27), and outdoors-within 10 yards of road (3.30). Few of the t values are negative, indicating that mean CO concentrations for most microenvironments were higher for Group H person-days than for Group L person-days.

PEI also attempted to determine whether geographic location affects exposure within a particular microenvironment. A file was compiled listing each nontransit PEM value that has an activity diary code indicating it was recorded in a census tract containing one of the 15 fixed-site monitors operating during the study. Figure 3 in Appendix A shows the locations of the 15 sites. To simplify the analysis, PEI divided the fixed sites into three groups according to the median (50th percentile) 8-hour daily maximum value reported during the study period at each site (Table 4-2). Note that the same grouping would occur if the 90th percentile were used. Under the headings N_H and N_L, Table 4-3 lists the number of PEM values recorded on Group H and Group L person-days which fall into each combination of microenvironment and site group. A total of 189 values were reported for Group H person-days; 1798 PEM values were reported for Group L person-days.

OER values were calculated for the various microenvironment-site group combinations listed in Table 4-3 using Equation 4-1 with N_H and N_L equal to the total PEM values in a particular site-group associated with Group H and Group L, respectively. For example, the OER for indoors-office/Site Group I is calculated as

$$\begin{aligned} OER &= n_H/m_H \\ &= (25)/[(25 + 81)(63)/(63 + 761)] \end{aligned}$$

to yield OER = 3.08. OER values that differ significantly from 1.0 at the p = 0.05 are flagged in the table. The largest flagged OER

(6.56) is associated with Site Group III and the microenvironment labeled "outdoors - within 10 yards of road." This is consistent with our expectations that high exposures would occur near roadways in areas with high ambient CO levels (i.e., the Group III areas) since it is likely the high levels are the result of heavy traffic.

TABLE 4-2. ASSIGNMENT OF DENVER FIXED-SITE MONITORS TO SITE GROUPS I, II, AND III

Site group	SAROAD code	Map code	Three-digit code	Daily maximum 8-hour CO value, ppm	
				50th percentile	90th percentile
I	060080002F01	M	HIG	1.3	3.3
	062080825F05	H	825	2.1	4.1
	062080823F05	G	823	2.6	5.1
	060140002F01	K	AUR	2.7	5.0
	062080817F05	O	817	2.7	5.2
	062080822F05	E	822	3.4	7.5
II	062080819F05	J	819	4.2	8.9
	062080818F05	I	818	4.2	9.3
	062080824F05	N	824	4.4	9.5
	060120002F01	L	ARV	4.5	8.1
	062080821F05	D	821	4.5	9.5
	062080820F05	F	820	4.9	9.0
III	060580013F01	C	013	5.7	10.3
	060580014F01	B	014	5.9	10.9
	060580002F01	A	002	6.8	13.7

TABLE 4-3. NUMBER OF PEM VALUES REPORTED FOR INDICATED COMBINATIONS OF MICROENVIRONMENT, EXPOSURE GROUP, AND SITE GROUP (INCLUDES ONLY PEM VALUES RECORDED IN CENSUS TRACTS CONTAINING A FIXED-SITE MONITOR)

B	D3	Microenvironment		Site Group I			Site Group II			Site Group III		
		Category	Subcategory	n_H	n_L	OER	n_H	n_L	OER	n_H	n_L	OER
52	a	Indoors	Public garage	0	2	0.00	0	0	-	0	12	0.00
54	bb	Indoors	Service station or motor vehicle repair facility	0	0	-	0	18	0.00	0	1	0.00
72	a	Outdoors	Public garage	0	0	-	0	0	-	0	0	-
71	bb	Outdoors	Residential garage or carport	0	6	0.00	0	0	-	0	0	-
62	bb	Indoors	Other location	0	12	0.00	2	17	0.98	0	16	0.00
55	bb	Indoors	Other repair shop	0	0	-	0	23	0.00	0	0	-
58	bb	Indoors	Shopping mall	0	0	-	0	5	0.00	0	0	-
51	bb	Indoors	Residential garage	0	0	-	0	0	-	0	0	-
07	c	Outdoors	Within 10 yards of road	0	14	0.00	0	16	0.00	8	3	6.56[e]
bb	bb	Not specified	Not specified	0	0	-	0	0	-	0	0	-
05	bb	Indoors	Restaurant	2	9	2.38	0	19	0.00	5	16	2.15
74	bb	Outdoors	Service station or motor vehicle repair facility	0	0	-	0	0	-	0	0	-
03	c	Indoors	Office	25	81	3.08[e]	25	93	1.98[e]	14	61	1.68
73	d	Outdoors	Parking lot	1	0	-	0	7	0.00	1	2	3.01
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	0	0	-	0	1	0.00	0	0	-
04	bb	Indoors	Store	10	14	5.45[e]	1	13	0.67	16	13	4.98[e]
80	bb	Outdoors	Other location	0	0	-	1	5	1.56	0	27	0.00
59	bb	Indoors	Health care facility	0	0	-	0	0	-	0	77	0.00
61	bb	Indoors	Other public building	0	0	-	0	12	0.00	0	12	0.00
53	bb	Indoors	Manufacturing facility	0	0	-	0	31	0.00	0	24	0.00
02	bb	Indoors	Residence	25	612	0.51[e]	40	375	0.90	3	78	0.33[e]
77	bb	Outdoors	School grounds	0	0	-	4	2	6.24[e]	0	0	-
60	bb	Indoors	School	0	2	0.00	6	20	2.16	0	34	0.00
57	bb	Indoors	Church	0	9	0.00	0	3	0.00	0	0	-
76	bb	Outdoors	Residential grounds	0	0	-	0	0	-	0	1	0.00
78	bb	Outdoors	Sports arena, amphitheater, etc.	0	0	-	0	0	-	0	0	-
79	bb	Outdoors	Park or golf course	0	0	-	0	0	-	0	0	-
			TOTAL	63	761		79	660		47	377	

[a]Includes D3 = bb, 01, and 02. [b]Blank. [c]Includes D3 = bb and 01. [d]Includes D3 = bb, 01, 02, and 03.
[e]Observed-to-expected ratio (OER) is significantly different from 1.0 at p = 0.05 level.

There are many zeros in Table 4-3 due to the small number of PEM values which were recorded in census tracts containing fixed-site monitors. To increase the sample size, PEI prepared a file which matched each PEM value in the SAMPLE-DATA file with the nearest fixed-site monitor and then divided the PEM values into three groups based on the site group to which the nearest fixed-site monitor was assigned. Table 4-4 lists the results in a format similar to Table 4-3. OER's are calculated in a similar manner. Combinations of microenvironments and site groups with OER's which are positive and significant ($p < 0.05$ level) are listed in Table 4-5. Significantly, the indoor-public garage and indoor-service station microenvironments have very large ratios for Site Group I, the group associated with low ambient CO levels. Apparently CO sources within these microenvironments are associated with high exposures even in the absence of high fixed-site monitor readings.

Associated with each in-transit PEM value are two census tract listings, one associated with the start address and the other with the end address. Realizing that neither may be a good indicator of the CO conditions encountered during the trip, PEI prepared two tables based on these data. Table 4-6 pairs each in-transit PEM value with the fixed-site nearest to the start census tract. Table 4-7 pairs each in-transit PEM value with the fixed-site nearest to the end census tract. The format of each of these tables is similar to that of Table 4-4 and OER values are calculated in a similar manner. The in-transit microenvironments are listed in the same order as Table 6-26 in Reference 1 with the addition of the bicycle microenvironment.

OER values significant at the $p = 0.05$ level are flagged in both tables. Surprisingly, only the truck microenvironment is flagged for Site Group III in the two tables. The largest car OER is only 1.01 and four of the six car ratios in the two tables are less than 1.00. The combinations of microenvironment and site group with the three largest significant OER values in Table 4-6 are motorcycle - Site Group I (4.66), truck - Site Group III (2.27, and truck - Site Group II (1.45). Only two combinations have significant OER values in Table 4-7: motorcyle - Site Group I (4.52) and truck - Site Group III (2.46).

TABLE 4-4. NUMBER OF PEM VALUES REPORTED FOR INDICATED COMBINATIONS OF MICROENVIRONMENT, EXPOSURE GROUP, AND SITE GROUP (PEM VALUES ARE MATCHED TO NEAREST FIXED-SITE MONITOR)

		Microenvironment		Site Group I			Site Group II			Site group III		
B	D3	Category	Subcategory	n_H	n_L	OER	n_H	n_L	OER	n_H	n_L	OER
52	a	Indoors	Public garage	43	19	6.19[e]	6	12	2.36	2	43	0.41
54	bb	Indoors	Service station or motor vehicle repair facility	28	10	6.58[e]	63	25	5.07[e]	0	2	0.00
72	a	Outdoors	Public garage	2	0	8.93[e]	9	13	2.90[e]	3	4	4.00
71	bb	Outdoors	Residential garage or carport	0	13	0.00	6	2	5.31[e]	1	4	1.86
62	bb	Indoors	Other location	24	142	1.29	29	159	1.09	22	103	1.64[e]
55	bb	Indoors	Other repair shop	0	0	-	14	35	2.02[e]	0	6	0.00
58	bb	Indoors	Shopping mall	2	25	0.66	9	13	2.90[e]	5	4	5.18[e]
51	bb	Indoors	Residential garage	5	35	1.12	0	14	0.00	0	16	0.00
07	c	Outdoors	Within 10 yards of road	68	159	2.67[e]	32	188	1.03	28	98	2.07[e]
bb	bb	Not specified	Not specified	0	0	-	0	2	0.00	0	0	-
05	bb	Indoors	Restaurant	30	199	1.17	76	137	2.53[e]	19	128	1.20
74	bb	Outdoors	Service station or motor vehicle repair facility	2	5	2.55	1	5	1.18	1	0	9.32
03	c	Indoors	Office	57	726	0.65[e]	143	709	1.19	98	828	0.99
73	d	Outdoors	Parking lot	9	36	1.79	3	15	1.18	1	15	0.58
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	19	33	3.26[e]	5	28	1.07	0	22	0.00
04	bb	Indoors	Store	52	297	1.33	26	206	0.79	46	178	1.91[e]
80	bb	Outdoors	Other location	9	42	1.58	29	39	3.02[e]	2	35	0.50
59	bb	Indoors	Health care facility	13	61	1.57	1	70	0.10[e]	9	223	0.36[e]
61	bb	Indoors	Other public building	0	29	0.00	1	43	0.16[e]	5	35	1.17
53	bb	Indoors	Manufacturing facility	0	0	-	0	48	0.00	0	25	0.00
02	bb	Indoors	Residence	1154	10064	0.92[e]	1104	7667	0.89[e]	386	3377	0.96
77	bb	Outdoors	School grounds	0	3	0.00	7	7	3.54[e]	0	0	-
60	bb	Indoors	School	9	147	0.51[e]	22	179	0.77	0	76	0.00
57	bb	Indoors	Church	6	64	0.77	9	61	0.91	5	43	0.97
76	bb	Outdoors	Residential grounds	2	34	0.50	5	31	0.98	1	7	1.17
78	bb	Outdoors	Sports arena, amphitheater, etc.	0	4	0.00	0	12	0.00	0	0	-
79	bb	Outdoors	Park or golf course	0	10	0.00	0	4	0.00	0	4	0.00
			TOTAL	1534	12157		1600	9724		634	5276	

[a]Includes D3 = bb, 01, and 02. [b]Blank. [c]Includes D3 = bb and 01. [d]Includes D3 = bb, 01, 02, and 03.

[e]Observed-to-expected ratio (OER) is significantly different from 1.0 at p = 0.05 level.

TABLE 4-5. COMBINATIONS OF MICROENVIRONMENTS AND SITE GROUPS WITH SAMPLE SIZES EXCEEDING FIVE AND SIGNIFICANT OBSERVED-TO-EXPECTED RATIOS IN TABLE 4-4 EXCEEDING 1.00

Code	Microenvironment	Site group	Sample size	OER
52a	Indoors-public garage	I	62	6.19
54bb	Indoors-service station or motor vehicle repair facility	I II	38 88	6.58 5.07
72a	Outdoors-public garage	II	22	2.90
71bb	Outdoors-residential garage or carport	II	8	5.31
62bb	Indoors-other location	III	125	1.64
58bb	Indoors-shopping mall	II III	22 9	2.90 5.18
07c	Outdoors-within 10 yards of road	I III	227 126	2.67 2.07
05bb	Indoors-restaurant	II	213	2.53
56bb	Indoors-auditorium, sports arena, concert hall, etc.	I	52	3.26
04bb	Indoors - store	III	224	1.91
80bb	Outdoors-other location	II	68	3.02
77bb	Outdoors - school grounds	II	14	3.54

[a]Includes D3 = bb, 01, and 02.

[b]Blank.

[c]Includes D3 = bb and 01.

TABLE 4-6. NUMBER OF "START" IN-TRANSIT PEM VALUES REPORTED FOR INDICATED COMBINATIONS OF MICROENVIRONMENT, EXPOSURE GROUP, AND SITE GROUP (PEM VALUES ARE MATCHED TO NEAREST FIXED-SITE MONITOR)

Code		In-transit subcategory	Site group I			Site group II			Site group III		
B	D3		n_H	n_L	OER	n_H	n_L	OER	n_H	n_L	OER
01	93	Motorcycle	11	8	4.66[a]	0	5	0.00	0	2	0.00
01	03	Bus	1	22	0.35	6	21	1.42	4	38	0.79
01	01	Walking	10	107	0.69	39	215	0.98	27	276	0.73
01	04	Truck	35	191	1.25[a]	36	123	1.45[a]	19	50	2.27[a]
01	02	Car	207	1529	0.96	206	1199	0.94	101	725	1.01
01	92	Bicycle	0	2	0.00	4	7	2.33	0	3	0.00
		TOTAL	264	1859		291	1570		151	1094	

[a]Observed-to-expected ratio (OER) is significantly different from 1.0 at p = 0.05 level.

TABLE 4-7. NUMBER OF "END" IN-TRANSIT PEM VALUES REPORTED FOR INDICATED COMBINATIONS OF MICROENVIRONMENT, EXPOSURE GROUP, AND SITE GROUP (PEM VALUES ARE MATCHED TO NEAREST FIXED-SITE MONITOR)

Code		In-transit subcategory	Site group I			Site group II			Site group III		
B	D3		n_H	n_L	OER	n_H	n_L	OER	n_H	n_L	OER
01	93	Motorcycle	9	7	4.52[a]	2	5	1.81	0	3	0.00
01	03	Bus	1	21	0.37	8	18	1.95	2	42	0.38
01	01	Walking	11	107	0.75	35	215	0.89	30	278	0.81
01	04	Truck	36	190	1.28	35	129	1.35	19	45	2.46[a]
01	02	Car	209	1547	0.96	207	1173	0.95	101	737	1.00
01	92	Bicycle	0	1	0.00	4	9	1.95	0	2	0.00
		TOTAL	266	1873		291	1549		152	1107	

[a]Observed-to-expected ratio (OER) is significantly different from 1.0 at $p = 0.05$ level.

Another exploratory analysis investigated whether high exposures occurred more often on days when ambient CO levels were high. Table 4-8 lists the calendar days in the Denver study monitoring period and indicates the number of Group H and Group L person-days associated with each calendar day. A person-day is associated with a calendar day if the daily maximum 8-hour exposure of the person-day begins with an hour that falls in the calendar day. Also listed for each calendar day is an OER value (x is the number of Group H person-days observed and m is the number of Group H persondays expected) and the daily average and daily maximum 8-hour values reported by the "composite" site. Two calendar days have significant ($p < 0.05$) OER values: November 5 and December 9. Daily average values at the composite site were quite high on these days (5.87 ppm and 6.32 ppm, respectively).

Each OER in Table 4-8 was paired with the corresponding daily average value and daily maximum 8-hour value, and the Spearman rank correlation test was performed. Both tests yielded a Spearman rho statistic which was positive and significant at the $p = 0.001$ level (one-sided test). This result suggests that the ratio is generally larger on days with high ambient CO concentrations. This in turn implies that person-days in Group H are strongly associated with days with high ambient CO concentration.

In an attempt to identify high exposure occupations, PEI determined the number of person-days in Groups H and L which were reported by persons with each three-digit occupation code used by the Bureau of Census. The results are listed in Table 4-9. OER values were calculated for each occupation and those found to be significant ($p < 0.05$) are listed in the table. Only three occupations are associated with significant OER values: Code 139 - education teachers (OER = 5.84), Code 243 - supervisors and proprietors, sales occupations (OER = 6.67), and Code 877 - stock handlers and baggers (OER = 5.84). In evaluating these results, it should be noted that some of the person-days assigned occupation categories in Table 4-9 may be nonwork days and thus do not represent occupation-related exposures. At this early stage in the analysis, no attempt was made to adjust for this potential bias.

TABLE 4-8. NUMBER OF DAILY MAXIMUM 8-HOUR VALUES OCCURRING ON INDICATED DATE BY EXPOSURE GROUP

Date	Number of daily maximum 8-hour values beginning on indicated date		OER	Composite fixed-site concentration for date	
	Group H	Group L		Daily average	Daily maximum 8-h
11-1	0	1	0.00	2.48	3.6
11-2	1	11	0.65	2.25	2.9
11-3	1	6	1.11	1.91	2.5
11-4	2	6	1.95	2.85	4.9
11-5	5	7	3.24[a]	5.87	7.4
11-6	1	7	0.97	3.37	7.1
11-9	0	2	0.00	3.17	6.4
11-10	4	9	2.40	5.94	7.2
11-11	0	1	0.00	1.39	1.6
11-12	1	14	1.56	2.34	5.3
11-13	0	10	0.00	2.91	5.0
11-14	0	5	0.00	1.76	3.9
11-15	2	4	2.60	3.77	5.8
11-16	2	10	1.30	4.17	6.1
11-17	1	5	1.30	3.85	5.3
11-18	2	1	5.19	4.07	5.8
11-19	1	4	1.56	2.68	4.7
11-20	0	13	0.00	2.32	5.0
11-21	0	4	0.00	1.73	2.9
11-22	0	7	0.00	1.87	3.2
11-23	1	2	2.60	1.76	3.7
11-29	0	2	0.00	2.75	4.5
11-30	1	4	1.56	2.33	4.5
12-1	0	5	0.00	2.58	3.6
12-2	0	2	0.00	2.76	3.6
12-3	1	8	0.87	3.15	5.6
12-4	4	12	1.95	3.20	6.2
12-5	0	1	0.00	1.87	3.1
12-6	1	14	0.52	3.46	5.3
12-7	1	2	2.60	0.92	1.3
12-8	0	6	0.00	1.42	2.0
12-9	6	6	3.89[a]	6.32	9.2
12-10	2	0	7.79	1.60	2.1
12-11	1	12	0.60	2.42	5.3
12-12	1	4	1.56	3.33	6.3
12-13	1	7	0.97	4.27	8.6
12-14	0	3	0.00	1.44	2.2
12-15	0	6	0.00	2.06	3.6
12-16	2	8	1.56	5.72	9.1
12-17	0	6	0.00	4.00	7.1
12-18	0	2	0.00	1.20	1.7

(continued)

TABLE 4-8 (continued)

Date	Number of daily maximum 8-hour values beginning on indicated date		OER	Composite fixed-site concentration for date	
	Group H	Group L		Daily average	Daily maximum 8-h
12-19	0	3	0.00	1.44	1.9
12-20	0	9	0.00	4.14	6.1
12-21	0	4	0.00	3.09	4.7
12-22	0	3	0.00	3.02	4.1
12-23	0	2	0.00	1.55	3.0
1-5	0	3	0.00	2.58	3.9
1-6	1	8	0.87	2.83	4.5
1-7	4	11	2.08	4.25	5.6
1-8	0	9	0.00	2.33	4.0
1-9	0	2	0.00	0.60	0.9
1-10	1	6	1.11	0.89	1.2
1-11	0	10	0.00	2.39	3.9
1-12	1	14	0.52	4.77	7.0
1-13	0	7	0.00	2.61	3.5
1-14	2	6	1.95	2.60	3.4
1-15	4	10	2.22	6.09	10.3
1-16	1	3	1.95	2.23	4.2
1-17	4	5	3.46	4.20	5.5
1-18	1	6	1.11	3.46	5.2
1-19	3	8	2.12	5.00	6.9
1-20	1	3	1.95	3.79	6.0
1-21	1	7	0.97	2.45	2.9
1-22	2	9	1.42	2.90	3.7
1-24	0	7	0.00	2.57	4.6
1-25	1	7	0.97	3.04	4.7
1-26	2	13	1.04	3.60	6.3
1-27	4	8	2.60	5.40	8.1
1-28	0	8	0.00	2.09	4.0
1-29	4	8	2.60	1.67	3.6
1-30	0	3	0.00	2.01	2.9
1-31	0	6	0.00	1.34	1.7
2-1	0	9	0.00	1.13	1.5
2-2	0	13	0.00	1.74	3.2
2-3	2	8	1.56	1.62	2.5
2-4	2	14	0.97	2.70	3.7
2-5	2	4	2.60	1.82	2.5
2-6	1	6	1.11	1.15	1.5
2-7	1	1	3.89	1.81	3.0
2-8	0	11	0.00	3.17	4.7
2-9	0	6	0.00	2.06	3.0
2-10	1	7	0.97	1.43	2.4

(continued)

TABLE 4-8 (continued)

Date	Number of daily maximum 8-hour values beginning on indicated date		OER	Composite fixed-site concentration for date	
	Group H	Group L		Daily average	Daily maximum 8-h
2-11	0	14	0.00	2.10	3.4
2-12	1	5	1.30	1.87	3.1
2-13	2	13	1.04	2.13	3.3
2-14	1	4	1.56	1.12	1.5
2-15	0	10	0.00	1.95	2.9
2-16	0	11	0.00	2.85	4.6
2-17	2	12	1.11	1.86	2.5
2-18	2	13	1.04	1.91	3.0
2-19	0	3	0.00	0.83	1.2
2-20	0	10	0.00	0.85	1.8
2-21	2	9	1.42	1.90	3.5
2-22	0	10	0.00	2.07	2.7
2-23	0	12	0.00	2.41	3.7
2-24	0	9	0.00	1.95	2.4
2-25	0	10	0.00	2.24	3.3
2-26	1	16	0.46	1.58	2.6
2-27	1	3	1.95	1.22	1.5
2-28	0	9	0.00	2.06	3.4
TOTAL	103	699			

[a]Observed-to-expected ratio (OER) is significantly different from 1.0 at p = 0.05 level.

TABLE 4-9. NUMBER OF PERSON-DAYS IN OCCUPATIONAL CATEGORIES USED BY U.S. BUREAU OF CENSUS BY EXPOSURE GROUP

Code	Occupational category	Number of person-days	
		Group H	Group L
005	Administrators and officials, public administration	0	4
007	Financial managers	0	3
008	Personnel and labor relations managers	0	2
009	Purchasing managers	1	0
013	Managers, marketing, advertising, and public relations	1	6
014	Administrators, education	0	4
015	Managers, medicine and health	0	9
016	Managers, properties and real estate	0	5
019	Managers and administrators, not elsewhere coded (n.e.c.)	3	17
023	Accountants and auditors	0	9
025	Other financial officers	1	3
026	Management analysts	0	3
027	Personnel, training, and labor relations specialists	0	2
029	Buyers, wholesale and retail, except farm products	0	2
037	Management-related occupations, n.e.c.	1	3
055	Electrical and electronic engineers	0	4
059	Engineers, n.e.c.	0	1
064	Computer systems analysts and scientists	1	2
065	Operations and systems researchers and analysts	0	2
067	Statistician	1	1
075	Geologists and geodesists	0	6
077	Agricultural and food scientists	0	2
078	Biological and life scientists	0	2
084	Physicians	1	11
095	Registered nurses	3	15
096	Pharmacists	0	5
097	Dietitians	0	2
124	Political science teachers	0	2
137	Art, drama, and music teachers	0	2
138	Physical education teachers	2	4
139	Education teachers	3[c]	1
143	English teachers	0	1
148	Trade and industrial teachers	0	2
155	Teachers, prekindergarten and kindergarten	0	4
156	Teachers, elementary school	2	27
157	Teachers, secondary school	1	3
158	Teachers, special education	0	2

(continued)

TABLE 4-9 (continued)

Code	Occupational category	Number of person-days	
		Group H	Group L
159	Teachers, n.e.c.	0	12
163	Counselors, educational and vocational	1	5
164	Librarians	0	4
173	Urban planners	0	1
174	Social workers	0	5
176	Clergy	0	2
178	Lawyers	3	11
185	Designers	0	4
186	Musicians and composers	0	2
189	Photographers	0	1
195	Editors and reporters	0	4
198	Announcers	0	1
203	Clinical lab technologists and technicians	0	3
207	Licensed practical nurses	1	4
208	Health technologists and technicians, n.e.c.	0	1
213	Electrical and electronic technicians	0	5
216	Engineering technicians, n.e.c.	0	4
228	Broadcast equipment operators	0	2
229	Computer programmers	1	4
235	Technicians, n.e.c.	0	2
243	Supervisors and proprietors, sales occupations	6[d]	1
253	Insurance sales occupations[a]	0	4
254	Real estate sales occupations	0	3
255	Securities and financial services sales occupations	0	2
257	Sales occupations, other business services	0	2
259	Sales representatives, mining, manufacturing and wholesale	0	5
263	Sales workers, motor vehicles and boats[a]	0	2
268	Sales workers, hardward and building supplies	2	0
274	Sales workers, other commodities	0	12
275	Sales counter clerks	0	2
276	Cashiers	0	1
277	Street and door-to-door sales workers[a]	0	2
278	News vendors	0	2
303	Supervisors, general office	0	2
309	Peripheral equipment operators	0	4

(continued)

TABLE 4-9 (continued)

Code	Occupational category	Number of person-days	
		Group H	Group L
313	Secretaries	1	23
315	Typists	3	8
319	Receptionists	0	2
323	Information clerks, n.e.c.	0	1
336	Records clerks	0	5
337	Bookkeepers, accounting, and auditing clerks	1	4
354	Postal clerks, except mail carriers	0	2
357	Messengers[a]	0	2
375	Insurance adjusters, examiners, and investigators	0	1
376	Investigators and adjusters, except insurance	2	2
377	Eligibility clerks, social welfare	0	2
378	Bill and account collectors	0	2
379	General office clerks	5	21
385	Data-entry keyers	0	2
406	Child care workers	0	2
418	Police detectives, public service[a]	0	1
426	Guards and police, except public service	1	3
427	Protective services occupations, n.e.c.	0	4
434	Bartenders[a]	0	2
435	Waiters and waitresses[a]	0	2
436	Cooks, except short order[a]	3	3
444	Miscellaneous food preparation occupations[a]	2	0
446	Health aides, except nursing	0	1
447	Nursing aides, orderlies, and attendants	0	4
449	Maids and housement	0	7
453	Janitors and cleaners	1	4
467	Homemakers	17	150
468	Child care workers	0	4
495	Forestry workers, except logging	0	2
503	Supervisors, mechanics, and repairers[a]	1	0
506	Auto mechanic apprentices[a]	0	1
507	Bus, truck, and stationary engine mechanics[a]	2	0
508	Aircraft engine mechanics[a]	0	1
509	Small engine repairers[a]	0	2
514	Auto body and related repairers[a]	1	0

(continued)

TABLE 4-9 (continued)

Code	Occupational category	Number of person-days	
		Group H	Group L
516	Heavy equipment mechanics[a]	0	2
518	Industrial machinery repairers	0	2
529	Telephone installers and repairers[a]	0	3
534	Heating, air conditioning, and refrigeration mechanics	0	1
535	Camera, watch, and musical instrument repairers	0	0
536	Locksmiths and safe repairers	1	0
539	Mechanical controls and valve repairers	2	0
555	Supervisors, electricians and power transmission installers	1	0
558	Supervisors, construction occupations, n.e.c.	1	3
567	Carpenters	1	7
577	Electrical power installers and repairers	1	1
588	Concrete and terrazzo finishers	0	1
599	Construction trades, n.e.c.	0	2
617	Mining occupations, n.e.c.	0	2
633	Supervisors, production occupations	0	4
637	Machinists	0	2
644	Precision grinders, fitters, and tool sharpeners	0	2
657	Cabinet makers and bench carpenters	0	2
677	Optical goods workers	0	2
678	Dental lab and medical appliance technicians	0	2
696	Stationary engineers	0	2
734	Printing machine operators	1	1
736	Typesetters and compositors	2	0
743	Textile cutting machine operators	0	0
744	Textile sewing machine operators	0	2
763	Roasting and baking machine operators, food[a]	0	2
765	Folding machine operators	0	2
774	Photographic process machine operators	0	2
777	Miscellaneous machine operators, n.e.c.	1	0
779	Machine operators, not specified	0	2
787	Hand molding, casting, and forming occupations	0	2
796	Production inspectors, checkers, and examiners	1	1
804	Truck drivers, heavy[a]	0	3
805	Truck drivers, light[a]	2	4
856	Industrial truck and tractor equipment operators[a]	0	2

(continued)

TABLE 4-9 (continued)

Code	Occupational category	Number of person-days	
		Group H	Group L
869	Construction laborers	2	4
877	Stock handlers and baggers	3[c]	1
885	Garage and service station related occupations[a]	2	1
888	Hand packers and packagers	0	2
889	Laborers, except construction	0	0
998[b]	Not employed	5	19
999[b]	Retired	1	37
Blank		1	8
	Total person-days	103	699

[a]Potential for high occupation-related exposure to CO because of proximity to motor vehicles, gas appliances, or cigarette smokers.

[b]Unofficial code used by PEI.

[c]OER = 5.84 (significant at p = 0.05 level).

[d]OER = 6.67 (significant at p = 0.05 level).

Table 4-10 lists the number of person-days by exposure group for selected aggregate occupation categories which might be expected to have higher CO exposures because of proximity to motor vehicles or gas appliances. Only the aggregate category "work which may involve proximity to running motor vehicles or internal combustion engines in enclosed space" has a significant ($p < 0.05$) OER value.

TABLE 4-10. NUMBER OF PERSON-DAYS IN SELECTED AGGREGATE OCCUPATION CATEGORIES BY EXPOSURE GROUP

Aggregate occupational category	Codes	Person-days Group H	Person-days Group L	OER
1. Work may require travel in vehicles in addition to commuting	253, 263, 277, 357, 418, 529, 804, 805, 856	2	23	0.62
2. Work may involve proximity to running motor vehicles or internal combustion engines in enclosed space	503, 506, 507, 508, 509, 514, 516, 885	6	7	3.59[a]
3. Work may involve proximity to street	277, 357	0	4	0.00
4. Work may involve proximity to gas appliances (excluding homemakers)	434, 435, 444, 763	2	6	1.95

[a]OER value is significantly different from 1.0 at $p = 0.05$ level.

The following tentative conclusions are suggested by the exploratory data analyses discussed above.

1. Person-days in Group H exhibit higher CO levels in most microenvironments.
2. The microenvironments which were visited more often during Group H person-days than would be expected are all associated with either outdoor locations and/or motor vehicles. Indoors-service station and outdoors - public garage have particularly large OER values.
3. The average durations of visits to the outdoors-service station and indoor-restaurant microenvironments are larger for Group H person-days than for Group L person-days.
4. The microenvironment "outdoors - within 10 yards of road" is associated with Group H person-days when it is located in a area with high ambient CO levels.
5. The microenvironments "indoor - public garage" and "indoor - service station" are associated with Group H person-days in areas with relatively low ambient CO levels.
6. Of the in-transit microenvironments, only truck is associated with Group H person-days when the start or end location of the trip is in a high ambient CO location. "Motorcycle" is associated with Group H for low ambient CO locations.

7. Group H person-days are strongly associated with periods of high ambient CO concentration, particularly November 5 and December 9, 1982.

8. The aggregate occupation category "work which may involve proximity to running motor vehicles or internal combustion engines in enclosed space" is strongly associated with Group H person-days.

Although the determination that a strong association exists is supported by a statistical significance level for each of the above conclusions, the conclusions should be considered as tentative where sample sizes are small or where confounding factors are likely to exist. More detailed analyses of the factors associated with high in-transit and high indoor exposures are described in Sections 4.2 and 4.3.

4.2 IN-TRANSIT EXPOSURES

Under the direction of EMSL, PEI investigated the effects of transit mode, smoking, time of day, and duration on in-transit exposures among the subjects of the Denver study. As in previous analyses, PEI assumed that personal CO exposures were accurately represented by the PEM values obtained for each subject. Mode of transit, smoking status, time of day, and duration were determined from the activity diary entries associated with each PEM value. Since PEI had files containing these data for Washington as well as Denver, a less extensive analysis of the Washington data was also performed.

4.2.1 General Approach and Notation

The general approach to analyzing the data was to perform analyses of variance (ANOVA) with the PEM values as the response variable and the remaining variables as factors which may explain variations in the PEM variable. Mode of transit, smoking status, and time of day were considered categorical variables. Duration was considered a continuous variable. Table 4-11 lists the variables considered in the analyses and indicates how the activity diary

TABLE 4-11. VARIABLES CONSIDERED IN ANALYSES OF VARIANCE AND COVARIANCE

Variable	Abbreviation	Category	Responses in category
CO concentration recorded by PEM, ppm	PEM	a	
Mode of transit, Denver	MDTR	walk car other	01: walking 02: car 03: bus 04: truck 93: motorcycle
Mode of transit, Washington	MDTR	walk car other	100: walking 661: jogging 200: car 300: bus 400: truck 500: train/subway 664: van
Smoking status	SM	yes no	Smokers present Uncertain Smokers not present
Time of day	TM	6-9 9-4 4-7 7-mid b	6:00 ≤ time < 9:00 9:00 ≤ time < 16:00 16:00 ≤ time < 19:00 19:00 ≤ time < 24:00 24:00 ≤ time < 6:00
Duration, minutes	DR	c	

[a]Continuous variable.

[b]No category.

[c]Continuous variable: $0 < DR \leq 60$.

responses were grouped into categories. The number of categories developed for each variable is smaller than the number of distinct activity diary responses to avoid the occurrence of empty cells in the ANOVA layout.

The mode-of-transit (MDTR) categories were selected so that walking/jogging and car would be distinct categories. The remaining category contains all other modes involving motor vehicles or trains. In developing the two smoking status (SM) categories, the "uncertain" response was combined with the "smokers present" response after noting that the distribution of "uncertain" PEM values was statistically more similar to the "smokers present" distribution than the "smokers not present" distribution. The time-of-day (TM) categories were selected so that the rush-hour periods of 6 a.m. to 9 a.m. and 4 p.m. to 7 p.m. would fall into distinct categories. The other categories correspond to late morning through early afternoon and post rush hour through midnight. The period from midnight through 6 a.m. was not assigned a category because of the small number of intransit PEM values which were recorded during these hours.

The ANOVA's were performed using BMDP program P2V. The Denver data set contained 4094 valid in-transit PEM values; the Washington data set contained 3176 valid in-transit PEM values. Cell sizes were unequal. The program provided statistical tests for null hypotheses such as "the means of PEM values corresponding to different transit modes are equal."

All analyses were performed on PEM values transformed using the Box-Cox transformation

$$y = (x^{\lambda} - 1)/\lambda, \qquad (4\text{-}3)$$

where x was the PEM value and λ was set equal to 0.25. A preliminary analysis suggested that setting λ equal to 0.25 would significantly reduce the skewness of the empirical distributions.

Two approaches were used to evaluate the effect of exposure duration. First, duration (DR) was used as a regressor in an analysis of covariance using MDTR, SM, and TM as factors. Second, DR was used as a cell weight in a weighted three-factor ANOVA. Note that duration values pertain to individual PEM readings and do not necessarily equal total "trip" time.

4.2.2 Statistical Procedures

Three-Way ANOVA and Interations--

A three-factor, fixed-effect linear model was assumed for the initial analysis of variance. The response variable Y was exposure; the factors were MDTR, TM, and SM. The method of incorporating the fourth variable, DR, in the model, is discussed below.

The general equation for the linear model is

$$Y_{ijkm} = \mu_{ijk} + \varepsilon_{ijkm} \tag{4-4}$$

where

μ_{ijk} = cell mean

ε_{ijkm} = iid $N(0,\sigma^2)$ random variable

$i = 1,\ldots,a$

$j = 1,\ldots,b$

$k = 1,\ldots,c$

$m = 1,\ldots,n.$

In general, the number of observations n is different for each unique set of values of the indices i, j, and k. The cell mean μ_{ijk} is expanded as follows:

$$\begin{aligned}\mu_{ijk} &= \alpha_i + \beta_j + \delta_k \\ &+ (\alpha\beta)_{ij} + (\beta\delta)_{jk} + (\delta\alpha)_{ki} \\ &+ (\alpha\beta\delta)_{ijk} .\end{aligned} \tag{4-5}$$

Here $\mu\ldots$ is the overall mean; α_i, β_i, and δ_i are the main effects; $(\alpha\beta)_{ij}$, $(\beta\delta)_{jk}$ and $(\delta\alpha)_{ki}$ are the two-factor interactions, and $(\alpha\beta\delta)_{ijk}$ is the three-factor interaction. So-called Σ restrictions are imposed by the BMDP routine to remove rank deficiency.

In a two-factor study, the interaction of the i-th level of factor A with the j-th level of factor B is defined as the difference between the cell mean μ_{ijk} and the value $\mu.. + \alpha_i + \beta_i$ which would be expected if the two factors were additive; in other words,

$$(\alpha\beta)_{ij} = \mu\mu_{ij} - (\mu.. + \alpha_i + \beta_i). \tag{4-6}$$

In a three-factor study the three-factor interaction $(\alpha\beta\delta)_{ijk}$ is defined as the difference between the cell mean μ_{ijk} and the value that would be expected if main effects plus two-factor interactions were sufficient to account for all factor effects; thus

$$(\alpha\beta\delta)_{ijk} = \mu_{ijk} - [\mu_{...} + \alpha_i + \beta_i + \delta_k + (\alpha\beta)_{ij} + (\beta\delta)_{jk} + (\delta\alpha)_{ki}]. \quad (4\text{-}7)$$

In the special case where cell sizes are equal (e.g., in a "designed" study), the total sum of squares

$$\sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{m=1}^{n} (Y_{ijkm} - \bar{Y}_{....})^2 \quad (4\text{-}8)$$

can be expanded as a sum of component sums-of-squares. The components include main effects, two-factor interactions, and three-factor interactions. Orthogonality exists and there is additivity of effects.

In the Denver and Washington data sets the cell sizes are generally unequal; thus, orthogonality is lost and the effects are no longer additive. The main consequences of the loss of additivity is that it becomes more difficult to test hypotheses concerning the presence of specified component effects. It is still possible to test for equality of means across levels of a given factor. The approach is to first test for significance of two-factor interactions. If these interactions are not significant, the test for equality of means across levels of each of the three factors can proceed either directly, or by first reducing the model to a no-interaction model. On the other hand, if two-factor interactions are significant, tests for equality of level means of one factor can proceed only if one conditions on each level of the other factor. This approach assumes that the three-factor interaction is not significant. If the three-factor interaction is significant, then the interactions between any two factors need to be studied separately for each level of the third factor.

Analysis of Covariance--

In covariance analysis one uses the relationship between the response variable and a regressor, or explanatory variable, to improve the model fit, i.e., to reduce the experimental error. Although one is usually not concerned with a test of the hypothesis that the regression coefficient equals zero, it was of interest in this study to discern a relationship between exposure and duration of exposure.

Weighted ANOVA--

As an alternative to the use of duration as a concomitant variable in the analysis of covariance, a weighted ANOVA was implemented with weight equal to duration.

4.2.3 Results

As indicated in the introduction, data were available for both Denver, Colorado and Washington, D.C. The results for Denver are more extensive and are given in Tables 4-12 through 4-17 and in Tables 4-21 through 4-23. The results for Washington, D.C. are given in Tables 4-18 through 4-20. All results are in the form of standard ANOVA tables. Tables 4-12 and 4-13 are unweighted ANOVA's with and without the variable DR as covariable, or regressor. Results for the weighted ANOVA, with weight = DR, are presented in Table 4-14. Note that all results apply to transformed (λ = 0.25) PEM values.

In Tables 4-15, 4-16, and 4-17 are presented the results of two-factor ANOVA's conditioned on the levels of the third factor. Conditioning factors are TM, MDTR, and SM, respectively.

In Tables 4-18, 4-19, and 4-20 are presented the results for Washington, D.C. Tables 4-18 and 4-19 are unweighted ANOVA's with and without the variable DR as covariable. Table 4-20 is the weighted ANOVA with weight equal to DR.

Tables 4-21, 4-22, and 4-23 present the Denver cell means, the cell standard deviations, and the cell counts for each of the possible cross-tabulations, conditioned on the alternate factor.

The goal of this analysis is to test for equality of means of the main effects. Such a test can be done provided interactions between the factor of interest and any other factor in the study are not significant. In the presence of interaction effects the test for equality of means of the main effects can still be done provided one conditions on the interacting factor(s).

TABLE 4-12. ANALYSIS OF VARIANCE TABLE FOR DENVER PERSONAL EXPOSURE DATA (CELL WEIGHT = 1, COVARIABLE = NONE)

Source	Sums of squares	Degrees of freedom	Mean square	F	Tail prob.
MDTR	138.06	2	69.03	13.50	0.0000
TM	91.36	3	30.45	5.95	0.0005
SM	4.44	1	4.44	0.87	0.3517
MDTR*TM	20.30	6	3.38	0.66	0.6808
MDTR*SM	0.52	2	0.26	0.05	0.9503
TM*SM	52.47	3	17.49	3.42	0.0167
MDTR*TM*SM	90.88	6	15.15	2.96	0.0069
Error	20817.20	4070	5.1148		

TABLE 4-13. ANALYSIS OF VARIANCE TABLE FOR DENVER PERSONAL EXPOSURE DATA (CELL WEIGHT = 1, COVARIABLE = DR)

Source	Sums of squares	Degrees of freedom	Mean square	F	Tail prob.
MDTR	150.08	2	75.04	14.69	0.0000
TM	87.59	3	29.20	5.72	0.0007
SM	3.42	1	3.42	0.67	0.4129
MDTR*TM	21.88	6	3.65	0.71	0.6383
MDTR*SM	0.28	2	0.14	0.03	0.9727
TM*SM	54.35	3	18.12	3.55	0.0139
MDTR*TM*SM	93.50	6	15.58	3.05	0.0056
Covariable[a]	35.80	1	35.80	7.01	0.0081
Error	20781.40	4069	5.11		

[a]Regression coefficient estimate = -0.0063.

TABLE 4-14. ANALYSIS OF VARIANCE TABLE FOR DENVER PERSONAL EXPOSURE DATA (CELL WEIGHT = DR, COVARIABLE = NONE)

Source	Sums of squares	Degrees of freedom	Mean square	F	Tail prob.
MDTR	2064.76	2	1032.38	12.10	0.0000
TM	1139.51	3	379.84	4.45	0.0040
SM	121.37	1	121.37	1.42	0.2330
MDTR*TM	688.57	6	114.76	1.35	0.2331
MDTR*SM	577.74	2	288.87	3.39	0.0339
TM*SM	43.04	3	14.35	0.17	0.9179
MDTR*TM*SM	1202.91	6	200.49	2.35	0.0287
Error	340554.16	3993	85.29		

TABLE 4-15. ANALYSIS OF VARIANCE TABLE FOR DENVER PERSONAL EXPOSURE DATA (CONDITIONED ON TM)

Conditioning factor, TM	Source	Sum of squares	Degrees of freedom	Mean square	F	Tail prob.
6-9	MDTR	18.51	2	9.25	1.81	0.1634
	SM	2.87	1	2.87	0.56	0.4532
	MDTR*SM	6.76	2	3.38	0.66	0.5159
	ERROR	20817.20	4070	5.11		
9-16	MDTR	109.97	2	54.98	10.77	0.0000
	SM	12.32	1	12.32	2.41	0.1205
	MDTR*SM	71.75	2	35.87	7.02	0.0009
	ERROR	20817.20	4070	5.11		
16-19	MDTR	92.43	2	46.21	9.05	0.0001
	SM	31.91	1	31.91	6.25	0.0125
	MDTR*SM	45.91	2	22.96	4.49	0.0112
	ERROR	20817.20	4070	5.11		
19-24	MDTR	34.56	2	17.28	3.38	0.0340
	SM	7.87	1	7.87	1.54	0.2145
	MDTR*SM	7.69	2	3.84	0.75	0.4713
	ERROR	20817.20	4070	5.11		

TABLE 4-16. ANALYSIS OF VARIANCE TABLE FOR DENVER PERSONAL EXPOSURE DATA (CONDITIONED ON MDTR)

Conditioning factor, MDTR	Source	Sum of squares	Degrees of freedom	Mean square	F	Tail prob.
Walk	TM	50.27	3	16.76	3.28	0.0200
	SM	0.64	1	0.64	0.12	0.7244
	TM*SM	44.04	3	14.68	2.87	0.0349
	ERROR	20817.20	4070	5.11		
Car	TM	103.43	3	34.48	6.75	0.0002
	SM	2.74	1	2.74	0.54	0.4638
	TM*SM	5.68	3	1.89	0.37	0.7743
	ERROR	20817.20	4070	5.11		
Other	TM	16.90	3	5.63	1.10	0.3465
	SM	1.46	1	1.46	0.29	0.5931
	TM*SM	51.98	3	17.33	3.39	0.0172
	ERROR	20817.20	4070	5.11		

TABLE 4-17. ANALYSIS OF VARIANCE TABLE FOR DENVER PERSONAL EXPOSURE DATA (CONDITIONED ON SM)

Conditioning factor, SM	Source	Sum of squares	Degrees of freedom	Mean square	F	Tail prob.
Yes	TM	39.75	3	13.25	2.59	0.0509
	MDTR	44.67	2	22.23	4.35	0.0129
	TM*MDTR	55.32	6	9.22	1.81	0.0940
	ERROR	20817.20	4070	5.11		
No	TM	a				
	MDTR	a				
	TM*MDTR	a				
	ERROR	a				

[a]Analysis not performed.

TABLE 4-18. ANALYSIS OF VARIANCE TABLE FOR WASHINGTON, D.C. PERSONAL EXPOSURE DATA (CELL WEIGHT = 1, COVARIABLE = NONE)

Source	Sums of squares	Degrees of freedom	Mean square	F	Tail prob.
MDTR	92.09	2	46.04	16.69	0.0000
TM	112.30	3	37.43	13.57	0.0000
SM	36.73	1	36.73	13.31	0.0003
MDTR*TM	21.45	6	3.57	1.30	0.2556
MDTR*SM	18.48	2	9.24	3.35	0.0353
TM*SM	3.58	3	1.19	0.43	0.7298
MDTR*TM*SM	10.01	6	1.67	0.60	0.7268
Error	8696.98	3152	2.76		

TABLE 4-19. ANALYSIS OF VARIANCE TABLE FOR WASHINGTON, D.C. PERSONAL EXPOSURE DATA (CELL WEIGHT = 1, COVARIABLE = DR)

Source	Sums of squares	Degrees of freedom	Mean square	F	Tail prob.
MDTR	91.00	2	45.50	16.48	0.0000
TM	112.39	3	37.46	13.57	0.0000
SM	36.16	1	36.16	13.10	0.0003
MDTR*TM	21.26	6	3.54	1.28	0.2611
MDTR*SM	18.36	2	9.18	3.33	0.0360
TM*SM	3.54	3	1.18	0.43	0.7333
MDTR*TM*SM	10.02	6	1.67	0.60	0.7266
Covariable[a]	0.13	1	0.13	0.05	0.8310
Error	8696.85	3151	2.76		

[a]Regression coefficient not significant.

TABLE 4-20. ANALYSIS OF VARIANCE TABLE FOR WASHINGTON, D.C. PERSONAL EXPOSURE DATA (CELL WEIGHT = DR, COVARIABLE = NONE)

Source	Sums of squares	Degrees of freedom	Mean square	F	Tail prob.
MDTR	1303.48	2	651.74	12.16	0.0000
TM	2743.88	3	914.63	17.06	0.0000
SM	919.10	1	919.10	17.15	0.0000
MDTR*TM	751.60	6	125.27	2.34	0.0296
MDTR*SM	1141.14	2	570.57	10.65	0.0000
TM*SM	100.06	3	33.35	0.62	0.6006
MDTR*TM*SM	472.87	6	78.81	1.47	0.1842
Error	168622.53	3146	53.60		

TABLE 4-21. CROSS TABULATED EXPOSURE MEANS AND STANDARD DEVIATIONS FOR DENVER MDTR VERSUS SM CONDITIONED ON TM

		SM					
		Yes			No		
TM	MDTR	Mean	sd	n	Mean	sd	n
6-9	walk	1.360	2.14	17	1.420	2.27	59
	car	1.908	2.65	37	2.072	2.41	453
	other	2.919	1.29	4	1.658	2.54	55
9-16	walk	0.934	1.70	68	-0.124	2.26	248
	car	1.037	2.47	161	1.367	2.15	1393
	other	1.214	1.60	25	1.105	2.53	179
16-19	walk	0.657	2.27	33	0.685	2.55	86
	car	1.747	2.23	69	1.769	2.31	648
	other	0.193	2.32	17	2.174	1.48	74
19-24	walk	-0.842	2.93	5	0.556	2.46	37
	car	1.249	2.52	43	1.302	2.27	336
	other	0.826	3.09	9	1.288	1.91	38

TABLE 4-22. CROSS TABULATED EXPOSURE MEANS AND STANDARD DEVIATION FOR DENVER TM VERSUS SM CONDITIONED ON MDTR

		SM					
		Yes			No		
MDTR	TM	Mean	sd	n	Mean	sd	n
Walk	6-9	1.360	2.14	17	1.420	2.27	59
	9-16	0.934	1.70	68	-0.124	2.26	248
	16-19	0.657	2.27	33	0.685	2.55	86
	19-24	-0.842	2.93	5	0.556	2.46	37
Car	6-9	1.908	2.65	37	2.072	2.41	453
	9-16	1.037	2.47	161	1.367	2.15	1393
	16-19	1.747	2.23	69	1.769	2.31	648
	19-24	1.249	2.52	43	1.302	2.27	336
Other	6-9	2.919	1.29	4	1.658	2.54	55
	9-16	1.214	1.60	25	1.105	2.53	179
	16-19	0.193	2.32	17	2.174	1.48	74
	19-24	0.826	3.09	9	1.288	1.91	38

TABLE 4-23. CROSS TABULATED EXPOSURE MEANS AND STANDARD DEVIATION FOR DENVER TM VERSUS MDTR CONDITIONED ON SM

		MDTR								
		Walk			Car			Other		
SM	TM	Mean	sd	n	Mean	sd	n	Mean	sd	n
Yes	6-9	1.360	2.14	17	1.908	2.65	37	2.919	1.29	4
	9-16	0.934	1.70	68	1.037	2.47	161	1.214	1.60	25
	16-19	0.657	2.27	33	1.747	2.23	69	0.193	2.32	17
	19-24	-0.842	2.93	5	1.249	2.52	43	0.826	3.09	9
No	6-9	1.420	2.27	59	2.072	2.41	453	1.658	2.54	55
	9-16	-0.124	2.26	248	1.367	2.15	1393	1.105	2.53	179
	16-19	0.685	2.55	86	1.769	2.31	648	2.174	1.48	74
	19-24	0.556	2.46	37	1.302	2.27	336	1.288	1.91	38

Denver--

The three-factor interaction was found to be significant; consequently, a series of two-factor ANOVA's conditioned on the level of the third factor were run. Displays are presented in Tables 4-15, 4-16, and 4-17. Two-factor interactions were found to be significant in some, though not all, combinations; consequently, some additional one-factor ANOVA's, conditioned on the levels of the interacting factor, are warranted. The indicated one-factor ANOVA's have not been carried out.

Some interim conclusions can be formulated, however. From Table 4-15 it can be inferred that interactions between MDTR and SM are not significant for the conditioning intervals 6-9 and 19-24. In these intervals the ANOVA's also yield tests for the equality of means in the main effects MDTR and SM. The null hypothesis is rejected for MDTR in the 19-24 interval, but cannot be rejected for SM in either interval.

From Table 4-16 it can be inferred that interaction is not significant for the conditioning factor MDTR = car. The main effect means for TM are not all equal, whereas such a claim cannot be made for the main effect means for SM.

Table 4-17 is incomplete at present. However, it can be inferred that the interaction is not significant for the conditioning factor SM = yes. The main effect MDTR is significant, while the main effect TM barely misses the critical region at the 0.05 level.

The results presented in Tables 4-12 (no covariable) and 4-13 (covariable = DR) are qualitatively identical. Entering the covariable DR into the model does not change the fit. It is of interest that the regression coefficient is significant; consequently, an association between personal exposure and duration of exposure does exist.

Table 4-14 presents the ANOVA results for a weighted analysis, with weight equal to DR. A comparison of the results of unweighted and weighted ANOVA's (Tables 4-12 and 4-14) reveals that the three-factor interaction is significant in both tables, suggesting the need for additional two-factor ANOVA's (unweighted and weighted) conditioned on the levels of the third factor. The unweighted analysis has been implemented while the weighted analysis remains to be carried out. In the unweighted analysis (Table 4-12), the two-factor interaction MDTR*SM is not significant, whereas TM*SM is significant. In the weighted analysis, the reverse is true: MDTR*SM is significant and TM*SM is not significant (Table 4-14). Further exploration via two-way and one-way conditioned ANOVA's is indicated.

Washington--

The results presented in Tables 4-18, 4-19, and 4-20 indicate that the three-factor interaction in each table is not significant. Table 4-19 suggests that no association between personal exposure and duration exists for Washington. Tables 4-18 and 4-19 suggest that two-factor interactions involving TM are not significant. The null hypotheses for equality of means of the main effect TM is rejected. It is concluded that the personal exposure means are different according to the time of day and independent of MDTR and of SM. Two one-factor ANOVA's, conditioned on the levels of the remaining factor, are needed to clarify the roles of MDTR and SM. They remain to be carried out.

Results from the weighted ANOVA are given in Table 4-20. The two-factor interactions between MDTR and TM, and between MDTR and SM, are both significant, whereas the interaction between TM and SM is not significant. Future analyses should consider (a) a set of one-way ANOVA's with MDTR as the main effect and conditioned on each of the levels of TM and SM; and (b) a set of two-way ANOVA's with TM and SM as main effects and MDTR as the conditioning variable.

4.2.4 Summary of Conclusions

The ANOVA's, analyses of covariance, and cross-tabulations presented above support the following general conclusions.

Denver--

1. The two motor vehicle categories (car and other) are associated with higher exposures than walking. Exposures in these two categories are particularly high during the time period 6-9 and 16-19. These two periods bracket the morning and afternoon rush hours.

2. The presence of smokers does not increase exposure.

3. Exposure decreases as duration increases.

Washington--

1. Exposure varies with mode-of-travel, time-of-day, and presence of smokers.

2. No associations exist between exposure and duration.

As indicated in Section 4.2.3, the Washington data received an incomplete analysis. In future analyses, cross-tabulation tables similar to Tables 4-21, 4-22, and 4-23 should be constructed so that the effect of the various variables can be quantified. Recommended ANOVA's for future Washington analyses are discussed in Section 4.2.3.

4.3 INDOOR EXPOSURES

EMSL directed PEI to identify specific factors which significantly affect indoor exposures in Denver. This section describes a number of analyses performed by PEI in this area and summarizes the major findings. Note that the principal data bases used in these analyses consisted of 1) PEM values, 2) the activity diary entries of the Denver study participants, and 3) participant responses to the study questionnaire.

4.3.1 Candidate Exposure Factors

Each PEM value in the Denver SAMPLE-DATA file (described in Section 4.10 of Reference 1) has a two-digit location code. Sixteen of these codes correspond to indoor microenvironments. Table 4-24 lists these microenvironments and provides selected summary statistics based on data with acceptable overall (i.e., PEM plus activity diary) quality codes. The minimum value reported for each microenvironment is zero. Note the large values of skewness and kurtosis listed for most microenvironments. To facilitate the use of statistical analyses requiring normal distributions, PEI investigated the use of the Box-Cox transformation as a means of reducing skewness and kurtosis. The general form of the transformation is given in Equation 4-3 with y the transformed value, x the PEM value, and λ a constant selected by the user. A preliminary analysis suggested that the choice of $\lambda = 0.35$ produced low skewness and kurtosis values for most microenvironments. Table 4-25 lists summary statistics of the transformed data. Note the dramatic reduction in most of the skewness and kurtosis values after transformation.

TABLE 4-24. SUMMARY STATISTICS FOR CARBON MONOXIDE CONCENTRATION VALUES RECORDED BY PERSONAL EXPOSURE MONITORS IN INDOOR MICROENVIRONMENTS

Code	Indoor microenvironment	n	Carbon monoxide concentration, ppm						Std. skewness[c]	Std. kurtosis[d]
			Maximum	Mean	s.d.[a]	s.e.[b]	Median	s.e.[b]		
02	Residence	21518	76.4	2.212	4.030	0.027	0.90	0.029	e	e
03	Office	2287	59.1	3.248	4.970	0.104	1.90	0.058	110.40	483.29
04	Store	734	56.3	3.385	4.754	0.175	2.00	0.115	47.05	167.26
05	Restaurant	524	35.0	4.313	4.674	0.204	3.15	0.231	21.76	44.53
51	Residential garage	66	28.4	3.364	5.059	0.623	1.40	0.318	9.02	14.49
52	Public garage	115	81.2	11.968	11.984	1.118	8.40	0.635	10.85	19.71
53	Manufacturing facility	42	8.0	1.750	2.366	0.365	0.00	0.577	2.75	-0.30
54	Service station or auto repair facility	125	73.1	9.409	9.704	0.868	5.80	1.212	13.13	31.32
55	Other repair shop	55	33.1	7.620	8.575	1.156	3.00	1.617	2.98	-0.26
56	Auditorium	100	31.2	4.523	5.649	0.565	3.50	0.577	9.72	13.97
57	Church	179	21.7	1.824	2.998	0.224	1.00	0.087	19.50	42.54
58	Shopping mall	58	33.9	5.271	6.493	0.853	3.10	0.462	7.35	9.58
59	Health care facility	351	31.3	2.334	3.632	0.194	1.20	0.173	29.28	79.80
60	School	426	21.6	2.056	3.090	0.150	0.80	0.144	24.52	47.92
61	Other public building	115	21.8	2.937	3.760	0.351	1.50	0.491	9.77	15.02
62	Other indoor location	425	66.4	4.923	7.958	0.386	2.90	0.202	34.45	85.67

[a] Standard deviation. [b] Standard error. [c] Std. skewness = $g_1/\sqrt{6/n}$.

[d] Std. kurtosis = $g_2/\sqrt{24/n}$. [e] Not computed because of large sample size.

TABLE 4-25. SUMMARY STATISTICS FOR CARBON MONOXIDE CONCENTRATION VALUES RECORDED BY PERSONAL EXPOSURE MONITORS IN INDOOR MICROENVIRONMENTS AFTER TRANSFORMATION

Code	Indoor microenvironment	n	Carbon monoxide concentration, ppm						Std. skewness[c]	Std. kurtosis[d]
			Maximum	Mean	s.d.[a]	s.e.[b]	Median	s.e.[b]		
02	Residence	21518	10.175	-0.311	2.170	0.015	-0.103	0.032	e	e
03	Office	2287	9.055	0.469	2.154	0.045	0.720	0.038	0.56	-0.52
04	Store	734	8.854	0.592	2.111	0.080	0.784	0.074	-0.25	-0.62
05	Restaurant	524	7.059	1.095	2.108	0.092	1.412	0.111	-3.21	-1.54
51	Residential garage	66	6.360	0.431	2.244	0.276	0.357	0.245	0.68	-0.67
52	Public garage	115	10.456	3.336	2.085	0.194	3.161	0.157	2.28	0.79
53	Manufacturing facility	42	3.059	-0.814	2.287	0.353	-2.857	1.051	0.91	-2.24
54	Service station or auto repair facility	125	9.975	2.744	2.111	0.189	2.430	0.348	0.37	1.53
55	Other repair shop	55	6.867	1.731	2.833	0.382	1.340	0.637	-0.27	-1.71
56	Auditorium	100	6.668	0.967	2.364	0.236	1.570	0.289	-0.60	-1.15
57	Church	179	5.532	-0.284	1.888	0.141	0.000	0.084	1.12	-0.55
58	Shopping mall	58	6.949	1.511	2.017	0.265	1.388	0.265	0.65	0.62
59	Health care facility	351	6.679	-0.033	2.044	0.109	0.188	0.156	1.19	-1.65
60	School	426	5.518	-0.255	2.045	0.099	-0.215	0.163	1.65	-3.46
61	Other public building	115	5.545	0.258	2.205	0.206	0.436	0.357	-0.14	-2.26
62	Other indoor location	425	9.551	0.983	2.467	0.120	1.290	0.103	1.55	1.38

[a]Standard deviation.
[b]Standard error.
[c]Std. skewness = $g_1/\sqrt{6/n}$.
[d]Std. kurtosis = $g_2/\sqrt{24/n}$.
[e]Not computed because of large sample size.

Section 5.3 summarizes the results of an analysis which used multiple comparison tests as a means of identifying and grouping similar microenvironments. The analysis found that the 16 microenvironments could be grouped into four aggregate microenvironments such that the microenvironments in each group were statistically similar with respect to exposure and the groups were statistically different. Thus microenvironment in general is a factor which affects exposure, but the effects of two specific microenvironments may not be statistically different.

Other data items appearing in the activity diary which might affect indoor exposure include the activity (e.g., laundry, cooking), address, attached garage, gas stove, and smokers present entries. A variety of analyses evaluating the relationships between exposures and activity diary items are described in Section 6 of Reference 1 and previous sections of this report. Table 4-26 lists the format of a special computer file created by PEI which provides the indoor PEM values and activity diary entries for each person-day of data. For each PEM value associated with a particular person, the file lists the background questionnaire entries for that person. In analyzing this file, it is understood that not all questionnaire responses listed for a given PEM value are pertinent to that exposure. For example, the presence of a heat pump in the home should not affect exposures at work.

4.3.2 Determination of Subject Location

Some of the analyses that follow involve relating exposures to questionnaire responses dealing with the home and workplace environments. Determining when a subject is "home" is not straightforward. Although the SAMPLE-DATA file indicates when a subject is in a residence, that residence is not necessarily his or her home. The address of the residence does not appear in the SAMPLE-DATA file, only the census tract. The subject could be visiting a neighbor or relative. Fortunately, one can identify many "indoors-residence" entries in the activity diary as not being the home residence. Usually the subject will be home when the first diary entry is made, when "sleeping" is recorded, and when "final entry" is recorded. If the same census tract is given in all three cases, there is a very high probability that the reported census tract is the "home census tract." We can assume that all "indoors-

TABLE 4-26. FORMAT OF COMPUTER FILE LISTING INDOOR PEM VALUES, ACTIVITY DIARY ENTRIES, AND SELECTED BACKGROUND QUESTIONNAIRE RESPONSES

Columns	Format	Description
1-6	A6	Monitor ID
7-13	A7	PID #
14-19	A6	Date sampled (MMDDYY)
20-21	I2	Sequence number
22-25	A4	Time (0000-2359)
26-29	F4.1	PEM CO concentration, ppm
30-31	I2	Activity Diary Item A
32-33	I2	Activity Diary Item B
34-39	F6.2	Activity Diary Item C
40-44	F5.2	Activity Diary Item D1
45-49	F5.2	Activity Diary Item D2
50-51	I2	Activity Diary Item D3
52-53	I2	Activity Diary Item E1
54-55	I2	Activity Diary Item E2
56-57	I2	Activity Diary Item F
58	I1	Class code for slope
59	I1	Class code for intercept
60	I1	Highest class code
61	I1	PEM quality code (1 = flag)
62	I2	Diary quality code
63	I1	Overall quality code
64-65	I2	Duration, minutes
66-71	A6	Nearest fixed-site code
72-76	F5.1	Nearest fixed-site CO concentration, ppm
77-85	F9.3	Weight (PEM)
86-94	F9.3	Weight (Diary)
95-103	F9.3	Weight (Overall)
104-108	F5.1	Composite site CO concentration
109-110	I2	Housing type
111-115	I5	Living area (sq. ft)
116-117	I2	Packs smoked per week
118-126	9(I1)	CO sources in residence
127-132	5(I1),A1	Energy-saving devices in residence
133-136	3(I1),A1	Fans in residence
137-138	I2	Main heating system in residence
139-140	I2	Air conditioning in residence
141-145	5(I1)	Pollution sources near residence
146-147	I2	Year of automobile
148-149	I2	Type of enclosed work area (EWA)
150-155	I6	Square feet in EWA
156-157	I2	Air conditioning in EWA
158-159	I2	Fan in EWA
160-161	I2	Main heating system in EWA
162-166	5(I1)	Pollution sources near work
167-169	I3	Occupation type
170-171	I2	Sex
172-173	I2	Age
174-175	I2	Construction of residence
176-181	F6.2	Census tract of residence

residence" entries with census tracts other than the "home census tract" were not recorded in the subject's home.

PEI wrote a computer program which performed the indicated logic tests and identified the home census tract. Where some of the necessary diary entries were missing, PEI reviewed the actual diaries and determined the correct home census tracts. As indicated in Table 4-26, home census tracts appear in columns 176 through 181. For the analyses described here, PEI assumed a subject was home when the activity diary LOCATION code indicated "indoors-residence" and the census tract listed under ADDRESS was identical to the "home" census tract appearing in columns 176 through 181.

A subject was considered to be indoors at work when the ACTIVITY code indicated "work or study." PEI required that the work location be a place other than residence for the analyses described in this memorandum. Since only indoor LOCATION codes were included in the special computer file, outdoor work exposure situations were automatically omitted from the analysis.

4.3.3 Results of One-Way Analyses of Variance

One-way analyses of variance were performed by BMDP program P2V on indoor exposures at home and indoor exposures at work using responses to selected questions on the background questionnaire as the grouping variables. Tables 4-27 through 4-33 present the results of these analyses for untransformed and transformed ($\lambda = 0.35$) PEM values. The p values listed in these tables indicate the probability that the means associated with the various responses to a question are identical.

Table 4-27 presents the results of an ANOVA of the effect of area on home exposure. Area responses were divided into four groups using cutpoints of 1000, 1425, and 2056 ft^2--the quartiles listed in Table 6-9 of Reference 1. As might be expected, the largest mean (2.49 ppm) is associated with small homes (area $\leq$ 1000 ft^2), which have less air volume to dilute CO from indoor sources. However, the smallest mean is not associated with large homes but with homes having areas between 1000 ft^2 and 1425 ft^2. This result suggests a possible confounding effect. Perhaps gas stoves are more common in certain size homes.

TABLE 4-27. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES AT HOME VERSUS AREA OF LIVING QUARTERS

Approximate area of living quarters, square feet[a]	n	Untransformed data		Transformed data	
		Mean	Std. dev.	Mean	Std. dev.
Area ≤ 1000	4828	2.49	3.42	0.01	2.14
1000 < area ≤ 1425	4401	1.80	3.30	-0.62	2.11
1425 < area ≤ 2056	4685	2.46	4.98	-0.22	2.23
2056 < area	4620	1.94	4.24	-0.50	2.09

[a]F test indicates $p < 0.0001$ for untransformed and transformed data.

TABLE 4-28. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES AT HOME VERSUS NUMBER OF CIGARETTE PACKS SMOKED PER WEEK BY OTHER HOUSEHOLD MEMBERS

Code	Cigarette packs smoked per week[a]	n	Untransformed data		Transformed data	
			Mean	Std. dev.	Mean	Std. dev.
0	No smokers in residence	14865	2.15	3.80	-0.34	2.15
01	Less than 1 pack	2159	2.00	3.57	-0.51	2.17
02	1 to 4 packs	1951	2.41	4.59	-0.18	2.17
03	5 to 7 packs	620	2.22	3.55	-0.21	2.13
04	8 or more packs	705	3.80	7.22	0.59	2.25

[a]F test indicates $p < 0.0001$ for untransformed and transformed data.

TABLE 4-29. RESULTS OF ANALYSES OF VARIANCE OF INDOOR EXPOSURES VERSUS RESPONSE TO SELECTED QUESTIONS CONCERNING COMBUSTION SOURCES IN LIVING QUARTERS

Combustion source in living quarters	Code	Response	n	Untransformed data		Transformed data	
				Mean	Std. dev.	Mean	Std. dev.
Fireplace[a]	1	Used and vented	7953	2.12	4.43	-0.38	2.13
	2	Used and not vented	292	1.94	3.11	-0.60	2.21
	3	Not used	11911	2.29	3.76	-0.24	2.19
Woodstove[b]	1	Used and vented	1963	2.20	4.96	-0.50	2.26
	2	Used and not vented	96	2.31	3.15	-0.30	2.29
	3	Not used	18097	2.22	3.92	-0.28	2.16
Gas furnace[c]	1	Used and vented	16188	2.18	3.99	-0.33	2.16
	2	Used and not vented	786	3.10	6.61	0.01	2.37
	3	Not used	3182	2.19	3.31	-0.23	2.12
Gas cooking stove[c]	1	Used and vented	1837	3.66	5.09	0.48	2.38
	2	Used and not vented	2837	3.24	4.34	0.53	2.11
	3	Not used	15482	1.86	3.76	-0.54	2.09
Gas hot water heater[d]	1	Used and vented	15271	2.21	4.04	-0.30	2.16
	2	Used and not vented	1638	2.35	4.94	-0.30	2.21
	3	Not used	3218	2.22	3.46	-0.26	2.16
Gas clothes dryer[c]	1	Used and vented	3729	2.68	4.62	-0.03	2.24
	2	Used and not vented	476	2.33	2.95	-0.09	2.14
	3	Not used	15951	2.11	3.90	-0.37	2.15
Gas or kerosene space heater[c]	1	Used and vented	291	1.82	4.85	-0.59	2.03
	2	Used and not vented	1286	3.07	4.90	0.18	2.29
	3	Not used	18579	2.17	3.95	-0.33	2.16

[a] F test indicates $p = 0.006$ for untransformed data and $p < 0.0001$ for transformed data.

[b] F test indicates $p = 0.958$ for untransformed data and $p = 0.0001$ for transformed data.

[c] F test indicates $p < 0.0001$ for untransformed and transformed data.

[d] F test indicates $p = 0.415$ for untransformed data and $p = 0.654$ for transformed data.

TABLE 4-30. RESULTS OF ANALYSES OF VARIANCE OF INDOOR EXPOSURE VERSUS RESPONSE TO SELECTED QUESTIONS CONCERNING ENERGY-SAVING DEVICES IN LIVING QUARTERS

Energy-saving devices in living quarters	Code	Response	n	Untransformed data		Transformed data	
				Mean	Std. dev.	Mean	Std. dev.
Storm windows[a]	1	Yes	12750	2.35	4.47	-0.23	2.19
	2	No	7259	1.97	3.08	-0.43	2.12
Storm door(s)[a]	1	Yes	13319	2.43	4.32	-0.17	2.20
	2	No	6481	1.78	3.36	-0.58	2.07
Extra insulation[b]	1	Yes	9859	2.18	3.91	-0.29	2.14
	2	No	7027	2.17	4.34	-0.36	2.16
Special dampers in stove or fireplace[a]	1	Yes	3602	2.53	5.08	-0.18	2.25
	2	No	12915	2.06	3.59	-0.38	2.12

[a]F test indicates $p < 0.0001$ for untransformed and transformed data.

[b]F test indicates $p = 0.885$ for untransformed data and $p = 0.0546$ for transformed data.

TABLE 4-31. RESULTS OF ANALYSES OF VARIANCE OF INDOOR EXPOSURES VERSUS MAIN HEATING SYSTEM IN LIVING QUARTERS

Code	Main heating system in living quarters[a]	n	Untransformed data		Transformed data	
			Mean	Std. dev.	Mean	Std. dev.
01	Steam or hot water system	2942	2.37	3.77	-0.10	2.13
02	Central warm air furnace with ducts to individual rooms, or central heat pump (forced air)	15552	2.13	4.05	-0.37	2.16
03	Built-in electric units, permanently installed in wall, ceiling, or baseboard	195	0.96	2.06	-1.26	1.76
04	Floor, wall, or unvented furnace	229	3.08	3.53	0.51	2.06
05	Circulating, radiant, or room heaters, WITH flue or vent, burning gas, oil, or kerosene	139	2.45	3.69	-0.44	2.43
06	Circulating radiant, or room heaters (not portable) WITHOUT flue or vent, burning gas, oil, or kerosene	119	1.96	3.22	-0.23	1.96
07	Portable room heaters of any kind	60	11.84	4.34	3.81	0.96
08	Fireplace(s) or stove(s) burning coal, wood, or coke	727	2.34	3.94	-0.21	2.17
11	Gravity gas	136	5.03	6.44	1.32	2.16

[a]F test indicates $p < 0.0001$ for untransformed and transformed data.

TABLE 4-32. RESULTS OF ANALYSES OF VARIANCE OF INDOOR EXPOSURES VERSUS MAIN HEATING SYSTEM IN WORKPLACE

Code	Main heating system in workplace	n	Untransformed data		Transformed data	
			Mean	Std. dev.	Mean	Std. dev.
01	Steam or hot water system	742	3.36	4.27	0.40	2.32
02	Central warm air furnace with ducts to individual rooms, or central heat pump (forced air)	1610	3.47	5.93	0.44	2.27
03	Built-in electric units, permanently installed in wall, ceiling, or baseboard	284	3.09	3.17	0.55	2.05
05	Circulating, radiant, or room heaters, WITH flue or vent, burning gas, oil, or kerosene	71	8.48	13.73	2.08	2.47
06	Circulating radiant, or room heaters (not portable) WITHOUT flue or vent, burning gas, oil, or kerosene	25	6.04	9.47	1.22	2.67
07	Portable room heaters of any kind	23	2.00	1.61	0.15	1.75

[a] F test indicates $p < 0.0001$ for untransformed and transformed data.

TABLE 4-33. RESULTS OF PAIRWISE COMPARISONS OF INDOOR EXPOSURES ASSOCIATED WITH COMBUSTION SOURCES IN LIVING QUARTERS

Combustion source in living quarters	Means of untransformed data, ppm				p value	
	Response A	Value	Response B	Value	Untrans-formed data	Transformed data
Fireplace	UV[a]	2.12	UNV[b]	1.94	0.3317	0.0922
	UV	2.12	NU[c]	2.29	0.0040[d]	0.0000[d]
	UNV	1.94	NU	2.29	0.0543	0.0063
Woodstove	UV	2.20	UNV	2.31	0.7519	0.3953
	UV	2.20	NU	2.22	0.8722	0.0000[d]
	UNV	2.31	NU	2.22	0.7827	0.9255
Gas furnace	UV	2.18	UNV	3.10	0.0001[d]	0.0001[d]
	UV	2.18	NU	2.19	0.8483	0.0226
	UNV	3.10	NU	2.19	0.0002[d]	0.0090[d]
Gas cooking stove	UV	3.66	UNV	3.24	0.0038[d]	0.4972
	UV	3.66	NU	1.86	0.0000[d]	0.0000[d]
	UNV	3.24	NU	1.86	0.0000[d]	0.0000[d]
Gas hot water heater	UV	2.21	UNV	2.35	0.2729	0.8911
	UV	2.21	NU	2.22	0.9449	0.3551
	UNV	2.35	NU	2.22	0.3268	0.6428
Gas clothes dryer	UV	2.68	UNV	2.33	0.0263	0.5150
	UV	2.68	NU	2.11	0.0000[d]	0.0000[d]
	UNV	2.33	NU	2.11	0.1050	0.0056[d]
Gas or kerosene space heater	UV	1.82	UNV	3.07	0.0001[d]	0.0000[d]
	UV	1.82	NU	2.17	0.2317	0.0297
	UNV	3.07	NU	2.17	0.0000[d]	0.0000[d]

[a]UV = used and vented.

[b]UNV = used and not vented.

[c]NU = not used.

[d]$p < 0.0167$.

Table 4-28 shows a large increase in CO exposure for homes where eight or more packs of cigarettes are smoked per week. The mean exposure associated with this response (3.80 ppm) is almost twice the mean exposure for homes where less than one pack is smoked per week (2.00 ppm).

Table 4-29 presents results of seven separate ANOVA's concerning combustion sources in the home. The possible responses to each question are 1) the source is used and vented, 2) the source is used and not vented, and 3) the source is not used. If a source produces significant quantities of CO, one would expect the means associated with response 2 to be significantly larger than those associated with response 3. If the mean for response 2 is significantly larger than the mean for response 1, one can assume that venting reduces CO exposure in the home. To identify these situations, PEI performed pairwise comparisons on transformed data using BMDP program P7D. Table 4-33 summarizes the results of these comparisons. If a pairings yields $p < 0.05/N$ where $N = 3$ (the number of possible pairings of 3 responses), the test is considered significant at the 0.05 level according to the Bonferroni test,[3] and the associated means are assumed to be different. Vented source which yield significantly higher exposures ($p < 0.0167$) than those that occur in the absence of the source include gas cooking stoves and gas clothes driers. Unvented sources which yield significantly higher exposures than those that occur in the absence of the source include gas furnaces, gas cooking stoves, gas clothes dryers, and space heaters (gas or kerosene). Sources for which venting appears to significantly decrease exposure include gas furnaces and space heaters (gas or kerosene). Some results are counter-intuitive; for example, exposures in homes with a vented woodstove are slightly lower than exposures in homes without a woodstove. Perhaps homes with woodstoves are less likely to have gas appliances.

Table 4-30 presents the results of four F tests comparing exposures with and without certain energy-saving devices in the home. The results suggest that storm windows, storm doors, and special dampers significantly ($p < 0.05$) increase exposure, whereas extra insulation does not appear to have a significant effect.

Table 4-31 presents the results of an ANOVA evaluating the effect of the main heating system on home exposures. The highest mean (11.84 ppm) is associated with portable room heaters. Gravity gas has the second highest mean (5.03 ppm). The lowest mean exposure is associated with built-in electric units (0.96 ppm).

Table 4-32 presents results of a similar analysis of the main workplace heating system. Contrary to the results in Table 4-31, portable room heaters yield the lowest mean exposure listed in the table. However, the sample size is quite small (n = 23) and probably represents the exposures of only a few subjects. The largest means (8.48 ppm and 6.04 ppm) are associated with nonportable room heaters burning gas, oil, or kerosene. Again, sample sizes are small.

4.3.4 Results of Two-Way Analyses of Variance

To separate the effects of area from those of indoor CO sources in the home, PEI used BMDP program P2V to perform a series of two-way ANOVA's with area as one grouping variable and indoor source type or source status as the other grouping variable. Tables 4-34 through 4-39 present the results of these ANOVA's. Note that the Box-Cox transformation was not used in these analyses.

Table 4-34 presents the results for an ANOVA where cigarette packs smoked per week is the indoor source variable. To prevent the occurrence of empty cells, the two classifications "area ≤ 1000" and "1000 < area ≤ 1425" listed in Table 4-27 were combined into the classification "area ≤ 1425." When area is held constant, one finds the expected general increase in CO with increasing number of packs smoked for only one area category, "area ≤ 1425," and only if one ignores the mean for "8 or more packs." When smoking is held constant, one does not find the expected general decrease in CO with increasing area.

Table 4-35 presents the results for an ANOVA where gas furnace status is the indoor source variable. Status categories are used and vented (UV), used and not vented (UNV), and not used (NU). No general patterns are evident in the cell means other than the UV mean exceeds the NU mean for all but the smallest area classification.

In Table 4-36, gas cooking stove status is the indoor source variable. The main pattern evident in this table is that NU means tend to be less than UV and UNV means when area is held constant.

TABLE 4-34. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES AT HOME VERSUS AREA OF LIVING QUARTERS AND CIGARETTE PACKS SMOKED PER WEEK BY OTHER HOUSEHOLD MEMBERS

Approximate area of living quarters, ft^2	Cigarette packs smoked per week	n	CO concentration, ppm	
			Mean	Std. dev.
Area ≤ 1425	No smokers	8574	2.19	3.31
	Less than 1 pack	1121	2.31	3.97
	1 to 4 packs	1006	2.36	3.84
	5 to 7 packs	200	2.90	3.68
	8 or more packs	94	2.00	1.71
1425 < area ≤ 2056	No smokers	3158	2.23	4.07
	Less than 1 pack	613	1.20	2.38
	1 to 4 packs	570	3.24	6.28
	5 to 7 packs	135	1.87	2.60
	8 or more packs	209	7.82	11.88
2056 < area	No smokers	3133	1.95	4.64
	Less than 1 pack	425	2.30	3.70
	1 to 4 packs	375	1.28	2.85
	5 to 7 packs	285	1.92	3.79
	8 or more packs	402	2.13	2.37

TABLE 4-35. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES AT HOME VERSUS AREA OF LIVING QUARTERS AND STATUS OF GAS FURNACE

Approximate area of living quarters, ft^2	Status of gas furnace	n	CO concentration, ppm	
			Mean	Std. dev.
Area ≤ 1000	UV[a]	4530	2.46	3.43
	UNV[b]	224	2.25	2.30
	NU[c]	1696	2.77	3.81
1000 < area ≤ 1425	UV	3820	1.81	3.43
	UNV	159	2.99	2.58
	NU	422	1.23	1.97
1425 < area ≤ 2056	UV	3868	2.58	5.30
	UNV	214	1.22	2.75
	NU	603	2.10	3.03
2056 < area	UV	3970	1.84	3.54
	UNV	189	6.31	12.12
	NU	461	1.08	1.82

[a]Used and vented. [b]Used and not vented. [c]Not used.

TABLE 4-36. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES AT HOME VERSUS AREA OF LIVING QUARTERS AND STATUS OF GAS COOKING STOVE

Approximate area of living quarters, ft²	Status of gas cooking stove	n	CO concentration, ppm	
			Mean	Std. dev.
Area ≤ 1000	UV[a]	941	4.33	4.55
	UNV[b]	1427	3.28	3.71
	NU[c]	4082	1.86	2.90
1000 < area ≤ 1425	UV	244	4.21	7.27
	UNV	599	2.84	3.14
	NU	3558	1.45	2.74
1425 < area ≤ 2056	UV	313	3.14	5.05
	UNV	389	4.71	7.51
	NU	3983	2.18	4.59
2056 < area	UV	339	1.84	4.08
	UNV	422	2.32	3.31
	NU	3859	1.91	4.34

[a]Used and vented.

[b]Used and not vented.

[c]Not used.

TABLE 4-37. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR-EXPOSURES AT HOME VERSUS AREA OF LIVING QUARTERS AND STATUS OF GAS CLOTHES DRYER

Approximate area of living quarters, ft²	Status of gas clothes dryer	n	CO concentration, ppm	
			Mean	Std. dev.
Area ≤ 1000	UV[a]	1036	2.98	4.00
	UNV[b]	286	2.66	2.99
	NU[c]	5128	2.44	3.41
1000 < area ≤ 1425	UV	915	2.43	3.66
	UNV	31	0.00	0.00
	NU	3455	1.64	3.19
1425 < area ≤ 2056	UV	541	2.38	4.11
	UNV	135	1.11	1.34
	NU	4009	2.51	5.15
2056 < area	UV	1237	2.73	5.80
	UNV	24	8.40	1.42
	NU	3359	1.60	3.41

[a]Used and vented.

[b]Used and not vented.

[c]Not used.

TABLE 4-38. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES AT HOME VERSUS AREA OF LIVING QUARTERS AND STATUS OF GAS OR KEROSENE SPACE HEATER

Approximate area of living quarters, ft^2	Status of space heater	n	CO concentration, ppm	
			Mean	Std. dev.
Area ≤ 1000	Used	381	3.60	5.16
	Not used	6213	2.45	3.35
1000 < area ≤ 1425	Used	286	2.93	5.10
	Not used	4115	1.72	3.12
1425 < area ≤ 2056	Used	482	1.81	2.43
	Not used	4203	2.53	5.19
2056 < area	Used	572	2.90	5.66
	Not used	4048	1.81	3.98

TABLE 4-39. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES AT HOME VERSUS AREA OF LIVING QUARTERS AND IDENTITY OF MAIN HEATING SYSTEM

Approximate area of living quarters, ft^2	Main heating system in living quarters	n	CO concentration, ppm	
			Mean	Std. dev.
Area ≤ 1000	Steam or hot water system	1406	2.51	3.49
	Central furnace or heat pump	4483	2.32	3.29
	Built-in electric units	102	1.30	2.67
	Floor, wall, or unvented furnace	99	5.44	3.94
	Heater with flue burning gas, oil, or kerosene	51	5.01	4.55
	Fireplace or stove	124	4.25	3.39
	Gravity gas	62	2.48	1.94
1000 < area	Steam or hot water system	1536	2.24	4.00
	Central furnace or heat pump	11039	2.06	4.31
	Built-in electric units	93	0.58	0.91
	Floor, wall, or unvented furnace	130	1.28	1.61
	Heater with flue burning gas, oil, or kerosene	88	0.97	1.93
	Fireplace or stove	603	1.95	3.93
	Gravity gas	74	7.16	7.96

In Table 4-37, gas clothes dryer status is the indoor source variable. No general patterns are evident in the cell means.

Status of space heater is the indoor source variable in Table 4-38. The UV and UNV responses have been combined into a "used" category to avoid empty cells. When area is held constant, the "used" means exceed the "not used" means for all area categories except "1425 < area $\leq$ 2056." Means for the "used" category decrease with increasing area except for the "2056 < area" category.

Table 4-39 presents results for an ANOVA where identity of the main heating source in the living quarters is the indoor source variable. To avoid empty cells, only two area categories are defined and two heating systems (06--heater without flue burning gas, oil, or kerosene, and 07--portable room heaters of any kind) are omitted. If heating system is held constant, cell means decrease with increasing area for all heating systems except gravity gas. Built-in electric units have the lowest cell mean in both area categories.

The ANOVA's summarized in Tables 4-34 through 4-39 all yield p values less than 0.0001 for the area variable, for the indoor source variable, and for the interaction of the two variables. However, clear patterns in the cell means occur only in Tables 4-36 (gas cooking stove), 4-38 (space heater), and 4-39 (main heating source). To determine if the effects of gas cooking stoves and space heaters are additive, PEI performed the ANOVA summarized in Table 4-40. As would be expected, the smallest cell mean (1.78 ppm) is associated with the absence of both indoor sources. However, the two largest cell means are associated with the presence of a gas cooking stove (either UV or UNV) and the <u>absence</u> of a space heater. An additive relationship between gas stoves and space heaters is not apparent, although the occurrence of several cells with small sample sizes makes it difficult to completely dismiss such a relationship. The ANOVA summary table lists $p = 0.9641$ (nonsignificant) for the space heater effect, $p < 0.0001$ for the gas stove effect, and $p < 0.0001$ for their interaction.

To determine if space heaters affect exposure in homes without gas stoves PEI performed a t test comparing two cell means: space heater used - gas stove

TABLE 4-40. RESULTS OF ANALYSIS OF VARIANCE OF INDOOR EXPOSURES VERSUS STATUS OF GAS OR KEROSENE SPACE HEATER AND STATUS OF GAS COOKING STOVE

Status of space heater	Status of gas cooking stove	n	CO concentration, ppm	
			Mean	Std. dev.
Used	UV[a]	165	3.02	3.01
	UNV[b]	171	2.96	3.33
	NU[c]	1241	2.80	5.29
Not used	UV	1672	3.72	5.25
	UNV	2666	3.26	4.39
	NU	14241	1.78	3.58

[a]Used and vented.

[b]Used and not vented.

[c]Not used.

not used (mean = 2.80 ppm) and space heater not used - gas stove not used (mean = 1.78 ppm). The results were highly significant ($p < 0.0001$), indicating that space heaters do increase exposure in homes without gas stoves.

4.3.5 Summary of Results

The ANOVA's discussed in Section 4.3 support the following conclusions:

1. CO exposures are higher in homes having living areas of 1000 ft^2 or less.
2. CO exposures are higher in homes where gas cooking stoves or gas clothes dryers are used (vented or not vented).
3. CO exposures are higher in homes where unvented gas furnaces or space heaters are used.
4. Venting of gas furnaces and space heaters decreases CO exposure in the home.
5. CO exposures are higher in homes which have storm windows, storm doors, or special dampers.
6. CO exposures are higher in homes where the main heating source is either a portable room heater or gravity gas system.

7. CO exposures are lower in homes where the main heating system consists of built-in electric units.

8. CO exposures are higher in work places where the main heating system consists of nonportable heaters burning gas, oil, or kerosene.

9. In homes without a gas cooking stove, the presence of a space heater significantly increases exposure.

10. In homes with gas cooking stoves, the presence of a space heater does not significantly increase exposure.

All of these conclusions are based on the assumption that all significant confounding factors have been identified and properly considered in the analyses. This assumption is probably unwarranted.

The dilution of CO from indoor sources is a function of the enclosed air volume and the air exchange rate. The basis for using area as an explanatory variable in some of the ANOVA's is that it is the best indicator of the volume of the enclosed living space available. Possible indicators of air exchange rates considered in this section are the heating system type and the presence of energy-saving devices. Other possible indicators of home air exchange rates listed in Table 4-26 are housing type, fans in residence, air-conditioning in residence (probably not pertinent for a winter study), and construction of residence. These factors should be considered in future analyses.

The analysis of factors affecting work exposures presented here is less detailed than the analysis of factors affecting home exposures. One reason is the small number of identifiable indoor sources. Another is the ambiguity concerning what constitutes a subject's enclosed work area. This ambiguity may affect the validity of the responses to many of the questions concerning work place. For this reason, the analyses discussed here focus more on the home environment which has more definite boundaries.

4.4 REFERENCES

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2. Bailar, J.C., and F. Ederer. 1964. Significance Factors for the Ratio of a Poisson Variable to its Expectation. Biometrics, 639-643.

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SECTION 5

MODELS FOR PREDICTING EXPOSURE IN DENVER

This section describes the evolutionary development of a model which, in its final form, explains approximately 34 percent of the observed variation in PEM values reported during the Denver CO study. As indicated below, a series of 14 general models were proposed and evaluated in a sequential manner such that the results of each evaluation were considered in constructing the next general model. The parameters considered in the general models included data obtained from the activity diaries, the background questionnaire completed by each participant, the fixed-site monitors, and a meteorological file containing data on temperature and daily average wind speed. Model evaluation was accomplished by performing step-wise linear regression on each general model and noting 1) which terms were retained in the "best-fit" model and 2) the R^2 value associated with the best-fit model.

Sections 5.1 and 5.2 present PEI analyses in the order in which they were performed. Section 5.1 discusses General Models 1 through 4; Section 5.2 discusses General Models 5 through 14. Section 5.3 discusses a method involving pairwise comparisons which was used to aggregate indoor microenvironments. These aggregate microenvironments were used in General Models 5 through 14 but not in General Models 1 through 4. Section 5.3 also discusses how the Box-Cox transformation can be used to reduce the skewness and kurtosis of PEM values grouped by microenvironment.

5.1 GENERAL MODELS 1 THROUGH 4

Table 5-1 lists the candidate exposure factors which were combined in various combinations to form the independent variables of General Models 1 through 4. The dependent value in each of these models is either PEM value or the logarithm of PEM value. Step-wise linear regression (weighted) with forward and backward stepping was performed on each general model to determine a "best-fit" model containing only those terms which make significant

TABLE 5-1. GROUP CODES USED IN STEPWISE LINEAR REGRESSION ANALYSIS

Data source item	Factor code	Description	Responses coded as 1 in file
Diary item A (Activity)	A1	Travel-related activities	01:all travel
	A2	Indoor activities near CO sources	03:cooking 04:laundry 08:eating 12:cafe or pub
	A3	Other indoor activities	05:other indoor chores and child care 11:social, political, or religious activities 09:sleeping 10:other personal needs 17:interview 18:final entry 20:begin breath sample 21:end breath sample
	A4	Outdoor activities	06:yard work and other outdoor activities 13:walking, bicycling, or jogging
	A5	Work-related activities	02:work and study
	A6	Other activities	07:errands and shopping 14:other leisure activities 15:uncertain of code 16:no entry in diary
Diary item B + D3 (Microenvironment)	B1	In-transit microenvironments (ME's) involving motor vehicles	0102:car 0103:bus 0104:truck 0193:motorcycle

(continued)

TABLE 5-1 (continued)

Data source item	Factor code	Description	Responses coded as 1 in file
	B2	Outdoor ME's near CO source	0101:walking 07c:outdoors within 10 yards of road 73d:parking lot 74bb:service station or motor vehicle repair facility
	B3	Other outdoor ME's	75bb:construction site 76bb:residential grounds 77bb:school grounds 78bb:sports arena, etc. 79bb:park or golf course 80bb:other location
	B4	Public garage, carport, or service station	52a:indoor public garage 54bb:indoor service station or motor vehicle repair facility 55bb:other indoor repair shop 71bb:outdoor carport 72a:outdoor public garage
	B5	Indoor residential garage	51bb:indoor residential garage
	B6	Indoor ME's with possible CO source	05bb:restaurant 58bb:shopping mall 62bb:other location
	B7	Other indoor ME's	02bb:residence 03c:office 04bb:store 53bb:manufacturing facility 56bb:auditorium, etc. 57bb:church 59bb:health care facility

(continued)

TABLE 5-1 (continued)

Data source item	Factor code	Description	Responses coded as 1 in file
			60bb:school 61bb:other public building
Diary item E1	GARAGE	Garage attached to building?	01:yes
Diary item E2	GAS	Gas stove in use?	01:yes
Diary item F	SMOKE	Smokers present?	01:yes
Diary time entry	T1	Time between 6:00 a.m. and 10:00 a.m.	6:00 $\leq$ time < 10:00
	T2	Time between 10:00 a.m. and 5:00 p.m.	10:00 $\leq$ time < 17:00
Fixed-site data file	C	Simultaneous concentration at the nearest fixed-site for nontransit ME's and at composite site for in-transit ME's	Continuous variable

[a]Includes D3 = bb, 01, and 02.

[b]Blank.

[c]Includes D3 = bb and 01.

[d]Includes D3 = bb, 01, 02, and 03.

contributions to explaining the observed variation in the dependent variable. In these regression analyses, most of the exposure factors are treated as binary variables. A binary variable has a value of 1 when one or more of the response codes listed in Table 5-1 are present and 0 when none of these codes is present. Note that one of the factors (C) is treated as a continuous variable.

General Model 1 is

$$\hat{C}_{PEM} = \alpha + (\beta_1)(A1) + (\beta_2)(A2) + \cdots + (\beta_6)(A6) +$$
$$(\beta_7)(B1) + (\beta_8)(B2) + \cdots + (\beta_{13})(B7) +$$
$$(\beta_{14})(GARAGE) + (\beta_{15})(GAS) + (\beta_{16})(SMOKE). \quad (5\text{-}1)$$

The coefficients α, β_1, β_2, $\cdots$, β_{16} were estimated during the regression analysis. Table 5-2 lists the sequence of steps followed by BMDP program P2R in adding and deleting terms to the model. The suggested "best fit" model is

$$\hat{C}_{PEM} = 3.705 - (0.528)(A3) + (4.165)(B1)$$
$$+ (5.145)(B4) - (1.694)(B7)$$
$$+ (0.546)(GARAGE) + (1.923)(GAS)$$
$$+ (1.221)(SMOKE). \quad (5\text{-}2)$$

The R^2 value for this model is 0.1285. The variables in Equation 5-2 entered the model in the following order: B1 (in-transit ME's), B7 (other indoor ME's), SMOKE, B4 (public garage, carport, or service station), GAS, GARAGE, and A3 (other indoor activities). It is interesting to note that inclusion of the single term B1 (in-transit ME) yields an R^2 value of 0.0917. Of the various explanatory variables considered in General Model 1, transit status appears to be the best single predictor of CO exposure. The activity codes (A1, A2, ..., A6) are generally poor predictors of CO exposure. Only A3 was included in the stepwise model, and it was the last term added. Note that both A3 and B7 have negative coefficients in Equation 5-2. The occurrence of "1" for either of these explanatory variables indicates the subject is indoors but not near a CO source. Multiplying 1 by a negative coefficient yields a reduction in estimated PEM value. This result is consistent with our expectations.

Stepwise linear regression (weighted) was likewise performed using General Model 2:

TABLE 5-2. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 1

Step	Operation	Resulting R^2	Change in R^2
1	Add B1[a]	0.0917	0.0917
2	Add B7[a]	0.1041	0.0124
3	Add SMOKE[a]	0.1150	0.0109
4	Add B4[a]	0.1205	0.0055
5	Add GAS[a]	0.1257	0.0052
6	Add GARAGE[a]	0.1271	0.0014
7	ADD A3[a]	0.1285	0.0014
8	ADD A4	0.1290	0.0005
9	ADD B3	0.1293	0.0003
10	ADD A2	0.1295	0.0002
11	ADD A5	0.1295	0.0001
12	Remove A5	0.1295	-0.0001
13	Remove A2	0.1293	-0.0002
14	Remove B3	0.1290	-0.0003
15	Remove A4	0.1285	-0.0005

[a]Retained in best-fit model.

$$\hat{C}_{PEM} = \alpha + (\beta_1)(B1) + (\beta_2)(B2) + \cdots + (\beta_7)(B7) + (\beta_8)(C) + (\beta_9)(GARAGE) + (\beta_{10})(GAS) + (\beta_{11})(SMOKE) + (\beta_{12})(B1)(C) + (\beta_{13})(B2)(C) + \cdots + (\beta_{18})(B7)(C) \qquad (5\text{-}3)$$

where C is the simultaneous concentration at the nearest fixed site for non-transit microenvironments and at the composite site for in-transit micro-environments. Note that this General Model 2 contains a series of interaction terms between microenvironment group (B1, B2, ..., B7) and C. Table 5-3 lists the results of the stepwise linear regression. The suggested "best-fitting" model is

TABLE 5-3. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 2

Step	Operation	Resulting R^2	Change in R^2
1	Add B1[a]	0.0924	0.0924
2	Add C[a]	0.1441	0.0517
3	Add (B7)(C)	0.1589	0.0148
4	Add SMOKE[a]	0.1690	0.0101
5	Add GAS[a]	0.1734	0.0044
6	Add B4	0.1780	0.0045
7	Add GARAGE	0.1788	0.0008
8	Add B7[a]	0.1795	0.0007
9	Add (B6)(C)	0.1799	0.0004
10	Add B6	0.1804	0.0005
11	Add (B2)(C)	0.1806	0.0002
12	Add B3	0.1807	0.0001
13	Add (B5)(C)	0.1808	0.0001
14	Add B5	0.1809	0.0001
15	Add (B4)(C)	0.1809	0.0001
16	Add B2	0.1810	0.0000
17	Add (B3)(C)	0.1810	0.0000
18	Add (B1)(C)[a]	0.1811	0.0001
19	Remove B5	0.1811	-0.0000
20	Remove (B6)(C)	0.1811	-0.0000
21	Remove B6	0.1811	-0.0000
22	Remove (B5)(C)	0.1810	-0.0000
23	Remove (B7)(C)	0.1809	-0.0001
24	Remove (B3)(C)	0.1805	-0.0004
25	Remove B3	0.1802	-0.0003
26	Remove B4	0.1796	-0.0006
27	Remove B2	0.1787	-0.0009
28	Remove (B2)(C)	0.1776	-0.0011
29	Remove GARAGE	0.1764	-0.0011

[a]Retained in best-fit model.

$$\hat{C}_{PEM} = 2.72 + (2.809)(B1) - (1.925)(B7) + (0.440)(C) + (1.799)(GAS) + (1.343)(SMOKE) + (0.440)(B1)(C) + (0.897)(B4)(C). \quad (5\text{-}4)$$

The R^2 value for this model is 0.1764; thus, Equation 5-4 is superior to Equation 5-2 in explaining the observed variation in PEM values. The addition of C to the general model appears to be the main cause of this improvement.

It is interesting to note that Equations 5-2 and 5-4 both contain microenvironment group codes B1, B4, and B7 and no other microenvironment group codes. The appearance of interaction terms (B1)(C) and (B4)(C) in Equation 5-4 suggests that exposures in these microenvironment groups reflect simultaneous fixed-site data to some degree. However, Table 5-3 demonstrates that these terms add little to the overall R^2 value.

Figures 6-8, 6-9, and 6-10 in the Denver CO report[1] suggest 1) that the composite fixed-site value exceeds average exposure between 6:00 and 10:00 and 2) that average personal exposure exceeds the composite fixed-site value between 10:00 and 17:00. Consequently, two new explanatory variables (T1 and T2) were defined as follows:

$$T1 = 1 \text{ if } 6{:}00 \leq \text{time} < 10{:}00$$
$$T1 = 0 \text{ otherwise;}$$

$$T2 = 1 \text{ if } 10{:}00 \leq \text{time} < 17{:}00$$
$$T2 = 0 \text{ otherwise.}$$

General Model 3 is

$$\begin{aligned}\hat{C}_{PEM} = {} & \alpha + (\beta_1)(B1) + (\beta_2)(B4) + (\beta_3)(B7) \\ & + (\beta_4)(C) + (\beta_5)(GARAGE) + (\beta_6)(GAS) \\ & + (\beta_7)(SMOKE) + (\beta_8)(B1)(C) + (\beta_9)(B4)(C) \\ & + (\beta_{10})(B7)(C) + (\beta_{11})(T1) + (\beta_{12})(T2) \\ & + (\beta_{13})(T1)(B1) + (\beta_{14})(T2)(B1) + \\ & (\beta_{15})(T1)(C) + (\beta_{16})(T2)(C). \end{aligned} \tag{5-5}$$

Note that only microenvironment group codes B1, B4, and B7 appear in this general model. The results of the stepwise regression analysis are listed in Table 5-4. The suggested "best-fit" model is

$$\begin{aligned}\hat{C}_{PEM} = {} & 0.845 + (4.576)(B1) + (4.977)(B4) \\ & + (1.010)(C) + (1.983)(GAS) + (1.322)(SMOKE) \\ & - (0.521)(B7)(C) - (0.252)(T1)(C). \end{aligned} \tag{5-6}$$

TABLE 5-4. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 3

Step	Operation	Resulting R^2	Change in R^2
1	Add B1[a]	0.0924	0.0924
2	Add C[a]	0.1441	0.0517
3	Add (B7)(C)[a]	0.1589	0.0148
4	Add SMOKE[a]	0.1690	0.0101
5	Add GAS[a]	0.1734	0.0044
6	Add (T1)(C)[a]	0.1782	0.0048
7	Add B4[a]	0.1829	0.0046
8	Add GARAGE	0.1835	0.0007
9	Add (T1)(B1)	0.1841	0.0006
10	Add (T2)(B1)	0.1851	0.0010
11	Add B7	0.1856	0.0005
12	Add T1	0.1860	0.0003
13	Add (B4)(C)	0.1861	0.0002
14	Add (B1)(C)	0.1864	0.0003
15	Add (T2)(C)	0.1865	0.0001
16	Remove (T2)(C)	0.1864	-0.0001
17	Remove (B1)(C)	0.1861	-0.0003
18	Remove (B4)(C)	0.1860	-0.0002
19	Remove T1	0.1856	-0.0003
20	Remove B7	0.1851	-0.0005
21	Remove GARAGE	0.1846	-0.0006
22	Remove (T2)(B1)	0.1835	-0.0010
23	Remove (T1)(B1)	0.1829	-0.0006

[a]Retained in best-fit model.

The R^2 value obtained with this model is 0.1829--a slight improvement over Equation 5-4. Note that T2 does not appear in Equation 5-6.

General Model 4 is the same as General Model 3 except that $\ln(\hat{c}_{PEM})$ is substituted for $\hat{c}_{PEM}$ in Equation 5-5. The results of the stepwise regression analysis are listed in Table 5-5. The suggested "best-fit" model is

$$\begin{aligned}\ln(\hat{C}_{PEM}) = &- 1.033 + (1.703)(B1) + (1.361)(B4) \\ &- (0.613)(B7) + (0.337)(C) - (0.196)(GARAGE) \\ &+ (0.897)(GAS) + (0.788)(SMOKE) - (0.133)(B1)(C) \\ &- (0.600)(T1) - (0.073)(T1)(C) + (0.825)(T1)(B1). \quad (5\text{-}7)\end{aligned}$$

The R^2 obtained with this model is 0.2694--a significant improvement over Equation 5-6. Note that the log transformation of $\hat{c}_{PEM}$ is totally responsible for this improvement in R^2.

TABLE 5-5. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 4

Step	Operation	Resulting R^2	Change in R^2
1	Add C[a]	0.1190	0.1190
2	Add B1[a]	0.2066	0.0876
3	Add SMOKE[a]	0.2315	0.0248
4	Add T1[a]	0.2449	0.0135
5	Add B7[a]	0.2543	0.0094
6	Add GAS[a]	0.2620	0.0077
7	Add B4[a]	0.2640	0.0020
8	Add (T1)(C)[a]	0.2653	0.0013
9	Add GARAGE[a]	0.2666	0.0013
10	Add (T1)(B1)[a]	0.2677	0.0011
11	Add (B1)(C)[a]	0.2694	0.0018
12	Add (T2)(C)	0.2703	0.0009
13	Add T2	0.2710	0.0006
14	Add (B4)(C)	0.2715	0.0005
15	Add (T2)(B1)	0.2718	0.0003
16	Add (B7)(C)	0.2718	0.0000
17	Remove (B7)(C)	0.2718	-0.0000
18	Remove (T2)(B1)	0.2715	-0.0003
19	Remove (B4)(C)	0.2710	-0.0005
20	Remove T2	0.2703	-0.0006
21	Remove (T2)(C)	0.2694	-0.0009

[a]Retained in best-fit model.

General Models 5 through 14 are discussed in Section 5.2. Section 5.3 describes a method for aggregating indoor microenvironments which was implemented prior to the analyses discussed in Section 5.2.

5.2 GENERAL MODELS 5 THROUGH 14

The analyses described in Section 5.1 yielded a model with an R^2 value of 0.27 (i.e., a model which explains 27 percent of the variation in PEM values). The model contains terms corresponding to various activity diary entries, fixed-site data, and time of day. Subsequent to these analyses, PEI performed the analyses described in Sections 2.2, 4.2, and 4.3. Results of the analyses suggest that wind speed; maximum daily temperature; exposure duration; and use of gas furnaces, gas cooking stoves, and gas or kerosene space heaters in a participant's home make significant contributions toward explaining variations in personal exposure. The analysis described in Section 5.3 provided alternatives to the aggregate indoor microenvironments considered in General Models 1 through 4. After considering these results, PEI developed a new set of candidate exposure factors, which are listed in Table 5-6.

These factors were combined in various ways to form the independent variables of General Models 5 through 14. PEM value or a function of PEM value is the dependent variable. Stepwise linear regression (weighted) with forward and backward stepping was performed on each general model to determine a "best-fit" model containing only those terms which make significant contributions to explaining the observed variation in the dependent variable. As in Section 5.1, most of the exposure factors are treated as binary variables. Note that five of the new factors (DUR, C1, C2, WIND, and TMAX) are treated as continuous variables.

General Model 5 is

$$\hat{C}_{PEM} = \alpha + (\beta_1)(A1) + (\beta_2)(A2) + \ldots + (\beta_6)(A6) + (\beta_7)(M1) + (\beta_8)(M2) + \ldots + (\beta_{14})(M8) + (\beta_{15})(GARAGE) + (\beta_{16})(GAS) + (\beta_{17})(SMOKE) + (\beta_{18})(DUR) + (\beta_{19})(P1) + (\beta_{20})(P2) + (\beta_{21})(P3) + (\beta_{22})(P4) + (\beta_{23})(GFN) + (\beta_{24})(GCS) + (\beta_{25})(SHN) + (\beta_{26})(IH) + (\beta_{27})(C) + (\beta_{28})(WIND)^{-1} + (\beta_{29}(TMAX). \quad (5\text{-}8)$$

Note that this model contains all factors listed in Table 5-6 except C1 and C2 and that there are no interactions among the factors. Table 5-7 lists the sequence of steps followed by BMDP program P2R in adding and removing terms from the model. The suggested "best-fit" model is

$$\hat{C}_{PEM} = 1.86 + (6.38)(M1) - (1.27)M3) - (1.62)(M4) + (4.07)(M5) + (1.64)(GAS) + (1.21)(SMOKE) - (0.0141)(DUR) - (0.82)(P2) + (0.75)(GCS) + (0.48)(C) - (6.62)(WIND)^{-1}. \quad (5\text{-}9)$$

TABLE 5-6. CANDIDATE EXPOSURE FACTORS USED IN STEPWISE LINEAR REGRESSION ANALYSES INVOLVING GENERAL MODELS 5 THROUGH 14

Data source	Factor code	Description	Responses coded as 1 in file
Diary item A (Activity)	A1	Travel-related activities	01:all travel
	A2	Indoor activities near CO sources	03:cooking 04:laundry 08:eating 12:cafe or pub
	A3	Other indoor activities	05:other indoor chores and child care 11:social, political, or religious activities 09:sleeping 10:other personal needs 17:interview 18:final entry 20:begin breath sample 21:end breath sample
	A4	Outdoor activities	06:yard work and other outdoor activities 13:walking, bicycling, or jogging
	A5	Work-related activities	02:work and study
	A6	Other activities	07:errands and shopping 14:other leisure activities 15:uncertain of code 16:no entry in diary
Diary item B + D3 (Microenvironment)	M1	Very high indoor exposures	52a:public garage 54bb:service station or motor vehicle repair facility
	M2	High indoor exposures	05bb:restaurant 55bb:other repair shop 56bb:auditorium, sports arena, concert hall, etc. 58bb:shopping mall 62bb:other location

(continued)

TABLE 5-6 (continued)

Data source	Factor code	Description	Responses coded as 1 in file
	M3	Medium indoor exposures	03c:office 04bb:store 51bb:residential garage 61bb:other public building
	M4	Low indoor exposures	02bb:residence 53bb:manufacturing facility 57bb:church 59bb:health care facility 60bb:school
	M5	High in-transit exposures	0102:car 0103:bus 0104:truck 0193:motorcycle
	M6	High outdoor exposures	71bb:residential garage or carport 72a:public garage
	M7	Medium in-transit and outdoor exposures	0101:walking 07c:with 10 yards of road 73d:parking lot 74bb:service station or motor vehicle repair facility 80bb:other location
	M8	Low in-transit and outdoor exposures	0192:bicycle 75bb:construction site 76bb:residential grounds 77bb:school grounds 78bb:sports arena, amphitheater, etc. 79bb:park of golf course
Diary item E1	GARAGE	Garage attached to building?	01:yes
Diary item E2	GAS	Gas stove in use?	01:yes
Diary item F	SMOKE	Smokers present?	01:yes

(continued)

TABLE 5-6 (continued)

Data source	Factor code	Description	Responses coded as 1 in file
Diary time entry	DUR	Duration of exposure in minutes	Continuous variable
	P1	Period from 24:00 to 6:00	24:00 $\leq$ time < 6:00
	P2	Period from 6:00 to 10:00	6:00 $\leq$ time < 10:00
	P3	Period from 10:00 to 16:00	10:00 $\leq$ time < 16:00
	P4	Period from 16:00 to 24:00	16:00 $\leq$ time < 24:00
Questionnaire item 4c	GFN	Gas furnace used and not vented	2:used and not vented
Questionnaire item 4d	GCS	Gas stove used (vented or not vented)	1:used and vented 2:used and not vented
Questionnaire item 4g	SHN	Gas or kerosene space heater used and not vented	2:used and not vented
Special file	IH	Indoors at home	B = indoors residence when census tract is "home" census tract[e]
Fixed-site data file	C	Simultaneous concentration at the nearest fixed site for non-transit ME's and at composite site for in-transit ME's	Continuous variable
	C1	C value one hour earlier	Continuous variable
	C2	C value two hours earlier	Continuous variable
Meteorological data file	WIND	Daily mean wind speed, mph	Continuous variable
	TMAX	Daily maximum temperature, °F	Continuous variable

[a]Includes D3 = bb, 01, and 02.

[b]Blank.

[c]Includes D3 = bb and 01.

[d]Includes D3 = bb, 01, 02, and 03.

[e]See Section 4.3.2.

TABLE 5-7. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 5

Step	Operation	Resulting R^2	Change in R^2
1	Add M5[a]	0.0924	0.0924
2	Add C[a]	0.1441	0.0517
3	Add M4[a]	0.1565	0.0123
4	Add M1[a]	0.1627	0.0062
5	Add GAS[a]	0.1676	0.0049
6	Add P2[a]	0.1706	0.0030
7	Add SMOKE[a]	0.1732	0.0026
8	Add M3[a]	0.1763	0.0031
9	Add GCS[a]	0.1785	0.0022
10	Add DUR[a]	0.1808	0.0023
11	Add $(\mathrm{WIND})^{-1}$[a]	0.1828	0.0020
12	Add GARAGE	0.1838	0.0011
13	Add TMAX	0.1847	0.0009
14	Add A4	0.1854	0.0007
15	Add SHN	0.1858	0.0004
16	Add M6	0.1862	0.0003
17	Add A6	0.1864	0.0002
18	Add M8	0.1866	0.0002
19	Add IH	0.1868	0.0002
20	Add A5	0.1869	0.0002
21	Add M2	0.1870	0.0001
22	Add P1	0.1870	0.0000
23	Remove P1	0.1870	-0.0000
24	Remove M2	0.1869	-0.0001
25	Remove A5	0.1868	-0.0002
26	Remove IH	0.1866	-0.0002
27	Remove M8	0.1864	-0.0002
28	Remove A6	0.1862	-0.0002
29	Remove M6	0.1858	-0.0003
30	Remove SHN	0.1854	-0.0004
31	Remove A4	0.1847	-0.0007

(continued)

TABLE 5-7 (continued)

Step	Operation	Resulting R^2	Change in R^2
32	Remove TMAX	0.1838	-0.0009
33	Remove GARAGE	0.1828	-0.0011

[a]Retained in best-fit model.

The R^2 value for this model is 0.1828. As indicated in Table 5-7, the variables in Equation 5-9 entered the model in the following order: M5 (high in-transit exposures), C (simultaneous fixed-site concentration), M4 (low indoor exposures), M1 (very high indoor exposures), GAS, P2 ($6{:}00 \leq$ time $< 10{:}00$), SMOKE, M3 (medium indoor exposures), GCS (gas cooking stove in residence), DUR, and $(WIND)^{-1}$. None of the activity codes (A1, A2, ..., A6) were retained in the model.

General Model 6 consists of the 32 possible interactions between aggregate microenvironments (M1, M2, ..., M8) and time periods (P1, P2, P3, and P4); that is,

$$\hat{C}_{PEM} = \alpha + (\beta_1)(P_1)(M1) + (\beta_2)(P_1)(M2) + \ldots + (\beta_8)(P1)(M8)$$
$$+ (\beta_9)(P2)(M1) + (\beta_{10})(P2)(M3) + \ldots + (\beta_{16})(P2)(M8)$$
$$+ \ldots + (\beta_{25})(P4)(M1) + (\beta_{26})(P4)(M2) + \ldots + (\beta_{32})(P4)(M8). \quad (5\text{-}10)$$

The best-fit model ($R^2 = 0.1330$) is

$$\hat{C}_{PEM} = 3.69 + (14.67)(P1)(M2) - (2.43)(P1)(M4) +$$
$$(8.16)(P2)(M1) + (3.32)(P2)(M2) - (2.15)(P2)(M4)$$
$$+ (5.87)(P2)(M5) + (5.69)(P3)(M1) - (1.95)(P3)(M4) +$$
$$(3.99)(P3)(M5) + (11.21)(P4)(M1) - (1.00)(P4)(M4) +$$
$$(3.92)(P4)(M5) . \quad (5\text{-}11)$$

Table 5-8 lists the sequence of add/remove steps which produced the best-fit model. Note that terms containing M3, M6, M7, and M8 do not appear in Equation

TABLE 5-8. ABRIDGED RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 6

Step	Operation	Resulting R^2	Change in R^2
1	Add (P3)(M5)[a]	0.0324	0.0324
2	Add (P2)(M5)[a]	0.0653	0.0329
3	Add (P4)(M5)[a]	0.0936	0.0283
4	Add (P1)(M4)[a]	0.1014	0.0078
5	Add (P1)(M2)[a]	0.1072	0.0058
6	Add (P4)(M1)[a]	0.1128	0.0056
7	Add (P2)(M4)[a]	0.1178	0.0050
8	Add (P3)(M4)[a]	0.1226	0.0049
9	Add (P4)(M4)[a]	0.1274	0.0048
10	Add (P2)(M1)[a]	0.1298	0.0024
11	Add (P3)(M1)[a]	0.1316	0.0019
12	Add (P2)(M2)[a]	0.1330	0.0014
13	Add (P2)(M3)	0.1341	0.0011
.	.	.	.
.	.	.	.
.	.	.	.
26	Add (P4)(M8)	0.1373	0.0000
27	Remove (P4)(M8)	0.1372	-0.0000
28	Remove (P4)(M6)	0.1372	-0.0001
.	.	.	.
.	.	.	.
.	.	.	.
34	Remove (P4)(M2)	0.1360	-0.0004
35	Remove (P4)(M7)	0.1357	-0.0003
36	Remove (P2)(M7)	0.1353	-0.0004
37	Remove (P4)(M3)	0.1350	-0.0003
38	Remove (P2)(M6)	0.1346	-0.0004
39	Remove (P3)(M8)	0.1341	-0.0005
40	Remove (P2)(M3)	0.1330	-0.0011

[a]Retained in best-fit model.

5-11. Terms containing M5 (high in-transit exposures) contribute 0.0936 to the R^2 value of the best-fit model.

General Model 7 is

$$\hat{C}_{PEM} = \alpha + (\beta_1)(P1)(C) + (\beta_2)(P2)(C) + (\beta_3)(P3)(C) + (\beta_4)(P4)(C) + (\beta_5)(M1)(C) + (\beta_6)(M2)(C) + \ldots + (\beta_{12})(M8)(C) \ . \qquad (5\text{-}12)$$

This model is composed of interactions between time period and simultaneous fixed-site concentration and between aggregate microenvironment and fixed-site concentration. The best-fit model ($R^2 = 0.1443$) is

$$\hat{C}_{PEM} = 1.70 + (0.77)(P1)(C) + (0.64)(P2)(C) + (1.06)(P3)(C) + (0.91)(P4)(C) + (0.94)(M1)(C) - (0.35)(M3)(C) - (0.55)(M4)(C) + (0.91(M5)(C) \ . \qquad (5\text{-}13)$$

Table 5-9 lists the add/remove steps of the stepwise regression.

General Model 8 is

$$\hat{C}_{PEM} = \alpha + (\beta_1)(GARAGE)(M1) + (\beta_2)(GARAGE)(M2) + (\beta_3)(GARAGE)(M3) + (\beta_4)(GARAGE)(M4) + (\beta_5)(GAS)(M1) + (\beta_6)(GAS)(M2) + (\beta_7)(GAS)(M3) + (\beta_8)(GAS)(M4) + (\beta_9)(SMOKE)(M1) + (\beta_{10})(SMOKE)(M2) + \ldots + (\beta_{16})(SMOKE)(M8). \qquad (5\text{-}14)$$

It contains interaction terms pairing aggregate indoor microenvironments with GARAGE and GAS and all eight aggregate microenvironments with SMOKE. The best-fit model ($R^2 = 0.0426$) is

$$\hat{C}_{PEM} = 3.10 + (8.05)(GARAGE)(M1) + (1.62)(GARAGE)(M3) - (0.85)(GARAGE)(M4) + (2.30)(GAS)(M3) + (1.53)(GAS)(M4) + (1.73)(SMOKE)(M2) + (7.10)(SMOKE)(M5) \ . \qquad (5\text{-}15)$$

TABLE 5-9. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 7

Step	Operation	Resulting R^2	Change in R^2
1	Add (C)(M5)[a]	0.0918	0.0918
2	Add (C)(P4)[a]	0.1092	0.0174
3	Add (C)(P3)[a]	0.1219	0.0127
4	Add (C)(M1)[a]	0.1311	0.0092
5	Add (C)(M7)	0.1353	0.0042
6	Add (C)(M2)	0.1390	0.0037
7	Add (C)(M3)[a]	0.1420	0.0029
8	Add (C)(M6)	0.1428	0.0009
9	Add (C)(P2)[a]	0.1434	0.0006
10	Add (C)(P1)[a]	0.1440	0.0006
11	Add (C)(M4)[a]	0.1446	0.0007
12	Add (C)(M8)	0.1448	0.0002
13	Remove (C)(M2)	0.1448	-0.0001
14	Remove (C)(M6)	0.1447	-0.0001
15	Remove (C)(M7)	0.1446	-0.0001
16	Remove (C)(M8)	0.1443	-0.0003

[a]Retained in best-fit model.

Table 5-10 lists the add/remove steps of the stepwise regression. Only the (SMOKE)(M5) term contributes more than 0.02 to the R^2 value of the best-fit model.

General Model 9 is

$$\hat{C}_{PEM} = \alpha + (\beta_1)(IH)(GFM)(P1) + (\beta_2)(IH)(GFN)(P2) + (\beta_3)(IH)(GFN)(P3) + (\beta_4)(IH)(GFN)(P4) + (\beta_5)(IH)GCS)(P1) + (\beta_6)(IH)(GCS)(P2) + (\beta_7)(IH)(GCS)(P3) + (\beta_8)(IH)(GCS)(P4) + (\beta_9)(IH)(SHN)(P1) + (\beta_{10})(IH)(SHN)(P2) + (\beta_{11})(IH)(SHN)(P3) + (\beta_{12})(IH)(SHN)(P4). \quad (5\text{-}16)$$

TABLE 5-10. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 8

Step	Operation	Resulting R^2	Change in R^2
1	Add (SMOKE)(M5)[a]	0.0218	0.0218
2	Add (GARAGE)(M1)[a]	0.0295	0.0077
3	Add (GARAGE)(M4)[a]	0.0347	0.0052
4	Add (GAS)(M3)[a]	0.0374	0.0028
5	Add (GARAGE)(M3)[a]	0.0394	0.0021
6	Add (GAS)(M4)[a]	0.0411	0.0016
7	Add (SMOKE)(M2)[a]	0.0426	0.0014
8	Add (SMOKE)(M4)	0.0432	0.0006
9	Add (SMOKE)(M3)	0.0435	0.0003
10	Add (SMOKE)(M7)	0.0438	0.0003
11	Add (GAS)(M2)	0.0440	0.0002
12	Add (SMOKE)(M1)	0.0441	0.0001
13	Add (GARAGE)(M2)	0.0442	0.0001
14	Add (SMOKE)(M8)	0.0442	0.0000
15	Remove (SMOKE)(M8)	0.0442	-0.0000
16	Remove (GARAGE)(M2)	0.0441	-0.0001
17	Remove (SMOKE)(M1)	0.0440	-0.0001
18	Remove (GAS)(M2)	0.0438	-0.0002
19	Remove (SMOKE)(M7)	0.0435	-0.0003
20	Remove (SMOKE)(M3)	0.0432	-0.0003
21	Remove (SMOKE)(M4)	0.0426	-0.0006

[a]Retained in best-fit model.

Each term contains the IH variable which is equal to 1 only when a subject is indoors at home. The GFN, GCS, and SHN variables indicate, respectively, the existence of a gas furnace, a gas cooking stove, and a space heater in the home (Table 5-6). Time periods are also included in the interaction terms. The best-fit model is

$$\hat{C}_{PEM} = 3.12 + (2.18)(IH)(GCS)(P4); \tag{5-17}$$

the R^2 value is only 0.0062. The add/remove steps are listed in Table 5-11. Only the term (IH)(GCS)(P4) is retained in the best-fit model.

TABLE 5-11. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 9

Step	Operation	Resulting R^2	Change in R^2
1	Add (IH)(GCS)(P4)[a]	0.0062	0.0062
2	Add (IH)(GFN)(P1)	0.0064	0.0002
3	Add (IH)(GCS)(P2)	0.0066	0.0001
4	Add (IH)(SHN)(P4)	0.0067	0.0001
5	Add (IH)(GCS)(P1)	0.0068	0.0001
6	Add (IH)(GFN)(P4)	0.0068	0.0001
7	Remove (IH)(GFN)(P4)	0.0068	-0.0001
8	Remove (IH)(GCS)(P1)	0.0067	-0.0001
9	Remove (IH)(SHN)(P4)	0.0066	-0.0001
10	Remove (IH)(GCS)(P2)	0.0064	-0.0002
11	Remove (IH)(GFN)(P1)	0.0062	-0.0002

[a]Retained in best-fit model.

General Model 10,

$$\hat{C}_{PEM} = \alpha + (\beta_1)(WIND)^{-1}(M1) + (\beta_2)(WIND)^{-1}(M2) + \ldots + (\beta_8)(WIND)^{-1}(M8) + (\beta_9)[\ln(WIND)](M1) + (\beta_{10})[\ln(WIND)](M2) + \ldots + (\beta_{16})[\ln(WIND)](M8) , \tag{5-18}$$

contains interactions between aggregate microenvironment and $WIND^{-1}$ and between aggregate microenvironment and ln(WIND). The best-fit model (R^2 = 0.1227) is

$$\hat{C}_{PEM} = 3.79 + (42.6)(WIND)^{-1}(M1) + (9.38)(WIND^{-1})(M2) + (28.7)(WIND^{-1})(M5) - (0.913)[\ln(WIND)](M4)$$

Table 5-12 lists the stepwise regression results. These results are consistent with the findings in Section 2.2, where $WIND^{-1}$ was found to be a generally better predictor of ambient CO levels (and presumably CO exposures) than ln(WIND). The aggregate microenvironments most affected by wind speed are M5 (high in-transit exposures), M4 (low indoor exposures), and M1 (very high indoor exposures). Other general models containing $WIND^{-1}$ are evaluated later in this section.

General Model 11 contains interactions between aggregate microenvironments and C (simultaneous fixed-site values), C1 (fixed-site values one hour earlier), and C2 (fixed-site values two hours earlier). The general model is

$$\hat{C}_{PEM} = \alpha + (\beta_1)(C)(M1) + (\beta_2)(C)(M2) + \ldots + (\beta_8)(C)(M8) + (\beta_9)(C1)(M1) + (\beta_{10})(C1)(M2) + \ldots + (\beta_{16})(C1)(M8) + (\beta_{17})(C2)(M1) + (\beta_{18})(C2)(M2) + \ldots + (\beta_{24})(C2)(M8). \quad (5\text{-}20)$$

The best-fit model (R^2 = 0.1470) is

$$\hat{C}_{PEM} = 1.66 + (1.77)(C)(M1) + (0.48)(C)(M3) + (1.99)(C)(M5) + (1.01)(C)(M6) + (0.93)(C)(M7) + (0.93)(C1)(M2) + (0.34)(C1)(M4) - (1.18)(C1)(M5) + (1.11)(C2)(M5). \quad (5\text{-}21)$$

Table 5-13 lists the stepwise regression sequence. Note that (C1)(M2) and (C1)(M4) appear in the best-fit model and that (C)(M2) and (C)(M4) do not. Apparently PEM values for M2 (high indoor exposures) and M4 (low indoor exposures) are better predicted by fixed-site values one hour earlier than the PEM reading than by simultaneous fixed-site values. However, (C1)(M2) and

TABLE 5-12. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 10

Step	Operation	Resulting R^2	Change in R^2
1	Add $(WIND)^{-1}(M5)$[a]	0.0908	0.0908
2	Add $[\ln(WIND)](M4)$[a]	0.1132	0.0224
3	Add $(WIND)^{-1}(M1)$[a]	0.1212	0.0080
4	Add $[\ln(WIND)](M3)$	0.1228	0.0016
5	Add $[\ln(WIND)](M8)$	0.1238	0.0009
6	Add $[\ln(WIND)](M7)$	0.1246	0.0008
7	Add $(WIND)^{-1}(M6)$	0.1249	0.0003
8	Add $(WIND)^{-1}(M2)$[a]	0.1251	0.0002
9	Add $[\ln(WIND)](M5)$	0.1254	0.0003
10	Add $(WIND)^{-1}(M4)$	0.1259	0.0005
11	Add $(WIND)^{-1}(M7)$	0.1262	0.0003
12	Add $(WIND)^{-1}(M3)$	0.1262	0.0001
13	Remove $[\ln(WIND)](M3)$	0.1262	-0.0001
14	Remove $(WIND)^{-1}(M3)$	0.1262	-0.0000
15	Remove $[\ln(WIND)](M7)$	0.1260	-0.0002
16	Remove $(WIND)^{-1}(M7)$	0.1258	-0.0002
17	Remove $[\ln(WIND)](M8)$	0.1253	-0.0005
18	Remove $(WIND)^{-1}(M6)$	0.1247	-0.0007
19	Remove $(WIND)^{-1}(M4)$	0.1237	-0.0010
20	Remove $[\ln(WIND)](M5)$	0.1227	-0.0010

[a]Retained in best-fit model.

TABLE 5-13. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 11

Step	Operation	Resulting R^2	Change in R^2
1	Add (C)(M5)[a]	0.0944	0.0944
2	Add (C)(M1)[a]	0.1046	0.0102
3	Add (C)(M2)[a]	0.1128	0.0082
4	Add (C1)(M4)[a]	0.1206	0.0078
5	Add (C)(M3)[a]	0.1316	0.0111
6	Add (C)(M7)[a]	0.1406	0.0090
7	Add (C2)(M5)[a]	0.1436	0.0031
8	Add (C1)(M5)[a]	0.1456	0.0020
9	Add (C)(M6)[a]	0.1470	0.0014
10	Add (C2)(M3)	0.1482	0.0012
11	Add (C2)(M4)	0.1486	0.0004
12	Add (C2)(M2)	0.1488	0.0001
13	Add (C1)(M1)	0.1489	0.0001
14	Add (C)(M4)	0.1489	0.0001
15	Remove (C)(M4)	0.1489	-0.0001
16	Remove (C1)(M1)	0.1488	-0.0001
17	Remove (C2)(M2)	0.1486	-0.0001
18	Remove (C2)(M4)	0.1482	-0.0004
19	Remove (C2)(M3)	0.1470	-0.0012

[a]Retained in best-fit model.

(C1)(M4) together add only 0.0160 to the R^2 value of the best-fit model. The sole term containing C2--(C2)(M5)--contributes only 0.0031 to the R^2 value.

Three general models were constructed using selected terms retained in the best-fit models corresponding to General Models 5 through 11. Each term contributed at least 0.0042 to the R^2 value of the corresponding best-fit model. These terms are listed in Table 5-14. Because of the large number of terms, the complete general models will not be listed here. However, they all have the form

$$F(\hat{C}_{PEM}) = \alpha + (\beta_1)(M5) + (\beta_2)(C) + \ldots + (C)(M3). \tag{5-22}$$

The dependent variable $[F(\hat{C}_{PEM})]$ is $\hat{C}_{PEM}$ for General Model 12, $\ln(\hat{C}_{PEM})$ for General Model 13, and $(C_{PEM}{}^{\lambda} - 1)/\lambda$ for General Model 14. The best-fit model (R^2 = 0.2013) for General Model 12 is

$$\begin{aligned}\hat{C}_{PEM} = 2.22 &+ (3.50)(M5) + (1.39)(GAS) \\ &+ (15.9)(P1)(M2) - (1.54)(P4)(M5) \\ &+ (0.86)(C)(M5) + (0.16)(C)(P4) \\ &+ (1.63)(C)(M1) + (0.73)(C)(M7) \\ &+ (2.92)(SMOKE)(M5) + (2.45)(IH)(GCS)(P4) \\ &- (0.75)[\ln(WIND)](M4) + (0.64)(C1)(M2) \\ &+ (0.34)(C1)(M4) + (0.28)(C)(M3).\end{aligned} \tag{5-23}$$

Table 5-15 lists the stepwise regression sequence. The best-fit model (R^2 = 0.3046) for General Model 13 is

$$\begin{aligned}\ln(\hat{C}_{PEM}) = -0.672 &+ (0.12)(C) + (1.93)(M1) + (0.59)(GAS) - \\ &(0.38)(P1)(M4) - (0.76)(P2)(M4) + (1.62)(P2)(M5) + \\ &(1.56)(P3)(M5) + (1.57)(P4)(M5) + (0.18)(C)(M7) + \\ &(0.65)(SMOKE)(M5) - (0.25)(GARAGE)(M4) + \\ &(0.90)(IH)(GCS)(P4) - (0.49)[\ln(WIND)](M4) + \\ &(0.15)(C1)(M2) + (0.22)(C1)(M4) + (0.11)(C)(M3) .\end{aligned} \tag{5-24}$$

Table 5-16 lists the stepwise regression sequence.

TABLE 5-14. TERMS SELECTED FROM GENERAL MODELS 5 THROUGH 11 FOR INCLUSION IN GENERAL MODELS 12, 13, AND 14

General model	Term	Contribution to R^2
5	M5	0.0924
	C	0.0517
	M4	0.0123
	M1	0.0062
	GAS	0.0049
6	(P3)(M5)	0.0324
	(P2)(M5)	0.0329
	(P4)(M5)	0.0283
	(P1)(M4)	0.0078
	(P1)(M2)	0.0058
	(P4)(M1)	0.0056
	(P2)(M4)	0.0050
7	(C)(M5)	0.0918
	(C)(P4)	0.0174
	(C)(P3)	0.0127
	(C)(M1)	0.0092
	(C)(M7)	0.0042
8	(SMOKE)(M5)	0.0218
	(GARAGE)(M1)	0.0077
	(GARAGE)(M4)	0.0052
9	(IH)(GCS)(P4)	0.0062
10	$(\text{WIND})^{-1}$(M5)	0.0852
	[ln(WIND)](M4)	0.0224
	$(\text{WIND})^{-1}$(M1)	0.0080
11	(C)(M5)[a]	0.0944
	(C)(M1)[a]	0.0102
	(C1)(M2)	0.0082
	(C1)(M4)	0.0078
	(C)(M3)	0.0111
	(C)(M7)[a]	0.0090

[a]Term also listed under General Model 7.

TABLE 5-15. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 12

Step	Operation	Resulting R^2	Change in R^2
1	Add M5[a]	0.0953	0.0953
2	Add C	0.1475	0.0522
3	Add [ln(WIND)](M4)[a]	0.1584	0.0109
4	Add (IH)(GCS)(P4)[a]	0.1693	0.0109
5	Add (P1)(M2)[a]	0.1754	0.0061
6	Add (C)(M1)[a]	0.1811	0.0057
7	Add (C)(M5)[a]	0.1849	0.0038
8	Add (SMOKE)(M5)[a]	0.1885	0.0037
9	Add (C1)(M4)[a]	0.1905	0.0020
10	Add (C1)(M2)[a]	0.1929	0.0024
11	Add (C)(M7)[a]	0.1955	0.0026
12	Add GAS[a]	0.1977	0.0022
13	Add (P2)(M4)	0.1989	0.0012
14	Add $(WIND)^{-1}$(M1)	0.1999	0.0010
15	Add (C)(M3)[a]	0.2009	0.0009
16	Add (P4)(M5)[a]	0.2018	0.0009
17	Add (C)(P4)[a]	0.2028	0.0010
18	Add (GARAGE)(M4)	0.2036	0.0009
19	Add $(WIND)^{-1}$(M5)	0.2042	0.0005
20	Add (C)(P3)	0.2045	0.0003
21	Add (P4(M1)	0.2047	0.0002
22	Add M1	0.2049	0.0002
23	Add M4	0.2049	0.0001
24	Remove M4	0.2049	-0.0001
25	Remove M1	0.2047	-0.0002
26	Remove (P2)(M4)	0.2045	-0.0002
27	Remove C	0.2044	-0.0001
28	Remove (P4)(M1)	0.2042	-0.0002
29	Remove $(WIND)^{-1}$(M5)	0.2038	-0.0005
30	Remove (C)(P3)	0.2032	-0.0005
31	Remove (GARAGE)(M4)	0.2024	-0.0009
32	Remove $(WIND)^{-1}$(M1)	0.2013	-0.0011

[a]Retained in best-fit model.

TABLE 5-16. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 13

Step	Operation	Resulting R^2	Change in R^2
1	Add [ln(WIND)](M4)[a]	0.1276	0.1276
2	Add C[a]	0.2221	0.0945
3	Add M5	0.2470	0.0249
4	Add (C1)(M4)[a]	0.2661	0.0191
5	Add (IH)(GCS)(P4)[a]	0.2802	0.0142
6	Add (P2)(M4)[a]	0.2883	0.0081
7	Add GAS[a]	0.2918	0.0035
8	Add (P1)(M4)[a]	0.2947	0.0029
9	Add (GARAGE)(M4)[a]	0.2968	0.0022
10	Add M1[a]	0.2988	0.0020
11	Add (SMOKE)(M5)[a]	0.3001	0.0013
12	Add (C)(M7)[a]	0.3009	0.0008
13	Add (C)(M3)[a]	0.3023	0.0014
14	Add (C1)(M2)[a]	0.3041	0.0018
15	Add (C)(M5)	0.3047	0.0006
16	Add M4	0.3053	0.0006
17	Add (P1)(M2)	0.3054	0.0001
18	Add (P3)(M5)[a]	0.3055	0.0001
19	Add (C)(P4)	0.3056	0.0001
20	Add (C)(P3)	0.3057	0.0001
21	Add $(WIND)^{-1}$(M1)	0.3057	0.0000
22	Add (P2)(M5)[a]	0.3057	0.0000
23	Add (P4)(M5)[a]	0.3061	0.0003
24	Add $(WIND)^{-1}$(M1)	0.3060	-0.0000
25	Remove M5	0.3060	-0.0001
26	Remove (C)(P3)	0.3059	-0.0001
27	Remove (C)(P4)	0.3058	-0.0001
28	Remove (P1)(M2)	0.3057	-0.0001
29	Remove M4	0.3051	-0.0006
30	Remove (C)(M5)	0.3046	-0.0006

[a]Retained in best-fit model.

Four values of λ (0.30, 0.35, 0.40, and 0.45) were used in exploratory stepwise linear regression analyses to determine the optimal λ for the "Box-Cox" function in General Model 14. The largest R^2 value (0.3366) resulted from λ = 0.40. The corresponding best-fit model is

$$
\begin{aligned}
(\hat{C}_{PEM}^{0.40} - 1)/0.40 = {} & -0.068 + (0.11)(C) + (0.68)(GAS) - \\
& (0.32)(P1)(M4) - (0.65)(P2)(M4) + (1.56)(P2)(M5) + \\
& (1.72)(P3)(M5) + (1.43)(P4)(M5) + (0.19)(C)(M5) + \\
& (0.27)(C)(M7) + (1.05)(SMOKE)(M5) + \\
& (1.15)(IH)(GCS)(P4) - (0.51)[\ln(WIND)](M4) + \\
& (15.2)(WIND)^{-1}(M1) + (0.23)(C1)(M2) + \\
& (0.22)(C1)(M4) + \\
& (0.13)(C)(M3). \qquad (5\text{-}25)
\end{aligned}
$$

Table 5-17 lists the stepwise regression sequence. Note that this best-fit model yields the highest R^2 value yet obtained. The three most important terms with respect to increasing R^2 are related to wind speed given to low exposure indoor microenvironment [ln(WIND)](M4), to simultaneous fixed-site readings (C), and to high exposure in-transit microenvironments (M5).

Because wind speed appears to be particularly significant in explaining the variation in PEM values, future models may benefit from higher resolution wind data. For example, five-minute average windspeeds collected every three hours are listed in monthly summaries published by the National Weather Service. A reasonable assumption is that eight windspeed readings per day would provide better resolution of wind-related effects than WIND which is a 24-hour average.

5.3 AGGREGATION OF INDOOR MICROENVIRONMENTS

PEI was directed by EMSL to compare concentrations observed in different indoor locations (e.g., residence, school, office) and to test for statistically significant differences between the locations. The results of these

TABLE 5-17. RESULTS OF STEPWISE LINEAR REGRESSION USING GENERAL MODEL 14

Step	Operation	Resulting R^2	Change in R^2
1	Add [ln(WIND)](M4)[a]	0.1430	0.1430
2	Add C[a]	0.2384	0.0954
3	Add M5	0.2806	0.0422
4	Add (IH)(GCS)(P4)[a]	0.3005	0.0200
5	Add (C1)(M4)[a]	0.3097	0.0091
6	Add (P2)(M4)[a]	0.3159	0.0062
7	Add GAS[a]	0.3199	0.0040
8	Add $(WIND)^{-1}$(M1)[a]	0.3236	0.0037
9	Add (SMOKE)(M5)[a]	0.3264	0.0028
10	Add (P1)(M4)[a]	0.3280	0.0016
11	Add (C)(M7)[a]	0.3296	0.0016
12	Add (C1)(M2)[a]	0.3312	0.0016
13	Add (C)(M5)[a]	0.3328	0.0015
14	Add (C)(M3)[a]	0.3357	0.0030
15	Add (C)(M1)	0.3364	0.0006
16	Add (P1)(M2)	0.3368	0.0005
17	Add (P3)(M5)[a]	0.3372	0.0004
18	Add (C)(P4)	0.3375	0.0003
19	Add (C)(P3)	0.3378	0.0003
20	Add (P2)(M5)[a]	0.3382	0.0003
21	Add (P4)(M5)[a]	0.3385	0.0003
22	Add (GARAGE)(M4)	0.3388	0.0003
23	Add M4	0.3389	0.0002
24	Add M1	0.3390	0.0000
25	Add (P4)(M1)	0.3390	0.0000
26	Remove (P4)(M1)	0.3390	-0.0000
27	Remove M1	0.3389	-0.0000
28	Remove M5	0.3389	-0.0001
29	Remove M4	0.3387	-0.0002

(continued)

TABLE 5-17 (continued)

Step	Operation	Resulting R^2	Change in R^2
30	Remove (GARAGE)(M4)	0.3385	-0.0003
31	Remove ((C)(P3)	0.3381	-0.0004
32	Remove (C)(P4)	0.3376	-0.0004
33	Remove (P1)(M2)	0.3372	-0.0005
34	Remove (C)(M1)	0.3366	-0.0006

[a]Retained in best-fit model.

tests were to be used to identify locations with similar pollutant concentration distributions. This section describes a methodology developed by PEI which uses the statistical technique known as pairwise comparisons to aggregate similar microenvironments into groups which differ significantly one from another.

5.3.1 The Indoor Microenvironments

Associated with each PEM value is a two-digit location code. Sixteen of these codes correspond to indoor microenvironments. Table 5-18 lists these microenvironments and provides selected summary statistics based on data with acceptable overall (i.e., PEM plus activity diary) quality codes. Data quality codes are explained in Section 4.11 of Reference 1. The minimum value reported for each microenvironment was zero. Note the large values of skewness and kurtosis listed for most microenvironments. To facilitate the use of statistical analyses requiring normal distributions, PEI investigated the use of the Box-Cox transformation as a means of reducing skewness and kurtosis. The general form of the transformation is

$$y = (x^{\lambda} - 1)/\lambda \qquad (5\text{-}29)$$

TABLE 5-18. SUMMARY STATISTICS FOR CARBON MONOXIDE CONCENTRATION VALUES RECORDED BY PERSONAL EXPOSURE MONITORS IN INDOOR MICROENVIRONMENTS

Code	Indoor microenvironment	n	Carbon monoxide concentration, ppm						Skewness / s.e.	Kurtosis / s.e.
			Maximum	Mean	s.d.[a]	s.e.[b]	Median	s.e.[b]		
02	Residence	21518	76.4	2.212	4.030	0.027	0.90	0.029	c	c
03	Office	2287	59.1	3.248	4.970	0.104	1.90	0.058	110.40	483.29
04	Store	734	56.3	3.385	4.754	0.175	2.00	0.115	47.05	167.26
05	Restaurant	524	35.0	4.313	4.674	0.204	3.15	0.231	21.76	44.53
51	Residential garage	66	28.4	3.364	5.059	0.623	1.40	0.318	9.02	14.49
52	Public garage	115	81.2	11.968	11.984	1.118	8.40	0.635	10.85	19.71
53	Manufacturing facility	42	8.0	1.750	2.366	0.365	0.00	0.577	2.75	-0.30
54	Service station or auto repair facility	125	73.1	9.409	9.704	0.868	5.80	1.212	13.13	31.32
55	Other repair shop	55	33.1	7.620	8.575	1.156	3.00	1.617	2.98	-0.26
56	Auditorium	100	31.2	4.523	5.649	0.565	3.50	0.577	9.72	13.97
57	Church	179	21.7	1.824	2.998	0.224	1.00	0.087	19.50	42.54
58	Shopping mall	58	33.9	5.271	6.493	0.853	3.10	0.462	7.35	9.58
59	Health care facility	351	31.3	2.334	3.632	0.194	1.20	0.173	29.28	79.80
60	School	426	21.6	2.056	3.090	0.150	0.80	0.144	24.52	47.92
61	Other public building	115	21.8	2.937	3.760	0.351	1.50	0.491	9.77	15.02
62	Other indoor location	425	66.4	4.923	7.958	0.386	2.90	0.202	34.45	85.67

[a]Standard deviation.

[b]Standard error.

[c]Not computed because of large sample size.

where y is the transformed value, x is the PEM value, and λ is a constant selected by the user. Evaluation of λ values between 0 and 1 suggested that $\lambda = 0.35$ was a nearly optimal choice in that it produced low skewness and kurtosis values for most microenvironments. Table 5-19 lists summary statistics of the transformed data. Note the dramatic reduction in most of the skewness and kurtosis values after transformation.

Table 5-20 ranks the microenvironments by mean value before and after transformation and by median value (transformation has no effect on the ranking of median values). In all three cases, the microenvironment with the largest value is public garage (Code 52). Other microenvironments which are ranked high on all lists (though not in the same order) are service station or auto repair facility (Code 54), other repair shop (Code 55), auditorium (Code 56), shopping mall (Code 58), and restaurant (Code 05). Manufacturing facility (Code 53) ranked last in all four lists. This result is somewhat surprising but may be partially explained by the small sample site (n = 42).

5.3.2 Iterative Aggregation Based on Pairwise Comparisons

Pairwise comparisons were performed on the transformed ($\lambda = 0.35$) data using BMDP program P7D. Figure 5-1 is the output of the program. Since there are 16 microenvironments, there are 120 possible pairings. For each pairing the program output provides the mean for each microenvironment, the difference in means, the results of a t test assuming unequal variances ("separate variance t test"), and the results of a t test assuming equal variances ("pooled variance t test"). Asterisks indicate the signficance level of the Bonferroni test as explained at the top of the printout.

PEI considered all pairings which were not significant at the 0.05 level as indicated by the Bonferroni test (i.e., all pairings with a separate variance t test p value greater than 0.05/number of pairings) as candidates for aggregation. The pairing in Figure 5-1 with the largest p value (0.9505) consists of Code 56 (auditorium, etc.) and Code 62 (other indoor location). Based on the assumption that these two microenvironments were not significantly different, they were combined into an aggregate microenvironment with Code 5662. The pairwise comparisons analysis was then repeated on the resulting 15 microenvironments. This time the largest p value (0.8930) was associated with Code 03 (office) and Code 51 (residential garage). These were aggregated

TABLE 5-19. SUMMARY STATISTICS FOR CARBON MONOXIDE CONCENTRATION VALUES RECORDED BY PERSONAL EXPOSURE MONITORS IN INDOOR MICROENVIRONMENTS AFTER TRANSFORMATION

Code	Indoor microenvironment	n	Carbon monoxide concentration, ppm						Skewness	Kurtosis
			Maximum	Mean	s.d.[a]	s.e.[b]	Median	s.e.[b]	s.e.	s.e.
02	Residence	21518	10.175	-0.311	2.170	0.015	-0.103	0.032	c	c
03	Office	2287	9.055	0.469	2.154	0.045	0.720	0.038	0.56	-0.52
04	Store	734	8.854	0.592	2.111	0.080	0.784	0.074	-0.25	-0.62
05	Restaurant	524	7.059	1.095	2.108	0.092	1.412	0.111	-3.21	-1.54
51	Residential garage	66	6.360	0.431	2.244	0.276	0.357	0.245	0.68	-0.67
52	Public garage	115	10.456	3.336	2.085	0.194	3.161	0.157	2.28	0.79
53	Manufacturing facility	42	3.059	-0.814	2.287	0.353	-2.857	1.051	0.91	-2.24
54	Service station or auto repair facility	125	9.975	2.744	2.111	0.189	2.430	0.348	0.37	1.53
55	Other repair shop	55	6.867	1.731	2.833	0.382	1.340	0.637	-0.27	-1.71
56	Auditorium	100	6.668	0.967	2.364	0.236	1.570	0.289	-0.60	-1.15
57	Church	179	5.532	-0.284	1.888	0.141	0.000	0.084	1.12	-0.55
58	Shopping mall	58	6.949	1.511	2.017	0.265	1.388	0.265	0.65	0.62
59	Health care facility	351	6.679	-0.033	2.044	0.109	0.188	0.156	1.19	-1.65
60	School	426	5.518	-0.255	2.045	0.099	-0.215	0.163	1.65	-3.46
61	Other public building	115	5.545	0.258	2.205	0.206	0.436	0.357	-0.14	-2.26
62	Other indoor location	425	9.551	0.983	2.467	0.120	1.290	0.103	1.55	1.38

[a]Standard deviation.

[b]Standard error.

[c]Not computed because of large sample size.

TABLE 5-20. MICROENVIRONMENTS LISTED IN DESCENDING ORDER OF MEAN AND MEDIAN VALUES BASED ON UNTRANSFORMED AND TRANSFORMED CARBON MONOXIDE VALUES

Rank	Microenvironment		
	Mean		Median
	Data untransformed	Data transformed	
1	52: Public garage	52: Public garage	52: Public garage
2	54: Service station	54: Service station	54: Service station
3	55: Other repair	55: Other repair	56: Auditorium
4	58: Mall	58: Mall	05: Restaurant
5	62: Other indoor	05: Restaurant	58: Mall
6	56: Auditorium	62: Other indoor	55: Other repair
7	05: Restaurant	56: Auditorium	62: Other indoor
8	04: Store	04: Store	04: Store
9	51: Res. garage	03: Office	03: Office
10	03: Office	51: Res. garage	61: Other public
11	61: Other public	61: Other public	51: Res. garage
12	59: Health care	59: Health care	59: Health care
13	02: Residence	60: School	57: Church
14	60: School	57: Church	02: Residence
15	57: Church	02: Residence	60: School
16	53: Manufacturing	53: Manufacturing	53: Manufacturing

PAGE 5 BMDP7D INDP

PAIRWISE COMPARISONS AMONG NONEMPTY CELL (GROUP) MEANS.
ASTERISKS DENOTE THE LEVELS OF SIGNIFICANCE OF THE BONFERRONI TESTS.
THE VALUE GIVEN FOR THE BONFERRONI TEST IS THE SIMULTANEOUS SIGNIFICANT P VALUE OF COMPARISONS OF ALL PAIRS OF MEANS. THAT IS, AFTER ADJUSTMENT FOR THE MULTIPLE COMPARISON OF ALL PAIRS OF MEANS, TO BE SIGNIFICANT AT THE .05 LEVEL THE P VALUE MUST BE LESS THAN .000417

SYMBOL	SIGNIFICANCE LEVEL	BONFERRONI TEST
*	.05	.000417
**	.01	.000083
***	.001	.000008

GROUP NAME	MEAN	GROUP NAME	MEAN	MEAN DIFF	SEPARATE VARIANCE T T-VALUE	DF	P-VALUE	POOLED VARIANCE T T-VALUE	DF	P-VALUE
2	-.31	3	.47	-.78	-16.47	2802.61	.0000 ***	-16.37	27104	.0000 ***
2	-.31	4	.59	-.90	-11.39	786.79	.0000 ***	-11.10	27104	.0000 ***
2	-.31	5	1.10	-1.41	-15.0[illegible]	550.34	.0000 ***	-14.68	27104	.0000 ***
2	-.31	51	.43	-.74	-2.69	65.37	.0092	-2.78	27104	.0055
2	-.31	52	3.34	-3.65	-18.70	115.32	.0000 ***	-18.00	27104	.0000 ***
2	-.31	53	-.81	.50	1.42	41.14	.1622	1.50	27104	.1333
2	-.31	54	2.74	-3.06	-16.13	125.53	.0000 ***	-15.71	27104	.0000 ***
2	-.31	55	1.73	-2.04	-5.34	54.16	.0000 ***	-6.98	27104	.0000 **
2	-.31	56	.97	-1.28	-5.40	99.78	.0000 ***	-5.88	27104	.0000 **
2	-.31	57	-.28	-.03	-.19	181.94	.8460	-.17	27104	.8653
2	-.31	58	1.51	-1.82	-6.87	57.36	.0000 ***	-6.39	27104	.0000 **
2	-.31	59	-.03	-.28	-2.53	362.99	.0117	-2.39	27104	.0169
2	-.31	60	-.26	-.06	-.56	444.16	.5749	-.53	27104	.5960
2	-.31	61	.26	-.57	-2.76	115.18	.0067	-2.81	27104	.0051
2	-.31	62	.98	-1.29	-10.74	437.06	.0000 ***	-12.19	27104	.0000 ***
3	.47	4	.59	-.12	-1.36	1259.62	.1726	-1.34	27104	.1818
3	.47	5	1.10	-.63	-6.11	792.74	.0000 ***	-5.96	27104	.0000 **
3	.47	51	.43	.04	.14	68.50	.8930	.14	27104	.8889
3	.47	52	3.34	-2.87	-14.36	126.54	.0000 ***	-13.84	27104	.0000 ***
3	.47	53	-.81	1.28	3.61	42.35	.0008	3.80	27104	.0002 *
3	.47	54	2.74	-2.27	-11.72	138.49	.0000 ***	-11.42	27104	.0000 ***
3	.47	55	1.73	-1.26	-3.28	55.51	.0018	-4.27	27104	.0001 **
3	.47	56	.97	-.50	-2.07	106.31	.0411	-2.25	27104	.0248
3	.47	57	-.28	.75	5.0[illegible]	215.95	.0000 ***	4.48	27104	.0001 **
3	.47	58	1.51	-1.04	-3.88	60.34	.0003 *	-3.61	27104	.0004 *
3	.47	59	-.03	.50	4.25	477.35	.0000 **	4.04	27104	.0001 *
3	.47	60	-.26	.72	6.65	613.63	.0000 ***	6.33	27104	.0000 **
3	.47	61	.26	.21	1.09	125.19	.3171	1.02	27104	.3077
3	.47	62	.98	-.51	-4.02	550.54	.0001 **	-4.49	27104	.0001 **
4	.59	5	1.10	-.50	-4.17	1127.51	.0000 **	-4.06	27104	.0001 *
4	.59	51	.43	.16	.56	75.71	.5774	.58	27104	.5643
4	.59	52	3.34	-2.74	-13.10	152.92	.0000 ***	-12.62	27104	.0000 ***
4	.59	53	-.81	1.41	3.89	45.09	.0003 *	4.09	27104	.0001 *
4	.59	54	2.74	-2.15	-10.53	168.99	.0000 ***	-10.26	27104	.0000 ***
4	.59	55	1.73	-1.14	-2.92	58.58	.0049	-3.76	27104	.0002 *
4	.59	56	.97	-.37	-1.51	121.47	.1348	-1.62	27104	.1049
4	.59	57	-.28	.88	5.43	296.42	.0000 ***	4.85	27104	.0001 **
4	.59	58	1.51	-.92	-3.33	67.25	.0014	-3.11	27104	.0020
4	.59	59	-.03	.62	4.66	709.91	.0000 ***	4.44	27104	.0001 **
4	.59	60	-.26	.85	6.72	910.96	.0000 ***	6.42	27104	.0000 **
4	.59	61	.26	.33	1.52	148.62	.1306	1.54	27104	.1243
4	.59	62	.98	-.39	-2.74	778.67	.0063	-2.96	27104	.0031
5	1.10	51	.43	.66	2.28	80.13	.0253	2.34	27104	.0191
5	1.10	52	3.34	-2.24	-10.42	169.[illegible]	.0000 ***	-10.[illegible]	27104	.0000 ***

Figure 5-1. Output of pairwise comparison test program (step one). (continued)

5	1.10	53	-.81	1.91	5.23	46.75	.0000 ***	5.49	27104	.0000 **
5	1.10	54	2.74	-1.65	-7.85	187.48	.0000 ***	-7.64	27104	.0000 **
5	1.10	55	1.73	-.64	-1.62	60.44	.1107	-2.07	27104	.0385
5	1.10	56	.97	.13	.51	130.74	.6134	.54	27104	.5870
5	1.10	57	-.28	1.38	8.19	340.91	.0000 ***	7.35	27104	.0000 **
5	1.10	58	1.51	-.42	-1.48	71.50	.1425	-1.39	27104	.1658
5	1.10	59	-.03	1.13	7.90	766.16	.0000 ***	7.54	27104	.0000 **
5	1.10	60	-.26	1.35	9.98	519.33	.0000 ***	9.55	27104	.0000 **
5	1.10	61	.26	.84	3.72	162.90	.0003 *	3.75	27104	.0002 *
5	1.10	62	.98	.11	.74	836.85	.4583	.79	27104	.4285
51	.43	52	3.34	-2.91	-8.60	127.54	.0000 ***	-8.68	27104	.0000 **
51	.43	53	-.81	1.25	2.78	86.21	.0067	2.91	27104	.0037
51	.43	54	2.74	-2.31	-6.91	125.57	.0000 ***	-7.01	27104	.0000 **
51	.43	55	1.73	-1.30	-2.76	102.05	.0069	-3.28	27104	.0011
51	.43	56	.97	-.54	-1.47	144.29	.1431	-1.56	27104	.1195
51	.43	57	-.28	.72	2.31	100.83	.0232	2.29	27104	.0221
51	.43	58	1.51	-1.08	-2.82	121.93	.0056	-2.77	27104	.0057
51	.43	59	-.03	.46	1.56	86.47	.1220	1.59	27104	.1109
51	.43	60	-.26	.69	2.34	82.60	.0217	2.39	27104	.0167
51	.43	61	.26	.17	.50	133.58	.6150	.52	27104	.6041
51	.43	62	.98	-.55	-1.83	91.20	.0700	-1.92	27104	.0544
52	3.34	53	-.81	4.15	10.30	67.44	.0000 ***	10.62	27104	.0000 ***
52	3.34	54	2.74	.59	2.19	236.79	.0298	2.12	27104	.0345
52	3.34	55	1.73	1.61	3.74	82.97	.0003 *	4.52	27104	.0001 **
52	3.34	56	.97	2.37	7.74	199.12	.0000 ***	8.00	27104	.0000 **
52	3.34	57	-.28	3.62	15.07	225.56	.0000 ***	13.97	27104	.0000 ***
52	3.34	58	1.51	1.83	5.56	117.90	.0000 ***	5.23	27104	.0000 **
52	3.34	59	-.03	3.37	15.11	190.88	.0000 ***	14.46	27104	.0000 ***
52	3.34	60	-.26	3.59	16.46	177.67	.0000 ***	15.77	27104	.0000 ***
52	3.34	61	.26	3.08	10.88	227.30	.0000 ***	10.77	27104	.0000 ***
52	3.34	62	.98	2.35	10.31	208.66	.0000 ***	10.33	27104	.0000 ***
53	-.81	54	2.74	-3.56	-8.89	66.04	.0000 ***	-9.20	27104	.0000 **
53	-.81	55	1.73	-2.55	-4.89	94.68	.0000 ***	-5.73	27104	.0000 **
53	-.81	56	.97	-1.78	-4.19	79.43	.0001 **	-4.47	27104	.0001 **
53	-.81	57	-.28	-.53	-1.40	54.83	.1686	-1.43	27104	.1537
53	-.81	58	1.51	-2.33	-5.27	81.57	.0000 ***	-5.29	27104	.0001 **
53	-.81	59	-.03	-.78	-2.12	49.16	.0394	-2.21	27104	.0273
53	-.81	60	-.26	-.56	-1.52	47.69	.1339	-1.59	27104	.1110
53	-.81	61	.26	-1.07	-2.62	70.62	.0106	-2.74	27104	.0062
53	-.81	62	.98	-1.80	-4.82	50.91	.0000 **	-5.13	27104	.0001 **
54	2.74	55	1.73	1.01	2.38	81.49	.0199	2.69	27104	.0040
54	2.74	56	.97	1.78	5.87	200.45	.0000 ***	6.11	27104	.0000 **
54	2.74	57	-.28	3.03	12.84	247.39	.0000 ***	11.98	27104	.0000 ***
54	2.74	58	1.51	1.23	3.79	115.91	.0002 *	3.58	27104	.0004 *
54	2.74	59	-.03	2.78	12.73	212.21	.0000 ***	12.30	27104	.0000 ***
54	2.74	60	-.26	3.00	14.06	197.34	.0000 ***	13.60	27104	.0000 ***
54	2.74	61	.26	2.49	8.91	234.22	.0000 ***	8.88	27104	.0000 **
54	2.74	62	.98	1.76	7.88	232.66	.0000 ***	7.98	27104	.0000 **
55	1.73	56	.97	.76	1.70	95.64	.0920	2.10	27104	.0357
55	1.73	57	-.28	2.02	4.95	69.34	.0000 ***	6.03	27104	.0000 **
55	1.73	58	1.51	.22	.47	97.12	.6365	.54	27104	.5891
55	1.73	59	-.03	1.76	4.44	63.10	.0000 **	5.61	27104	.0000 **
55	1.73	60	-.26	1.99	5.03	61.48	.0000 ***	6.40	27104	.0000 **
55	1.73	61	.26	1.47	3.40	86.37	.0010	4.15	27104	.0001 *
55	1.73	62	.98	.75	1.87	65.04	.0661	2.41	27104	.0161
56	.97	57	-.28	1.25	4.54	170.06	.0000 **	4.62	27104	.0001 **
56	.97	58	1.51	-.54	-1.53	134.77	.1276	-1.52	27104	.1283

Figure 5-1. Output of pairwise comparison test program (step one). (continued)

56	.97	59	-.03	1.00	3.84	143.79	.0002 *	4.07	27104	.0001 *
56	.97	60	-.26	1.22	4.77	135.86	.0000 ***	5.07	27104	.0001 **
56	.97	61	.26	.71	2.26	204.01	.0247	2.39	27104	.0169
56	.97	62	.98	-.02	-.06	153.67	.9505	-.07	27104	.9455
57	-.28	58	1.51	-1.79	-5.98	91.58	.0000 ***	-5.48	27104	.0000 **
57	-.28	59	-.03	-.25	-1.41	384.56	.1596	-1.26	27104	.2070
57	-.28	60	-.26	-.03	-.17	360.23	.8682	-.15	27104	.9821
57	-.28	61	.26	-.54	-2.17	215.98	.0309	-2.09	27104	.0367
57	-.28	62	.98	-1.27	-6.85	432.36	.0000 ***	-6.56	27104	.0000 **
58	1.51	59	-.03	1.54	5.39	77.62	.0000 ***	5.02	27104	.0001 **
58	1.51	60	-.26	1.77	6.25	73.88	.0000 ***	5.82	27104	.0000 **
58	1.51	61	.26	1.25	3.74	123.89	.0003 *	3.59	27104	.0004 *
58	1.51	62	.98	.53	1.82	82.19	.0730	1.74	27104	.0821
59	-.03	60	-.26	.22	1.51	747.03	.1312	1.42	27104	.1543
59	-.03	61	.26	-.29	-1.25	182.52	.2139	-1.25	27104	.2128
59	-.03	62	.98	-1.02	-6.27	773.99	.0000 ***	-6.50	27104	.0000 **
60	-.26	61	.26	-.51	-2.25	170.65	.0259	-2.25	27104	.0244
60	-.26	62	.98	-1.24	-7.97	820.10	.0000 ***	-8.33	27104	.0000 **
61	.26	62	.98	-.73	-3.05	198.24	.0026	-3.18	27104	.0015

Figure 5-1. Output of pairwise comparison test program (step one).

into a new microenvironment (Code 0351), and the pairwise comparison analysis was repeated with 14 microenvironments. This iterative procedure was continued until the largest p value was found to be less than the critical Bonferroni value. Table 5-21 summarizes the results of these runs. The procedure terminated at Step 13 which yielded a largest p value less than the indicated critical value.

TABLE 5-21. RESULTS OF PAIRWISE COMPARISON TESTS

Step	N[a]	Largest t-test p value[b]	Bonferroni critical p value[c]	Resulting group code
1	120	0.9505	0.00042	5562
2	105	0.8930	0.00048	0351
3	91	0.8682	0.00055	5760
4	78	0.6355	0.00064	5558
5	66	0.5632	0.00076	025760
6	55	0.4141	0.00091	055662
7	45	0.3193	0.00111	035161
8	36	0.1612	0.00139	02535760
9	28	0.1343	0.00179	03045161
10	21	0.0298	0.00238	5254
11	15	0.0169	0.00333	0555565862
12	10	0.0118	0.00500	0253575960
13	6	0.0000	0.00833	None

[a]Number of pairwise comparisons.
[b]Separate variance t test.
[c]Critical value = 0.05/N.

Four microenvironment groups were obtained through the aggregation process (Table 5-22). The results are generally consistent with our expectations. Public garages and service stations make up the group with the largest mean. The group with the smallest mean contains health care facilities, schools, churches, residences, and manufacturing facilities.

The procedure described above appears to be a reasonable basis for partitioning a list of user-defined microenvironments into groups which are

TABLE 5-22. MICROENVIRONMENT GROUPS SUGGESTED BY PAIRWISE COMPARISONS ANALYSIS

Group code	n	Untransformed data		Transformed data		Constituent microenvironments
		Mean	Std. dev.	Mean	Std. dev.	
5254	240	10.635	10.909	3.028	2.115	Public garage Service station or auto repair
0555565862	1162	4.759	6.457	1.094	2.304	Other repair shop Shopping mall Restaurant Other indoor location Auditorium
03045161	3202	3.271	4.883	0.489	2.148	Store Office Residential garage Other public building
0253575960	22516	2.207	3.998	-0.307	2.164	Health care facility School Church Residence Manufacturing facility

statistically similar. In future analyses of the Denver data, this procedure could be applied easily to alternative sets of indoor microenvironments. For example, the residential microenvironment could be subdivided according to gas stove use or type of heating system.

5.4 REFERENCE

1. Johnson, T. A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/54-84-014, March 1983.

SECTION 6

COMPARISON OF CONSECUTIVE DAILY MAXIMUM EXPOSURES

The subjects in the Denver study were requested to participate for two consecutive 24-hour sampling periods. An analysis of the resulting PEM data revealed that a pair of valid daily maximum 8-hour exposure values (i.e., one for each sampling period) could be calculated from the data obtained from each of 335 subjects. The first of the two values in each pair is hereafter referred to as the A value; the second of the two values is the B value. PEI performed a series of statistical analyses to determine 1) if the distribution of A values differs significantly from the distribution of B values, 2) if the mean difference between paired values differs significantly from zero, and 3) if there is a high correlation between A and B values. This section presents the results of these analyses.

6.1 DISTRIBUTIONS OF A AND B VALUES

Table 6-1 lists summary statistics for the A and B values. The mean of the A values is 4.70 ppm; the mean of the B values is 5.24 ppm. Figure 6-1 presents histograms for the two groups. Because both distributions are skewed and have large kurtosis values (Table 6-1), PEI investigated taking the natural logarithms of the exposure values as a means of obtaining more normal distributions. Table 6-2 lists summary statistics for the transformed data; Figure 6-2 provides histograms. The values for skewness and kurtosis are much smaller in Table 6-2 than in Table 6-1, but are still significant. For this reason, both parametric and nonparametric tests were performed on the grouped data. Table 6-3 lists the results of these tests.

The Levene test is a test for homogeneity of variance. The large p value (0.4354) suggests the variances of the logarithms of the two groups are equal. Consequently, the t (pooled) test is more appropriate than the t (separate) test for determining if the means of the two groups are equal

TABLE 6-1. SUMMARY STATISTICS FOR DAILY MAXIMUM 8-HOUR CARBON MONOXIDE EXPOSURES

Statistic	A values	B values	All
Number of cases	335	335	670
Minimum, ppm	0.0	0.0	0.0
Maximum, ppm	44.0	38.7	44.0
Mean, ppm	4.70	5.24	5.05
Mode, ppm	a	3.1	a
Standard deviation, ppm	4.86	4.65	4.73
Skewness/std. error	28.65	22.34	36.48
Kurtosis/std. error	83.04	55.47	95.76
10th percentile, ppm	0.9	1.1	1.0
25th percentile, ppm	1.9	2.4	2.2
50th percentile, ppm	3.5	4.2	3.9
75th percentile, ppm	6.0	6.9	6.6
90th percentile, ppm	9.6	9.6	9.7
95th percentile, ppm	12.0	12.6	12.8
98th percentile, ppm	18.1	16.9	17.6
99th percentile, ppm	24.4	25.4	25.0

[a]Not unique.

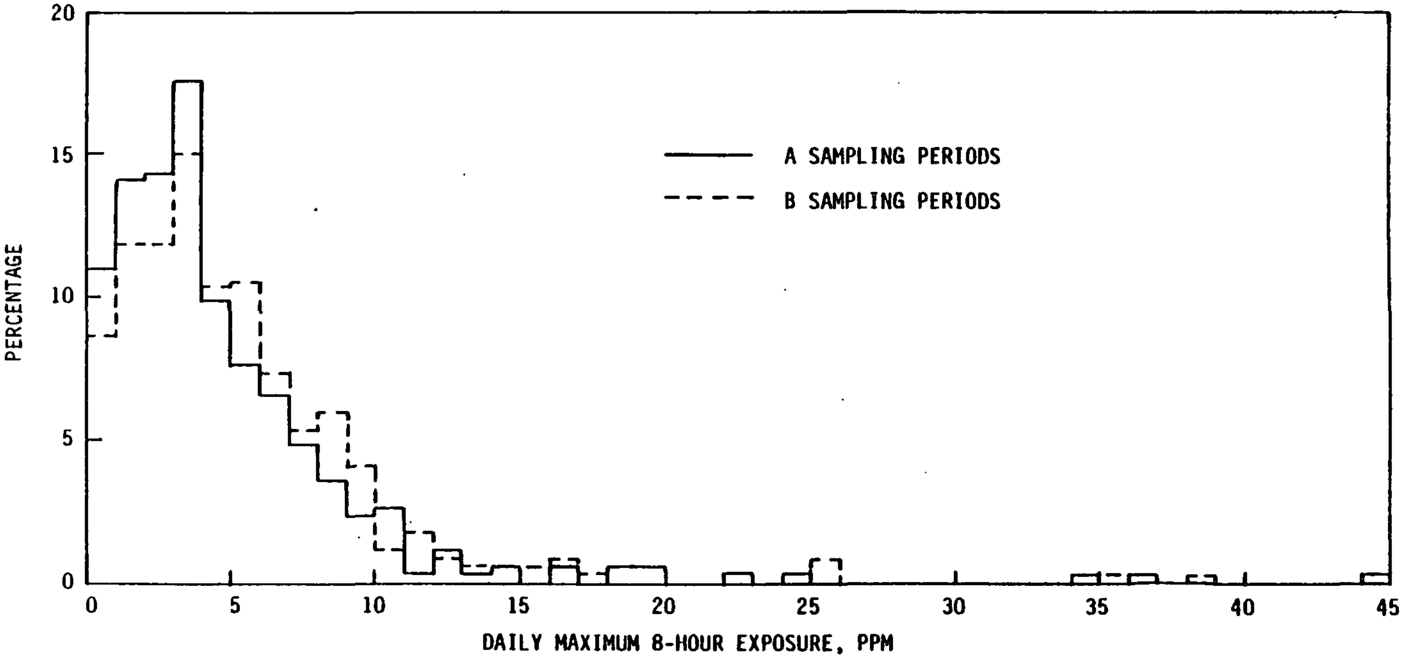


Figure 6-1. Histograms of daily maximum 8-hour exposures to carbon monoxide.

TABLE 6-2. SUMMARY STATISTICS FOR LOGARITHMS OF DAILY MAXIMUM 8-HOUR CARBON MONOXIDE EXPOSURES

Statistic	A values	B values	All
Number of cases	335	335	670
Minimum, ppm	-3.69	-3.69	-3.69
Maximum, ppm	3.78	3.66	3.78
Mean, ppm	1.11	1.28	1.22
Mode, ppm	a	1.13	a
Standard deviation, ppm	1.09	1.01	1.04
Skewness/std. error	-11.10	-10.14	-15.99
Kurtosis/std. error	17.17	13.50	23.84
10th percentile, ppm	-0.11	0.10	0.00
25th percentile, ppm	0.64	0.88	0.79
50th percentile, ppm	1.25	1.44	1.36
75th percentile, ppm	1.79	1.93	1.89
90th percentile, ppm	2.26	2.26	2.27
95th percentile, ppm	2.48	2.53	2.55
98th percentile, ppm	2.90	2.83	2.87
99th percentile, ppm	3.19	3.23	3.22

[a]Not unique.

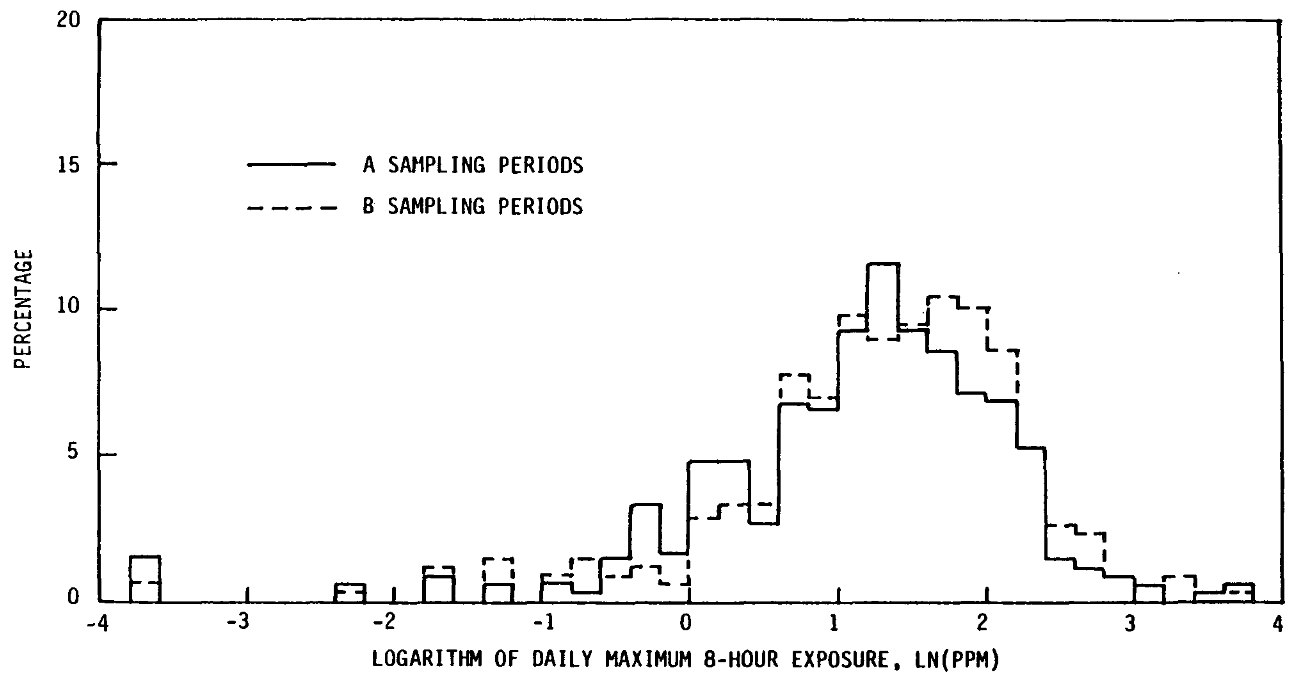


Figure 6-2. Histograms of logarithms of daily maximum 8-hour exposures to carbon monoxide.

TABLE 6-3. RESULTS OF STATISTICAL TESTS COMPARING THE LOGARITHMS OF A VALUES AND B VALUES

Test	Assumed distributions	Test statistic	D.F.	p
t (separate)	Normal, unequal variances	-2.08	664	0.0381
t (pooled)	Normal, equal variances	-2.08	668	0.0381
Levene	Normal	0.61	1, 668	0.4354
Mann-Whitney[a]	None	49967.00	-	0.0141
Kruskal-Wallis[a]	None	6.02	1	0.0141

[a]Results are independent of log transformation.

under the assumption of normality. Since $p < 0.05$ for the t (pooled) test, it can be concluded that the means of the logarithms are not equal.

The two nonparametric tests (Mann-Whitney and Kruskal-Wallis) also yielded p values less than 0.05. These results suggest that the null hypothesis that the two groups have the same distributions should be rejected. Usually when the null hypothesis is rejected, the assumption is made that one group has a higher median.

The general conclusion suggested by these analyses is that the median concentrations of the two groups differ significantly. The median for the B values is 4.2 ppm--an increase of 0.7 ppm (20%) over the A value median of 3.5 ppm. Because both distributions are nonnormal, it is not possible to determine if the means of the two groups are significantly different.

6.2 DISTRIBUTION OF DIFFERENCES BETWEEN A AND B VALUES

For each pair of A and B values, there is the difference $C = B - A$. It is also possible to determine a difference between the natural logarithms of the values, i.e., $D = \ln(B) - \ln(A)$. Table 6-4 lists summary statistics for the C and D values. The mean of the C values is 0.55 ppm; the mean of the D values is 0.17. The D values have less skewness and kurtosis than the C values. If normality is assumed, the one-sample (a.k.a. matched pairs) t test can be used to determine if the means of the C and D values are significantly different than zero. The t statistic for the C values is 1.92 and the

TABLE 6-4. SUMMARY STATISTICS FOR DIFFERENCE VALUES

Statistic[a]	C = B - A	D = ln(B) - ln(A)
Number of cases	335	335
Minimum, ppm	-41.4	-5.15
Maximum, ppm	32.1	5.86
Mean, ppm	0.55	0.17
Mode, ppm	b	0.69
Standard deviation, ppm	5.21	1.28
Skewness/std. error	-9.14	0.27
Kurtosis/std. error	65.66	12.14
5th percentile, ppm	-6.9	-2.12
10th percentile, ppm	-4.9	-1.29
25th percentile, ppm	-1.6	-0.43
50th percentile, ppm	0.9	0.29
75th percentile, ppm	2.8	0.84
90th percentile, ppm	5.3	1.44
95th percentile, ppm	6.5	2.17

[a]Replace ppm with ln(ppm) for D statistics.
[b]Not unique.

p value is 0.0563. This result suggests that the mean of the C values is not different than zero at the $p = 0.05$ significance level. In the case of the D values, the t statistic is 2.42 and the p value is 0.0160. This result suggests that the mean of the D values is different than zero at the $p = 0.05$ significance level. Note that $D > 0$ implies $B/A > 1$ since $D = \ln(B/A)$ and $\ln(1) = 0$.

Two nonparametric tests were also performed on the paired values. The sign test yielded a p value of 0.0000 to four decimal places; the Wilcoxon signed rank test yielded a p value of 0.0004. The sign test results suggest the A and B values have different medians; the Wilcoxon results suggest that the difference between A and B values is not zero.

6.3 CORRELATION BETWEEN A AND B VALUES

Linear regression analysis with B as the dependent variable yielded the regression equation

$$\hat{B} = 3.44 \text{ ppm} + (0.383)(A); \qquad (6\text{-}1)$$

$R^2 = 0.16$. The small R^2 value suggests that the A and B values are not highly correlated. Repeating the analysis using ln(B) as the dependent variable and ln(A) as the independent variable yielded the regression equation

$$\ln(\hat{B}) = 1.01 + (0.244)\ [\ln(A)]. \qquad (6\text{-}2)$$

In this case, the correlation was even less ($R^2 = 0.07$).

The Kendall and Spearman rank correlations for the paired A and B values were also computed. The Kendall rank correlation (t_b) is 0.2431; the Spearman rank correlation (r_s) is 0.3477. Both of the statistics suggest that the ranks of the paired A and B values are not highly correlated.

The analyses discussed above did not yield an explanation for the finding that B values tend to be slightly larger ($\simeq$ 0.5 ppm) than A values. The analyses discussed below were subsequently performed to determine if the occurrence of unequal sample sizes with respect to day of the week could account for the observed difference between A and B values.

6.4 DISTRIBUTIONS OF A AND B VALUES BY DAY OF WEEK

The data base under investigation contains 670 valid daily maximum 8-hour exposures (i.e., 335 A values and 335 B values). Each exposure is associated with a sample period which started around 7 p.m. one night and ended around 7 p.m. the next night. In the discussion which follows, each sampling period is referred to in terms of the day the period ends. For example, a sampling period which starts Friday night and ends Saturday night is referred to as a Saturday sampling period. This labeling method was selected because the maximum 8-hour exposure during a sampling period usually occurs during the latter half of the sampling period. Using this labeling method, the daily maximum 8-hour exposure values are distributed as follows:

Monday	78
Tuesday	90
Wednesday	105
Thursday	104
Friday	101
Saturday	100
Sunday	92
	670

If the values were evenly distributed among the days of the week, each day would have 95.7 values. The extremes are Monday (19% low) and Wednesday (10% high). If the values were proportionally distributed between weekdays and weekend days, the weekdays would have 478.6 values and the weekend days would have 191.4 values. The actual breakdown is 478 values for weekdays and 192 values for weekend days.

Table 6-5 lists summary statistics for the maximum 8-hour exposure values of the week. Monday and Friday vie for the high exposure day. Monday has the largest median exposure (4.6 ppm), the largest 75th percentile exposure (7.9 ppm), and the largest 99th percentile exposure (44.0 ppm). Friday has the largest mean exposure (6.4 ppm), the largest 90th percentile exposure (18.1 ppm), and the largest 98th percentile exposure (35.8 ppm). In a similar manner, Tuesday and Sunday vie for low exposure day.

The weighted average of the weekday means is 5.1 ppm; the weighted average of the weekend means is 4.6 ppm. The weighted average of the weekday medians is 4.1 ppm; the weighted average of the weekend medians is 3.4 ppm. These results suggest that weekdays have higher daily maximum 8-hour exposure values than weekend days ($\simeq$ 0.6 ppm higher).

6.5 DISTRIBUTION OF DIFFERENCES BETWEEN A AND B VALUES BY DAY OF THE WEEK

For each pair of A and B values, the differences $C = B - A$ and $D = \ln(B) - \ln(A)$ were determined. Tables 6-6 and 6-7 list summary statistics for the C and D values according to the day of the week of the A value.

PEI tested the null hypothesis that the median C or D value for each day is not greater than zero, i.e.,

$$H_o\text{: median} \leq 0.$$

TABLE 6-5. SUMMARY STATISTICS FOR DAILY MAXIMUM 8-HOUR CARBON MONOXIDE EXPOSURES

Statistic	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	All
Number of cases	78	90	105	104	101	100	92	670
Minimum, ppm	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.0
Maximum, ppm	44.0	16.1	15.0	22.1	38.7	34.8	25.5	44.0
Mean, ppm	5.7	3.8	4.6	5.0	6.4	4.9	4.3	5.1
Mode, ppm	a	2.6	a	2.3	a	1.4	a	a
Standard deviation, ppm	5.6	2.8	3.0	3.7	6.9	5.3	4.3	4.7
Std. skewness[b]	15.2	6.6	4.7	5.8	11.9	11.1	10.8	36.5
Std. kurtosis[c]	46.2	8.1	3.1	7.2	20.0	20.7	19.3	95.8
10th percentile, ppm	1.4	0.8	1.2	1.0	1.4	0.5	0.7	1.0
25th percentile, ppm	2.7	2.0	2.6	2.3	2.7	1.4	1.6	2.2
50th percentile, ppm	4.6	3.2	4.0	4.3	4.5	3.5	3.2	3.9
75th percentile, ppm	7.9	5.0	5.9	7.2	7.5	6.3	5.2	6.6
90th percentile, ppm	9.6	6.7	8.7	9.7	12.3	8.9	9.4	9.7
95th percentile, ppm	13.5	8.5	10.3	11.2	18.1	15.3	11.1	12.8
98th percentile, ppm	16.1	13.4	13.7	12.0	35.8	19.3	25.0	17.6
99th percentile, ppm	44.0	16.1	14.2	16.9	36.8	24.4	25.5	25.0

[a] Not unique.

[b] Std. skewness = $g_1/\sqrt{6/n}$.

[c] Std. kurtosis = $g_2/\sqrt{24/n}$.

TABLE 6-6. SUMMARY STATISTICS FOR C DIFFERENCE VALUES[a]

Statistic	Day of A value						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Number of differences	36	53	52	52	49	50	42
Minimum, ppm	5.4	-5.2	-7.0	-8.1	-20.3	-23.7	-7.3
Maximum, ppm	-41.4	6.0	11.8	32.1	6.4	16.7	10.4
Mean, ppm	-1.5	1.4	1.1	2.3	-1.0	-1.0	1.9
Mode, ppm	b	1.7	b	b	b	b	2.0
Standard deviation, ppm	7.5	2.4	4.0	5.9	5.2	5.7	3.7
Std. skewness[c]	-10.0	-0.7	1.4	8.4	-3.4	-2.6	0.1
Std. kurtosis[d]	23.4	-0.2	-0.2	16.1	2.6	6.5	0.3
5th percentile, ppm	-5.7	-2.3	-4.9	-2.6	-9.6	-9.6	-4.1
10th percentile, ppm	-5.6	-1.7	-3.4	-2.0	-7.2	-8.0	-2.1
25th percentile, ppm	-3.3	0.1	-1.5	-0.3	-4.2	-2.8	-0.1
50th percentile, ppm	0.1	1.7	0.6	1.2	0.4	-0.6	1.4
75th percentile, ppm	1.5	2.8	3.0	2.7	3.1	2.6	3.7
90th percentile, ppm	3.7	4.6	6.1	6.4	4.3	4.2	7.0
95th percentile, ppm	5.4	5.8	8.8	16.6	5.0	4.7	8.6
Percentage exceeding zero	52.8	77.4	57.7	73.1	53.1	48.0	73.8

[a]C = B - A.

[b]Not unique.

[c]Std. skewness = $g_1/\sqrt{6/n}$.

[d]Std. kurtosis = $g_2/\sqrt{24/n}$.

TABLE 6-7. SUMMARY STATISTICS FOR D DIFFERENCE VALUES[a]

Statistic	Day of A value						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Number of differences	36	53	52	52	49	50	42
Minimum, ppm	-2.8	-2.3	-3.6	-1.4	-4.2	-5.1	-2.4
Maximum, ppm	2.9	4.2	5.9	2.5	2.3	5.0	5.3
Mean, ppm	0.0	0.6	0.1	0.4	-0.3	-0.1	0.5
Mode, ppm	b	b	b	1.1	b	b	0.4
Standard deviation, ppm	1.1	1.0	1.5	0.7	1.4	1.6	1.1
Std. skewness[c]	0.4	1.9	2.0	1.4	-1.7	0.1	4.0
Std. kurtosis[d]	0.9	3.3	5.1	1.3	-0.4	2.6	8.1
5th percentile, ppm	-1.7	-1.1	-2.4	-0.9	-2.7	-2.8	-0.6
10th percentile, ppm	-1.0	-0.4	-1.8	-0.4	-2.4	-1.9	-0.4
25th percentile, ppm	-0.8	0.0	-0.4	-0.1	-1.2	-0.9	0.0
50th percentile, ppm	0.0	0.4	0.1	0.4	0.2	-0.2	0.4
75th percentile, ppm	0.5	1.0	0.8	0.6	0.8	0.7	0.9
90th percentile, ppm	1.2	1.8	1.5	1.2	1.2	1.6	1.5
95th percentile, ppm	2.1	2.3	2.2	2.0	1.6	2.3	2.2
Percentage exceeding zero	52.8	77.4	57.7	73.1	53.1	48.0	73.8

[a] $D = \ln(B) - \ln(A)$.

[b] Not unique.

[c] Std. skewness $= g_1/\sqrt{6/n}$.

[d] Std. kurtosis $= g_2/\sqrt{24/n}$.

The test statistic is

$$T = (2N - n)/\sqrt{n} \qquad (6\text{-}3)$$

where N is the number of positive values and n is the total number of values. For $n > 25$, T follows the unit normal distribution.[1] Table 6-8 lists the results of this test. The results apply to both the C and D values. Since Tuesday, Thursday, and Sunday have p values less than 0.05, one can conclude that the median C and D values for these days are significantly greater than zero and thus that B values tend to be larger than A values. The medians for the other days are not significantly larger than zero.

As Table 6-6 indicates, the median C values for Tuesday, Thursday, and Sunday are 1.7 ppm, 1.2 ppm, and 1.4 ppm, respectively. Since one would expect weekday exposures to be somewhat uniform, it is surprising that for 50 percent of the subjects Wednesday exposures exceed Tuesday exposures by at least 1.7 ppm and Friday exposures exceed Thursday exposures by at least 1.2 ppm. The Sunday result is not particularly surprising, however, as one would expect the Sunday exposure of a typical subject to be less than his or her Monday exposure.

One possible explanation for the unexpected results for Tuesday and Thursday is that the ambient CO concentrations during the Denver CO study may have been higher on Wednesdays and Fridays than on other days. An investigation of this hypothesis had not been carried out at the time of this report.

6.6 REFERENCE

1. Pollard, J. H. A Handbook of Numerical and Statistical Techniques. Cambridge University Press, London. 1977.

TABLE 6-8. RESULTS OF NONPARAMETRIC TEST OF NULL HYPOTHESIS THAT MEDIAN C OR D VALUE IS NOT GREATER THAN ZERO

Statistic	Day of A value						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
n	36	53	52	52	49	50	42
N	19	41	30	38	26	24	31
T	0.33	3.98	1.11	3.33	0.43	-0.28	3.09
p	0.37	<0.01	0.13	<0.01	0.33	0.61	<0.01

SECTION 7

TIME SPENT IN SELECTED MICROENVIRONMENTS

One of the principal reasons for collecting activity diary data during the Denver study was to provide a means for relating exposure to a subject's microenvironment, i.e., the subject's immediate physical surroundings. As illustrated in Section 3.6 of Reference 1, the codes assigned to activity diary entries can be combined in a variety of ways to designate microenvironments of interest. In the initial analyses, four-digit microenvironment codes were created by combining the two-digit B (location) code with the two-digit D3 (transit mode) code. Examples of microenvironment codes occurring in the SAMPLE-DATA file include 0193 (in transit - motorcycle), 52bb (indoors - public garage), and 09bb (uncertain).

Table IV in Appendix A lists the weighted mean (in minutes) of the occupancy periods for each microenvironment except indoors - residence (Code 02bb). An occupancy period begins when a subject enters a new microenvironment and ends when the subject leaves the microenvironment. Mean occupancy periods for the indoor residential microenvironment could not be determined accurately from activity diary data because subjects were usually occupying residences before the first diary entry and after the last diary entry.

Mean occupancy periods range from 431.9 minutes (indoors - manufacturing facility) to 7.4 minutes (outdoors - residential garage or carport). Mean occupancy periods for in-transit microenvironments associated with motor vehicles and high CO levels are 30.8 minutes for trucks, 28.0 minutes for buses, 25.9 minutes for cars, and 23.0 minutes for motorcycles. The value for indoors - public garage (29.4 minutes) is higher than expected and may be the result of errors in recording activity diary information.

Statistics have also been compiled on the total time spent per day in selected microenvironments. Table 7-1 lists 10 microenvironments of particular interest to EMSL and percentiles (weighted) for the total time spent per day in each (here labeled total person-day exposure duration). Also

TABLE 7-1. WEIGHTED SUMMARY STATISTICS FOR CO EXPOSURES BY MICROENVIRONMENT CONSIDERING ONLY PERSON-DAYS WITH NONZERO EXPOSURE DURATIONS[a]

Microenvironment	Number of person-days with nonzero durations	CO exposure, ppm			Percentiles for total person-day exposure duration, minutes				
		Mean	Std. dev.	Std. error	10%	25%	50%	75%	90%
Indoors - parking garage	31	18.8	27.6	4.96	3	6	14	60	120
In transit - car	643	8.0	8.1	0.32	30	48	71	114	166
In transit - other	107	7.9	6.3	0.61	19	44	66	125	196
Outdoors - near roadway	188	3.8	4.9	0.36	5	8	33	77	102
In transit - walking	171	4.2	5.9	0.45	6	11	28	52	124
Indoors - restaurant	205	4.2	4.1	0.29	22	34	58	85	232
Indoors - office	283	3.0	3.4	0.20	70	229	478	541	628
Indoors - store/mall	243	3.0	3.5	0.22	11	21	50	88	170
Indoors - residence	776	1.7	2.7	0.10	668	820	975	1225	1359
Indoors - total	776	2.1	2.5	0.09	1162	1263	1343	1381	1408

[a]Standard error statistics are approximations.

listed are the mean CO exposures reported for each microenvironment. Note that person-days with zero time spent in a particular microenvironment were not considered in calculating these statistics.

The Strategies and Air Standards Division of EPA has developed the NAAQS Exposure Model (NEM) as a means of estimating human exposure to criteria pollutants such as CO and ozone. Six microenvironments have been defined for NEM analyses of CO exposure. Table 7-2 shows how the microenvironments defined for the Denver study can be aggregated into the six NEM microenvironments. The E2 diary entry (gas stove) was used to determine whether or not a gas stove was in operation.

Omitting all data flagged as invalid, PEI calculated various unweighted summary statistics on time spent per day in each microenvironment (Table 7-3). Median times are 76 minutes for motor vehicles, 0 minutes for indoors-residence (gas stove on), 980 minutes for indoors-residence (no gas stove or gas stove off), 207 minutes for indoors-other locations, 0 minutes for outdoors-near road, and 0 minutes for outdoors-other locations. Statistics on time spent in activities for which the microenvironment was not recorded are provided in the column labeled "uncategorized time." Statistics on the duration of each sampling period (nominal duration = 24 hours or 1440 minutes) are provided in the column labeled "all microenvironments."

Table 7-4 is similar to Table 7-3 except that person-days with zero time spent in a microenvironment are not considered in calculating the summary statistics for that microenvironment. As expected, median times are higher: 83 minutes for motor vehicles, 80 minutes for indoors-residence (gas stove on), 985 minutes for indoors-residence (no gas stove or gas stove off), 299 minutes for indoors-other locations, 35 minutes for outdoors-near road, and 26 minutes for outdoors-other locations.

Although the study covered a period of cold weather (November-February), it is nevertheless surprising that the Denver subjects spent so little time outdoors. Subjects were instructed to record all activities expected to last 5 minutes or more. Yet 59.0 percent of the person-days contained no entries categorized as outdoors-near road, and 85.5 percent of the subject-days contained no entries categorized as outdoors-other.

Another somewhat surprising result is the large quantity of time spent in motor vehicles. More than 90 percent of the person-days contained entries

TABLE 7-2. AGGREGATION OF MICROENVIRONMENTS DEFINED FOR DENVER CARBON MONOXIDE STUDY INTO MICROENVIRONMENTS DEFINED FOR NEM ANALYSES OF CARBON MONOXIDE EXPOSURE

NEM microenvironment	Denver CO study microenvironment: Code	Denver CO study microenvironment: Description
Motor vehicle	0102	In transit - car
	0103	In transit - bus
	0104	In transit - truck
	0193	In transit - motorcycle
	5202	Indoors - public garage (in car)
	7202	Outdoors - public garage (in car)
	7302	Outdoors - parking lot (in car)
	7303	Outdoors - parking lot (in bus)
Indoors-residence (gas stove on)	02bb[a]	Indoors - residence
	51bb[a]	Indoors - residential garage
Indoors-residence (other)	02bb[c]	Indoors - residence
	51bb[c]	Indoors - residential garage
Indoors-other locations	03bb	Indoors - office
	0301	Indoors - office
	04bb	Indoors - store
	05bb	Indoors - restaurant
	52bb	Indoors - public garage
	5201	Indoors - public garage
	53bb	Indoors - manufacturing facility
	54bb	Indoors - service station or motor vehicle repair facility
	55bb	Indoors - other repair shop
	56bb	Indoors - auditorium, sports arena, concert hall, etc.
	57bb	Indoors - church
	58bb	Indoors - shopping mall
	59bb	Indoors - health care facility
	60bb	Indoors - school
	61bb	Indoors - other public building
	62bb	Indoors - other location
Outdoors-near road	0101	In transit - walking
	0192	In transit - bicycle
	07bb	Outdoors - within 10 yards of road
	0701	Outdoors - within 10 yards of road
	72bb	Outdoors - public garage
	7201	Outdoors - public garage
	7202	
	73bb	Outdoors - parking lot
	7301	Outdoors - parking lot

(continued)

TABLE 7-2 (continued)

NEM microenvironment	Denver CO study microenvironment	
	Code	Description
Outdoors-other locations	71bb	Outdoors - residential garage or carport
	74bb	Outdoors - service station or motor vehicle repair service
	76bb	Outdoors - residential grounds
	77bb	Outdoors - school grounds
	78bb	Outdoors - sports arena, amphi-theater, etc.
	79bb	Outdoors - park or golf course
	80bb	Outdoors - other location

[a]E2 = 01.

[b]Blank.

[c]E2 = 02.

TABLE 7-3. UNWEIGHTED SUMMARY STATISTICS FOR TIME SPENT PER DAY BY DENVER SUBJECTS IN MICROENVIRONMENTS USED IN NEM ANALYSES

Statistic	Motor vehicle	Indoors-residence (gas on[a])	Indoors-residence (other[b])	Indoors-other locations	Outdoors-near road	Outdoors-other locations	Uncategorized time	All microenvironments[c]
Cases	851	851	851	851	851	851	851	851
Minimum, minutes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1134.0
Maximum, minutes	1313.0	1373.0	1594.0	1329.0	778.0	972.0	445.0	1671.0
Mean, minutes	99.7	26.4	1004.2	259.7	25.0	10.2	17.8	1443.0
Mode, minutes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1442.0
Standard deviation, minutes	105.1	118.4	273.1	222.7	61.4	58.7	50.8	44.7
5th percentile, minutes	0.0	0.0	636.0	0.0	0.0	0.0	0.0	1375.0
10th percentile, minutes	8.0	0.0	717.0	0.0	0.0	0.0	0.0	1407.0
25th percentile, minutes	41.0	0.0	805.0	49.0	0.0	0.0	0.0	1430.0
50th percentile, minutes	76.0	0.0	980.0	207.0	0.0	0.0	0.0	1442.0
75th percentile, minutes	125.0	0.0	1231.0	475.0	25.0	0.0	2.0	1454.0
90th percentile, minutes	198.0	49.0	1360.0	557.0	71.0	12.0	54.0	1481.0
95th percentile, minutes	282.0	144.0	1412.0	608.0	134.0	41.0	126.0	1515.0
Percentage of zero values	9.5	85.3	0.7	17.3	59.0	85.5	73.8	0.0

[a]Gas stove on. [b]No gas stove or gas stove off. [c]Includes uncharacterized time.

TABLE 7-4. UNWEIGHTED SUMMARY STATISTICS FOR TIME SPENT PER DAY BY DENVER SUBJECTS IN MICROENVIRONMENTS USED IN NEM ANALYSES. STATISTICS FOR EACH MICROENVIRONMENT OMIT PERSON-DAYS WITH ZERO TIME SPENT IN THE MICROENVIRONMENT

Statistic	Motor vehicle	Indoors-residence (gas on[a])	Indoors-residence (other[b])	Indoors-other locations	Outdoors-near road	Outdoors-other locations	Uncategorized time	All micro-environments[c]
Cases	770	125	845	704	349	123	222	851
Minimum, minutes	2.0	1.0	3.0	2.0	1.0	1.0	1.0	1134.0
Maximum, minutes	1313.0	1373.0	1594.0	1329.0	778.0	972.0	445.0	1671.0
Mean, minutes	110.2	179.9	1011.3	313.9	61.1	70.8	68.2	1443.0
Mode, minutes	d	45.0	d	85.0	d	2.0	d	1442.0
Standard deviation, minutes	105.1	261.1	260.6	207.2	83.7	140.5	80.3	44.7
5th percentile, minutes	20.0	6.0	655.0	29.0	4.0	2.0	2.0	1375.0
10th percentile, minutes	29.0	10.0	728.0	54.0	6.0	4.0	4.0	1407.0
25th percentile, minutes	51.0	44.0	810.0	117.0	13.0	9.0	12.0	1430.0
50th percentile, minutes	83.0	80.0	985.0	299.0	35.0	26.0	37.0	1442.0
75th percentile, minutes	136.0	185.0	1231.0	504.0	70.0	62.0	102.0	1454.0
90th percentile, minutes	204.0	527.0	1360.0	572.0	142.0	161.0	187.0	1481.0
95th percentile, minutes	299.0	819.0	1412.0	617.0	214.0	307.0	245.0	1515.0

[a]Gas stove on.

[b]No gas stove or gas stove off.

[c]Includes uncharacterized time.

[d]Not unique.

categorized as "in motor vehicle." The median time spent in motor vehicles per day by persons using motor vehicles is 76 minutes (Table 7-4). Ten percent of those using motor vehicles spent 204 minutes (3.4 hours) or more in motor vehicles.

SECTION 8

FACTORS ASSOCIATED WITH INSTRUMENT FAILURE

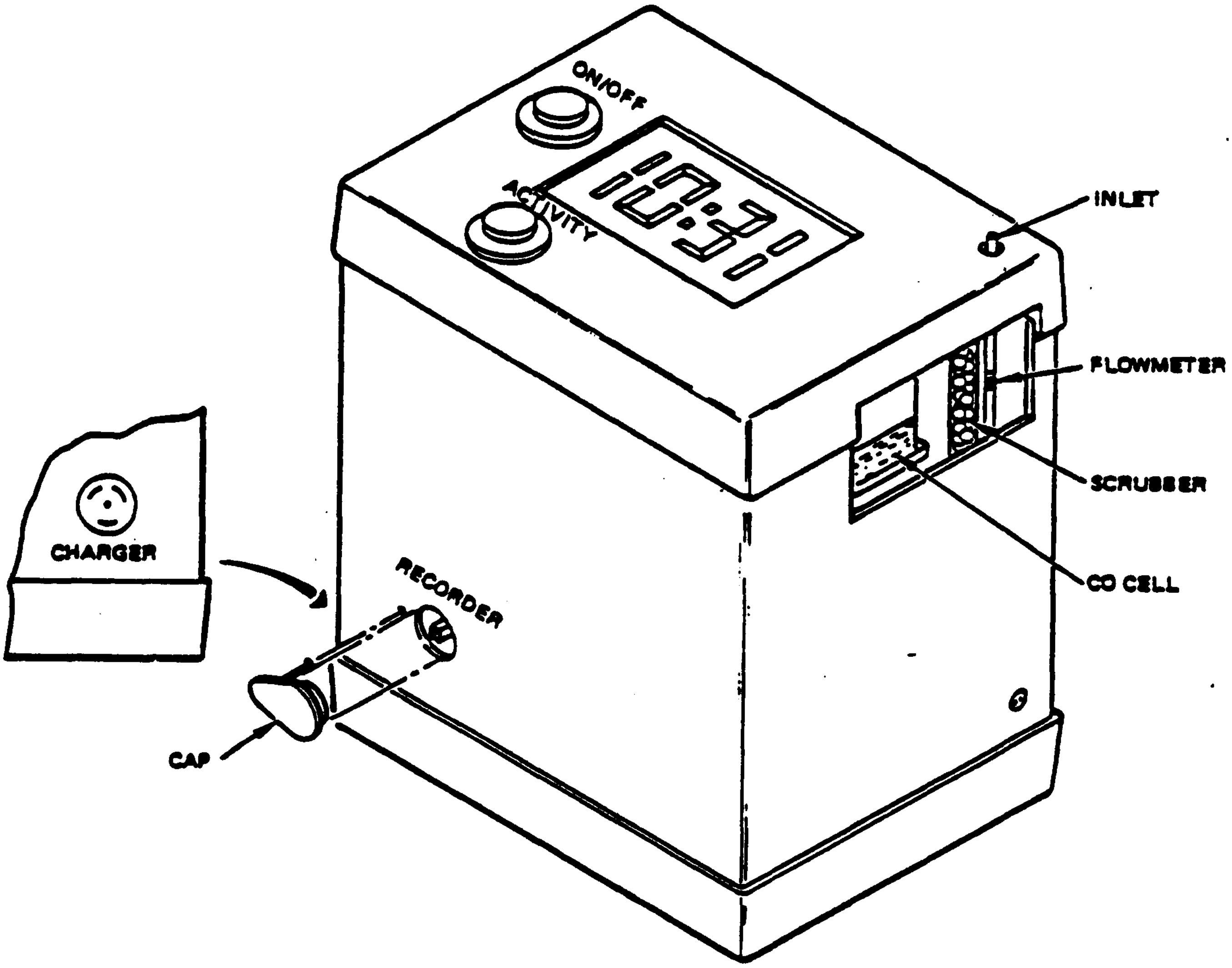
The personal exposure monitors (PEM's) used in the Denver study received zero-span checks before and after each sampling period and were frequently checked for loose connections, clogged pumps, and other conditions likely to cause failure under use. Despite these precautions, a small percentage of the units did fail. PEI was directed by EMSL to determine if some of these failures were related to temperature or other meteorological variables. This section contains a summary of PEI's analyses in this area.

8.1 PERSONAL EXPOSURE MONITOR

The PEM is a modified General Electric (GE) Carbon Monoxide Detector, Model 15EC53003, mated with a modified Magus DL-1 Data Logger and mounted in a compact, tamperproof casing. The PEM records the time and a CO concentration value every time the "activity button" on the top of the instrument is pushed and every hour on the hour. In both cases, the CO value is the absolute value of the integrated average CO concentration since the last recorded value. The PEM is capable of operating continuously for 24 hours and logging up to 113 data points.

Figure 8-1 shows the PEM controls, liquid crystal display (LCD), and access points with cover in place. The activity button is located under a flexible black cover on the left side of the instrument. The on/off push-button switch controls power from the battery pack to the pump. Power is constantly applied to the CO sensor cell to maintain its stability regardless of the position of the on/off switch. The on/off switch is located under a hard plastic cap and is not accessible to study participants.

An ambient air sample is drawn into the detector through a potassium permanganate filter by an integral sample air pump. The sample is discharged to the CO sensor cell, the CO is oxidized, and an electrical signal proportional



(SCALE 1:2 APPROXIMATELY)

Figure 8-1. Personal exposure monitor.

to the CO level is produced. The air sample is then exhausted through the flow indicator inside the case. The filter provides selectivity of the detector to CO by removing most interfering gases. Hydrogen, ethylene, and acetylene are potential interferents that may not be completely removed by the filter.

Under normal operating conditions, the LCD displays the time. When the activity button is pressed, the LCD momentarily displays the word GULP to indicate that the instrument has received the signal to log data.

Procedures for calibrating and programming the PEM are discussed in Section 4.5 of the report by Johnson.[1] The general specifications of the instrument are listed in Table 3-1 of the same report.

8.2 DATA BASE

Two sets of PEM's were used during the course of the Denver CO Study. The primary set contained 26 PEM's that were used throughout the Denver study. A supplementary set of six PEM's were put into operation on February 9, 1983, and were used during the remainder of the study. These six PEM's had been used previously by RTI as part of the parallel study of CO exposure in Washington, D.C., which ended February 7, 1983. Consequently, each of the 32 PEM's used in the Denver study experienced several months of constant use.

A log was maintained on each PEM, which listed all instances <u>during the Denver study</u> in which the PEM failed a zero-span check, all other instrument failures that occurred (whether or not data were affected), and any other situations in which nonroutine servicing was performed. Table N-1 in the report by Johnson[1] lists all malfunctions recorded in these logs. PEI identified a subset of these malfunctions which might be temperature-related. Table 8-1 lists these malfunctions and assigns each an individual failure mode code (1, 2, ..., 7) and group failure mode (A, B, or C). Group A contains failure modes related to zero-span problems. Group B contains failure modes related to problems with the MAGUS unit. In each case the MAGUS unit switched from the normal data-recording mode (LOG) into an alternative mode (ALOG, SCLR, DONE, or unspecified). A third group, Group C, was formed by combining Group B and Failure Mode 7 ("lock-up"). When a PEM locked-up,

TABLE 8-1. PEM FAILURE MODES ANALYZED BY LOGISTIC REGRESSION MODEL

Group[a]	Failure mode	Failure description
A	1	PEM failed zero-span check
	2	PEM exhibited excessive zero and/or span drift
B	3	MAGUS switched to unspecified mode
	4	MAGUS switched to ALOG mode
	5	MAGUS switched to SCLR mode
	6	MAGUS switched to DONE mode
-	7	No change in time displayed and no data stored ("lock up")

[a]Group C combines Failure Modes 3 through 7.

the liquid crystal display (LCD) display and MAGUS data subsystem stopped working, the LCD time did not advance, and the MAGUS data subsystem would not log CO data.

A computer file was constructed listing 1) the number of PEM's which malfunctioned during each 24-hour sampling period by individual failure mode, 2) the maximum temperature (TMAX) of the day on which the sampling period ended, 3) the minimum temperature (TMIN), and 4) the mean temperature (TAVG). This computer file comprised the entire data base used in the analysis discussed below.

8.3 MODEL USED FOR STATISTICAL ANALYSIS

The proportion (PROPN) of PEM's associated with a given temperature and a given individual failure mode (or failure mode group) was assumed to follow the logistic regression model (LRM)

$$E\left[\log_e\left(\frac{\text{PROPN}}{1-\text{PROPN}}\right)\right] = \alpha + \beta_i * G(T_i), \qquad (8\text{-}1)$$

where E is expectation; α is a constant; β_i, i = 1,2,3, are regression coefficients; $G(T_1)$ = TMAX; $G(T_2)$ = TMIN; and $G(T_3)$ = TAVG. Regression coefficients were estimated by the method of maximum likelihood, as implemented in program PLR of the BMDP statistical software package. Models with more than one explanatory variable (EV); e.g.,

$$\alpha + \sum_{i=1}^{2} \beta_i * G(T_i),$$

$$E\left[\log_e\left(\frac{PROPN}{1-PROPN}\right)\right] = \alpha + \sum_{i=1}^{3} \beta_i * G(T_i), \tag{8-2}$$

etc.

were found to provide no improvement in fit over models with a single explanatory variable and are not discussed here.

8.4 TEST STATISTICS

Two basic test statistics were provided in the output of each run of the PLR program. They were 1) the approximate F statistic, and 2) the improvement chi-square statistic.

8.4.1 Approximate F Statistic

In linear logistic regression, the expected value of the logit of the observed proportions is a linear function of one (or more) explanatory variable(s). Consider a design with one EV. For each discrete value of the EV, the corresponding observed proportion is an unbiased estimate of a Bernouilli parameter θ which is the probability of failure in a single event given the value of the EV; that is,

$$E(X) = n\theta \tag{8-3}$$

$$VAR(X) = n\theta(1-\theta) \tag{8-4}$$

where X = number of failures and n = number of events (or trials). In the case that θ is known for each discrete value of the EV, the weights for weighted linear regression are given by the expression

$$\text{weight} = \sqrt{n\theta(1-\theta)}\ , \tag{8-5}$$

and the response variables are given by the expression

$$\text{response variable} = \log_e \left(\frac{\text{PROPN}}{1\text{-PROPN}}\right) . \qquad (8\text{-}6)$$

Because the value of θ is unknown, the weighted linear regression can be done only approximately. In fact, one uses in place of θ, its estimate x/n. Consequently, an "approximate" F statistic is computed in weighted linear regression to test the significance of the addition, or removal, of regression terms.

8.4.2 Improvement Chi-Square Statistic

The extremum of the logarithm of the likelihood function is determined with, and without, a designated regression term in the model. Twice the natural logarithm of the ratio of the two extrema is distributed, asymptotically, as a chi-square random variable with one degree of freedom. The results of applying this test to the data are similar to those obtained with the approximate F test discussed above.

8.5 DISCUSSION OF RESULTS

Results for individual failure modes are displayed in Table 8-2. For Failure Modes 1, 2, and 7 the regression coefficients are significant (i.e., $p < 0.05$), and the LRM is judged to provide a good fit. For Failure Mode 1, each of the temperature measures can be used to "explain" the data. For Failure Mode 2, the variable TMIN is an appropriate EV. For Failure Mode 7, both TMAX and TAVG are qualified EV's. With respect to Failure Modes 3 through 6, no statistical significance was found; consequently, no temperature dependence is inferred.

The regression coefficients have a negative sign for Failure Mode 1 and positive signs for Failure Modes 2 and 7. With increasing temperature, the proportion of failures decreases for Failure Mode 1, increases for Failure Mode 2, and increases for Failure Mode 7.

The analysis was repeated using grouped failure modes. As discussed above, Group A contains Failure Modes 1 and 2, which involve zero/span problems. Group B contains Failure Modes 3 through 6, which involve problems with the MAGUS unit.

TABLE 8-2. RESULTS OF FITTING LOGISTIC REGRESSION MODEL TO FAILURE DATA

		Temperature-related variable											
		TMAX				TMIN				TAVG			
FM[a]	FC[b]	β	c	Value	p	β	c	Value	p	β	c	Value	p
1	31	-0.076	F	15.20	0.000	-0.098	F	7.41	0.007	-0.117	F	15.02	0.001
			X^2	15.79	0.000		X^2	7.77	0.005		X^2	16.29	0.000
2	2	d	F	d	d	0.381	F	6.75	0.010	d	F	d	d
			X^2	d	d		X^2	6.78	0.009		X^2	d	d
3	2	d	F	d	d	d	F	d	d	d	F	d	d
			X^2	d	d		X^2	d	d		X^2	d	d
4	25	d	F	d	d	d	F	d	d	d	F	d	d
			X^2	d	d		X^2	d	d		X^2	d	d
5	6	d	F	d	d	d	F	d	d	d	F	d	d
			X^2	d	d		X^2	d	d		X^2	d	d
6	4	d	F	d	d	d	F	d	d	d	F	d	d
			X^2	d	d		X^2	d	d		X^2	d	d
7	22	0.044	F	4.31	0.038	d	F	d	d	0.060	F	4.06	0.044
			X^2	4.28	0.039		X^2	d	d		X^2	3.95	0.047
A[e]	33	-0.065	F	11.97	0.001	-0.068	F	3.95	0.047	-0.093	F	10.76	0.001
			X^2	12.34	0.000		X^2	4.08	0.043		X^2	11.46	0.001
B[f]	37	d	F	d	d	d	F	d	d	d	F	d	d
			X^2	d	d		X^2	d	d		X^2	d	d
C[g]	59	0.023	F	3.06	0.081	d	F	d	d	0.036	F	3.62	0.057
			X^2	3.05	0.081		X^2	d	d		X^2	3.56	0.059

[a]FM = failure mode.
[b]FC = failure count.
[c]Statistic (F = approximate F, X^2 = improvement chi-square).
[d]Not significant at p = 0.10 level.
[e]Includes Failure Modes 1 and 2.
[f]Includes Failure Modes 3 through 6.
[g]Includes Failure Modes 3 through 7.

Group C consists of Failure Modes 3 through 7; in other words Groups B and Failure Mode 7 have been combined into one group.

The results for Group A are only slightly different than the results reported above for Failure Mode 1. Group B showed no temperature dependence based on 37 failure events. Statistical significance for Group C was not quite reached at a critical level of 0.05 (p = 0.0574 for TAVG) based on a total of 59 failure events. Grouping did not affect the sign of the regression coefficients.

8.6 CONCLUSIONS

The results of applying the logistic regression model to the data base described above suggest that PEM's used in the Denver study were more likely to experience zero-span problems on cold days and were more likely to experience lock-up on warm days. Problems with the MAGUS unit other than lock-up do not appear to be associated with temperature.

8.7 REFERENCE

1. Johnson, T. A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/54-84-014, March 1983.

SECTION 9

SUMMARY OF RESULTS

This section summarizes the major results of the statistical analyses described in Sections 2 through 8. Results of earlier analyses are summarized in Appendix A.

9.1 FIXED-SITE MONITORS

Ten of the 15 maximum values reported by Denver fixed-site monitors occurred during either the morning or the evening high traffic period (8:00, 17:00, or 18:00). Four of the 15 maximum values occurred on January 27, 1983. The maximum value in the composite data set was 15.8 ppm and occurred at 8:00 on December 17, 1982.

Two of the permanent Denver monitors (Map Codes A and B) and three of the temporary monitors (Map Codes D, F, and J) reported daily maximum 8-hour values exceeding 15 ppm. These five monitors were all located in the central business district of Denver, an area of high traffic density.

Stepwise linear regression results suggest that hourly average CO concentration at the Denver composite site increases with maximum daily temperature, decreases with minimum daily temperature, and decreases with windspeed. The modeled relationship is weak, however ($R^2 = 0.12$).

Denver experienced much higher ambient CO levels during the study period than did Washington. With respect to the composite daily maximum 1-hour CO concentrations, Denver had a mean of 6.6 ppm--more than twice Washington's mean of 3.2 ppm.

9.2 RELATIONSHIPS BETWEEN EXPOSURES AND FIXED-SITE READINGS

Stepwise linear regression analyses of Denver data suggest that 1-hour values reported by a particular fixed-site monitor or "optimized" group of monitors do not provide a good means of predicting simultaneous PEM values. The site at 2105 Broadway produced the largest R^2 value (0.049) when sites were considered individually.

Linear regression analyses relating Washington PEM values grouped by microenvironments to 1-hour readings reported by the nearest fixed-site or the composite site yielded R^2 values from 0.00 to 0.66 for nontransit microenvironments and from 0.01 to 0.61 for in-transit microenvironments. Microenvironments with relatively large R^2 values include indoors-hospital (0.66), indoors-church (0.60), indoors-garage (0.19), outdoors-park (0.15), train/subway (0.61), jogging (0.30), truck (0.17), and bicycle (0.16). Results suggest that in-transit PEM values are better paired to fixed-site values reported by the composite site or site nearest the end address than to those reported by the site nearest the start address. A similar analysis of Denver data is summarized in Appendix A.

Based on linear regression analysis, the adjustment of Denver PEM values by subtracting the simultaneously recorded fixed-site value does not appear to be a promising approach for characterizing indoor sources of CO.

Linear regression analyses suggest that composite fixed-site daily maximum values are poor predictors of daily maximum exposures (1-hour and 8-hour) in Denver.

The results of t tests and various nonparametric tests suggest that daily maximum 8-hour exposures in Denver are higher on days when fixed-site daily maximum 8-hour values exceed 9 ppm.

9.3 RELATIONSHIP BETWEEN EXPOSURES AND SELECTED EXPLORATORY VARIABLES

A series of exploratory analyses were conducted to identify factors associated with "Group H" person-days, that is, person-days for which the daily maximum 8-hour exposure exceeds 9 ppm. Group L contains the remaining person-days. The following results apply to the Denver study only.

1. Person-days in Group H exhibited higher CO levels in most microenvironments.
2. The microenvironments which were visited more often during Group H person-days than would be expected are all associated with either outdoor locations and/or motor vehicles. Indoors-service station and outdoors-public garage have particular large OER values.

3. The average durations of visits to the outdoors-service station and indoor-restaurant microenvironments are larger for Group H than for Group L person-days.
4. The microenvironment "outdoors - within 10 years of road" is associated with Group H person-days when it is located in an area with high ambient CO levels.
5. The microenvironments "indoor - public garage" and "indoor - service station" are associated with Group H person-days in areas with relatively low ambient CO levels.
6. Of the in-transit microenvironments, only "truck" is associated with Group H person-days when the start or end location of the trip is in a high ambient CO location. "Motorcycle" is associated with Group H for low ambient CO locations.
7. Group H person-days are strongly associated with periods of high ambient CO concentration, particularly November 5 and December 9, 1982.
8. The aggregate occupation category "work which may involve proximity to running motor vehicles or internal combustion engines in enclosed space" is strongly associated with Group H person-days.

Results of analyses of variance and covariance performed on Denver in-transit exposure data support the following conclusions:

1. The two motor vehicle categories (car and other) are associated with higher exposures than walking. Exposures in these two categories are particularly high during the time periods 6-9 and 16-19. These two periods bracket the morning and afternoon rush hours.
2. The presence of smokers does not increase exposure.
3. Exposure decreases as duration increases.

Similar analyses performed on the Washington in-transit exposure data support the following conclusions:

1. Exposure varies with mode-of-travel, time-of-day, and presence of smokers.
2. No associations exists between exposure and duration.

Analyses of variance performed on indoor exposure data from the Denver study support the following conclusions:

1. CO exposures are higher in homes having living areas of 1000 ft^2 or less.

2. CO exposures are higher in homes where gas cooking stoves or gas clothes dryers are used (vented or not vented).
3. CO exposures are higher in homes where unvented gas furnaces or space heaters are used.
4. Venting of gas furnaces and space heaters decreases CO exposure in the home.
5. CO exposures are higher in homes which have storm windows, storm doors, or special dampers.
6. CO exposures are higher in homes where the main heating source is either a portable room heater or gravity gas system.
7. CO exposures are lower in homes where the main heating system consists of built-in electric units.
8. CO exposures are higher in work places where the main heating system consists of nonportable heaters burning gas, oil, or kerosene.
9. In homes without a gas cooking stove, the presence of a space heater significantly increases exposure.
10. In homes with gas cooking stoves, the presence of a space heater does not significantly increase exposure.

9.4 MODELS FOR PREDICTING EXPOSURE IN DENVER

A series of 14 general models for predicting exposure in Denver were proposed and evaluated in a sequential manner such that the results of each evaluation were considered in constructing the next general model. The parameters considered in the general models included data obtained from the activity diaries, the background questionnaire completed by each participant, the fixed-site monitors, and a meteorological file containing data on temperature and daily average wind speed. Model evaluation was accomplished by performing step-wise linear regression on each general model and noting 1) which terms were retained in the "best-fit" model and 2) the R^2 value associated with the best-fit model.

The best-fit model yielding the largest R^2 values (0.34) is

$$(\hat{C}_{PEM}^{0.40} - 1)/0.40 = -0.068 + (0.11)(C) + (0.68)(GAS) - (0.32)(P1)(M4) - (0.65)(P2)(M4) + (1.56)(P2)(M5) + (1.72)(P3)(M5) + (1.43)(P4)(M5) + (0.19)(C)(M5) + (0.27)(C)(M7) + (1.05)(SMOKE)(M5) + (1.15)(IH)(GCS)(P4) - (0.51)[\ln(WIND)](M4) + (15.2)(WIND)^{-1}(M1) + (0.23)(C1)(M2) + (0.22)(C1)(M4) + (0.13)(C)(M3),$$

where $\hat{C}_{PEM}$ is the estimated PEM value. The other terms are defined in Table 5-6. The three most important terms in the model with respect to increasing the R^2 value are related to wind speed given a low exposure indoor microenvironment [ln(WIND)](M4), to simultaneous fixed-site readings (C), and to high-exposure in-transit microenvironments (M5).

Four terms (M1, M2, M3, and M4) which appear in the general models relate to aggregate indoor microenvironments. These were defined through the use of a pairwise comparison procedure which aggregated similar microenvironments into groups which differ significantly one from another with respect to CO exposure. Table 5-22 lists the four aggregate indoor microenvironments.

9.5 COMPARISON OF CONSECUTIVE DAILY MAXIMUM EXPOSURES

The subjects in the Denver study were requested to participate for two consecutive 24-hour sampling periods. An analysis of the resulting PEM data revealed that a pair of valid daily maximum 8-hour exposure values (i.e., one for each sampling period) could be calculated from the data obtained from each of 335 subjects. The first of the two values in each pair is referred to as the A value; the second of the two values is the B value. The results of a series of statistical analyses support the following conclusions:

1. The distribution of A values differs significantly from the distribution of B values ($p < 0.05$).
2. The mean difference between paired A and B values differs significantly from zero ($p < 0.05$).
3. The A and B values are not highly correlated ($R^2 = 0.16$).
4. Weekdays have higher daily maximum 8-hour exposures than weekend days ($\simeq$ 0.6 ppm higher).

9.6 TIME SPENT IN SELECTED MICROENVIRONMENTS

The Strategies and Air Standards Division of EPA has developed the NAAQS Exposure model (NEM) as a means of estimating human exposure to criteria pollutants such as CO and ozone. Six microenvironments have been defined for NEM analyses of CO exposure. Table 7-2 shows how the microenvironments defined for the Denver study can be aggregated into the six NEM microenvironments. The E2 diary entry (gas stove) was used to determine whether or not a gas stove was in operation.

Omitting all data flagged as invalid, PEI calculated various unweighted summary statistics on time spent per day in each microenvironment. Median times are 76 minutes for motor vehicles, 0 minutes for indoors-residence (gas stove on), 980 minutes for indoors-residence (no gas stove or gas stove off), 207 minutes for indoors-other locations. Statistics on time spent in activities for which the microenvironment was not recorded are provided in the column labeled "uncategorized time." Statistics on the duration of each sampling period (nominal duration = 24 hours or 1440 minutes) are provided in the column labeled "all microenvironments."

Different results occur when person-days with zero time spent in a microenvironment are excluded when calculating the summary statistics for that microenvironment. As expected, median times are higher: 83 minutes for motor vehicles, 80 minutes for indoors-residence (gas stove on), 985 minutes for indoors-residence (no gas stove or gas stove off), 299 minutes for indoors-other locations, 35 minutes for outdoors-near road, and 26 minutes for outdoors-other locations.

More than 90 percent of the person-days contained entries categorized as "in motor vehicle." The median time spent in motor vehicles per day by persons using motor vehicles is 76 minutes. Ten percent of those using motor vehicles spent 204 minutes (3.4 hours) or more in motor vehicles.

9.7 FACTORS ASSOCIATED WITH INSTRUMENT FAILURE

A logistic regression model was used to evaluate the relationship between the fraction of PEM's failing each day and three indicators of ambient temperature: daily maximum temperature (TMAX), daily minimum temperature (TMIN), and daily mean temperature (TAVE). PEM failures were grouped into seven failure modes. The results of the analysis suggest that PEM's used in the Denver study were more likely to experience zero-span problems on cold days and were more likely to experience lock-up on warm days. Problems with the MAGUS unit other than lock-up do not appear to be associated with temperature.

APPENDIX A

A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado

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Introduction

The National Ambient Air Quality Standard (NAAQS) for carbon monoxide (CO) states that 1-hour CO concentrations shall not exceed 35 ppm more than once per year and that 8-hour CO concentrations shall not exceed 9 ppm more than once per year. Compliance with these standards is usually determined by fixed-site monitoring data. However, fixed-site monitoring data may not provide an accurate indication of personal exposure within an urban population, which is a function of both geographic location (e.g., downtown versus suburbia) and immediate physical surroundings (e.g., indoors versus outdoors). Better estimates of personal exposure can be developed by equipping a large number of subjects with portable monitors and activity diaries. If the subjects are properly selected, their exposures can be extrapolated to the larger urban population.

Such a study was conducted in Denver, Colorado, by PEDCo Environmental, Inc., for the Environmental Monitoring Systems Laboratory (EMSL) of the U.S. Environmental Protection Agency (EPA). Each of 454 subjects was asked to carry a personal exposure monitor (PEM) and an activity diary for two consecutive 24-hour sampling periods and to provide a breath sample at the end of each sampling period. Each participant also completed a detailed background questionnaire. The questionnaire results and approximately 900 subject-days of PEM and activity diary data collected between November 1, 1982, and February 28, 1983, were analyzed to determine if factors such as microenvironment and the presence of indoor CO sources significantly affect personal CO exposure. In addition, the exposure of the entire Denver population was extrapolated from exposures recorded by the study participants. PEDCo also compared CO levels recorded by fixed-site monitors to levels recorded simultaneously by PEM's.

Sample Selection

The target population of the study included all noninstitutionalized, nonsmoking residents of the urbanized portion of the Denver, Colorado, metropolitan area who were between 18 and 70 years of age at the time of the study. Research Triangle Institute (RTI) and PEDCo developed a two-phase scheme for sampling this population, which is estimated to be 245,000. In the first phase, a two-stage sample of housing units was selected. Data on the individuals residing within these housing units were collected using a brief screening questionnaire administered by telephone or in the field. Individuals who exhibited rare characteristics with respect to CO exposure were identified and oversampled in the second-phase of sample selection.

Individuals entered the sample by three paths. The majority of study participants (402) were identified by means of a telephone screening questionnaire administered to members of housing units appearing on a list prepared by Donnelley Marketing Information Services. The remaining 52 study participants were identified by field screening of housing units which 1) appeared on the Donnelley list but for which no telephone number was available or 2) were identified through a special survey of housing units which did not appear on the Donnelley list. The original sample selection protocol was designed to yield 500 study participants. The reduced sample size (454) resulted from a higher than expected refusal rate and unexpected equipment problems early in the study.

Further information on sample selection is provided by Johnson[1] and by Hartwell, et al.[2]

Data Collection Instruments and Procedures

The data collection instruments used in the Denver CO study included three questionnaires [screening questionnaire, computer model input questionnaire (CMIQ), and participant questionnaire] providing background data on subjects and their families, a network of 15 fixed-site monitors, the PEM's and activity diaries carried by each subject, and breath sample bags. These instruments and the procedures employed in using them are described in detail by Johnson.[1]

The screening questionnaire was administered on a household basis as a means of identifying persons eligible for the study. It requested the name of each household member, relationship to head of household, sex, age, smoking status, occupation, and typical commute time. The completed screening questionnaires yielded a list of 2232 eligible individuals from which were selected a stratified sample of 1139 potential subjects. An attempt was made to administer the CMIQ to each potential subject. Part A of the CMIQ requested detailed data about the commuting habits of the respondent's household and determined if any member of the household was employed in one of nine occupational categories associated with high CO exposure. These data were collected for use in SHAPE, a population exposure model developed by Wayne Ott,[3] and NEM, a population exposure model developed by the Strategies and Air Standards Division of EPA.[4] Part B of the CMIQ verified the respondent's address and attempted to set up an appointment for the first visit by an interviewer. The participant questionnaire was administered to each of the 454 persons who actually participated in the study. It included detailed questions about the subject's home environment, work environment, commuting habits, occupation, leisure-time activities, and shopping habits. The participant questionnaire also requested age, sex, and education data.

A PEM and an activity diary were provided to each subject for each of two 24-hour periods. The PEM was a modified General Electric (GE) Carbon Monoxide Detector, Model 15EC53003, mated with a modified Magus DL-1 Data Logger and mounted in a compact, tamperproof casing (Figure 1). The PEM recorded the time and a CO concentration value every time the "activity button" on the top of the instrument was pushed and every hour on the hour. In both cases, the CO value was the integrated average CO concentration since the last recorded value. Each PEM was capable of operating continuously for 24 hours and logging up to 113 data points. Quality assurance activities associated with the PEM's included daily zero-span checks, frequent multipoint calibrations, special studies evaluating precision, and two independent audits.

The activity diary contained instructions for completing the diary, examples of properly completed diary pages, and 64 blank pages for recording activities. The subject was instructed to fill out a diary page whenever the subject changed location or activity. Data entered on each diary page included time, activity (e.g., cooking dinner), location (e.g., indoors residence), address, mode of transit if applicable, and whether smokers were present (Figure 2). For indoor locations, subjects

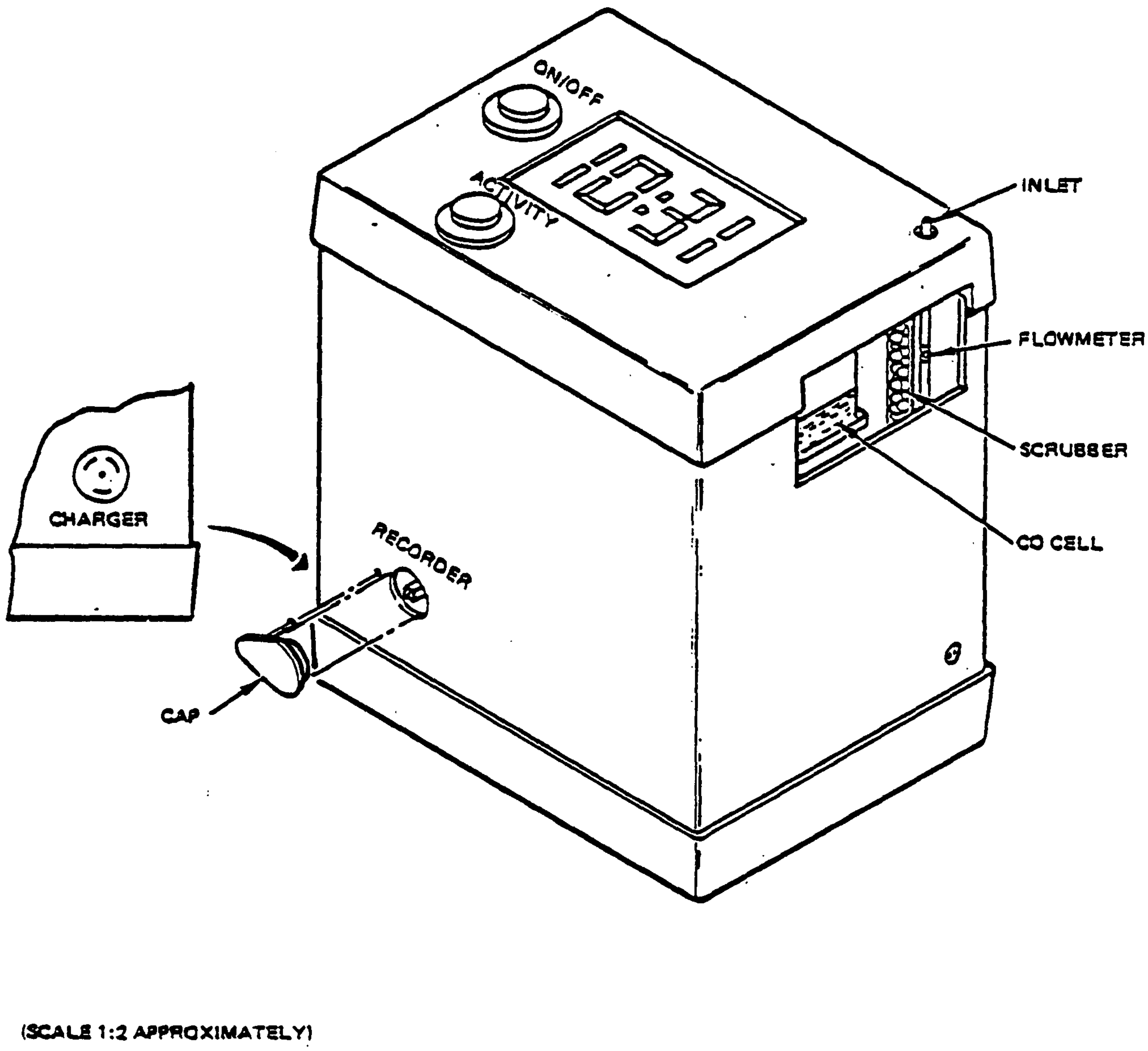

Figure 1. Personal exposure monitor.

TIME FROM MONITOR [| | |]

A. ACTIVITY

____

____

____

____

B. LOCATION

In transit 1

Indoors, residence 2

Indoors, office 3

Indoors, store 4

Indoors, restaurant 5

Other indoor location 6

Specify: __________

____

Outdoors, within 10 yards of road or street 7

Other outdoor location 8

Specify: __________

____

Uncertain 9

C. ADDRESS (if not in transit)

____

____

____

D. ONLY IF IN TRANSIT

(1) Start address __________

____

(2) End address __________

____

(3) Mode of travel:

Walking 1

Car 2

Bus 3

Truck 4

Train/subway 5

Other 6

Specify: __________

____

E. ONLY IF INDOORS

(1) Garage attached to building?

Yes 1

No 2

Uncertain 3

(2) Gas stove in use?

Yes 1

No 2

Uncertain 3

F. ALL LOCATIONS

Smokers present?

Yes 1

No 2

Uncertain 3

Figure 2. Page from activity diary.

indicated whether a garage was attached to the building and whether a gas stove was in use.

Thirteen interviewers were employed during the course of this study to deliver PEM's, activity diaries, and participant questionnaires to the subjects according to prescheduled appointments. Because different PEM's and activity diaries were used for the two sampling periods, an interviewer visited each subject on three consecutive days. In most cases, the first PEM and activity diary were delivered between 7 p.m. and 9 p.m. on Day A and picked up 24 hours later on Day B. During pickup, problems encountered during the first sampling period were addressed and a second PEM and a second activity diary were delivered. These were subsequently picked up 24 hours later on Day C. Breath samples were taken during pickups on Days B and C. The participant questionnaire was delivered on Day A and picked up on Day C.

A field data sheet was used to record the PEM values and corresponding coded activity diary data for each subject-day. These sheets were validated using a special computer program which checked for 83 different types of data anomalies, including missing entries, illegal entries, and logical inconsistencies.

Breath samples were taken by having each subject blow through a disposable mouth piece into a 600 ml plastic carboxyhemoglobin bag. To measure the CO concentration of the breath sample, a prefilter containing potassium permanganate and activated carbon was inserted between the mouthpiece and a General Electric CO-3 portable CO monitor.

Fifteen fixed-site monitors operated in Denver during the period of the study (Figure 3). Nine of these monitors were temporary and were discontinued at the conclusion of the study. All of the monitors reported hourly-average CO data and operated continuously.

Study Results

Response Rates and Instrument Performance

A total of 1094 subject-days of participation were scheduled. The 454 individuals who actually participated in the study yielded 900 subject-days; 446 subjects participated in two sampling periods, while 8 subjects participated in only one sampling period. Of the remaining 194 subject-days scheduled, 120 were lost because subjects requested rescheduling, 33 were lost because of last-minute refusals to participate, and 41 were lost for other reasons (e.g., subject missed appointment, interviewer experienced car problems).

Of the 899 person-days of data obtained from the participants, 808 data sets (90%) were coded as acceptable for statistical analysis of PEM values. Of the remaining 91 data sets, 50 were coded as unacceptable because the difference between pre and post zero-span values was judged excessive. Other frequently occurring instrument problems included clogged pumps, low battery voltage, instances when the PEM logic system switched out of the data recording mode, and fragile parts.

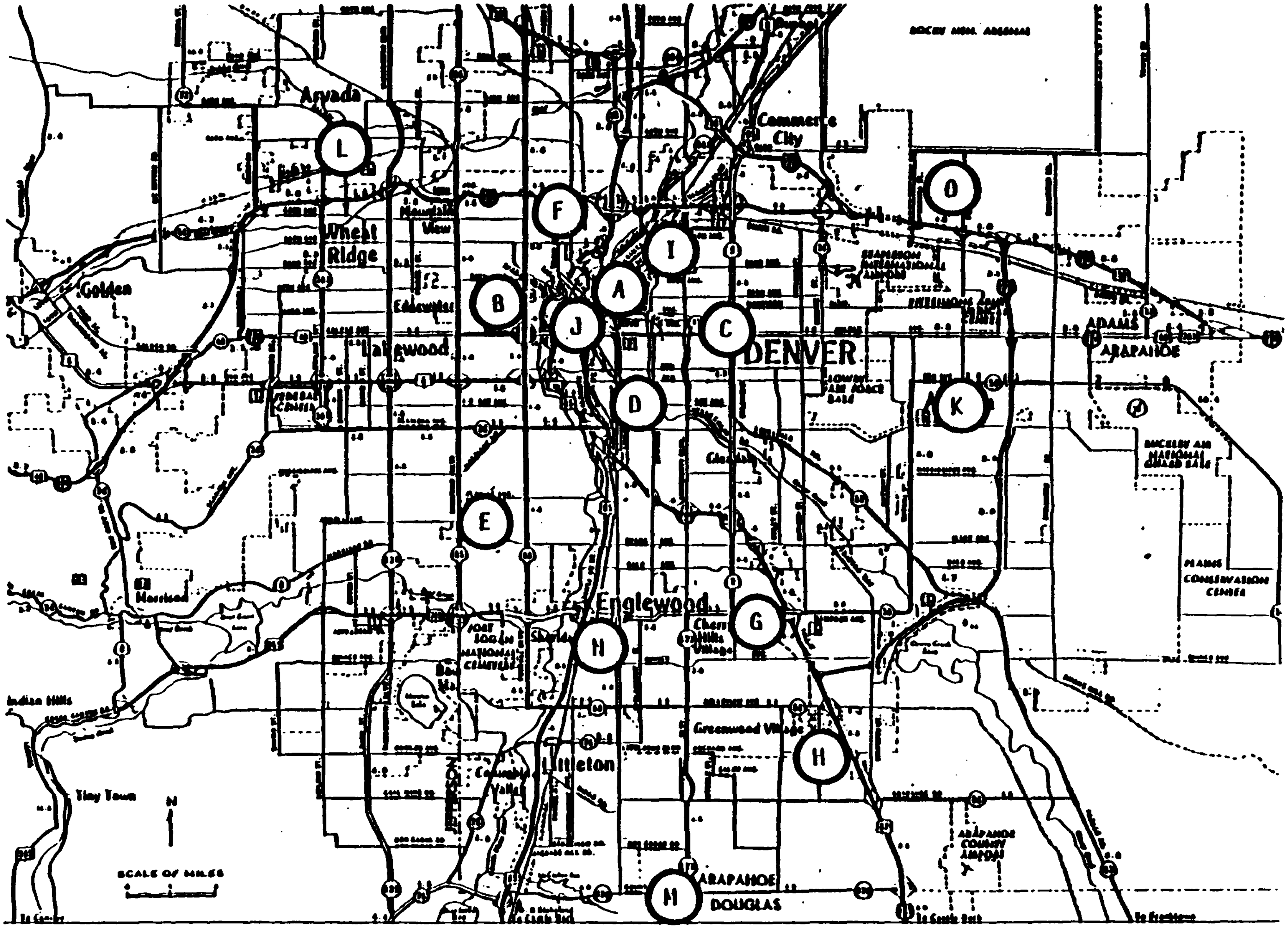

Figure 3. Locations of fixed-site monitors.

84-121.3

Multipoint calibrations performed early in the study revealed a potential nonlinearity problem in the low concentration portion of the PEM's operating range. The adverse affects of this nonlinearity on the overall data quality were minimized by insuring that the PEM GE sensor outputs were properly balanced to the output of the Magus data subsystem outputs.

The accuracy of PEM measurements was determined daily based on a pre- and post-sampling check of zero and span. Using the change in slope as a measure of accuracy, 95 percent of the measurements were estimated to be within ±10 percent of the true concentration value. PEM's operated in pairs showed a mean percent difference in paired values of 5.0 percent with a standard deviation of 14.2 percent. PEM's attached to manifolds supplying sample ambient air to fixed-site monitors yielded paired values with a mean difference of 8.3 percent (fixed-site being higher) and a standard deviation of 22 percent.

A total of 859 data sets (96%) were coded as acceptable for statistical analysis of diary entries. In addition, 778 data sets (87%) were coded as acceptable for statistical analyses involving both PEM and diary data.

A total of 859 breath samples were obtained and successfully analyzed for CO content. Thirty samples were lost because of leaks in the sample bag. One subject refused to provide a breath sample, and another was unable to provide a sample because of illness. Nine samples were not obtained for other reasons (e.g., subject could not fill breath bag). An analysis relating breath sample CO concentrations to CO exposures has been performed by L.A. Wallace, et al.[5]

Fixed-Site Monitoring Data

The highest 1-hour CO concentration reported by any of the 15 fixed-site monitors during the study period was 44.1 ppm. Only one fixed-site monitor (060580002F01) reported any daily maximum 1-hour values exceeding 35 ppm, the current 1-hour NAAQS. The highest 8-hour CO concentration reported by any of the 15 fixed-site monitors was 20.7 ppm. Eleven of the 15 fixed-site monitors reported daily maximum 8-hour values exceeding 9 ppm, the current 8-hour NAAQS (Table I). Five fixed-site monitors reported daily maximum 8-hour values exceeding 15 ppm.

Frequency Distribution of Daily Maximum One-Hour and Eight-Hour Exposures

The daily maximum 1-hour and 8-hour exposures calculated for the study sample were extrapolated to the Denver target population using weighting factors which accounted for the probability of selecting a particular subject into the sample and for nonresponse caused by refusals, instrument problems, and unacceptable activity diary data. Table II summarizes these results. The weighted means for daily maximum 1-hour and 8-hour exposures during the study period are 10.0 ppm and 4.9 ppm, respectively. Approximately 3 percent of the daily maximum 1-hour exposures exceeded 35 ppm; approximately 11 percent of the daily maximum 8-hour exposures exceeded 9 ppm.

Table I. Summary statistics for daily maximum 8-hour carbon monoxide values reported by Denver monitoring sites between November 1, 1982, and February 28, 1983.

Map code	SAROAD code	Number of daily max. values	Daily maximum 8-hour carbon monoxide concentration, ppm								
			Minimum	Maximum	Mean	Std. dev.	Percentiles				
							10	25	50	75	90
A	060580002F01	120	1.2	20.7	7.66	3.97	3.4	4.9	6.8	9.6	13.7
B	060580014F01	108	0.4	18.5	6.11	3.60	1.9	3.3	5.9	7.9	10.9
C	060580013F01	107	1.4	13.1	6.31	2.86	2.5	3.9	5.7	8.5	10.3
D	062080821F05	113	0.8	15.2	5.13	2.85	1.9	3.1	4.5	6.2	9.5
E	062080822F05	118	0.4	14.1	4.14	2.45	1.5	2.4	3.4	5.6	7.5
F	062080820F05	118	0.5	15.1	5.16	2.84	1.9	3.0	4.9	6.6	9.0
G	062080823F05	114	0.7	7.8	3.05	1.51	1.6	2.0	2.6	4.0	5.1
H	062080825F05	113	0.6	7.2	2.48	1.40	1.1	1.4	2.1	3.2	4.1
I	062080818F05	112	0.7	13.6	4.97	2.93	1.8	2.8	4.2	6.4	9.3
J	062080819F05	108	0.5	15.2	5.00	2.96	2.1	3.1	4.2	6.2	8.9
K	060140002F01	118	1.0	9.3	2.98	1.51	1.5	1.9	2.7	3.7	5.0
L	060120002F01	118	0.7	13.2	4.86	2.40	2.0	2.8	4.5	6.5	8.1
M	060080002F01	116	0.2	5.8	1.57	1.08	0.5	0.9	1.3	1.8	3.3
N	062080824F05	116	1.2	13.5	5.01	2.79	2.2	2.7	4.4	6.4	9.5
O	062080817F05	114	0.1	8.6	3.01	1.58	1.3	1.9	2.7	3.8	5.2
	Composite	120	0.6	10.3	4.16	2.01	1.7	2.9	3.7	5.3	7.0

Table II. Summary statistics for daily maximum 1-hour and 8-hour carbon monoxide exposures (weighted).

Statistic	Daily maximum exposure, ppm	
	1-hour	8-hour
Minimum	0.0	0.0
Maximum	91.2	44.0
Mean	10.0	4.9
10th percentile	2.2	1.1
25th percentile	4.1	2.0
50th percentile	8.0	3.5
75th percentile	12.7	6.9
90th percentile	18.5	9.4
95th percentile	26.3	12.1
99th percentile	47.0	25.6

Linear regression analyses were performed to relate daily maximum 1-hour exposures ($c_{1,max}$) to daily maximum 8-hour exposures ($c_{8,\ max}$). Omitting one outlier and using the daily maximum 8-hour value as the independent variable, weighted linear regression of 801 person-days of data yields the relationship

$$\hat{c}_{1,\ max} = 2.57 + (1.53)(c_{8,\ max}), \tag{1}$$

with $R^2 = 0.69$. Omitting the same outlier and using the daily maximum 1-hour value as the independent variable yields the relationship

$$\hat{c}_{8,\ max} = 0.36 + (0.45)(c_{1,\ max}); \tag{2}$$

again $R^2 = 0.69$. Equation 1 predicts that a member of the Denver target population who receives a daily maximum 8-hour exposure of 9 ppm would receive a daily maximum 1-hour exposure of 16.3 ppm. Similarly, Equation 2 predicts a person receiving a daily maximum 1-hour exposure of 35 ppm would receive a daily maximum 8-hour exposure of 16.1 ppm.

Variation in Exposure with Microenvironment

One of the principal reasons for collecting activity diary data is to provide a means for relating exposure to a subject's microenvironment, i.e., the subject's immediate physical surroundings. The activity diary codes used in the Denver study can be combined in a variety of ways to designate microenvironments of interest. The initial analyses discussed here considered the four-digit code created by combining the two-digit location code (diary item B) with the two-digit transit mode code (diary item D3).

Using valid individual PEM values with durations of 60 minutes or less, the weighted means and standard deviations of PEM values grouped by microenvironment code were calculated. Listing the microenvironments in descending order by mean CO concentration (Table III) suggests that microenvironments associated with motor vehicles had the highest CO levels in Denver during the study period.

Occupancy period was defined as the time a subject spends in a microenvironment during a single visit. Table IV lists the weighted mean of the occupancy periods for each microenvironment except indoors - residence (Code 02bb). Mean occupancy periods for the indoor residential microenvironment could not be determined accurately from activity diary data because subjects were usually occupying residences before the first diary entry and after the last diary entry.

Mean occupancy periods range from 431.9 minutes (indoors - manufacturing facility) to 7.4 minutes (outdoors - residential garage or carport). Mean occupancy periods for in-transit microenvironments associated with motor vehicles and high CO levels are 30.8 minutes for trucks, 28.0 minutes for buses, 25.9 minutes for cars, and 23.0 minutes for motorcycles. The value for indoors - public garage (29.4 minutes) is higher than expected and may be the result of errors in recording activity diary information.

An analysis was conducted of residential indoor exposures to determine the contribution of three potential CO sources. Mean exposure was increased 2.59 ppm (134 percent) by gas stove operation, 1.59 ppm (84 percent) by smokers other than study participants, and 0.41 ppm (22 percent) by attached garages. As noted previously, only nonsmokers were invited to participate in the study.

Relationships Between Fixed and Personal Monitor Values

Some models used for estimating population exposure assume that a strong, linear relationship exists between CO levels in certain microenvironments and CO levels measured simultaneously at fixed-site monitors. This assumption was investigated by performing linear regression analyses that used PEM values grouped by microenvironment as the dependent variable and fixed-site values as the independent variable. For in-transit microenvironments, the independent variable was the mean of the simultaneously-recorded values at all 15 sites. For nontransit microenvironments, the independent variable was the simultaneously-recorded value at the nearest fixed-site monitor. Coefficients of determination (R^2) range from 0 to 0.58 (Tables V and VI). Most are less than 0.50. Microenvironments with R^2 values exceeding 0.30 include parks and golf courses, motorcycles, and buses. The residential garage microenvironment has an R^2 value of zero.

An untried method of assigning fixed-site monitors to census tracts is to determine the traffic density of each census tract and then select a fixed-site monitor located in a census tract with similar traffic density. Such an approach may yield higher correlations between the nontransit PEM values and the fixed site values than those listed in Table V.

Table III. Microenvironments listed in descending order of weighted mean CO concentration.

Code		Microenvironment			CO concentration, ppm	
B	D3	Category	Subcategory	n	Mean	Std. dev.
52	a	Indoors	Public garage	116	13.46	18.14
01	93	In transit	Motorcycle	22	9.79	8.15
54	bb	Indoors	Service station or motor vehicle repair facility	125	9.17	9.33
01	03	In transit	Bus	76	8.52	7.08
72	a	Outdoors	Public garage	29	8.20	5.33
01	02	In transit	Car	3632	8.10	9.88
71	bb	Outdoors	Residential garage or carport	22	7.53	8.93
62	bb	Indoors	Other location	427	7.40	17.97
01	04	In transit	Truck	405	7.03	9.89
55	bb	Indoors	Other repair shop	55	5.64	7.67
58	bb	Indoors	Shopping mall	58	4.90	6.50
51	bb	Indoors	Residential garage	66	4.35	7.06
07	c	Outdoors	Within 10 yards of road	496	4.05	5.44
01	01	In transit	Walking	619	3.88	6.61
bb	bb	Not specified	Not specified	586	3.79	6.57
05	bb	Indoors	Restaurant	524	3.71	4.35
74	bb	Outdoors	Service station or motor vehicle repair facility	12	3.68	3.84
03	c	Indoors	Office	2287	3.59	4.18
73	d	Outdoors	Parking lot	61	3.45	4.23
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	100	3.37	4.76
04	bb	Indoors	Store	734	3.23	5.56
80	bb	Outdoors	Other location	126	3.17	5.47
59	bb	Indoors	Health care facility	351	2.22	4.25
61	bb	Indoors	Other public building	115	2.15	3.26
53	bb	Indoors	Manufacturing facility	42	2.04	2.55
02	bb	Indoors	Residence	21543	2.04	4.06
77	bb	Outdoors	School grounds	16	1.99	3.39
60	bb	Indoors	School	426	1.64	2.76
57	bb	Indoors	Church	179	1.56	3.35
76	bb	Outdoors	Residential grounds	74	1.36	2.24
01	92	In transit	Bicycle	9	1.34	3.61
78	bb	Outdoors	Sports arena, amphitheater, etc.	29	0.97	2.80
79	bb	Outdoors	Park or golf course	21	0.69	1.01

[a] Includes D3 = bb, 01, and 02.

[b] Blank.

[c] Includes D3 = bb and 01.

[d] Includes D3 = bb, 01, 02, and 03.

Table IV. Microenvironments listed in descending order of weighted mean occupancy period.

Code		Microenvironment[a]			Occupancy period, minutes	
B	D3	Category	Subcategory	n	Mean	Std. dev.
53	bb	Indoors	Manufacturing facility	8	431.9	199.8
03	c	Indoors	Office	610	206.9	167.3
55	bb	Indoors	Other repair shop	11	192.4	121.3
78	bb	Outdoors	Sports arena, amphitheater, etc.	6	191.6	111.0
60	bb	Indoors	School	100	165.0	159.8
59	bb	Indoors	Health care facility	91	162.4	142.5
57	bb	Indoors	Church	57	115.7	57.3
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	38	112.0	77.0
80	bb	Outdoors	Other location	60	93.1	182.8
62	bb	Indoors	Other location	188	91.1	103.9
05	bb	Indoors	Restaurant	267	79.1	109.2
61	bb	Indoors	Other public building	52	77.8	60.8
58	bb	Indoors	Shopping mall	24	77.3	65.0
54	bb	Indoors	Service station or motor vehicle repair facility	53	72.3	87.1
79	bb	Outdoors	Park or golf course	11	60.4	84.3
04	bb	Indoors	Store	400	48.4	73.2
bb	bb	Not specified	Not specified	320	37.3	57.1
07	c	Outdoors	Within 10 yards of road	379	31.2	56.6
01	04	In transit	Truck	300	30.8	43.4
76	bb	Outdoors	Residential grounds	49	30.8	36.2
52	d	Indoors	Public garage	77	29.4	77.1
01	03	In transit	Bus	68	28.0	24.3
01	02	In transit	Car	2593	25.9	46.1
01	93	In transit	Motorcycle	17	23.0	9.9
51	bb	Indoors	Residential garage	49	23.0	39.5
01	01	In transit	Walking	511	20.0	46.9
73	e	Outdoors	Parking lot	67	16.4	37.8
01	92	In transit	Bicycle	13	16.1	10.2
77	bb	Outdoors	School grounds	15	12.8	6.8
72	d	Outdoors	Public garage	26	10.7	26.0
74	bb	Outdoors	Service station or motor vehicle repair service	12	7.5	2.4
71	bb	Outdoors	Residential garage or carport	20	7.4	17.5

[a]Omits indoor residential microenvironment (Code 02bb).

[b]Blank.

[c]Includes D3 = bb and 01.

[d]Includes D3 = bb, 01, and 02.

[e]Includes D3 = bb, 01, 02, and 03.

Table V. Results of weighted linear regression analyses with nontransit PEM value as dependent variable and simultaneous value at nearest fixed site as independent variable.

Code		Microenvironment[a]		Linear regression				
B	D3	Category	Subcategory	n	Intercept	Slope	R^2	p
80	bb	Outdoors	Other location	115	0.35	1.11	0.46	0.000
79	bb	Outdoors	Park or golf course	18	-0.09	0.39	0.44	0.003
77	bb	Outdoors	School grounds	15	-0.37	1.15	0.27	0.049
54	bb	Indoors	Service station or motor vehicle repair facility	112	4.18	1.68	0.27	0.000
05	bb	Indoors	Restaurant	486	1.69	0.76	0.25	0.000
74	bb	Outdoors	Service station or motor vehicle repair facility	11	1.61	1.21	0.23	0.134
07	c	Outdoors	Within 10 yards of road	468	1.58	0.89	0.21	0.000
57	bb	Indoors	Church	178	0.09	0.70	0.21	0.000
73	d	Outdoors	Parking lot	51	2.26	0.60	0.21	0.001
55	bb	Indoors	Other repair shop	46	3.69	0.88	0.18	0.003
78	bb	Outdoors	Sports arena, amphitheater, etc.	16	3.05	-1.76	0.15	0.128
61	bb	Indoors	Other public building	111	0.74	0.42	0.14	0.000
58	bb	Indoors	Shopping mall	55	1.24	1.43	0.14	0.005
04	bb	Indoors	Store	675	1.67	0.56	0.09	0.000
59	bb	Indoors	Health care facility	336	0.97	0.45	0.09	0.000
02	bb	Indoors	Residence	20969	1.00	0.43	0.07	0.000
60	bb	Indoors	School	342	0.97	0.32	0.07	0.000
03	bb	Indoors	Office	2090	2.53	0.34	0.05	0.000
71	bb	Outdoors	Residential garage or carport	22	5.67	0.61	0.05	0.304
bb	bb	Not specified	Not specified	583	2.07	0.63	0.05	0.000
76	bb	Outdoors	Residential grounds	70	0.84	0.30	0.04	0.099
e		-	Public garage	139	8.44	0.72	0.04	0.019
56	bb	Indoors	Auditorium, sports arena, concert hall, etc.	94	2.25	0.38	0.04	0.060
53	bb	Indoors	Manufacturing facility	41	1.41	0.18	0.03	0.246
51	bb	Indoors	Residential garage	66	3.98	0.14	0.00	0.662
62	bb	Indoors	Other location	381	7.94	0.07	0.00	0.791

[a]Listed in order of R^2 value.

[b]Blank.

[c]Includes D3 = bb and 01.

[d]Includes D3 = bb, 01, 02, and 03.

[e]Includes codes 52bb, 5201, 5202, 72bb, 7201, and 7202.

[p]Probability that slope = 0.

Table VI. Results of weighted linear regression analyses with in-transit PEM value as dependent variable and simultaneous value from composite data set as independent variable.

Code		In-transit subcategory	Linear regression				
B	D3		n	Intercept	Slope	R^2	p
01	93	Motorcycle	22	4.50	2.14	0.58	0.000
01	03	Bus	76	3.17	2.02	0.36	0.010
01	01	Walking	619	0.06	1.47	0.23	0.000
01	04	Truck	405	3.27	1.54	0.11	0.000
01	02	Car	3632	6.01	0.78	0.04	0.000
01	a	All	4763	5.15	0.92	0.05	0.000

[a]Includes D3 codes 01, 02, 03, 04, 92, and 93.

[p]Probability that slope = 0.

Diurnal patterns for weekdays (Figure 4), Saturdays, and Sundays were developed for hourly average exposures and composite fixed-site values. In general, diurnal patterns for exposure were similar in shape to those for fixed-site data, although the morning rush hour peaks were much higher in the composite fixed-site patterns than in the exposure patterns.

Conclusions

In developing and implementing the Denver study, the attempt was made to investigate the appropriateness of a general approach to determining the exposure of a large urban population. The overall success of the Denver study suggests that the approach is valid. The study has also provided a rich data base that should prove invaluable in answering questions concerning the factors which affect exposure, the ability of fixed-site data to represent personal exposures, the performance of newly-developed instruments, and similar issues. The analyses discussed in this report suggest that 1) CO exposures in microenvironments associated with motor vehicles are higher than exposures in microenvironments not associated with motor vehicles, 2) CO exposures in the microenvironments defined for this study are not strongly correlated with CO concentrations simultaneously recorded at fixed-site monitors, and 3) indoor residential exposures are increased by gas stoves, smokers, and attached garages.

References

1. T. Johnson, A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado, report by PEDCo Environmental, Inc., to the U.S. Environmental Protection Agency, Research Triangle Park, N.C., December 1983.

2. T. Hartwell, et al., Study of Carbon Monoxide Exposure of Residents of Washington, DC and Denver, Colorado, report by Research Triangle Institute to U.S. Environmental Protection Agency, Research Triangle Park, N.C., January 1984.

3. W.R. Ott, "Exposure estimates based on computer generated activity patterns," paper no. 81-57.6, 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, June 21-26, 1981.

4. T. Johnson and R. Paul, The NAAQS Exposure Model (NEM) Applied to Carbon Monoxide, draft report by PEDCo Environmental, Inc., to the U.S. Environmental Protection Agency, Research Triangle Park, N.C., September 1983.

5. L.A. Wallace, et al., "Alveolar CO Measurements of 1000 Residents of Denver and Washington, D.C.--A Comparison with Preceding Personal Exposure," paper no. 121.5, to be presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, June 24-29, 1984.

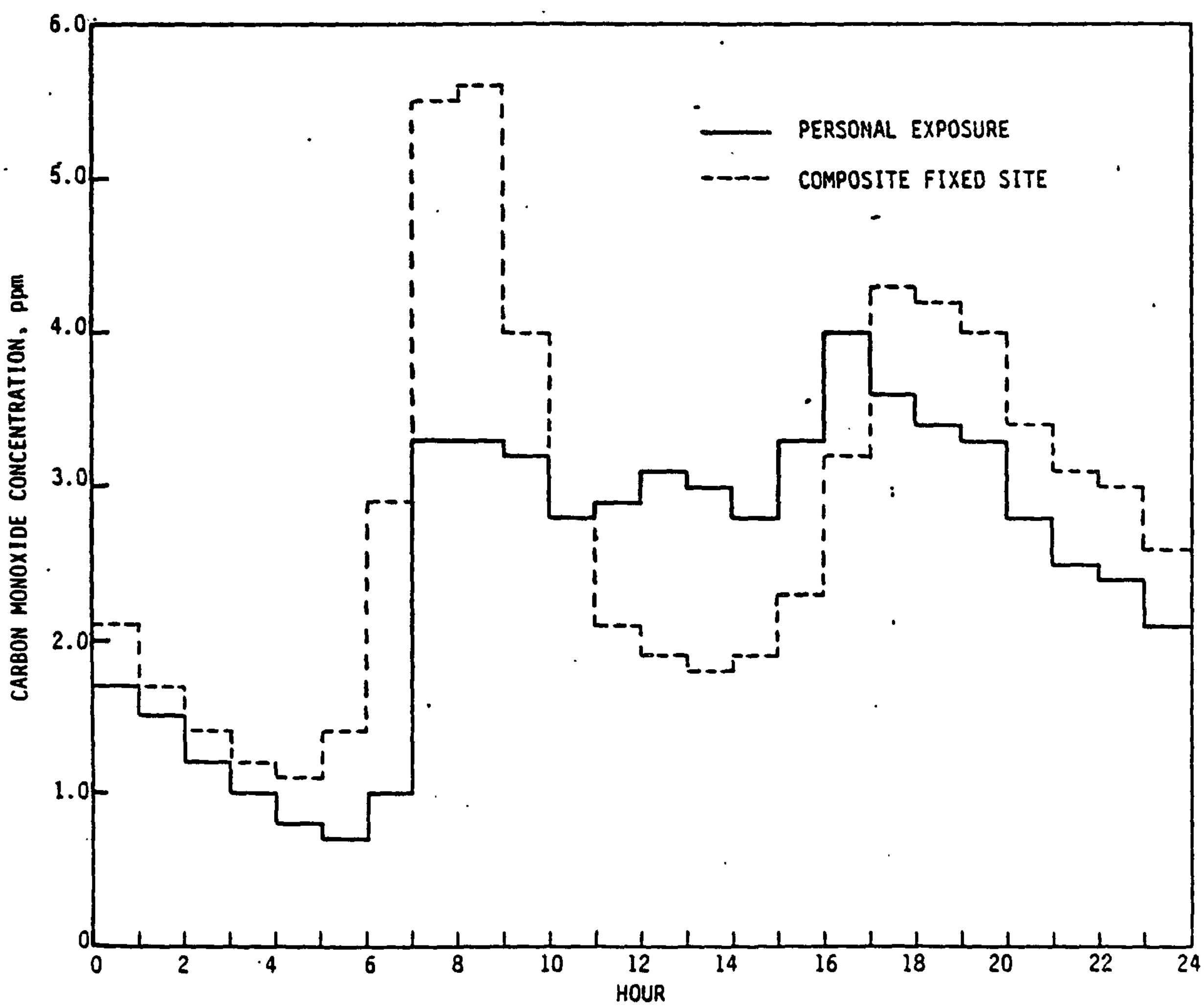

Figure 4. Weekday diurnal patterns.

APPENDIX B

SITE DESCRIPTIONS AND SUMMARY STATISTICS FOR WASHINGTON FIXED-SITE MONITORS

EMSL provided PEI with a file containing hourly average carbon monoxide (CO) data for 11 fixed sites in the Washington, D.C., area. Tables 1 and 2 provide site characteristics for these 11 sites. As discussed in Section 5.1 of Reference 1, TDEN is an indicator of traffic density, and RDEN is an indicator of population density. Figure 1 shows the approximate location of each site.

A twelfth data set was created by taking the hour-by-hour mean of the hourly values reported by the 11 fixed sites. This data set is referred to as the "composite site" in the discussion that follows.

Table 3 summarizes the results of analyzing the hourly average values for November 8, 1982, through February 25, 1983, using BMDP program P2D. None of the sites reported hourly average values exceeding 35 ppm. Table 4 lists the date and time of the maximum value reported at each site. Eight of the 11 maximum values occurred during either the morning or the evening high traffic periods. Three days (11-8-82, 2-15-83, and 2-22-83) account for all but one of the maximum values. The maximum value at the composite site was 8.6 ppm and occurred at 18:00 on 2-15-83.

PEI created a supplementary file which contains daily maximum 1-hour and 8-hour values. Tables 5 and 6 summarize the results of analyzing these data using BMDP program P2D. As indicated in Table 6, two sites had daily maximum 8-hour values exceeding 9 ppm. Site 090020023I02 reported one exceedance; site 210220001F01 reported five exceedances. None of the sites had daily maximum 8-hour values exceeding 15 ppm.

Reference

1. Johnson, T. A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/54-84-014, March 1983.

TABLE 1. SITE CHARACTERISTICS OF WASHINGTON CARBON MONOXIDE MONITORS OPERATING DURING STUDY

Map code	Location	SAROAD code	Address	Scale[a]	Probe ht, ft	Distance to road, ft	Vehicles per day[b]	Immediate area land use
A	District of Columbia	090020017I01	24th and L. Sts., NW (West End Library)	N	33	83 70 345	12,000 4,500 27,000	Commercial
B		090020023I02	L St. between 20th and 21st Sts., NW	M	11	18 210 250	20,900 13,100 12,800	Street corridor
C		090020031I02	First and C Sts., SW	?	11	50 80	? ?	Office buildings
D	Bladensburg, MD	210220001F01	Educational Media Bldg.	?	13	180	37,000	Residential and light commercial
E	Suitland-Silver Hill, MD	211560001F01	Suitland Parkway (near Bramley Ave.)	N	14	150	19,700	Field near commercial street
F	Alexandria, VA	480080009H01	517 N. St. Asaph St. (near Pendleton)	N	36	40 40	3,900 3,700	Light commercial and residential
G	Arlington, VA	480200020G01	S. 18th and S. Hayes Sts.	N	16	200 200 180	<500 <200 6,000	Commercial and residential
H	Fairfax, VA	481040005G01	10600 Page Avenue	N	12	<100	<200	Office buildings
I	Mt. Vernon, VA	481060018G01	2675 Sherwood Hall Cn.	N	12	190 250 180	17,900 8,250 ?	Light commercial and residential

(continued)

TABLE 1 (continued)

Map code	Location	SAROAD code	Address	Scale[a]	Probe ht, ft	Distance to road, ft	Vehicles per day[b]	Immediate area land use
J	McLean, VA	481850001G01	1437 Balls Hill Rd.	N	12	260 216 430	31,750 3,189 10,832	Light commercial and residential
K	Seven Corners, VA	482870004G01	6100 Arlington Blvd. (roof of Montgomery Ward)	N	30	328 800 800	50,000 11,658 1,265	Strip development near residential

[a]N = neighborhood, M = micro.

[b]Estimate, accuracy uncertain.

TABLE 2. LAND USE CHARACTERISTICS OF CENSUS TRACTS CONTAINING WASHINGTON CO MONITORS

Map code	Location	SAROAD code	1980 census tract	1970 census tract	TDEN	RDEN
A	District of Columbia	090020017I01	55.02	55.00	62.94	26.19
B		090020023I02	54.01	54.10	243.97	21.51
C		090020031I02	62.02	62.00	19.39	0.04
D	Bladensburg, MD	210220001F01	8043.00	8040.00	7.96	7.44
E	Suitland-Silver Hill, MD	211560001F01	8024.01	8024.01	7.34	6.03
F	Alexandria, VA	480080009H01	2018.02	18.00	12.45	6.82
G	Arlington, VA	480200020G01	1035.00	1035.00	18.63	19.88
H	Fairfax, VA	481040005G01	4405.00	4031.00	1.64	3.08
I	Mt. Vernon, VA	481060018G01	4159.00	4008.00	0.76	3.03
J	McLean, VA	481850001G01	4706.00	4083.00	8.11	5.29
K	Seven Corners, VA	482870004G01	5003.00	5003.00	5.93	6.58

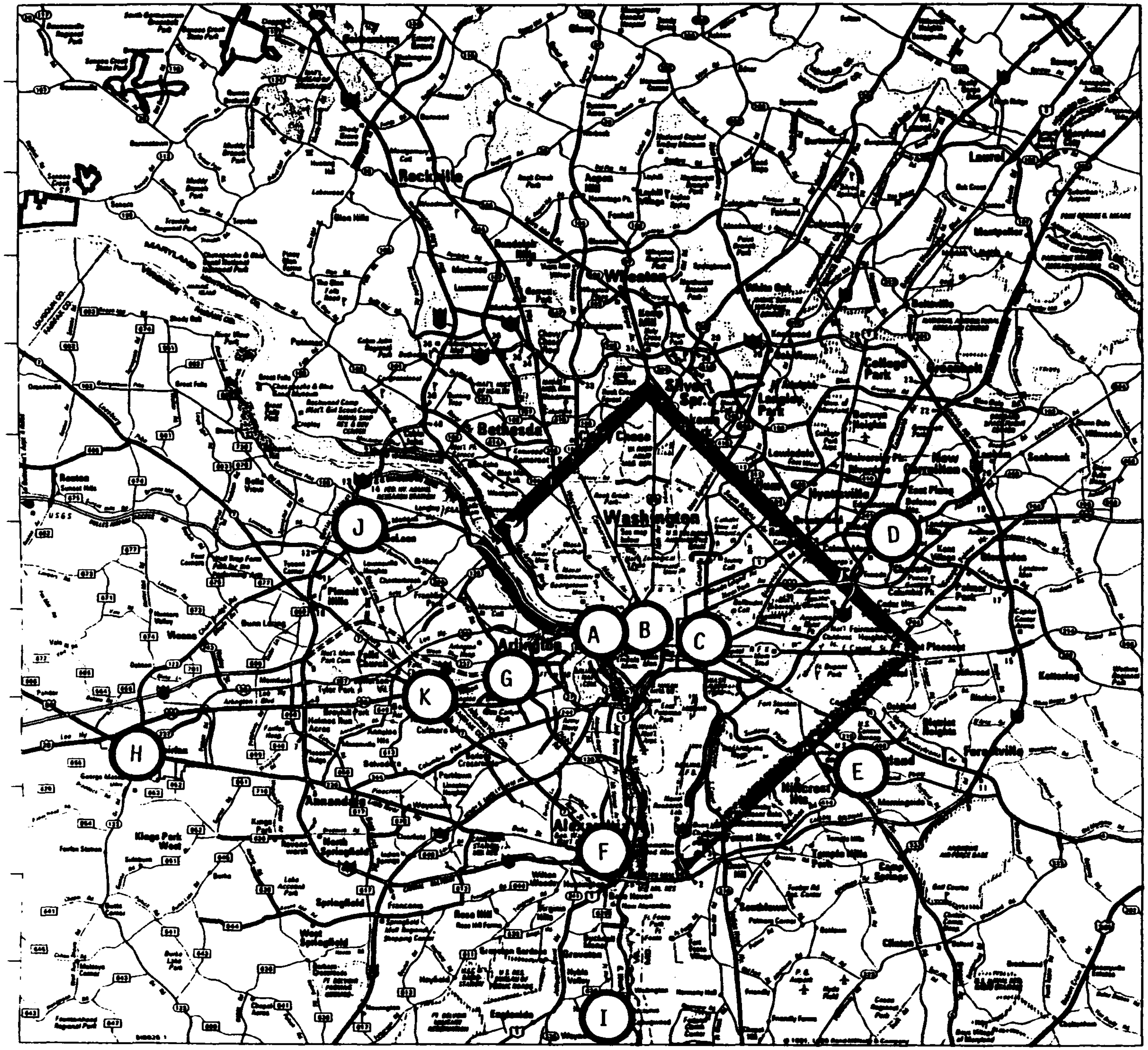

Figure 1. Locations of fixed-site monitors (base map © Rand McNally and Company, used by permission).

TABLE 3. SUMMARY STATISTICS FOR HOURLY AVERAGE CARBON MONOXIDE VALUES REPORTED BY WASHINGTON MONITORING SITES BETWEEN NOVEMBER 8, 1982 AND FEBRUARY 25, 1983

Map code	SAROAD code	Number of hourly values	Hourly average carbon monoxide concentration, ppm									
			Minimum	Maximum	Mean	Std. dev.	Percentiles					
							10	25	50	75	90	98
A	090020017I01	2626	0.1	11.2	1.48	1.22	0.5	0.7	1.2	1.8	2.8	5.4
B	090020023I02	2611	0.1	16.0	2.72	2.22	0.5	1.1	2.1	3.7	5.7	9.0
C	090020031I02	2377	0.1	10.0	1.84	1.14	0.8	1.1	1.6	2.2	3.1	5.4
D	210220001F01	2317	0.0	22.4	1.65	2.22	0.2	0.4	0.9	1.9	4.0	8.9
E	211560001F01	2015	0.0	9.1	1.39	0.97	0.4	0.7	1.2	1.8	2.6	4.1
F	480080009H01[a]	2563	0.0	14.0	1.38	1.24	0.5	0.5	1.0	1.5	3.0	5.0
G	480200020G01[a]	2619	0.0	8.5	1.29	1.05	0.5	0.5	1.0	1.5	2.5	5.0
H	481040005G01[a]	2527	0.0	8.0	1.26	0.94	0.5	1.0	1.0	1.5	2.0	4.5
I	481060018G01[a]	2608	0.0	17.0	1.78	1.82	0.5	1.0	1.0	2.0	4.0	7.5
J	481850001G01[a]	2572	0.0	9.5	1.05	1.06	0.0	0.5	0.5	1.5	2.5	4.5
K	482870004G01[a]	2564	0.0	13.0	0.98	0.91	0.0	0.5	1.0	1.0	2.0	3.5
	Composite	2640	0.2	8.6	1.54	1.09	0.6	0.8	1.2	1.9	2.8	5.0

[a]Data reported in units of 0.5 ppm.

TABLE 4. DATE AND TIME OF MAXIMUM HOURLY AVERAGE CARBON MONOXIDE VALUE

Map code	SAROAD code	Maximum hourly avg., ppm	Date	Time
A	090020017I01	11.2	11-08-82	20:00
B	090020023I02	16.0	2-15-83	19:00
C	090020031I02	10.0	11-08-82	17:00
D	210220001F01	22.4	2-22-83	7:00
E	211560001F01	9.1	2-22-83	7:00
F	480080009H01	14.0	2-15-83	19:00
G	480200020G01	8.5	2-22-83	8:00
H	481040005G01	8.0	2-22-83	8:00
I	481060018G01	17.0	12-08-82	8:00
J	481850001G01	9.5	2-15-83	18:00
K	482870004G01	13.0	11-08-82	9:00

TABLE 5. SUMMARY STATISTICS FOR DAILY MAXIMUM 1-HOUR CARBON MONOXIDE VALUES REPORTED BY WASHINGTON MONITORING SITES BETWEEN NOVEMBER 8, 1982 AND FEBRUARY 25, 1983

Map code	SAROAD code	Number of daily values	Daily maximum 1-hour carbon monoxide concentration, ppm									
			Minimum	Maximum	Mean	Std. dev.	Percentiles					
							10	25	50	75	90	98
A	090020017I01	110	0.7	11.2	3.56	2.28	1.4	1.8	2.7	4.5	6.9	9.3
B	090020023I02	108	1.5	16.0	6.74	3.30	2.4	4.0	6.6	9.3	11.0	14.1
C	090020031I02	96	0.9	10.0	3.61	1.97	1.8	2.4	3.0	4.3	6.9	9.5
D	210220001F01	93	0.2	22.4	5.12	4.31	1.4	2.4	3.9	6.5	9.2	19.8
E	211560001F01	80	0.4	9.1	2.84	1.66	0.9	1.8	2.3	3.6	5.2	7.6
F	480080009H01[a]	108	0.5	14.0	3.59	2.34	1.5	1.5	3.0	5.0	7.0	9.0
G	480200020G01[a]	110	0.5	8.5	2.97	1.86	1.0	1.5	2.5	4.5	5.5	7.5
H	481040005G01[a]	105	0.5	8.0	2.86	1.78	1.0	1.5	2.5	3.5	5.5	7.0
I	481060018G01[a]	108	0.5	17.0	4.86	3.20	1.5	2.0	4.5	6.5	9.5	12.0
J	481850001G01[a]	106	0.5	9.5	2.85	2.00	1.0	1.5	2.5	4.5	5.5	8.0
K	482870004G01[a]	104	0.5	13.0	2.32	1.79	1.0	1.0	2.0	3.0	4.5	7.5
	Composite	110	0.8	8.6	3.24	1.78	1.4	1.9	2.8	4.1	5.9	7.9

[a]Data reported in units of 0.5 ppm.

TABLE 6. SUMMARY STATISTICS FOR DAILY MAXIMUM 8-HOUR CARBON MONOXIDE VALUES REPORTED BY WASHINGTON MONITORING SITES BETWEEN NOVEMBER 8, 1982 AND FEBRUARY 25, 1983

Map code	SAROAD code	Number of daily values	Daily maximum 8-hour carbon monoxide concentration, ppm									
			Minimum	Maximum	Mean	Std. dev.	Percentiles					
							10	25	50	75	90	98
A	090020017I01	110	0.6	7.7	2.35	1.34	1.1	1.3	2.0	2.9	4.2	5.6
B	090020023I02	109	0.8	10.0	4.33	1.98	1.9	2.8	4.4	5.6	7.1	8.2
C	090020031I02	96	0.7	5.9	2.55	1.14	1.4	1.8	2.2	3.1	4.2	5.5
D	210220001F01	89	0.2	12.5	3.12	2.76	0.8	1.4	2.1	4.1	7.2	12.2
E	211560001F01	79	0.3	5.6	1.97	1.05	0.7	1.2	1.9	2.6	3.4	4.3
F	480080009H01[a]	105	0.5	7.1	2.22	1.42	0.8	1.3	1.8	2.8	4.2	6.4
G	480200020G01[a]	110	0.5	6.3	2.04	1.27	0.9	1.0	1.6	2.8	3.6	5.2
H	481040005G01[a]	105	0.5	6.1	1.86	1.05	0.9	1.3	1.6	2.3	2.9	5.0
I	481060018G01[a]	107	0.6	8.5	3.11	1.98	1.0	1.6	2.3	4.2	6.3	8.2
J	481850001G01[a]	105	0.4	6.5	1.79	1.21	0.6	0.8	1.5	2.4	3.6	4.9
K	482870004G01[a]	103	0.3	6.5	1.46	0.86	0.5	0.9	1.3	1.8	2.3	3.6
	Composite	110	0.7	6.4	2.29	1.20	1.1	1.4	1.9	2.7	4.1	5.4

[a]Data reported in units of 0.5 ppm.