ESTIMATION OF CARBON MONOXIDE EXPOSURES AND ASSOCIATED CARBOXYHEMOGLOBIN LEVELS FOR RESIDENTS OF DENVER AND LOS ANGELES USING pNEM/CO (VERSION 2.1)

by

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DISCLAIMER

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ACKNOWLEDGMENTS

In 1992, the U.S. Environmental Protection Agency (EPA) funded the development of a probabilistic version of NEM applicable to carbon monoxide (pNEM/CO). This report describes an updated version of pNEM/CO developed during 1998 - 1999 (hereafter referred to as Version 2.1) through the efforts of the ICF Consulting (ICF), IT Air Quality Services (ITAQS), TRJ Environmental, Inc. (TRJ), and Jim Capel. This report also presents the results of applying the updated model to residents of urbanized areas within Denver, Colorado, and Los Angeles, California.

The updated version of pNEM/CO consists of three principal parts: a main program which estimates carbon monoxide (CO) exposures within a defined population, a special module which estimates the carboxyhemoglobin (COHb) levels which result from these exposures, and a program which tabulates the exposure and COHb estimates. Supplementary programs are used to process air quality and population data for input into the main program.

Mr. Ted Johnson of TRJ was the principal author of this report. He developed the general pNEM/CO methodology described in Section 2 and many of the specific algorithms used to simulate various exposure factors within the model. Mr. Gary Mihlan of TRJ processed commuting data provided by ICF to create the origin-destination table for Denver and Los Angeles. Ms. Jacky LaPointe and Ms. Kristen Fletcher reviewed the scientific literature on selected indoor sources of CO and provided recommendations for modifying pNEM/CO to account for these sources.

Mr. Jim Capel wrote the main pNEM/CO program, the COHb module, and the majority of supplementary programs. He also converted the Comprehensive Human Activity Database (CHAD) into an input database suitable for use with pNEM/CO. In addition, he set up all input data files and run streams required for application of pNEM/CO to Denver and Los Angeles, ran the model, and tabulated the results. Mr. Graham Glen of ManTech Environmental Technology, Inc., wrote parts of the tables/output program.

Mr. Dib Paul served as the project manager for ITAQS. He also performed a literature review to identify data useful in implementing the ventilation rate algorithm.

Mr. Andy Law of ITAQS developed input data for the mass-balance and gas-stove models described Section 4. Mr. Sri Pangaluri of ITAQS assisted Mr. Jim Capel in converting the CHAD database into an input database suitable for pNEM/CO.

Ms. Arlene Rosenbaum served as the project manager for ICF Consulting (ICF). Ms. Pat Stiefer of ICF prepared the census and commuting data files for Denver and Los Angeles; she also provided many of the data sets used in implementing the mass-balance model described in Section 4. Dr. Jonathan Cohen, Mr. Sergey Nikiforov, and Ms. Rosenbaum performed the statistical comparison of exertion levels for persons with and without heart disease described in Section 5.6. Dr. Cohen and Ms. Rosenbaum assisted Ted Johnson in developing many of the algorithms described in Section 4, including the algorithm for estimating outdoor CO concentrations.

The COHb module is based on algorithms developed by Dr. William F. Biller for the 1992 version of pNEM/CO under an earlier contract with EPA's Office of Air Quality Planning and Standards. Dr. Biller also developed the hourly average version of the mass-balance model in the 1992 version of pNEM/CO which continues to be used in the current version. Mr. Harvey Richmond of EPA assisted in developing the COHb algorithm and in characterizing the distributions of many of the variables contained in the COHb algorithm.

The method for estimating alveolar ventilation rates described in Section 5 was developed by Mr. Ted Johnson, Ms. Jill Mozier, and Mr. Mark Weaver of TRJ with assistance from Dr. Jonathan Cohen of ICF. The method is based on an approach suggested by Mr. Tom McCurdy of EPA's Office of Research and Development. Mr. McCurdy also provided estimates for various parameters used in implementing the method. The CHAD database was created jointly by Mr. McCurdy and by Mr. Yeshpal Lakkadi, Mr. Graham Glen, Mr. Luther Smith, Ms. Jo Ann Tippett, and Ms. Maria del Valle-Torres of ManTech Environmental Technology, Inc.

The authors gratefully acknowledge the assistance of Dr. Irving Billick and the Gas Research Institute, who provided references and reports containing useful information on gas stove emission rates and operating conditions. The authors would also like to express their appreciation to Dr. A. L. Wilson for providing data useful in developing a relationship between CO measured outside residences and CO reported by nearby fixed-site monitoring stations.

The development of Version 2.1 of pNEM/CO and its application to Denver and Los Angeles were funded by EPA under Contract Nos. 68-D3-0094 and 68-D6-0064. Mr. Harvey Richmond of EPA's Health and Ecosystem Effects Group was the EPA Work Assignment Manager for all work assignments associated with this effort. Mr. Richmond also developed the prevalence estimates for ischemic heart disease presented in Section 2.5.2.

SECTION 1
INTRODUCTION

In 1997, the U.S. Environmental Protection Agency (EPA) initiated its periodic review of the national ambient air quality standards (NAAQS) for carbon monoxide (CO) as required under the Clean Air Act Amendments of 1990. As part of its review, EPA will prepare a Staff Paper that provides the EPA Administrator, the Clean Air Scientific Advisory Committee (CASAC), and the public with the staff's interpretation of the scientific evidence reviewed in the revised Air Quality Criteria Document, also prepared by EPA, as well as the results of technical air quality and human exposure analyses conducted as part of this review. EPA presented a development plan for the CO NAAQS review (EPA, 1998) to the CASAC at a public meeting on November 16, 1998, which describes the scope of the review and presents the status and schedule for various aspects of the review, including the development of human exposure estimates to CO.

One of the key inputs to the review is the estimation of human exposure. Exposure is being characterized using an updated version of the probabilistic NAAQS Exposure Model for CO (pNEM/CO) which was previously developed in 1992 as part of the last review of the CO NAAQS (see Johnson et al., 1992). An earlier draft of this report presented a description of a revised version of pNEM/CO and a preliminary application of the model to the Denver urban area (Johnson et al., 1999). After completing a review of comments on this report received from CASAC and the public, EPA made a series of refinements to the model and then applied the enhanced model (hereafter referred to as Version 2.1) to study areas in both Denver and Los Angeles. EPA selected Denver as one of the study areas to provide a basis for comparison with the previous review and because it is one of the few areas where a personal exposure study has been conducted that can be used to provide a limited evaluation of the model. Los Angeles is being included because (1) Los Angeles poses the largest public health burden in terms of ambient CO levels and potential population exposure, (2) the city has an extensive ambient monitoring network, and (3) there is a study of indoor and ambient CO concentrations for residents in southern California that provides information useful in developing exposure estimates.

1.1 Applications of pNEM/CO to Denver and Los Angeles Under Recent Air Quality Conditions

The original version of pNEM applicable to CO (pNEM/CO) was developed for EPA in 1991. Unlike the pNEM/O3 model which provides only exposure estimates, pNEM/CO also provides an estimate of internal dose [the carboxyhemoglobin (COHb) level] associated with each exposure. Johnson et. al. (1992) have described the use of pNEM/CO to estimate CO exposures and resulting COHb levels in the residents of Denver, Colorado. In this 1992 application, researchers estimated exposures expected under recent air quality conditions and under conditions in which a specific NAAQS was just attained in the city.

Each version of pNEM has a modular structure, with separate computer subroutines being used to prepare input databases, calculate exposures, and tabulate results. This modular feature permits researchers to construct a new version of pNEM by combining features from existing versions with new components that address application-specific modeling needs. EPA has recently updated the pNEM/CO methodology to permit the use of 1990 census data. Analysts have also enhanced the algorithms in the model which simulate gas stove use, determine indoor and outdoor CO concentrations, account for passive smoking, estimate alveolar ventilation rate (a measure of human respiration), and model home-to-work commuting patterns. This report describes Version 2.1 of pNEM/CO and presents results of applying the model to Denver and Los Angeles under simulated air quality conditions representing recent “as is” conditions in each city. For comparison purposes, this report also provides estimated exposures for Los Angeles under simulated conditions in which the current CO NAAQS is just attained. As recent air quality in Denver has been roughly equivalent to attainment conditions, analysts assumed that the “as is” conditions in Denver were representative of attainment conditions and did not perform a separate pNEM/CO analysis in which attainment conditions were simulated.

1.2 Report Organization

This report is divided into eight sections. Section 2 presents an overview of the updated pNEM/CO methodology. Section 3 outlines the methods used to select and process the fixed-site monitoring data used in applying pNEM/CO to Denver and Los Angeles. Section 4 provides a detailed description of the mass-balance model used to estimate CO concentrations for indoor and in-vehicle microenvironments. Section 5 provides a summary of the procedure used to estimate alveolar ventilation rate. Section 6 describes the development of origin-destination tables for home-to-work commuting trips in Denver and Los Angeles. Section 7 presents the results of applying pNEM/CO to special populations within the Denver and Los Angeles metropolitan areas. A discussion of the limitations of Version 2.1 of pNEM/CO can be found in Section 8. Section 8 also provides recommendations for further research.

1.3 References for Section 1

Johnson, T., J. Capel, R. Paul, and L. Wijnberg. 1992. **Estimation of Carbon Monoxide Exposures and Associated Carboxyhemoglobin Levels in Denver Residents Using a Probabilistic Version of NEM**. Report prepared by International Technology Air Quality Services under EPA Contract No. 68-D0-0062. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Johnson, T., G. Mihlan, J. LaPointe, K. Fletcher, and J. Capel. 1999. **Estimation of Carbon Monoxide Exposures and Associated Carboxyhemoglobin Levels in Denver Residents Using pNEM/CO (Version 2.0)**. Report prepared by ICF Consulting and TRJ Environmental, Inc., under EPA Contract No. 68-D6-0064. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

U.S. Environmental Protection Agency. 1998. **Carbon Monoxide NAAQS Review Development Plan.** Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, November.

SECTION 2
OVERVIEW OF THE METHODOLOGY

Version 2.1 of pNEM/CO follows the same general approach used in the original 1992 version (Johnson et al., 1992). Figure 2-1 shows the conceptual overview of the logic and data flow of the model. The various inputs to the model (e.g., activity patterns, ambient monitoring data, air exchange rates, commuting data, population census data) are shown in the rounded boxes, and the model calculations take place in the rectangular boxes (e.g., mass-balance model for indoor microenvironments). The general pNEM methodology can be viewed as the following five steps:

1. Define a study area, one or more populations-of-interest, appropriate subdivisions of the study area, and an exposure period.
2. Divide the population-of interest into an exhaustive set of cohorts.
3. Develop an exposure event sequence for each cohort for the exposure period.
4. Estimate the pollutant concentration, alveolar ventilation rate, and physiological indicator (if applicable) associated with each exposure event.
5. Extrapolate the cohort exposures to each population-of-interest.

The remainder of this section describes how Version 2.1 implements each step of the pNEM/CO methodology. Pertinent information concerning the application of the methodology to the Denver and Los Angeles study areas is included as appropriate.

2.1 Define Study Area, Populations-of-Interest, Subdivisions of Study Area, and Exposure Period

The pNEM/CO methodology provides estimates of the distribution of CO exposures and associated COHb levels within a defined population (the population-of-interest) for a specified exposure period. The exposure period is usually a recent

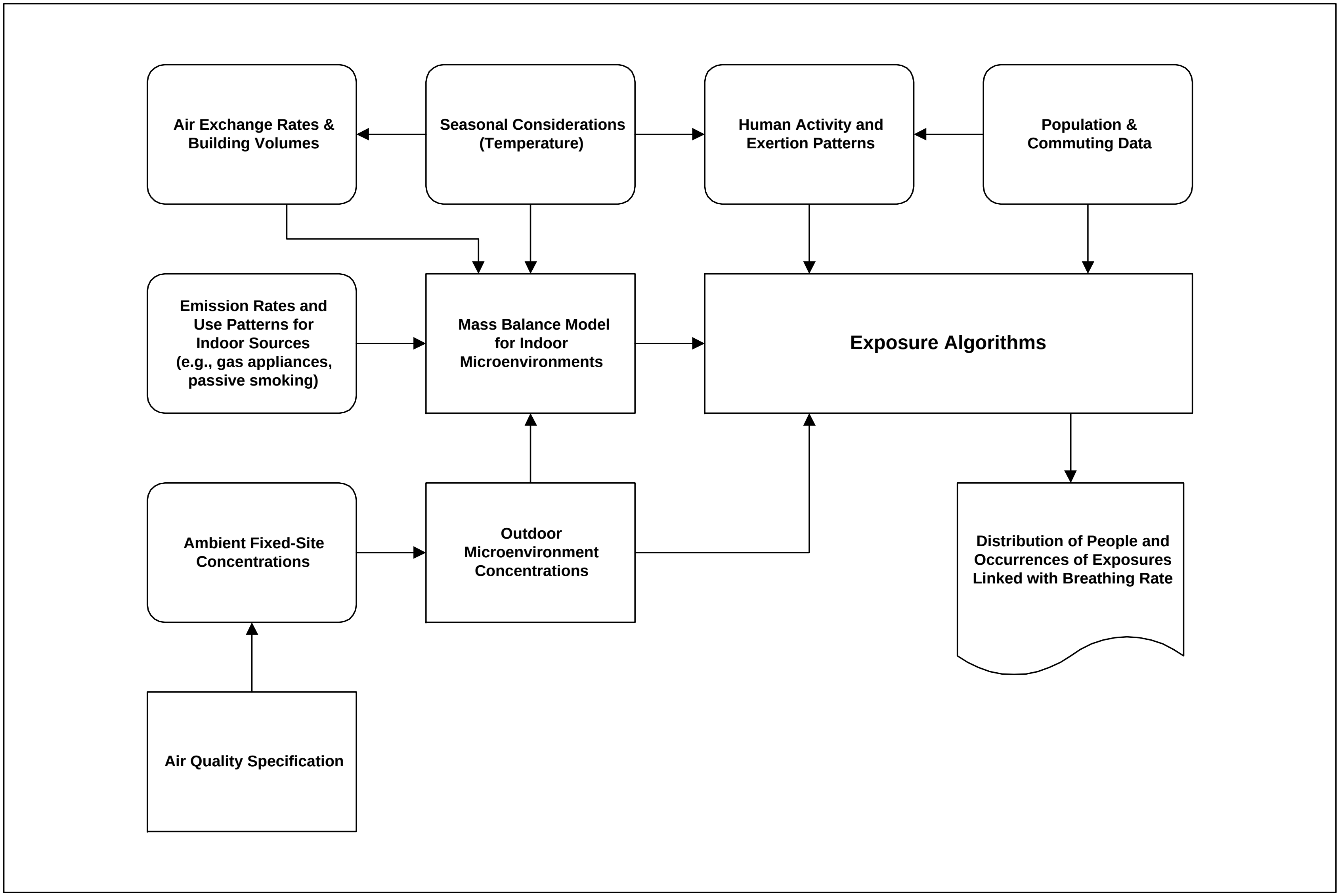

Figure 2-1. Conceptual Model and Data Flow of pNEM/CO

calendar year for which good data are available with respect to ambient CO levels. The population-of interest is typically defined as people with specific demographic characteristics (e.g., adults with ischemic heart disease) who live and work within a defined set of exposure districts. Each exposure district is a contiguous set of census units surrounding one or more fixed-site CO monitors selected as representative of the district.

Analysts selected seven fixed-site monitors as the basis for developing the Denver exposure districts. Subsection 3.1.1 describes in detail the process used to select these monitors and to define the district boundaries. Briefly, analysts identified seven which (1) were located within 50 km of the center of Denver, (2) were located in areas of appropriate urban land use, and (3) reported sufficient air quality data for 1995 through 1997. Five of the seven sites were identical to sites used in the 1992 Denver analysis; the remaining two sites were located in downtown Boulder (28th Street and Marine Street). The locations of five sites used in the 1992 analysis were considered appropriate for defining five separate exposure districts with 10 km radii. However, the Boulder sites were considered too close together to support separate exposure districts. Consequently, analysts defined six exposure districts -- one for each of the 1992 Denver sites and a “composite” Boulder site. For purposes of constructing the associated exposure district, the composite site was assigned a location midway between the two Boulder sites.

Analysts evaluated the quality and completeness of the data available for the seven monitors for the years 1995 through 1997. Based on this evaluation, EPA selected 1995 as the year for the pNEM/CO analysis of Denver. Each of the selected monitors provided an hourly average data set that was at least 96 percent complete for this year. Section 3.2 describes the method used to estimate the missing values in each data set. Table 2-1 provides descriptive statistics for the data sets after missing values were estimated.

A similar approach was used in selecting fixed-site monitors for the application of pNEM/CO to Los Angeles. As discussed in Subsection 3.1.2, analysts designated all sites within Los Angeles, Orange, Riverside, San Bernardino, and Ventura Counties which reported CO data between 1995 and 1997 as <u>potential</u> sites for the pNEM/CO analysis.

Table 2-1. Descriptive Statistics for Hourly Average Values in 1995 Data Sets Selected to Represent Denver Exposure Districts After Estimation of Missing Values.

Location	Monitor ID	Descriptive statistics for hourly-average CO concentrations, ppm					
		50th	90th	95th	99th	99.5th	Maximum
Littleton	005-0002	0.3	0.7	1.0	1.8	2.2	3.6
Broadway	031-0002	1.2	2.7	3.4	6.1	7.7	24.5
Albion	031-0013	0.9	2.5	3.4	5.5	6.4	14.6
Julian	031-0014	0.7	2.3	3.2	5.3	6.5	10.4
Arvada	059-0002	0.6	2.0	2.7	4.8	5.8	11.9
Boulder 28th St.	013-0010	0.8	2.1	2.8	4.8	5.5	10.6
Boulder Marine St.	013-1001	0.4	0.9	1.3	2.3	2.9	8.3
Composite Boulder monitor	---	0.7	1.5	2.0	3.3	3.8	9.5

Of the 30 CO sites which met these criteria, 24 satisfied a further requirement that the site reported data that were at least 75 percent complete for each of the three years. Analysts omitted seven of these monitors which were located in outlying areas and reported relatively low CO levels (three-year averages for the second largest 8-hour maximum CO concentration less than 4.5 ppm). EPA evaluated the siting characteristics and locations of the remaining 17 monitors and selected the 10 monitors listed in Table 2-2. These monitors all reported relatively high CO levels, and they appeared to provide good coverage of the highly urbanized areas within greater Los Angeles.

EPA selected 1997, the most recent of the three years evaluated, as the year for the pNEM/CO analysis of Los Angeles. All 10 sites had adequate data completeness for 1997. Table 2-2 provides descriptive statistics for each data set after estimation of missing values.

Table 2-2. Descriptive Statistics for Hourly Average Values in 1997 Data Sets Selected to Represent Los Angeles Exposure Districts After Estimation of Missing Values.

Location	Monitor ID	Descriptive statistics for hourly-average CO concentrations, ppm					
		50th	90th	95th	99th	99.5th	Maximum
West Los Angeles	60370113	0.6	2.0	2.6	3.6	4.1	7.3
Burbank	60371002	1.4	3.5	4.4	6.0	6.6	8.8
Los Angeles	60371103	1.0	3.0	3.8	5.4	5.8	8.9
Lynwood	60371301	1.7	4.9	6.7	11.2	13.5	19.2
Pico Rivera	60371601	1.2	3.0	3.6	5.0	5.6	9.2
Pasadena	60372005	0.9	2.1	2.8	4.2	4.7	8.1
Long Beach	60374002	0.7	2.7	3.6	5.2	5.9	9.0
Hawthorne	60375001	0.5	3.7	5.1	7.3	8.2	12.4
Anaheim	60590001	0.8	2.3	2.9	4.6	5.5	8.4
La Habra	60595001	1.0	2.8	3.6	6.1	7.1	11.9

After application of the fill-in procedure described in Subsection 3.2, each district in the Denver and Los Angeles study areas was represented by a complete, year-long sequence of 1-hour outdoor concentrations. These sequences were assumed to represent existing (“as is”) outdoor air quality conditions in each study area. To represent outdoor air quality that just meets the current 8-hour NAAQS for CO, the concentration values in each Los Angeles sequence were adjusted according to the procedure described in Subsection 3.3. The Denver data were not adjusted, as the “as is” air quality was judged to be roughly equivalent to conditions expected to occur when the current 8-hour NAAQS is attained.

The focus of the previous review of the CO NAAQS was on the population with ischemic heart disease[1]. As the incidence of ischemic heart disease for individuals younger than age 18 is extremely small (about 0.01%), EPA has chosen to define the

[1]EPA’s Criteria Document and OAQPS Staff Paper use several terms (i.e., coronary heart disease, cardiovascular disease, coronary heart disease, and ischemic heart disease) which all refer to the same population group.

population of interest as adults (18 and older) with ischemic heart disease who lived and worked within the exposure districts in each urban study area.

2.2 Divide the Population-of-Interest into an Exhaustive Set of Cohorts

In a pNEM analysis, the population-of-interest is divided into a set of cohorts such that each person is assigned to one and only one cohort. Each cohort is assumed to contain persons with identical exposures during the specified exposure period. Cohort exposure is typically assumed to be a function of demographic group, location of residence, and location of work place. Specifying the home and work district of each cohort provides a means of linking cohort exposure to ambient CO concentrations. Specifying the demographic group provides a means of linking cohort exposure to activity patterns which vary with age, work status, and other demographic variables. In some analyses, cohorts are further distinguished according to factors relating to proximity to emission sources or time spent in particular microenvironments.

In the application of pNEM/CO (Version 2.1) to Denver and Los Angeles, each cohort was identified as a distinct combination of (1) home district, (2) demographic group, (3) work district (if applicable), (4) residential cooking fuel, and (5) replicate number. The home district and work district of each cohort were identified according to the districts defined above. Table 2-3 lists 10 adult demographic groups defined for the pNEM/CO analyses. Four of the demographic groups were identified as workers. Each cohort associated with one of these groups was identified by both home and work district. The remaining cohorts were identified only by home district. Note that although children have been included within the demographic groups defined for previous pNEM/CO analyses, the exposure analyses summarized in this report were limited to adult demographic groups.

The residential cooking fuel of each cohort was identified as either “natural gas” or “other.” This cohort index was used because a personal monitoring study (Johnson, 1984) conducted in Denver suggested that proximity to operating natural gas stoves contributed significantly to CO exposure. A review of the scientific literature concerning five other sources (kerosene space heaters, gas space heaters, wood stoves, fireplaces, and attached garages) indicated that (1) fireplaces and stoves did not contribute significantly to indoor CO levels, (2) kerosene and gas space heaters were used in less than 1 percent of the residences in each study area, and (3) attached garages could not be adequately characterized by available data (Fletcher and LaPointe, 1998). Section 3.5 of the CD (EPA, 2000) also provides a review of the available information on indoor and in-vehicle sources of CO and observed CO concentrations.

Table 2-3. Demographic Groups Defined for the pNEM/CO Analyses and Number of Associated Cohorts by Study Area.

Demographic group	Includes commuting cohorts?	Number of cohorts associated with demographic group	
		Los Angeles	Denver
Males, 18 to 44, working	yes	600	360
Males, 18 to 44, nonworking	no	60	60
Males, 45 to 64, working	yes	600	360
Males, 45 to 64, nonworking	no	60	60
Males, 65+	no	60	60
Females, 18 to 44, working	yes	600	360
Females, 18 to 44, nonworking	no	60	60
Females, 45 to 64, working	yes	600	360
Females, 45 to 64, nonworking	no	60	60
Females, 65+	no	60	60
Total		2,760	1,800

Earlier versions of pNEM/CO have defined cohorts solely according to home district, demographic group, work district (if applicable), and residential cooking fuel. A new feature was installed in pNEM/CO (Version 2.1) which permitted the user to specify a “replication” value (n) such that the model will produce n cohorts for each combination of these four indices. Because pNEM/CO uses a Monte Carlo process to construct an activity pattern for each cohort, each of the n cohorts associated with a particular combination of home district, demographic group, work district, and residential cooking fuel is associated with a distinct exposure sequence. The replication feature permits the analyst to divide the population-of-interest into a larger number of smaller cohorts -- a process that decreases the “lumpiness” of the exposure simulation. Replication values of n = 5 and n = 3, respectively, were specified for the Denver and Los Angeles exposure analyses described in this report. Consequently, the pNEM/CO model analyzed n times the number of cohorts it would have considered for each city had the cohorts been defined solely by home district, demographic group, work district, and residential cooking fuel.

Table 2-3 lists the number of cohorts associated with each demographic group by study area. Each of the six nonworking demographic groups defined for Los Angeles is associated with 60 cohorts, one for each combination of home district, residential cooking fuel, and replicate number (10 x 2 x 3 = 60). Each of the four working demographic groups is associated with 600 cohorts, one for each combination of home district, work district, residential cooking fuel, and replicate number (10 x 10 x 2 x 3 = 600). The total number of Los Angeles cohorts is thus (6 x 60) + (4 x 600) or 2,760. As indicated in Table 2-3, a similar process using a replicate number of 5 produced 1,800 cohorts for the Denver study area.

2.3 Develop an Exposure Event Sequence for Each Cohort for the Exposure Period

In the pNEM/CO methodology, the exposure of each cohort is determined by an exposure event sequence (EES) specific to the cohort. Each EES consists of a series of events with durations from 1 to 60 minutes. To permit the analyst to determine average exposures for specific clock hours, the exposure events are defined such that no event falls within more than one clock hour. Each exposure event assigns the cohort to a particular combination of geographic area and microenvironment. In addition, each event specifies whether or not the cohort is in the presence of smokers. Each event also provides an indication of respiration rate. In the original (1992) version of pNEM, this indicator was a classification of breathing rate as sleeping, slow, medium, or fast.

In Version 2.1 of pNEM/CO, this indicator is a specific activity descriptor such as "raking" or "playing baseball."

In typical pNEM applications, the EESs are determined by assembling activity diary records relating to individual 24-hour periods into a year-long series of records. Because each subject of a typical activity diary study provides data for only a few days, the construction of a year-long EES requires either the repetition of data from one subject or the use of data from multiple subjects. The latter approach is used in pNEM analyses to better represent the variability of exposure that is expected to occur among the persons included in the cohort.

In the pNEM/CO (Version 2.1) analysis, activity diary data were obtained from the Consolidated Human Activity Database (CHAD). As of 1999, CHAD was comprised of approximately 17,000 person-days of 24-hour time/activity data developed from eight surveys (Tippett et al., 1997). The surveys include probability-based recall studies conducted by EPA and the California Air Resources Board, as well as real-time diary studies conducted in individual U.S. metropolitan studies using both probability-based and volunteer subject panels. All ages of both genders are represented in CHAD. The data for each subject consist of one or more days of sequential activities, in which each activity is defined by start time, duration, activity type (140 categories), and microenvironment classification (110 categories). Activities vary from one minute to one hour in duration, with longer activities being subdivided into clock-hour durations to facilitate exposure modeling. A distribution of values for the ratio of oxygen uptake rate to body mass (referred to as metabolic equivalents or "METs") is provided for each activity type listed in CHAD. The forms and parameters of these distributions were determined through an extensive review of the exercise and nutrition literature. The primary source of distributional data was Ainsworth et al. (1993), a compendium developed specifically to "facilitate the coding of physical activities and to promote comparability across studies."

The CHAD database was processed to create a special database appropriate for input in pNEM/CO. This database consisted of diary records organized by study subject and calendar day. The diary records for one subject for one calendar day were designated a "person-day." The CHAD-derived database contained 14,048 usable person-days, each of which was indexed by the following factors:

1. Demographic group
2. Season: “summer” (June through August) or “winter” (all other months)
3. Temperature classification: cool or warm
4. Day type: weekday or weekend.

The demographic group index was determined by the demographic group to which the subject filling out the diary belonged. The season and day indices were based on the date of the calendar day. The temperature classification was based on the daily maximum temperature (in °F) of the associated geographic location on that date. The cool range was defined as temperatures below 55° in winter and temperatures below 84° in summer.

The EES for each cohort was determined by a computerized sampling algorithm. The algorithm was provided with the sequence of daily maximum temperatures reported by the city for the year of the analysis and with a list of cohorts. The temperature data were used to assign each calendar day to one of the temperature ranges used in classifying the activity diary data. To construct the EES for a particular cohort, the algorithm selected a person-day from the CHAD-derived database for each calendar day according to the demographic group of the cohort and the season, day type, and temperature classification associated with the time period.

Each exposure event within an EES was defined by (1) district, (2) CHAD location descriptor, (3) microenvironment, (4) CHAD activity descriptor, and (5) passive smoking status. The district was either the home or work district associated with the cohort. The home/work determination was based on a decision rule which was applied to the sequence of exposure events associated with each person-day. Starting with the midnight event, each event was assigned to the home district unless the activity code associated with the event explicitly indicated the subject was at work. Whenever an explicit work code was encountered in the sequence, each subsequent event was assigned to the work district until an explicit home event was encountered. Each subsequent event was then assigned to the home district until an explicit work event was encountered. This assignment procedure was continued until the end of the person-day was reached.

The CHAD location descriptor refers to the location code associated with the event in the CHAD database. The location descriptor was used to assign the event to a microenvironment and to determine the contribution of passive smoking (if applicable) to the CO concentration experienced during the event. Table 2-4 lists the 120 codes used to define the location descriptors of exposure events.

Table 2-5 lists the 15 microenvironments used for event assignments. Each microenvironment is identified as to a general location (e.g., outdoors) and a specific location (e.g., near road). The list includes two indoor microenvironments related to residences, seven indoor microenvironments related to nonresidential buildings, three outdoor microenvironments, and three vehicle microenvironments. The majority of these microenvironments are aggregates of two or more of the CHAD location descriptors. Only location descriptions associated with similar average CO exposures were combined in defining the aggregate microenvironments. Researchers determined these similarities through an analysis of personal CO monitoring data obtained from the Denver activity diary study (Johnson, 1984). Table 2-4 shows the assignment of CHAD location descriptors to microenvironments.

Activity descriptors were defined according to activity classifications appearing in CHAD. CHAD provides a distribution of energy expenditure rate for each activity classification which was used in a later step to estimate a ventilation rate for each activity (see Section 5). Appendix A lists the CHAD descriptors and associated distributions for energy expenditure rate.

The effects of active smoking on CO exposure were not addressed in the exposure analysis described here. Because of the coding conventions used in the CHAD diary studies, passive smoking patterns could be determined for nonsmoking subjects only. Consequently, the activity diaries sampled in constructing EESs were limited to those of nonsmokers (a total of 8,077 adult person-days of data). The diary record associated with each exposure event provided information on whether or not the subject was in the presence of smokers. This information was used to assign a passive smoking status to each event.

Table 2-4. Assignment of CHAD Location Codes to pNEM/CO Microenvironments

CHAD Location Code	pNEM/CO Microenvironment Code
<30> Home	
30000: residence, general	1
30010: your residence	1
30020: other’s residence	1
30100: residence, indoor	1
30120: your residence, indoor	1
30121: kitchen	1
30122: living room/ family room	1
30123: dining room	1
30124: bathroom	1
30125: bedroom	1
30126: study/ office	1
30127: basement	1
30128: utility room/ laundry room	1
30129: other indoor	1
30130: other’s residence, indoor	1
30131: kitchen	1
30132: living room/ family room	1
30133: dining room	1
30134: bathroom	1
30135: bedroom	1
30136: study/ office	1
30137: basement	1
30138: utility room/ laundry room	1
30139: other indoor	1

CHAD Location Code	pNEM/CO Microenvironment Code
30200: residence, outdoor	11
30210: your residence, outdoor	11
30211: pool, spa	11
30219: other outdoor	11
30220: other's residence, outdoor	11
30221: pool, spa	11
30229: other outdoor	11
30300: garage	9
30310: indoor garage	9
30320: outdoor garage	11
30330: your garage	9
30331: indoor garage	9
30332: outdoor garage	11
30340: other's garage	9
30341: indoor garage	9
30342: outdoor garage	11
30400: other, residence	1
<31> Travel	
31000: travel, general	12
31100: motorized travel	12
31110: car	12
31120: truck	13
31121: truck (pick-up or van)	13
31122: truck (other than pick-up or van)	13
31130: motorcycle/ moped/ motorized scooter	10
31140: bus	14

CHAD Location Code	pNEM/CO Microenvironment Code
31150: train/ subway/ rapid transit	14
31160: airplane	CO = 0
31170: boat	11
31171: motorized boat	11
31172: unmotorized boat	11
31200: non-motorized travel	11
31210: walk	11
31220: bicycle/ skateboard/ roller-skates	10
31230: in a stroller or carried by an adult	11
31300: waiting	11
31310: wait for bus, train, ride (at stop)	10
31320: wait for travel, indoors	7
31900: other travel	14
31910: other vehicle	14
<32-34> Other Indoor	
32000: other indoor, general	7
32100: office building/ bank/ post office	7
32200: industrial plant/ factory/ warehouse	8
32300: grocery store/ convenience store	7
32400: shopping mall/ non-grocery store	3
32500: bar/ night club/ bowling alley	5
32510: bar/ night club	5
32520: bowling alley	6
32600: repair shop	
32610: auto repair shop/ gas station	2
32620: other repair shop	3

CHAD Location Code	pNEM/CO Microenvironment Code
32700: indoor gym/ sports or health club	8
32800: childcare facility	8
32810: childcare facility, house	1
32820: childcare facility, commercial	8
32900: public building/ library/ museum/ theater	7
32910: auditorium, sport's arena, concert hall	6
32920: library, courtroom, museum, theater	7
33100: laundromat	7
33200: hospital/ health care facility/ doctor's office	8
33300: beauty parlor/ barber shop/ hair dresser's	7
33400: at work: no specific location, moving among locations	7
33500: school	8
33600: restaurant	4
33700: church	8
33800: hotel/ motel	7
33900: dry cleaners	8
34100: parking garage	15
34200: laboratory	7
34300: other, indoor (specify)	7
<35-36> Other Outdoor	
35000: other outdoor, general	11
35100: sidewalk/ street/ neighborhood	10
35110: within 10 yards of street	10
35200: public garage/ parking lot	15
35210: public garage	15
35220: parking lot	15

CHAD Location Code	pNEM/CO Microenvironment Code
35300: service station/ gas station	15
35400: construction site	11
35500: amusement park	11
35600: school grounds/ playground	11
35610: school grounds	11
35620: playground	11
35700: sports stadium and amphitheater	11
35800: park/ golf course	11
35810: park	11
35820: golf course	11
35900: pool, river, lake	11
36100: restaurant, picnic	11
36200: farm	11
36300: other outdoor (specify)	11

Table 2-5. Methodology Used to Estimate Carbon Monoxide Concentrations in Each Microenvironment Defined for the Denver and Los Angeles pNEM/CO Analyses

Microenvironment			Activity diary locations included in microenvironment	CO sources treated by hour mass-balance model	CO sources treated by minute mass-balance model
Code	General location	Specific location			
1	Indoors	Residence	Indoors - residence	Outdoor CO Gas stoves	ETS
2	Indoors	Nonresidence A	Service station Auto repair	Outdoor CO	
3	Indoors	Nonresidence B	Other repair shop Shopping mall	Outdoor CO	
4	Indoors	Nonresidence C	Restaurant	Outdoor CO ETS	
5	Indoors	Nonresidence D	Bar	Outdoor CO ETS	
6	Indoors	Nonresidence E	Other indoor location Auditorium	Outdoor CO	
7	Indoors	Nonresidence F	Store Office Other public building	Outdoor CO	
8	Indoors	Nonresidence G	Health care facility School Church Manufacturing facility	Outdoor CO	
9	Indoors	Residential garage	Residential garage	Outdoor CO	
10	Outdoors	Near road	Near road Bicycle Motorcycle	Not applicable	
11	Outdoors	Other locations	Outdoor residential garage Construction site Residential grounds School grounds Sports arena Park or golf course Other outdoor location	Not applicable	
12	Vehicle	Automobile	Automobile		Outdoor CO ETS
13	Vehicle	Truck	Truck		Outdoor CO ETS
14	Vehicle	Mass transit vehicles	Bus Train/subway Other vehicle	Outdoor CO	
15	Outdoor	Public parking or fueling facility	Indoor parking garage Outdoor parking garage Outdoor parking lot Outdoor service station	Not applicable	

2.4 Estimate the Pollutant Concentration, Alveolar Ventilation Rate, and COHb Level Associated with Each Exposure Event

In the pNEM/CO analyses described in this report, each cohort was represented by a sequence of exposure events spanning a calendar year. Probabilistic algorithms within pNEM/CO provided estimates of the CO concentration and alveolar ventilation rate associated with each exposure event. A biokinetics model within pNEM/CO then processed these estimates together with physiological data specific to the cohort to develop an estimate of the COHb level at the end of each hour.

2.4.1 Pollutant Concentration

In the pNEM/CO analysis, each exposure event within a particular EES was indexed according to district d, microenvironment m, person-day p, clock hour h, start time t, and duration u. The exposure associated with a particular event, CEXP(d,m,p,h,t,u) was estimated by the expression

$$CEXP(d,m,p,h,t,u) = CHR(d,m,p,h) + CMIN(d,m,t,u). \qquad (2\text{-}1)$$

CHR(d,m,p,h) is the hourly-average CO concentration determined for microenvironment m in district d for person-day p and hour h. Values of CHR(d,m,p,h) for enclosed microenvironments (i.e., buildings and enclosed vehicles) were obtained from a mass-balance model with an averaging time of <u>one hour</u>. CMIN(d,m,t,u) is the average of u one-minute CO concentrations spanning the exposure event. A mass-balance model with an averaging time of <u>one minute</u> was used to estimate values of CMIN(d,m,t,u). As discussed in Section 4, each of the two mass-balance models was capable of accounting for the effects of outdoor CO concentration, air exchange rate, indoor sources, and enclosure volume.

The method used in applying the mass-balance models varied according to the microenvironment where the event occurred. Table 2-5 lists the 15 microenvironments defined for Version 2.1 of pNEM/CO and indicates the CO sources considered in modeling each microenvironment.

The <u>one-hour</u> mass-balance model was used to estimate the contribution of outdoor CO levels to indoor CO levels in Microenvironments Nos. 2, 3, 6, 7, 8, and 9. These indoor microenvironments were assumed to have no significant indoor CO sources. The one-hour model was also used to estimate the combined contribution of outdoor CO and indoor gas stove emissions to indoor CO levels for Microenvironment No. 1 (indoors - residence). In addition, this model was used to estimate the combined contribution of outdoor CO and indoor environmental tobacco smoke (ETS) to CO levels in Microenvironment Nos. 4 (restaurants) and 5 (bars), when smoking was permitted by local regulations (i.e., Denver only).

The <u>one-minute</u> mass-balance model was used to estimate the minute-by-minute contribution of ETS to CO levels in Microenvironment No. 1 (indoors - residence). The one-minute model was also used to estimate the combined minute-by-minute contribution of outdoor CO and inside ETS to CO levels in Microenvironments Nos. 12 (automobiles) and 13 (trucks).

ETS was assumed to occur in Microenvironments Nos. 1 (indoors - residence), 12 (automobiles), and 13 (trucks) whenever the presence of one or more smokers was indicated by the diary data used to define the exposure event. In applications of pNEM/CO to Denver, ETS was assumed to occur constantly in Microenvironment Nos. 4 (restaurants) and 5 (bars), as Denver does not restrict smoking in these microenvironments. As California currently bans smoking in bars and restaurants, analysts assumed that Microenvironments Nos. 4 and 5 were always free of ETS when applying pNEM/CO to Los Angeles.

ETS was not considered to be a significant source of CO in the remaining microenvironments. This assumption may underestimate CO levels in some of these microenvironments. However, analysts were unable to find sufficient data to develop realistic estimates for the contribution of passive smoking to these microenvironments.

As mentioned previously, a review of the scientific literature concerning five other sources (kerosene space heaters, gas space heaters, wood stoves, fireplaces, and attached garages) indicated that (1) fireplaces and stoves did not contribute significantly to indoor CO levels, (2) kerosene and gas space heaters were used in less than 1 percent of the residences in each study area, and (3) attached garages could not be adequately characterized by available data (Fletcher and LaPointe, 1998). EPA and the authors of this report recognize that Version 2.1 of pNEM/CO does not characterize the elevated CO exposures that may occur in certain circumstances related to these additional indoor sources (e.g., extended use of unvented kerosene space-heaters with inadequate room ventilation).

In general, the CHR(d,m,p,h) term was used to represent the component of exposure contributed by ambient (outdoor) CO concentrations, by the operation of residential gas stoves, and by ETS in smokey environments such as bars and restaurants. An array of CHR(d,m,p,h) values was created for each cohort. Each array consisted of a set of year-long sequences of hourly-average CHR(d,m,p,h) values, one sequence for each combination of microenvironment and district. The district was either the home or work district specified for the cohort. When an exposure event occurring during hour h assigned a cohort to a particular combination of microenvironment and district, the cohort was assigned the CHR(d,m,p,h) value specified for hour h in the designated microenvironment/district sequence.

Each year-long sequence of hourly average CHR(d,m,p,h) values was generated by the hour mass-balance algorithm described in Section 4. Briefly, this algorithm estimated the hourly average indoor CO concentrations during hour h as a function of the indoor CO concentration during the preceding hour (i.e., hour h - 1), the CO concentration outdoors during hour h, the air exchange rate during hour h, and the indoor emissions of CO from gas stoves (Microenvironment No. 1) or ETS (Microenvironment Nos. 4 and 5) during hour h. Values for the air exchange rate, gas stove emission rate, and ETS emission rate were sampled from appropriate distributions on a yearly, seasonal, or daily basis. During each clock hour, gas stoves were probabilistically determined as “on” for 30 minutes, “on” for 60 minutes, or “off’ for the entire hour. The probability of being on varied with time of day according to use patterns observed during the Denver activity diary study (Akland et al., 1985; Johnson et al., 1984).

The CMIN(d,m,t,u) term was used for two purposes: (1) representing total CO exposure for exposure events occurring in automobiles (Microenvironment No. 12) and trucks (Microenvironment No. 13) and (2) representing the contribution of ETS to exposures occurring in the indoors - residence microenvironment. In both cases, the minute mass-balance model was used to generate one-minute CO concentrations on an “as needed” basis. These values were then averaged over the duration of the event.

Whenever a cohort was assigned to an automobile or truck for a trip consisting of one or more sequential exposure events, the minute mass-balance model was used to estimate one-minute CO concentrations for the total duration of the trip. These calculations accounted for outdoor CO levels, air exchange rate, vehicle volume, and CO emissions from ETS (if any). The resulting one-minute CO concentrations were averaged over each exposure event of the trip.

Whenever a cohort was assigned to the indoors - residence microenvironment <u>and</u> the exposure event indicated one or more smokers were present, the minute mass-balance model was used to generate a series of one-minute CO concentrations spanning the event. These calculations accounted for air exchange rate, building volume, and CO emissions from ETS. The one-minute CO concentrations were averaged over the exposure event to determine a value for CMIN(d,m,t,u). Note that this value represented the contribution of ETS only. The contribution of outdoor CO and gas stoves emissions were included in the CHR(d,m,p,h) term associated with the exposure event.

The outdoor CO concentration required by each mass-balance algorithm was determined for each hour through a Monte Carlo process based on the equation

$$CO_{out}(c,m,d,h) = M(m) \times L(c, m, d) \times T(c,m,d,h) \times [CO_{mon}(d,h)]^{A} \qquad (2\text{-}2)$$

in which

$CO_{out}(c,m,d,h)$ = outdoor CO concentration for cohort c with respect to microenvironment m in district d during hour h,

M(m) = multiplier (> 0) specific to microenvironment m,

L(c,m,d) = location multiplier (> 0) specific to cohort c, microenvironment m, and district d (held constant for all hours),

T(c,m,d,h) = time-of-day multiplier (> 0) specific to cohort c, microenvironment m, district d, and hour h,

$CO_{mon}(d,h)$ = monitor-derived CO concentration for hour h in district d, and

A = exponent (A > 0).

This equation was used to generate a year-long sequence of outdoor one-hour CO concentrations for each combination of cohort (c), microenvironment (m), and district (d). The exponent A was set equal to 0.621 and held constant for all sequences. The value of M(m) varied only with microenvironment as indicated in Table 2-6.

A value of the location factor L(c, m, d) was specified for each individual sequence and held constant for all hours in the sequence. The value was randomly selected from a lognormal distribution with geometric mean (GM_L) equal to 1.0 and geometric standard deviation (GSD_L) equal to 1.5232. The natural logarithms of this distribution can be characterized by a normal distribution with an arithmetic mean (μ_L) equal to zero and an arithmetic standard deviation (σ_L) equal to 0.4208.

A value of the time-of-day factor T(c, m, d, h) was randomly selected for each hour within a sequence from a lognormal distribution with geometric mean (GM_T) equal to 1.0 and geometric standard deviation (GSD_T) equal to 1.6289. The natural logarithms of this distribution follow a normal distribution with an arithmetic mean (μ_T) equal to zero and an arithmetic standard deviation (σ_T) equal to 0.4879.

The CO_{out}(c, m, d, h) term is interpreted as the outdoor CO concentration in the immediate vicinity of microenvironment m in district d during hour h. CO_{mon}(d, h) is the CO concentration reported for hour h by a nearby fixed-site monitor selected to represent district d.

Equation 2-2 is based on the results of data analyses that suggest that the relationship between CO_{out}(c, m, d, h) and CO_{mon}(d, h) should account for the identity of the microenvironment, the geographic location of the microenvironment, and the time of day. Numerous statistical models could be developed. In specifying the Equation 2-2 model, analysts attempted to balance the need for simplicity and parsimony with the need to model the most important patterns in the available data. Most of the model development was based on a comparison of hourly averages of 10-minute concentrations measured outside residences in southern California (Wilson, Colome, and Tian, 1995) with hourly averages measured at the nearest fixed site monitor. For this case, m represents the residence microenvironment in the district d. The district d was initially taken to be the entire study region (i.e., San Diego and Los Angeles areas).

Table 2-6. Estimated Values of Parameters in Equation 2-2.

Microenvironment[a]			Activity diary locations included in microenvironment	Parameter Estimates for Equation 2-2			
Code	General location	Specific location		A	σ_L	σ_T	M(m)
1	Indoors	Residence	Indoors - residence	0.621	0.4208	0.4879	1.034
2	Indoors	Nonresidence A	Service station Auto repair	0.621	0.4208	0.4879	2.970
3	Indoors	Nonresidence B	Other repair shop Shopping mall	0.621	0.4208	0.4879	1.213
4	Indoors	Nonresidence C	Restaurant	0.621	0.4208	0.4879	1.213
5	Indoors	Nonresidence D	Bar	0.621	0.4208	0.4879	1.213
6	Indoors	Nonresidence E	Other indoor location Auditorium	0.621	0.4208	0.4879	1.213
7	Indoors	Nonresidence F	Store Office Other public building	0.621	0.4208	0.4879	1.213
8	Indoors	Nonresidence G	Health care facility School Church Manufacturing facility	0.621	0.4208	0.4879	0.989
9	Indoors	Residential garage	Residential garage	0.621	0.4208	0.4879	1.034
10	Outdoors	Near road	Near road Bicycle Motorcycle	0.621	0.4208	0.4879	1.607
11	Outdoors	Other locations	Outdoor res. garage Construction site Residential grounds School grounds Sports arena Park or golf course Other outdoor location	0.621	0.4208	0.4879	1.436
12	Vehicle	Automobile	Automobile	0.621	0.4208	0.4879	3.020
13	Vehicle	Truck	Truck	0.621	0.4208	0.4879	3.020
14	Vehicle	Mass transit vehicles	Bus Train/subway Other vehicle	0.621	0.4208	0.4879	3.020
15	Outdoor	Public parking or fueling facility	Indoor parking garage Outdoor parking garage Outdoor parking lot Outdoor service station	0.621	0.4208	0.4879	2.970

[a]Aggregate microenvironments defined for statistical analysis of Denver PEM data: residence (1 and 9), service/parking (2 and 15), commercial (3 through 7), and vehicle (12 through 14).

Analysts began model development by considering a simple linear regression model of the form

$$CO_{out}(c,m,d,h) = a(m,d) + A \times [CO_{mon}(d,h)] + e(c,m,d,h),$$

in which the residual term e(c,m,d,h) is assumed to be independent and normally distributed with mean zero. For simplicity and parsimony, the slope coefficient A was assumed to be the same for all microenvironments (m) and districts (d). Although the coefficient of determination (R^2) for this model was a reasonably high 0.53, the model was found to be unacceptable because it does not properly reflect the strong correlations that were observed between concentrations measured outside the same location. Instead, this regression model assumes that the residuals associated with a particular residential location are independent. In other words, this model does not properly separate out the variation between locations from the variation within locations. Note that the R^2 goodness-of-fit statistic is not an appropriate measure of model adequacy when the true, underlying errors are highly correlated.

Analysts identified two other deficiencies in this model: (1) large negative values of the randomly-selected e(c,m,d,h) term could produce impossible negative outdoor concentrations and (2) the model did not generate outdoor concentrations characterized by lognormal distributions. Various researchers (e.g., Ott, 1995) have demonstrated that ambient CO concentrations tend to be characterized by lognormal distributions rather than normal distributions.

To better address these latter concerns, analysts evaluated an alternative model in which the natural logarithm of outdoor concentration was expressed as a linear function of the natural logarithm of monitor concentration:

$$LN[CO_{out}(c,m,d,h)] = a(m,d) + A \times LN[CO_{mon}(d,h)] + e(c,m,d,h),$$

In this equation and those that follow, LN[ ] indicates the natural logarithm of the quantity in brackets. To properly separate the variability between and within locations, the intercept term a(m,d) was also permitted to vary with the cohort location, c, leading to the final model:

$$LN[CO_{out}(c,m,d,h)] = a(c,m,d) + A \times LN[CO_{mon}(d,h)] + e(c,m,d,h). \qquad (2\text{-}3)$$

Exponentiating both sides of this equation yields the equivalent formulation:

$$CO_{out}(c,m,d,h) = M(m) \times L(c,m,d) \times T(c,m,d,h) \times [CO_{mon}(d,h)]^{A},$$

in which

$$LN[M(m)] = \text{mean } [a(c,m,d)], \text{ averaged over cohorts,}$$

$$L(c,m,d) = \exp\{a(c,m,d) - \text{mean } [a(c,m,d)]\}, \text{ and}$$

$$T(c,m,d,h) = \exp[e(c,m,d,h)].$$

This equation is identical to the model formulation presented above in Equation 2-2.

Several alternative statistical models were considered during the development of the selected model formulation. Early in the process, analysts evaluated a series of autoregressive time series models, in which model predictions were influenced by the past history of CO concentrations at the monitor and outdoors of the microenvironment. These models were rejected for several reasons: (1) they were inherently complex, (2) they yielded a wide variation in model coefficients which did not always produce reasonable estimates when applied to specific California residences, and (3) they required microenvironment-specific time series data for coefficient estimation which were not readily available for non-residential microenvironments. Analysts also evaluated models similar to Equation 2-2 in which the exponent A varies with microenvironment. These models were rejected due to the need for parsimony and the lack of sufficient, suitable data for estimating microenvironment-specific values of A. A simpler model in which the exponent A is fixed at 1 was rejected because fits of Equation 2-2 to California data indicated that A differed significantly from 1, at statistical significance levels well below 1%. In addition, the assumption that A equals 1 produced unrealistically high predictions for outdoor CO concentrations when the model was applied to monitoring data obtained from the Denver Broadway site. These high values were found to be a direct result of setting A equal to 1, which forced the geometric standard deviation of the estimated outdoor concentrations to significantly exceed the geometric standard deviation of the monitor values.

Analysts ultimately arrived at Equation 2-2 (equivalent to Equation 2-3), which permits the A exponent to differ from 1.0. This model, considered a reasonable compromise between model simplicity and performance, is completely specified by four parameters [M(m), σ_L, σ_T, and A]. Note that σ_L, σ_T, and A are defined to be independent of the microenvironment, whereas M(m) is microenvironment-specific. Researchers were unable to find a single data source capable of providing estimates of all four parameters. Consequently, values for σ_L, σ_T, and A were estimated by analyzing data obtained from the California study conducted by Wilson, Colome, and Tian (1995), whereas the M(m) values were based on data provided by the Denver Personal Monitoring Study (Akland et al, 1985; Johnson, 1984).

During the residential monitoring study described by Wilson, Colome, and Tian (1995), researchers measured 10-minute CO concentrations outside 293 residences throughout California in 1992. These residences were customers of Pacific Gas and Electricity (129 residences in Northen California), San Diego Gas and Electric Company (89 residences in the San Diego area), and Southern California Gas Corporation (75 residences in the Los Angeles area). After excluding the PG&E data (not part of the Los Angeles study area) and homes for which valid CO data were not available, analysts used the remaining subset of 156 residences, 70 from Los Angeles and 86 from San Diego, as the basis for estimating values of σ_L, σ_T, and A applicable to the Los Angeles study area. (These coefficient values were also applied to Denver, as researchers were unable to identify a usable data set specific to the Denver study area). The data subset contained 44,726 valid 10-minute averages measured outside of residences, of which less than 1% were negative (smallest value = -1.0 ppm), 14,817 (33 %) were equal to 0 ppm, and the remainder were positive (maximum = 68.7 ppm). The valid 10-minute values were averaged by clock hour to permit comparison with hourly-average CO concentrations reported by nearby fixed-site monitors.

Analysts determined that the negative values in the data set were most likely caused by the subtraction of an offset from all measured values to account for monitor drift. To adjust for this offset and to prevent the occurrence of negative and zero values (which could not be used in fitting Equation 2-2), analysts added a constant offset of 0.5 ppm to each hourly-average value measured outside a residence. In addition, seventeen (0.2%) of the original hourly averages less than or equal to -0.5 ppm were discarded. Each of the resulting one-hour outdoor CO concentrations was paired with the one-hour CO concentration measured simultaneously at the nearest fixed-site monitor [based on data obtained from EPA's Aerometric Information Retrieval System (AIRS)]. This approach yielded a final database containing 6,330 pairs of hourly average concentrations, in which each pair was indexed by date, time, residence identifier, fixed-site monitor identifier, and fixed-site monitor scale (e.g., neighborhood).

The proposed model (Equation 2-2) was fitted to the final database using statistical software for a mixed (random and fixed effects) model which employed restricted maximum likelihood estimation. The fit yielded estimates of σ_L = 0.4208, σ_T = 0.4879, and A = 0.621, the values subsequently used in the pNEM/CO runs described in this report. The fitted value of M(m), representing residences in Los Angeles during 1992, was 0.9706. An alternative value (1.034), based on the analyses described below, was applied to the indoor - residence microenvironment in the pNEM/CO runs (Table 2-6).

Researchers conducted a series of sensitivity analyses to evaluate the potential effects on parameter estimates of variations in (1) region and (2) scale of the fixed-site monitor. Equation 2-2 was fitted to a series of data subsets defined by region (Los Angeles or San Diego) or by the scale of the fixed monitor (based on the estimated maximum distance from the monitor represented by the measured concentrations: micro, middle, neighborhood, or urban scale). The fitted values of σ_L, σ_T, A, and M(m) were very similar across the different subsets, supporting the assumption that these parameters can be assumed to be representative of concentration patterns outside residences in other regions and for other time periods, and can be chosen to be the same value for all monitoring scales. Due to a lack of suitable data, the values of σ_L, σ_T, and A are also assumed to be applicable to concentrations outside all other microenvironments, although M(m) varies with the microenvironment.

The M(m) values were based on data provided by the Denver Personal Monitoring Study (Akland et al, 1985; Johnson, 1984). During this study, each of approximately 450 subjects carried a personal exposure monitor (PEM) for two 24-hour periods. Each PEM measured CO concentration continuously. The PEM readings were averaged by exposure event such that each event was associated with a single microenvironment and a single clock hour (e.g., 1 pm to 2 pm). Event durations ranged from one minute to one hour. The microenvironment assigned to each PEM reading was determined from entries made in a real-time diary carried by the subject.

In Equation 2-2, the CO_{out}(c, m, d, h) term represents the outdoor CO concentration associated with a particular microenvironment m, even when the microenvironment is an indoor location. Few of the outdoor PEM values reported by the Denver study could be reliably associated with particular indoor microenvironments. Consequently, researchers employed a simplified procedure for estimating M(m) values which assumed that the mean of the indoor PEM values associated with each indoor microenvironment was approximately equal to the mean of the outdoor concentration for the microenvironment. This assumption is consistent with the results of applying mass-balance modeling to non-reactive pollutants in enclosed spaces where the only source of the pollutant is the outside air. In such cases, the mean indoor concentration approximates the mean outdoor concentration, with the instantaneous indoor concentration exhibiting a lower degree of variability than the corresponding outdoor concentration.

Because the simplified approach was also less sensitive to the wide variation in averaging times exhibited by the PEM values (i.e., one minute to 60 minutes), analysts were able to use the majority of PEM values in the statistical analysis. Limiting the analysis to one-hour PEM values would have significantly reduced the pool of usable data.

Researchers created a data base in which each PEM value was matched to the corresponding hourly-average CO concentration reported by the nearest fixed-site monitor. The data were first processed by excluding cases with missing measurements, cases in which measurements failed a quality control check, and cases in which applicable diary data indicated the potential presence of smokers or gas stoves. Each PEM CO concentration was then assigned to a microenvironment, m, based on entries in the activity dairy. In some cases, as indicated in the footnote to Table 2-6, the data for two or more similar microenvironments were aggregated to provide more stable estimates than those based on the very limited amount of data available for specific microenvironments. For consistency with the analyses performed on the Wilson, Colome, and Tian (1995) database, all cases with a zero measurement from the personal exposure monitor were excluded, as were all cases in which the fixed site monitor concentration was zero after rounding to the nearest integer ppm. Note that the Denver fixed-site data were recorded to the nearest 0.1 ppm, whereas the Los Angeles fixed site data were only recorded to the nearest integer.

When Equation 2-2 is expressed in logarithmic form (i.e., as Equation 2-3) and averaged over cohorts, one obtains the equation

$$\begin{aligned}
&\text{Mean}\{\text{LN}[CO_{out}(c, m, d, h)\} \\
&\quad = \text{Mean}[a(c, m, d)] + A \times \text{Mean}\{\text{LN}[CO_{mon}(d, h)]\} + \text{Mean}[e(c, m, d, h)] \\
&\quad = \text{LN}[M(m)] + A \times \text{Mean}\{\text{LN}[CO_{mon}(d, h)]\}.
\end{aligned}$$

Therefore, the value of M(m) equals

$$M(m) = \exp\{\text{Mean LN}[CO_{out}(c, m, d, h)] - A \times \text{Mean LN}[CO_{mon}(d, h)]\},$$

where A = 0.621 (as above). This equation was used to obtain estimates of M(m) for each microenvironment, or aggregate of microenvironments, as indicated in Table 2-6. The same value of M(m) was applied to each specific microenvironment within an aggregate.

Equation 2-2 requires a complete (gapless) year of hourly average fixed-site monitoring values for each district. Section 3.2 describes the method used to fill in missing hourly-average values. The resulting filled-in data sets were assumed to represent existing conditions at each monitor.

As discussed previously, each exposure event assigned the cohort to a district and a microenvironment. For exposure events occurring in <u>non-vehicle microenvironments</u>, it seemed reasonable to assign the event to a single district represented by a single fixed-site monitor. Consequently, the values of $CO_{mon}(d,h)$ for a non-vehicle microenvironment in district d were obtained from the fixed-site monitoring station assigned to district d. The locations of exposure events occurring in <u>vehicle microenvironments</u> were more difficult to characterize, as some trips were likely to have crossed two or more districts. Researchers assumed that an average of the fixed-site monitoring values from all districts would be more appropriate in these situations. Consequently, the value of $CO_{mon}(d,h)$ for a vehicle microenvironment during hour h was obtained by averaging the $CO_{mon}(d,h)$ values for all districts for hour h. Note that this approach is likely to underestimate the occurrence of high ambient CO levels during periods when people are assigned to the vehicle microenvironments.

2.4.2 Alveolar Ventilation Rate

In addition to CO concentration, a value for alveolar ventilation rate (V_A) value was estimated for each exposure event. V_A is expressed as liters of air respired per minute (liters min^{-1}). The algorithm used to estimate V_A was developed for Version 2.1 of pNEM/CO and has not been used previously in pNEM analyses. Section 5 provides a detailed description of the algorithm.

Briefly, the CHAD database provided an activity indicator for each exposure event. Each activity type was assigned a distribution of values for the metabolic equivalent of work (MET). MET is a dimensionless quantity defined by the ratio

$$MET = EE/RMR, \qquad (2\text{-}4)$$

where EE is the rate of energy expenditure during a particular activity (expressed in kcal/min), and RMR is a person's typical resting metabolic rate (also expressed in kcal/min). For example, activity no. 11300 -- "outdoor chores" -- was represented by a normal distribution of MET values with mean equal to 5 and a standard deviation equal to 1. Appendix A lists the distribution assigned to each of the CHAD activity codes.

A probabilistic procedure was used to assign a RMR value to each cohort for the entire 365-day exposure period. An EE value was calculated for each exposure event by the equation

$$EE_a(i,j,k) = [MET(i,j,k)][RMR(k)], \qquad (2\text{-}5)$$

in which $EE_a(i,j,k)$ was the average energy expenditure rate (kcal min^{-1}) for cohort k during exposure event i on day j; MET(i,j,k) was a value for MET randomly selected from the distribution associated with activity type a; a was the activity type associated with exposure event e; and RMR(c,d) was the RMR value randomly generated for cohort k. Section 5.5 describes the methods used to randomly select or generate the required parameter values.

Energy expenditure requires oxygen which is supplied by ventilation (respiration). Let ECF(k) indicate an energy conversion factor defined as the volume of oxygen required to produce one kilocalorie of energy in person k. The oxygen uptake rate (VO_2) associated with a particular activity can be expressed as

$$VO_2(i,j,k) = [ECF(k)][EE_a(i,j,k)], \tag{2-6}$$

in which $VO_2(i,j,k)$ has units of liters oxygen min^{-1}, ECF(k) has units of liters oxygen $kcal^{-1}$, and EE(i,j,k) has units of kcal min^{-1}. In pNEM/CO, the value of $VO_2(i,j,k)$ is determined from MET(i,j,k) by substituting Equation 2-5 into Equation 2-6 to produce the relationship

$$VO_2(i,j,k) = [ECF(k)][MET(i,j,k)][RMR(k)]. \tag{2-7}$$

Subsection 5-5 describes the probabilistic methods used to estimate values of ECF(k) and RMR(k) for person k.

V_A represents the portion of the minute ventilation that is involved in gaseous exchange with the blood. VO_2 is the oxygen uptake that occurs during this exchange. The absolute value of V_A is known to be affected by total lung volume, lung dead space, and respiration frequency -- parameters which vary according to person and/or exercise rate. However, it is reasonable to assume that the ratio of V_A to VO_2 is relatively constant regardless of a person's physiological characteristics or energy expenditure rate. Consistent with this assumption, Version 2.1 of pNEM/CO converts each estimate of $VO_2(i,j,k)$ to an estimate of $V_A(i,j,k)$ by the proportional relationship

$$V_A(i,j,k) = (19.63)[VO_2(i,j,k)] \tag{2-8}$$

in which both V_A and VO_2 are expressed in units of liters min^{-1}. This relationship was obtained from an article by Joumard et al. (1981), who based it on research by Galetti (1959). Equation 2-8 was applied to all cohorts under all energy expenditure rates.

The V_A algorithm included a method for identifying "impossible" values which were occasionally generated by the estimation process. This method determined a maximum VO_2 value for each exposure event which accounted for the duration of the activity and for the age, weight, and gender of the person. No estimate of VO_2 (and the corresponding estimate of V_A) was permitted to exceed this limit. Subsection 5.4 provides a more detailed description of this procedure.

2.4.3 Carboxyhemoglobin Level

An algorithm developed by Biller and Richmond (included as an appendix in Johnson et al., 1992) was used by pNEM/CO to estimate the COHb level at the end of each exposure event. The algorithm is based on a differential equation proposed by Coburn, Forster, and Kane (1963). Inputs to the algorithm include

Percent COHb at the start of the event
Average CO exposure concentration during the event, ppm
Time duration of the event, min
Alveolar ventilation rate, ml/min
Haldane Constant
Atmospheric pressure at sea level, torr
Altitude above sea level, feet
Blood volume, ml
Total hemoglobin content of blood, gm/100 ml
Pulmonary CO diffusion rate, ml/min per torr
Endogenous CO production rate, ml/min

An updated version of the Biller and Richmond Appendix appears as Appendix E to this report and provides a detailed description of the COHb algorithm, the various physiological parameters that are inputs to the COHb algorithm, and a list of related references.

2.4.4 The Physiological Profile Generator

As discussed in Subsections 2.4.2 and 2.4.3, the algorithms used to estimate V_A and COHb required values for various physiological parameters such as body mass, blood volume, and RMR. Appendix E provides a complete list of these parameters. A special algorithm within pNEM probabilistically generated a value for each parameter on the list (collectively referred to as a "physiological profile") for each cohort processed by pNEM/CO. Each of the generated physiological profiles was internally consistent, in that the functional relationships among the various parameters were maintained. For example, blood volume was determined as a function of weight and height, where height was estimated as a function of weight. Weight was in turn selected from a distribution specific to gender and age. Appendix E describes the method used to estimate values for each parameter in the application of pNEM/CO to Denver and Los Angeles.

2.4.5 Hourly Average Exposure Estimates

Algorithms within pNEM/CO provided four estimates for each exposure event: average CO concentration, average V_A, the product of average CO concentration and V_A (represented as "CO x V_A"), and the COHb level at the end of the event. These estimates were processed to produce time-weighted estimates of CO concentration, V_A, and CO x V_A for each clock hour, as well as end-of-hour estimates of COHb. The result was a year-long sequence of hourly values for CO, V_A, CO x V_A, and COHb for each cohort. These sequences were statistically analyzed to determine the value of various multihour exposure indicators of interest, including the largest eight-hour daily maximum CO concentration occurring each year and the number of times the end-of-hour COHb level exceeded a specified percentage value.

2.5 Extrapolate the Cohort Exposures to the Population-of-Interest and to Individual Sensitive Groups

2.5.1 General Population

The cohort-specific exposure estimates developed in Step 4 of the pNEM methodology (Section 2.4) were extrapolated to the general study area population by estimating the population size of each cohort. Cohort populations were estimated in three steps. The 1990 population of each demographic group within a particular home district [$Pop_{90}(d,h)$] was first estimated from 1990 census data specific to that district. Each of these groups was subdivided into a group residing in homes with gas stoves and a group residing in homes with other cooking fuels. The population of each of these groups in the target year specified for the pNEM/CO analysis (Denver - 1995, Los Angeles -1997) was determined by the expression

$$POP_{9x}(d,h,f) = F(h,f) \times AF_{9x} \times POP_{90}(d,h) \qquad (2\text{-}9)$$

where $POP_{9x}(d,h,f)$ is the target-year population of a group associated with demographic group d, home district h, and cooking fuel f. F(h,f) is the fraction of homes in Home district h that use cooking fuel f.

Analysts estimated that F(h,f) = 19. 6 percent for the Denver study area and F(h,f) = 79 percent for the Los Angeles area. Subsection 4.4.3 describes the methodology used in developing these estimates.

AF_{9x} is a city-specific factor which adjusts 1990 census data to provide 1997 population estimates for Los Angles and 1995 population estimates for Denver. In developing the Los Angeles AF_{9x} value (1.051), analysts first determined the average annual growth rate of Los Angeles and Orange Counties from 1990 to 1998 (0.72 percent/year). Based on this assumed annual growth rate, analysts estimated the Los Angeles study area population increased by 5.1 percent from 1990 to 1997. The Denver AF_{9x} value (1.087) was developed in a similar manner based on the population growth of the four counties containing parts of the Denver study area (Arapahoe, Boulder, Denver, and Jefferson). Analysts determined that the annual rate of population increase was 1.69 percent. Using this value, they estimated that the population of the population of the Denver study area increased by 8.7 percent from 1990 to 1995.

The $POP_{9x}(d,h,f)$ values provided an estimate of the target-year population of each non-commuting cohort residing within home district h. The target-year populations of the commuting cohorts (assumed to include all working cohorts) were determined by the expression

$$COM_{9x}(d,h,f,w) = POP_{9x}(d,h,f) \times COM(h,w)/WORK(h). \qquad (2\text{-}10)$$

$COM_{9x}(d,h,f,w)$ is the number of persons in the commuting cohort associated with demographic group d, home district h, cooking fuel f, and work district w; COM(h,w) is the number of workers in all demographic groups that commute from home district h to work district w; and WORK(h) is the total number of workers in home district h. Estimates of WORK(h) were developed from census data specific to each district. Section 6 describes the method used to estimate COM(h,w) from origin-destination data provided by the BOC.

2.5.2 Persons with Ischemic Heart Disease

The cohort-specific exposure estimates developed in Step 4 of the pNEM methodology were also extrapolated to the sensitive population defined as persons with diagnosed and undiagnosed ischemic heart disease (IHD). The extrapolation was performed using the procedure described in Subsection 2.5.1 with a single variation: the following equation was substituted for Equation 2-7.

$$POP_{9x}(d,h,f) = IHD(d) \times F(h,f) \times AF_{9x} \times POP_{90}(d,h). \qquad (2\text{-}11)$$

The term IHD(d) is the fraction of persons in demographic group d with IHD.

Estimates of the prevalence of IHD by demographic group were provided by H. Richmond (memorandum, August 25, 1998). Table 2-7 lists these estimates as percentages. In each case, a total prevalence rate is provided which is the sum of a

Table 2-7. Percentage of Persons with Ischemic Heart Disease (IHD) by Demographic Group

Demographic group	Percentage of persons with IHD		
	Diagnosed[a]	Undiagnosed[b]	Total
1. Children, 0 to 17	0.01	0.004	0.014
2. Males, 18 to 44, working	0.38	0.17	0.55
3. Males, 18 to 44, nonworking	0.38	0.17	0.55
4. Males, 45 to 64, working	8.19	3.60	11.8
5. Males, 45 to 64, nonworking	8.19	3.60	11.8
6. Males, 65+	19.2	8.45	27.7
7. Females, 18 to 44, working	0.13	0.06	0.19
8. Females, 18 to 44, nonworking	0.13	0.06	0.19
9. Females, 45 to 64, working	3.25	1.43	4.68
10. Females, 45 to 64, nonworking	3.25	1.43	4.68
11. Females, 65+	12.3	5.41	17.7

[a]Source: Richmond (1998) compilation based on Adams and Marano (1995).
[b]Source: Richmond (1998) based on American Heart Association (1990) estimate and assumption that persons with undiagnosed IHD are distributed within the population in the same proportions as persons with diagnosed IHD.

prevalence rate for diagnosed IHD and a prevalence rate for undiagnosed IHD. Estimates of diagnosed IHD were obtained from the National Health Interview Survey (Adams and Marano, 1995), in which U.S. prevalence rates were disaggregated by age and gender. The estimated prevalence of diagnosed IHD for children (age 0 to 17) is 0.01 percent. According to the National Health Interview Survey, approximately 8.0 million individuals are estimated to have diagnosed IHD in the civilian, non-institutionalized population. These estimates do not include individuals in the military or individuals in nursing homes or other institutions.

The estimates of undiagnosed IHD in Table 2-7 were based on two assumptions: (1) there are 3.5 million persons in the U.S. with undiagnosed IHD and (2) persons with undiagnosed IHD are distributed within the population in the same proportions as persons with diagnosed IHD. The 3.5 million statistic was based on an estimate by the American Heart Association (1990) that there are between three and four million persons with undiagnosed IHD.

Table 2-8 lists the resulting Denver population estimates by exposure district for (1) all adults and (2) adults with IHD. The total number of adults with IHD in the six-district study area is approximately 48,400. District No. 3 has the largest number of adults with IHD (about 14,700), accounting for 30 percent of the total. On average, 5.7 percent of the adults are estimated to have IHD.

Table 2-9 provides similar estimates for Los Angeles. As expected, the Los Angeles study area has a larger number of adults with IHD (approximately 258,000). Accounting for 16 percent of the total number, District No. 3 has the largest number of adults with IHD (about 41,800). The Los Angeles study area is estimated to have a slightly lower prevalence rate of adults with IHD (5.3 percent).

In extrapolating the cohort-specific exposure estimates developed in Step 4 to persons with IHD, analysts assumed the activity patterns of IHD were similar to those of the general population. Subsection 5.6 presents the results of a statistical analysis performed to evaluate the reasonableness of this assumption.

Table 2-8. Estimates of Population Residing in Each Denver Exposure District.

Denver exposure district	All adults		Adults with ischemic heart disease	
	Number	Percent of total	Number	Percent of total
1	119,085	14.0	6,430 (5.4)[a]	13.3
2	83,805	9.9	4,740 (5.7)	9.8
3	237,061	28.0	14,703 (6.2)	30.3
4	161,963	19.1	10,665 (6.6)	22.0
5	154,395	18.2	8,369 (5.4)	17.3
6	91,584	10.8	3,550 (3.9)	7.3
All	847,892	100.0	48,457 (5.7)	100.0

[a] Number in parentheses is percentage of adults with ischemic heart disease.

Table 2-9. Estimates of Population Residing in Each Los Angeles Exposure District.

Los Angeles exposure district	All adults		Adults with ischemic heart disease	
	Number	Percent of total	Number	Percent of total
1	514,488	10.6	31,701 (6.2)[a]	12.3
2	437,960	9.0	25,631 (5.8)	9.9
3	888,622	18.3	41,813 (4.7)	16.2
4	571,207	11.8	25,388 (4.4)	9.8
5	298,199	6.1	15,701 (5.3)	6.1
6	443,409	9.1	26,678 (6.0)	10.3
7	453,220	9.3	25,336 (5.6)	9.8
8	506,428	10.4	26,010 (5.1)	10.1
9	484,451	10.0	25,268 (5.2)	9.8
10	257,760	5.3	14,653 (5.7)	5.7
All	4,855,744	100.0	258,180 (5.3)	100.0

[a] Number in parentheses is percentage of adults with ischemic heart disease.

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SECTION 3

PREPARATION OF FIXED-SITE MONITORING DATA AND CREATION OF EXPOSURE DISTRICTS

3.1 Selection of Monitoring Sites and Definition of Exposure Districts

3.1.1 Denver

Analysts began the process of selecting monitoring sites for the Denver pNEM analysis by obtaining a Quick Look report for Colorado from AIRS for the years 1993 through 1997. Appendix B contains a facsimile of this report. Analysts designated all sites within Adams, Arapahoe, Boulder, Denver, and Jefferson Counties which reported CO data between 1993 and 1997 as potential sites for the pNEM/CO analysis. Figure 3-1 shows the locations of the sites which met these criteria plotted on a map indicating population density. (The Greeley site did not qualify as a potential site, as it was located in Weld County. It is included in Figure 3-1 to show its relative location to the other sites). Table 3-1 lists the CO sites initially under evaluation and indicates the number of 1-hour values reported by each site during each year in the 1993-1997 period. Note that the list includes all five of the monitoring sites used in 1992 pNEM/CO analysis. These sites are identified by the codes A, B, C, L, and M. Site descriptions for these monitors are provided in Appendix A of the report by Johnson et al. (1992).

After reviewing the data for the 1993 - 1997 period, EPA directed analysts to select a "best year" from the 1995 - 1997 period. Table 3-2 lists the second highest daily maximum 8-hour concentration reported by each site in Table 3-1 for 1995, 1996, and 1997. Five of the sites did not meet the 75% completeness criterion for each of the three years: Commerce City, Englewood, Denver 031-0018, Denver 031-0019, and Denver 031-0020. These sites were dropped from further consideration.

Figure 3-2 shows the locations of the remaining nine sites. Consistent with guidance received from EPA, analysts next omitted the 78th Avenue (Welby) and Longmont sites. The 78th Avenue site is located in a predominately agricultural area which was considered unrepresentative of urban or suburban residential locations. The Longmont site was considered to be too distant from other sites.

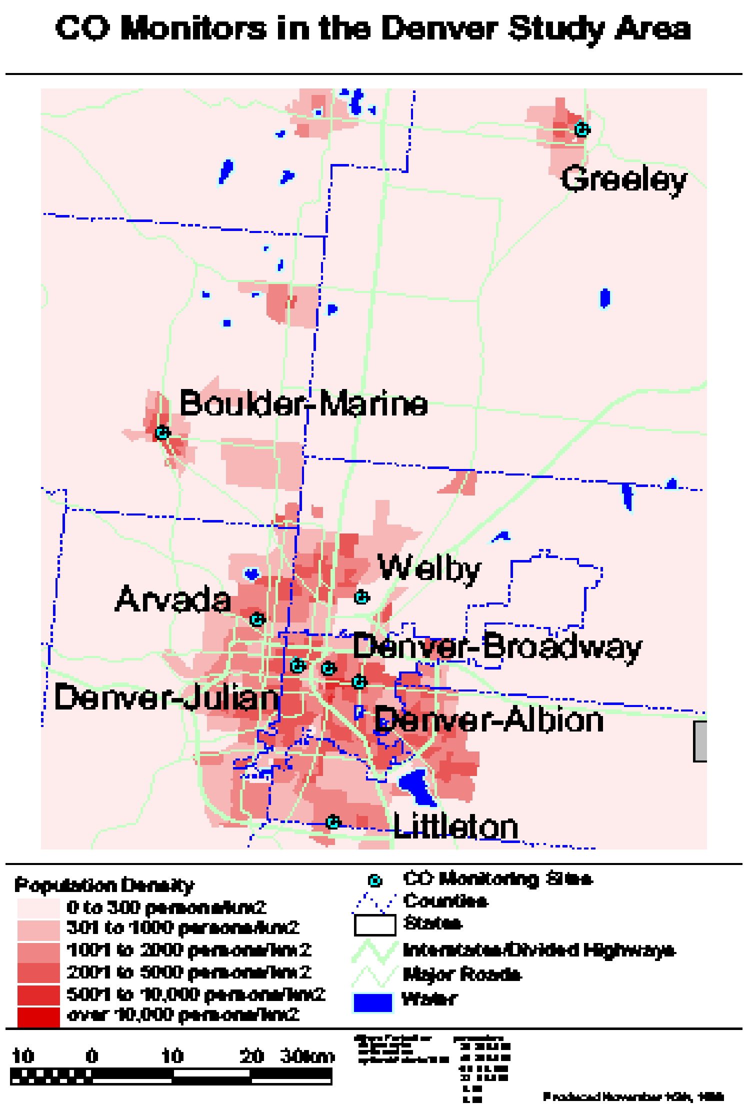

Figure 3-1. Monitoring Sites in the Greater Denver Metropolitan Area.

Table 3-1. Fixed-Site Monitors Reporting Carbon Monoxide Data for the Denver Area Between 1993 and 1997.

County	Monitor Description			1992 pNEM/CO monitor ID	Number of one-hour values reported by year				
	Site ID	City	Address		1993	1994	1995	1996	1997
Adams	001-3001	Welby	78^{th} Ave. and Steele Street	-	8632	8687	8681	8712	8661
	001-7015	Commerce City	Rocky Mountain Arsenal	-	7919	3595	0	0	0
Arapahoe	005-0002	Littleton	8100 So. University Blvd. (Highlands)	M	8589	8705	8670	8677	8463
	005-0003	Englewood	3300 S. Huron Street	-	8717	7126	0	0	0
Boulder	013-0009	Longmont	440 Main Street	-	8701	8557	8690	8735	8617
	013-0010	Boulder	2150 28^{th} Street	-	353	8639	8608	8576	8697
	013-1001	Boulder	2320 Marine Street	-	8708	8565	8651	8669	8517
Denver	031-0002	Denver	2105 Broadway (Broadway)	A	8687	8700	8697	8673	8687
	031-0013	Denver	14^{th} and Albion St. (Albion)	C	8675	8665	8647	8516	8690
	031-0014	Denver	23rd and Julian (Julian)	B	8676	8543	8701	8736	8677
	031-0018	Denver	Blake St. side of Speer	-	1021	1591	0	0	0
	031-0019	Denver	Speer and Auraria Parkway	-	997	3049	3658	8694	8354
	031-0020	Denver	935 Colorado Blvd., UCHS	-	0	1370	2141	0	0
Jefferson	059-0002	Arvada	W. 57^{th} Ave and Garrison	L	8723	8525	8680	8724	8697

Table 3-2. Second Largest Daily Maximum 8-Hour CO Concentration Reported by Denver Area Monitors for Years 1995, 1996, and 1997.

County	Monitor Description			1992 pNEM/CO monitor ID	Second largest daily maximum 8-hour concentration, ppm			
	Site ID	City	Address		1995	1996	1997	avg
Adams	001-3001	Adams County	78th Ave. And Steele Street	-	5.1	3.9	4.3	4.4
	001-7015	Commerce City	Rocky Mountain Arsenal	-	-	-	-	-
Arapahoe	005-0002	Littleton	8100 So. University Blvd. (Highlands)	M	2.1	2.6	2.8	2.5
	005-0003	Englewood	3300 S. Huron Street	-	-	-	-	-
Boulder	013-0009	Longmont	440 Main Street	-	4.7	5.5	5.4	5.2
	013-0010	Boulder	2150 28th Street	-	5.2	4.3	3.9	4.5
	013-1001	Boulder	2320 Marine Street	-	3.7	2.5	3.3	3.2
Denver	031-0002	Denver	2105 Broadway (Broadway)	A	9.5	7.3	5.5	7.4
	031-0013	Denver	14th and Albion St. (Albion)	C	6.2	5.2	4.7	5.4
	031-0014	Denver	23rd and Julian (Julian)	B	5.9	5.7	6.2	5.9
	031-0018	Denver	Blake St. side of Speer	-	-	-	-	-
	031-0019	Denver	Speer and Auraria Parkway	-	(7.1)[a]	7.0	6.4	6.8
	031-0020	Denver	935 Colorado Blvd., UCHS	-	(6.0)[b]	-	-	-
Jefferson	059-0002	Arvada	W. 57th Ave and Garrison	L	4.6	4.3	4.9	4.6

[a] Number of values = 3658
[b] Number of values = 2141

Fixed-Site Monitors with 1995-1997 Data

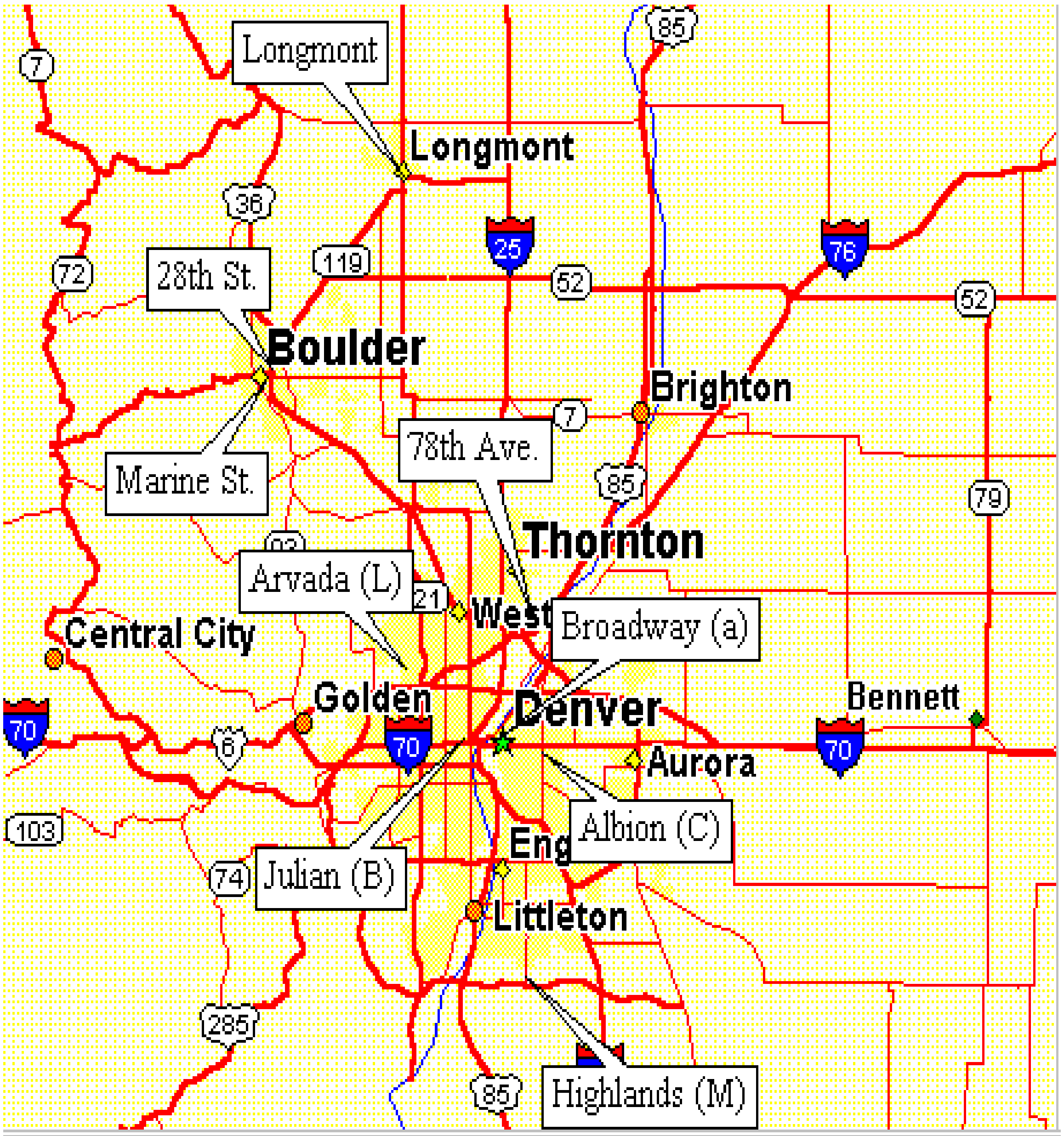

Figure 3-2. Monitoring Sites in the Denver Area Which Reported Data for 1995 Through 1997.

Seven sites remained at this stage of the selection procedure: the five sites used in the 1992 Denver analysis and two Boulder sites (28th Street and Marine Street). The locations of five sites used in the 1992 analysis were considered appropriate for defining five separate exposure districts with 10 km radii. However, the Boulder sites were considered too close together to support separate exposure districts. With EPA's approval, analysts defined six exposure districts -- one for each of the 1992 Denver sites and a "composite" Boulder site. For purposes of constructing the associated exposure district, the composite site was assigned a location midway between the two Boulder sites (UTM Zone 13: Northing 4429.6495, Easting 477.625). The outdoor CO concentration for hour h in this district was defined as the average of values reported by the two Boulder sites for hour h.

Analysts evaluated the quality of the monitoring data available for each of the seven sites over the calendar years 1995, 1996, and 1997. The statistics listed in Table 3-1 indicate that each of these 21 "site-years" was at least 96.6 percent complete and thus satisfied the 75 percent completeness requirement for use in the pNEM/CO analysis. EPA selected 1995 as the year for the Denver pNEM/CO analysis because the air quality that year was very close to just meeting the current CO NAAQS. For purposes of the review of the CO NAAQS, EPA policy makers are interested in population exposure estimates that would represent conditions in a given city when that area just attains the specified standard.

Table 3-3 provides site characteristics for each of the seven Denver-area monitors included in the exposure analysis. The information in the table was obtained from the Aerometric Information Retrieval System (AIRS) by Mr. David Lutz of EPA's Environmental Monitoring and Analysis Division.

3.1.2 Los Angeles

Consistent with the Denver approach, analysts began the process of selecting CO monitoring sites for the Los Angeles pNEM analysis by obtaining a "Quick Look" report for California CO sites from the EPA AIRS for the years 1995 through 1997. Appendix B of this report contains a facsimile of the Quick Look report. Analysts designated all sites within Los Angeles, Orange, Riverside, San Bernardino, and

Table 3-3. Characterization of Monitoring Sites Used in pNEM/CO for the Denver Urban Area.

City	Site Name and Address	AIRS ID	Land Use	Spatial Scale	Elevation (meters)	Monitor Height (meters)	Distance to Roads (meters)[a]	Traffic Volumes (vehicles per day)[b]
Littleton	Highlands 8100 University Blvd.	005-0002	site terminated 12/31/97	---	---	---	---	---
Denver	Camp 2105 Broadway	031-0002	commercial	microscale	1591	3	#1 - 6 #2 - 16 #3 - 7	#1 - 17200 #2 - 1000 #3 - 10000 #4 - 8000 #5 - 8000
Denver	NJHE 14th and Albion St.	031-0013	residential	neighborhood	1615	3	---	---
Denver	Carriage 23rd and Julian	031-0014	residential	neighborhood	1609	4	#1 - 51 #2 - 59	#1 - 5000 #2 - 1000
Arvada	W. 57th Ave. and Garrison	059-0002	residential	---	1641	5	179	#1 - 22000 #2 - 4000
Boulder	2150 28th St.	013-0010	commercial	microscale	---	3	9	28000
Boulder	2320 Marine St.	013-1001	residential	---	1619	4	#1 - 67 #2 - 179 #3 - 219	#1 - 500 #2 - 1000 #3 - 5000

[a]When the monitoring site is near more than one roadway, the distance is provided for each roadway separately.
[b]When the monitoring site is near more than one roadway, the traffic volume is provided for each roadway separately.

Ventura Counties which reported CO data between 1995 and 1997 as potential sites for the pNEM/CO analysis. Table 3-4 lists the 30 CO sites which met these criteria and indicates the number of 1-hour values reported by each site during each year in the 1995-1997 period. The table lists 14 sites in Los Angeles County, 4 sites in Orange County, 3 sites in Riverside County, 7 sites in San Bernardino County, and 2 sites in Ventura County. Maps in Appendix B of a memorandum prepared by Johnson (1999) show the locations of the 30 monitors.

Table 3-5 lists the number of one-hour CO concentrations reported by each of the 30 monitors in the years 1995 through 1997. Ideally, each site-year of data used in a pNEM/CO analysis should be at least 75 percent complete prior to the estimation of missing values. The following site-years did not meet this requirement.

Site location	Year(s)
Diamond Bar	1997
Long Beach	1996
Phelan	all
Victorville	1995, 1996
Twentynine Palms	1995, 1997
Mount Baldy	all

Table 3-5 lists the second highest daily maximum 1-hour and 8-hour concentrations reported by each of the 30 sites for 1995, 1996, and 1997. It also lists the three-year average for each of these indices.

Table 3-6 lists the 17 monitors with three-year averages for the second largest 8-hour maximum CO concentration which exceeded 4.5 ppm. The 12 monitors marked with X's are located within a central area which extends west to Hawthorne, north to Pasadena, east to Pomona, and south to Costa Mesa. Table 3-7 provides site characteristics for these monitors.

EPA evaluated the 17 monitors listed in Table 3-6 and selected the 10 monitors marked with double X's for the application of pNEM/CO to Los Angeles. These monitors all reported relatively high CO levels, and they appear to provide good coverage of highly urbanized areas within greater Los Angeles. EPA's goal in creating the Los Angeles study area was not to estimate exposure for the entire Los Angeles metropolitan, but rather to create a contiguous study area that captures population

Table 3-4. Fixed-Site Monitors Reporting Carbon Monoxide Data for the Los Angeles Area Between 1995 and 1997.

County	Monitor Description			Number of 1 hr values[a]		
	Site ID	City	Address	1995	1996	1997
Los Angeles	06-037-0002	Azusa	803 N. Loren Ave.	8300	8025	8007
	06-037-0113	West Los Angeles	Va Hospital	7774	8057	8360
	06-037-0206	Diamond Bar	21865 E. Copley Drive	8357	***3073***	***0***
	06-037-1002	Burbank	228 W. Palm Ave	8291	7696	8025
	06-037-1103	Los Angeles	1630 N. Main Street	8165	8390	8292
	06-037-1201	Reseda	18330 Gault Street	7670	8012	8245
	06-037-1301	Lynwood	11220 Long Beach Blvd.	8290	8326	8302
	06-037-1601	Pico Rivera	3713 San Gabriel River	8372	8303	7881
	06-037-1701	Pomona	924 N. Garey Ave.	8307	8290	8350
	06-037-2005	Pasadena	752 S. Wilson Ave.	8387	8282	8250
	06-037-4002	Long Beach	3648 N. Long Beach Blvd.	8326	***6015***	8347
	06-037-5001	Hawthorne	5234 W. 120th Street	8241	8258	8125
	06-037-6002	Santa Clarita	San Fernando Road	8241	8413	8289
	06-037-9002	Lancaster	315 W. Pondera Street	8383	8406	7759
Orange	06-059-0001	Anaheim	1610 S. Harbor Blvd.	8259	8298	8354
	06-059-1003	Costa Mesa	2850 Mesa Verde Dr, East	8213	8191	8325
	06-059-2001	El Toro	23022 El Toro Road	8321	8400	8385
	06-059-5001	La Habra	621 W. Lambert	8363	8345	8230
Riverside	06-065-1003	Riverside	7002 Magnolia Ave.	8432	8404	8345
	06-065-5001	Palm Springs	FS-590 Racquet Club Ave.	8258	8030	8170
	06-065-8001	Rubidoux	5888 Mission Blvd.	8374	8311	7057
San Bernardino	06-071-0001	Barstow	200 E. Buena Vista	7114	8071	7712
	06-071-0012	Phelan	Berkeley Rd. and Phelan Rd.	***6338***	***4543***	***0***
	06-071-0014	Victorville	14029 Amargosa Road	***2812***	***5686***	8082
	06-071-0017	Twentynine Palms	6136 Adobe Road	***2876***	7695	***2996***
	06-071-0217	Mount Baldy	6945 Mt. Baldy Road	***0***	***0***	***1779***
	06-071-4001	Hesperia	17288 Olive Street	8032	8265	8115
	06-071-9004	San Bernardino	24302 4th Street	8322	8260	7312
Ventura	06-111-2002	Simi Valley	5400 Cochran Street	7766	8005	8114
	06-111-3001	El Rio	Rio Mesa School	7741	8235	8065

[a]Shaded years have less than 75 percent completeness.

Table 3-5. Descriptive Statistics for Fixed-Site Monitors Reporting Carbon Monoxide Data for the Los Angeles Area Between 1995 and 1997.

County	Monitor Description		2nd highest 1 hr daily max.				2nd highest 8 hr daily max.			
	Site ID	City[a]	95	96	97	Avg	95	96	97	Avg
Los Angeles	06-037-0002	AZUSA	7.3	5.9	5.5	6.2	6.2	3.9	4.2	4.8
	06-037-0113	WEST LA	7.4	6.7	6.4	6.8	5.6	4.3	4.1	4.7
	06-037-0206	Diamond Bar	6.1	5.4	--	5.8	4.9	3.9	--	4.4
	06-037-1002	BURBANK	12.5	11.0	8.6	10.7	11.0	8.5	7.2	8.9
	06-037-1103	LOS ANGELES	9.2	10.1	8.7	9.3	7.9	7.5	5.9	7.1
	06-037-1201	RESEDA	11.8	10.2	11.1	11.0	9.4	6.7	7.7	7.9
	06-037-1301	LYNWOOD	16.6	21.3	18.8	18.9	11.6	14.5	15.0	13.7
	06-037-1601	PICO RIVERA	9.3	9.1	7.9	8.8	7.6	6.5	6.1	6.7
	06-037-1701	POMONA	7.7	8.1	7.1	7.6	6.0	4.7	4.9	5.2
	06-037-2005	PASADENA	11.4	9.9	7.7	9.7	8.6	6.9	5.4	5.0
	06-037-4002	LONG BEACH	8.1	9.2	8.6	8.6	6.2	6.5	6.4	6.4
	06-037-5001	HAWTHORNE	11.1	12.3	12.3	11.9	8.7	10.5	7.9	9.0
	06-037-6002	SANTA CLARITA	6.5	6.3	7.0	6.6	3.8	3.9	6.5	4.7
	06-037-9002	Lancaster	6.8	6.4	5.5	6.2	4.5	4.6	4.0	4.4
Orange	06-059-0001	ANAHEIM	9.8	8.9	8.2	9.0	7.3	6.1	5.4	6.3
	06-059-1003	COSTA MESA	7.5	8.6	7.1	7.7	5.3	6.6	5.0	5.6
	06-059-2001	El Toro	6.0	6.0	4.6	5.5	3.9	4.0	3.0	3.6
	06-059-5001	LA HABRA	11.5	12.0	11.0	11.5	6.4	6.3	5.7	6.1
Riverside	06-065-1003	RIVERSIDE	9.0	8.2	9.3	8.8	5.8	5.0	4.8	5.2
	06-065-5001	Palm Springs	3.1	3.0	2.4	2.8	1.5	1.3	1.3	1.4
	06-065-8001	RUBIDOUX	6.7	7.4	6.2	6.8	5.2	4.6	5.1	5.0
San Bernardino	06-071-0001	Barstow	3.1	3.7	2.5	3.1	2.1	2.1	1.5	1.9
	06-071-0012	Phelan	1.7	1.5	--	1.6	1.3	1.0	--	1.2
	06-071-0014	Victorville	3.1	8.2	3.8	5.0	2.4	6.6	2.3	3.8
	06-071-0017	29 Palms	3.3	1.8	1.6	2.2	1.8	1.2	0.9	1.3
	06-071-0217	Mount Baldy	--	--	0.8	0.8	--	--	0.3	0.3
	06-071-4001	Hesperia	3.0	3.5	3.4	3.3	2.0	2.1	2.3	2.1
	06-071-9004	San Bernardino	7.4	5.8	7.0	6.7	5.9	4.3	5.4	4.4
Ventura	06-111-2002	Simi Valley	7.5	6.7	7.1	7.1	3.9	3.3	3.2	3.5
	06-111-3001	El Rio	2.8	2.0	2.2	2.3	2.4	1.4	1.5	1.8

[a] Upper case indicates that three-year average of second-largest 8-hour concentrations exceeds 4.5 ppm.

Table 3-6. Fixed-Site Monitors in Los Angeles Study Area with Three-Year Averages for Second Largest 8-hour Maximum Carbon Monoxide Concentration That Exceed 4.5 ppm.

Rank	Three-Year Average of Second Largest 8-hour Maximum (ppm)	Monitor Location	County	X = Site Listed In Table 3-7	XX = Selected pNEM/CO Site
1	13.7	Lynwood	Los Angeles	X	XX
2	9.0	Hawthorne	Los Angeles	X	XX
3	8.9	Burbank	Los Angeles	X	XX
4	7.9	Reseda	Los Angeles	X	
5	7.1	Los Angeles	Los Angeles	X	XX
6	6.7	Pico Rivera	Los Angeles	X	XX
7	6.4	Long Beach	Los Angeles	X	XX
8	6.3	Anaheim	Orange	X	XX
9	6.1	La Habra	Orange	X	XX
10	5.6	Costa Mesa	Orange		
11	5.2	Pomona	Los Angeles	X	
12	5.2	Riverside	Riverside		
13	5.0	Pasadena	Los Angeles	X	XX
14	5.0	Rubidoux	Riverside		
15	4.8	Azusa	Los Angeles		
16	4.7	West LA	Los Angeles	X	XX
17	4.7	Santa Clarita	Los Angeles		

Table 3-7. Site Characteristics for Selected Fixed-Site Monitors Reporting Carbon Monoxide Data for the Los Angeles Area

County	Monitor Identification and Location			Site Characteristics		
	Site ID	City	Address	Land Use & Location Setting	Monitor Height, meters	Traffic Volumes, vehicles per day (distance between monitor and road where available)
Los Angeles	06-037-0113	West Los Angeles	Va Hospital	mobile urban and center city	5	
	06-037-1002	Burbank	228 W. Palm Ave	commercial urban and center city	5	#1: 2,400
	06-037-1103	Los Angeles	1630 N. Main Street	residential urban and center city	11	#1: 9,000 (distance 77 meters) #2: 9,000 #3: 1,000 #4: 999 (distance 108 meters)
	06-037-1201	Reseda	18330 Gault Street	commercial suburban	6	
	06-037-1301	Lynwood	11220 Long Beach Blvd.	commercial urban and center city	7	#1: 35,000 (distance 20 meters) middle scale - 100 to 500 m
	06-037-1601	Pico Rivera	3713 San Gabriel River	commercial suburban	6	#1: 11,600 (distance 69 meters) #2: 3,120
	06-037-1701	Pomona	924 N. Garey Ave.	commercial suburban	6	
	06-037-2005	Pasadena	752 S. Wilson Ave.	residential urban and center city	4	#1: 18,000 (distance 18 meters) #2: 2,000 (distance 71 meters)
	06-037-4002	Long Beach	3648 N. Long Beach Blvd.	residential suburban	6	#1: 24,000 #2: 24,000 #3: 4,000 #4: 24,000
	06-037-5001	Hawthorne	5234 W. 120th Street	commercial urban and center city	?	#1: 5,000
Orange	06-059-0001	Anaheim	1610 S. Harbor Blvd.	residential suburban	5	#1: 31,000 (distance 90 meters)
	06-059-2001	La Habra	621 W. Lambert	residential suburban	5	#1: 35,000

centers with adequate ambient monitoring and captures areas where ambient CO levels tend to be highest.

EPA selected 1997, the most recent of the three years evaluated, as the year for the pNEM/CO analysis of Los Angeles. All 10 sites had adequate data completeness for 1997.

3.2 Estimation of Missing Values

The pNEM/CO model requires that each input site-year of monitoring data be complete (gapless). The missing values in each data set were estimated using a time series model developed by Johnson and Wijnberg (1981). The time series model is based on the assumption that hourly average air quality values can be represented by a combination of cyclical, autoregressive, and random processes. The parameter values of these processes are determined by a statistical analysis of the reported data.

3.2.1 Denver

Table 3-8 provides descriptive statistics by monitoring site for the 1-hour CO concentrations in each Denver data set before and after estimation of the missing values, based on the 1995 data sets selected for the pNEM/CO analysis. The statistics indicate that the addition of missing-value estimates did not significantly affect the distribution of any data set. Each table also provides descriptive statistics for running-average 8-hour concentrations after estimation of missing values.

Table 3-8 also provides both 1-hour and 8-hour descriptive statistics for the Boulder "composite" site after estimation of missing values.

3.2.2 Los Angeles

Table 3-9 provides descriptive statistics by monitoring site for the 1-hour CO concentrations in each 1997 data set before and after estimation of the missing values. The statistics indicate that the addition of missing-value estimates did not significantly affect the distribution of any data set. Each table also provides descriptive statistics for running-average 8-hour concentrations after estimation of missing values.

Table 3-8. Descriptive Statistics for One-Hour Carbon Monoxide Concentrations Reported by Denver Monitors Before and After Estimation of Missing Values.

Site	Data set[a]	No. of obs.	Descriptive statistics for 1-hour CO concentrations, ppm						
			50th	90th	95th	99th	99.5th	second largest	largest value
005-002 (Highlands, M)	1 h (o)	8670	0.3	0.7	1.0	1.8	2.2	3.3	3.6
	1 h (s)	8760	0.3	0.7	1.0	1.8	2.2	3.3	3.6
	8 h (s)	8760	0.3	0.7	0.8	1.4	1.7	2.5	2.6
031-0002 (Broadway, A)	1 h (o)	8697	1.2	2.7	3.4	6.1	7.7	16.4	24.5
	1 h (s)	8760	1.2	2.7	3.4	6.1	7.7	16.4	24.5
	8 h (s)	8760	1.3	2.4	3.0	4.7	5.8	10.8	11.0
031-0013 (Albion, C)	1 h (o)	8647	0.9	2.5	3.4	5.5	6.4	13.6	14.6
	1 h (s)	8760	0.9	2.5	3.4	5.5	6.4	13.6	14.6
	8 h (s)	8760	1.1	2.2	2.7	3.7	4.3	8.5	8.5
031-0014 (Julian, B)	1 h (o)	8701	0.7	2.3	3.2	5.3	6.4	9.9	10.4
	1 h (s)	8760	0.7	2.3	3.2	5.3	6.5	9.9	10.4
	8 h (s)	8760	0.8	2.1	2.7	4.1	4.8	7.2	7.3
059-0002 (Arvada, L)	1 h (o)	8680	0.6	2.0	2.7	4.8	5.8	8.9	11.9
	1 h (s)	8760	0.6	2.0	2.7	4.8	5.8	8.9	11.9
	8 h (s)	8760	0.8	1.8	2.3	3.1	3.5	5.0	5.1

Site	Data set[a]	No. of obs.	Descriptive statistics for 1-hour CO concentrations, ppm						
			50th	90th	95th	99th	99.5th	second largest	largest value
013-0010 (Boulder, 28th Street)	1 h (o)	8608	0.8	2.1	2.8	4.8	5.5	10.3	10.6
	1 h (s)	8760	0.8	2.1	2.8	4.8	5.5	10.3	10.6
	8 h (s)	8760	0.9	1.8	2.2	3.1	3.6	5.2	5.3
013-1001 (Boulder, Marine Street)	1 h (o)	8651	0.4	0.9	1.3	2.3	2.9	8.2	8.3
	1 h (s)	8760	0.4	0.9	1.3	2.3	2.9	8.2	8.3
	8 h (s)	8760	0.5	0.9	1.1	1.8	2.1	3.8	3.9
Composite Boulder site	1 h (s)	8760	0.7	1.5	2.0	3.3	3.8	8.7	9.5
	8 h (s)	8760	0.7	1.3	1.6	2.3	2.7	4.5	4.6

[a] 1 h (o): original 1-hour data set as down-loaded from AIRS.
1 h (s): supplemented 1-hour data set (includes estimates of missing values)
8 h (s): supplemented 8-hour running average data set [based on 1 h (s) data].

Table 3-9. Descriptive Statistics for One-Hour Carbon Monoxide Concentrations Reported by Los Angeles Monitors Before and After Estimation of Missing Values.

Site	Data set[a]	No. of obs.	Descriptive statistics for 1-hour CO concentration, ppm						
			50th	90th	95th	99th	99.5th	second largest	largest value
60370113 (West Los Angeles)	1 h (o)	8360	0.6	2.0	2.6	3.7	4.2	6.4	7.3
	1 h (s)	8760	0.6	2.0	2.6	3.6	4.1	6.4	7.3
	8 h (s)	8760	0.6	1.8	2.2	3.0	3.3	4.1	4.2
60371002 (Burbank)	1 h (o)	8025	1.4	3.5	4.5	6.1	6.6	8.6	8.8
	1 h (s)	8760	1.4	3.5	4.4	6.0	6.6	8.6	8.8
	8 h (s)	8760	1.5	3.3	4.1	5.3	5.7	7.2	7.3
60371103 (Los Angeles)	1 h (o)	8292	0.9	3.1	3.9	5.4	5.9	8.7	8.9
	1 h (s)	8760	1.0	3.0	3.8	5.4	5.8	8.7	8.9
	8 h (s)	8760	1.0	2.8	3.4	4.5	4.8	7.7	7.8
60371301 (Lynwood)	1 h (o)	8302	1.7	4.9	6.8	11.2	13.5	18.8	19.2
	1 h (s)	8760	1.7	4.9	6.7	11.2	13.5	18.8	19.2
	8 h (s)	8760	1.7	4.8	6.1	8.8	10.3	16.8	17.0
60371601 (Pico Rivera)	1 h (o)	7881	1.1	3.0	3.6	5.1	5.6	7.9	9.2
	1 h (s)	8760	1.2	3.0	3.6	5.0	5.6	7.9	9.2
	8 h (s)	8760	1.2	2.7	3.3	4.3	4.6	6.0	6.0

Site	Data set[a]	No. of obs.	Descriptive statistics for 1-hour CO concentration, ppm						
			50th	90th	95th	99th	99.5th	second largest	largest value
60372005 (Pasadena)	1 h (o)	8250	0.9	2.1	2.8	4.2	4.7	7.7	8.1
	1 h (s)	8760	0.9	2.1	2.8	4.2	4.7	7.7	8.1
	8 h (s)	8760	1.0	2.0	2.4	3.4	3.7	5.8	6.0
60374002 (Long Beach)	1 h (o)	8347	0.7	2.7	3.6	5.2	5.9	8.6	9.0
	1 h (s)	8760	0.7	2.7	3.6	5.2	5.9	8.6	9.0
	8 h (s)	8760	0.7	2.5	3.2	4.5	4.9	6.4	6.4
60375001 (Hawthorne)	1 h (o)	8125	0.5	3.7	5.1	7.4	8.3	12.3	12.4
	1 h (s)	8760	0.5	3.7	5.1	7.3	8.2	12.3	12.4
	8 h (s)	8760	0.7	3.4	4.5	6.1	6.9	10.1	10.3
60590001 (Anaheim)	1 h (o)	8354	0.8	2.3	2.9	4.6	5.5	8.2	8.4
	1 h (s)	8760	0.8	2.3	2.9	4.6	5.5	8.2	8.4
	8 h (s)	8760	0.9	2.1	2.6	3.5	3.8	5.7	5.7
60595001 (La Habra)	1 h (o)	8230	1.0	2.8	3.7	6.2	7.2	11.0	11.9
	1 h (s)	8760	1.0	2.8	3.6	6.1	7.1	11.0	11.9
	8 h (s)	8760	1.1	2.8	3.3	4.2	4.5	5.6	5.7

[a] 1 h (o): original 1-hour data set as down-loaded from AIRS.
1 h (s): supplemented 1-hour data set (includes estimates of missing values)
8 h (s): supplemented 8-hour running average data set [based on 1 h (s) data].

3.3 The Air Quality Adjustment Procedure

The fill-in procedure described in Subsection 3.2 produced a complete sequence of 1-hour outdoor concentrations for each district in the Denver and Los Angeles study areas. These sequences were assumed to represent existing ("as is") outdoor air quality conditions in each study area. Analysis of these sequences indicated that CO levels in Denver were in approximate attainment with the current 8-hour NAAQS, whereas Los Angeles CO levels exceeded the NAAQS. Researchers assumed that the Denver data required no further adjustment to represent attainment conditions. The adjustment procedure described in this subsection was applied to the Los Angeles data to simulate outdoor air quality under attainment conditions.

The adjustment procedure is similar to the approach described in Section 2.4.2 of Johnson et al. (1992). The general version of this air quality adjustment procedure (AQAP) can be expressed as

$$\mathrm{CMON}(m,h,s) = \mathrm{BG} + \rho(s) \times \mathrm{CDIF}(m,h,e), \tag{3-1}$$

in which CMON(m,h,s) is the adjusted 1-hour CO concentration for monitor m at hour h under scenario s, BG is the assumed background concentration, and ρ(s) is the adjustment factor specific to scenario s.

The CDIF(m,h,e) term is calculated by the expression

$$\mathrm{CDIF}(m,h,e) = \mathrm{CMON}(m,h,e) - \mathrm{BG} \tag{3-2}$$

in which CMON(m,h,e) is the 1-hour CO concentration associated with monitor m at hour h under existing conditions. The value of ρ(s) is calculated by the expression

$$\rho(s) = [\mathrm{CMAX}(s) - \mathrm{BG}]/[\mathrm{CMAX}(e) - \mathrm{BG}] \tag{3-3}$$

when CDIF(m,h,e) > 0 and by the expression

$$\rho(s) = 1 \tag{3-4}$$

when CDIF(m,h,e) $\leq$ 0. In Equation 3-3, CMAX(s) is the highest concentration permitted under scenario s for a specified air quality indicator (AQI) and CMAX(e) is the value of this AQI based on the monitoring data selected to represent existing conditions.

Note that although the adjustment procedure (Equation 3-1) is applied to one-hour data, the values of CMAX(s) and CMAX(e) required by Equation 3-3 are determined according to the relevant averaging time of the CO standard under evaluation. As discussed in Subsection 7.0, EPA is currently evaluating a CO standard expressed in terms of the second highest eight-hour non-overlapping average. Consequently, the values for CMAX(s) and CMAX(e) inserted in Equation 3-3 are based on this averaging time.

As described in Subsection 3.1, analysts used 1997 monitoring data to represent existing conditions in Los Angeles. The AQAP was applied to these data sets with the goal of simulating attainment of the current eight-hour NAAQS for CO, which states that the second highest non-overlapping eight-hour average shall not exceed 9 ppm. Thus, the AQI of interest for is the largest "second highest non-overlapping eight-hour average" reported by the monitoring sites of Los Angeles in the baseline year (1997). In implementing the current NAAQS, EPA uses a rounding convention which specifies that AQI values above 9.4 ppm are to be treated as nonattainment. Consequently, the AQAP should adjust a city's monitoring data so that the largest "second highest non-overlapping eight-hour average" is equal to 9.4 ppm. Consistent with this goal, analysts specified that CMAX(s) equals 9.4 ppm in Equation 3-3.

To complete the adjustment procedure, analysts required values for CMAX(e) and BG specific to Los Angeles. Table 3-10 lists the value of second highest non-overlapping eight-hour average associated with each of the monitors previously selected to represent CO conditions in Los Angeles. The Los Angeles values range from 3.9 to 15.0 ppm. Based on the maximum value in this range, the value of CMAX(e) would be 15.0 ppm for Los Angeles.

In the 1992 exposure analyses using Version 1.0 of pNEM/CO, BG was defined as the smallest <u>annual average</u> CO concentration reported by a monitoring site within the defined study area. Analysts evaluated the results of using this same approach for the current pNEM/CO analysis. In implementing the approach, they considered only those monitors previously selected to represent CO conditions in Los Angeles. Table 3-10 lists the annual average for each monitor. The annual averages range from 0.84 to 2.33 for Los Angeles. Referring to the smallest value in the range, the value of BG would be 0.84 ppm for Los Angeles.

The new criteria document (CD) for CO (EPA, 2000) supports a lower estimate for BG. In a discussion of CO measured at remote sites, the CD provides the following information concerning the relationship between global background CO and latitude.

> Carbon monoxide concentrations range from a minimum of about 30 ppb during the summer in the Southern Hemisphere to about 200 ppb at high latitudes in the Northern Hemisphere during winter. Thus, CO concentration in remote areas of the Northern Hemisphere are only a small fraction (~ 1 to 2%) of those of concern to human health (as given by the National Ambient Air Quality Standards [NAAQS] for CO of 9 ppm for the second highest, nonoverlapping 8-h average concentration). [page 3-3]

For Version 2.1 of pNEM/CO, EPA has provided technical direction that a reasonable estimate of BG for Los Angeles is approximately 200 ppb (or 0.20 ppm). This value is based on the winter maximum for remote sites observed at northern latitudes cited in the revised CD.

Table 3-11 lists the parameters used in Equation 3-3 when adjusting Los Angeles monitoring data. Table 3-12 lists descriptive statistics for the Los Angeles 1-hour data sets before and after application of the AQAP. The table also lists descriptive statistics for 8-hour running-average concentrations based on the adjusted data sets.

The Los Angeles results exhibit a significant difference between the unadjusted and adjusted one-hour data sets, with high values showing a slightly greater proportional reduction than low values. The adjustment procedure reduced the maximum one-hour values listed in Table 3-12 by approximately 37 percent. Depending on the site, the 50th percentile of the one-hour values was reduced by 30 to 35 percent. After adjustment, the second highest non-overlapping eight-hour average at the controlling Los Angeles site (Lynwood) was exactly equal to 9.4 ppm. [Note that this is the second highest <u>non-overlapping</u> eight-hour average at Linwood ; the second highest eight-hour average based on all Linwood values (including overlapping averages) is 10.5 ppm, as indicated by Table 3-12.

Table 3-10. Selected Descriptive Statistics for Denver and Los Angeles Monitoring Sites.

Study area (year)	Monitoring site		Carbon monoxide concentration, ppm	
	AIRS ID	Name or location	Second highest non-overlapping eight-hour average	Annual average
Denver (1995)	8-005-0002	Littleton	2.1	0.39
	8-031-0002	Broadway	9.5	1.50
	8-031-0013	Albion	6.0	1.25
	8-031-0014	Julian	5.9	1.09
	8-059-0002	Arvada	4.6	0.96
	Composite	Boulder	4.4	0.82
	Max/min values		Maximum = 9.5	Minimum = 0.39
Los Angeles (1997)	6-037-0113	West LA	3.9	0.84
	6-037-1002	Burbank	7.2	1.76
	6-037-1103	Los Angeles	5.8	1.36
	6-037-1301	Lynwood	15.0	2.33
	6-037-1601	Pico Rivera	5.9	1.49
	6-037-2005	Pasadena	5.4	1.10
	6-037-4002	Long Beach	6.2	1.11
	6-037-5001	Hawthorne	7.9	1.28
	6-059-0001	Anaheim	5.4	1.11
	6-0595001	La Habra	5.3	1.36
	Max/min values		Maximum = 15.0	Minimum = 0.84

Table 3-11. Proposed Parameter Values for Application of Air Quality Adjustment Procedure to Los Angeles.

Parameter	Los Angeles value
CMAX(e), ppm	15.0
CMAX(s), ppm	9.4
BG, ppm	0.2
ρ(s), dimensionless	0.622

3.4 References for Section 3

Johnson, T., J. Capel, R. Paul, and L. Wijnberg. 1992. **Estimation of Carbon Monoxide Exposures and Associated Carboxyhemoglobin Levels in Denver Residents Using a Probabilistic Version of NEM**. Report prepared by International Technology Air Quality Services under EPA Contract No. 68-D0-0062. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Johnson, T., and L. Wijnberg. 1981. "Time Series Analysis of Hourly Average Air Quality Data," presented at the 74th Annual meeting of the Air Pollution Control Association, Philadelphia, Pennsylvania.

Johnson, T. 1999. "Memo No. 1: Proposed Fixed-Site Monitors for Representing Los Angeles Exposure Districts in Version 2.0 of pNEM/CO." Memorandum to Harvey Richmond prepared by TRJ Environmental, Inc., under Work Assignment 2-30 of EPA Contract No. 68-D0-0064. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

U. S. Environmental Protection Agency. 2000. **Air Quality Criteria for Carbon Monoxide**. Report No. EPA/600/P-99/001F. U. S. Environmental Protection Agency, National Center for Environmental Assessment, Research Triangle Park, North Carolina.

Table 3-12. Descriptive Statistics for Carbon Monoxide Concentrations Reported by 10 Los Angeles Monitors Before and After Adjustment to Simulate Attainment of Eight-Hour CO NAAQS.

Site	Data set[a]	Descriptive statistics for CO concentration, ppm						
		50th	90th	95th	99th	99.5th	second maximum	maximum
60370113 (West Los Angeles)	1 h (u)	0.6	2.0	2.6	3.6	4.1	6.4	7.3
	1 h (a)	0.4	1.3	1.7	2.3	2.6	4.1	4.6
	8 h (a)	0.5	1.2	1.4	2.0	2.1	2.6	2.7
60371002 (Burbank)	1 h (u)	1.4	3.5	4.4	6.0	6.6	8.6	8.8
	1 h (a)	0.9	2.3	2.8	3.8	4.2	5.4	5.5
	8 h (a)	1.0	2.1	2.6	3.4	3.6	4.5	4.6
60371103 (Los Angeles)	1 h (u)	1.0	3.0	3.8	5.4	5.8	8.7	8.9
	1 h (a)	0.7	1.9	2.4	3.4	3.7	5.5	5.6
	8 h (a)	0.7	1.8	2.2	2.8	3.1	4.8	4.9
60371301 (Lynwood)	1 h (u)	1.7	4.9	6.7	11.2	13.5	18.8	19.2
	1 h (a)	1.1	3.1	4.2	7.0	8.5	11.8	12.0
	8 h (a)	1.1	3.0	3.9	5.5	6.5	10.5	10.6
60371601 (Pico Rivera)	1 h (u)	1.2	3.0	3.6	5.0	5.6	7.9	9.2
	1 h (a)	0.8	1.9	2.3	3.2	3.6	5.0	5.8
	8 h (a)	0.8	1.8	2.1	2.7	2.9	3.8	3.8

Site	Data set[a]	Descriptive statistics for CO concentration, ppm						
		50th	90th	95th	99th	99.5th	second maximum	maximum
60372005 (Pasadena)	1 h (u)	0.9	2.1	2.8	4.2	4.7	7.7	8.1
	1 h (a)	0.6	1.4	1.8	2.7	3.0	4.9	5.1
	8 h (a)	0.7	1.3	1.6	2.2	2.4	3.7	3.8
60374002 (Long Beach)	1 h (u)	0.7	2.7	3.6	5.2	5.9	8.6	9.0
	1 h (a)	0.5	1.8	2.3	3.3	3.7	5.4	5.7
	8 h (a)	0.5	1.6	2.1	2.9	3.1	4.0	4.1
60375001 (Hawthorne)	1 h (u)	0.5	3.7	5.1	7.3	8.2	12.3	12.4
	1 h (a)	0.4	2.4	3.2	4.6	5.2	7.7	7.8
	8 h (a)	0.5	2.2	2.9	3.9	4.3	6.3	6.5
60590001 (Anaheim)	1 h (u)	0.8	2.3	2.9	4.6	5.5	8.2	8.4
	1 h (a)	0.6	1.5	1.9	2.9	3.5	5.2	5.3
	8 h (a)	0.6	1.4	1.7	2.3	2.4	3.6	3.6
60595001 (La Habra)	1 h (u)	1.0	2.8	3.6	6.1	7.1	11.0	11.9
	1 h (a)	0.7	1.8	2.3	3.9	4.5	6.9	7.5
	8 h (a)	0.8	1.8	2.1	2.7	2.9	3.6	3.6

[a] 1 h (u): unadjusted 1-hour data (with missing values filled in).
1 h (a): adjusted 1-hour data set.
8 h (a): adjusted 8-hour running average data set [based on 1 h (a) data].

SECTION 4
THE MASS-BALANCE MODEL

The 1992 application of pNEM/CO to Denver marked a milestone in the evolution of the NEM methodology in that it represented the first time that a mass-balance model had been incorporated directly into the NEM methodology. Researchers updated the mass-balance model for use in Version 2.1 of pNEM/CO. This section provides an overview of the pNEM/CO mass-balance model together with descriptions of the algorithms used in the model to estimate air exchange, emissions from gas stoves, and emissions from passive smoking. It also describes the data used for the input parameters to the mass-balance model.

4.1 Overview of the Model

The pNEM/CO methodology includes a mass-balance model which is used to estimate CO concentrations when a cohort is assigned to an indoor or motor vehicle microenvironment. The mass-balance model is based on the generalized mass-balance model presented by Nagda, Rector, and Koontz (1987). As originally proposed, this model assumed that pollutant concentration decays indoors at a constant rate. For use in pNEM/CO, the Nagda model was revised to incorporate an alternative assumption that the indoor decay rate is proportional to the indoor concentration. The resulting model can be expressed by the differential equation

$$dC_{in}/dt = (1 - F_B)(\nu)(C_{out}) + S/(cV) - (m)(\nu)(C_{in}) - (F_d)(C_{in}) - (q)(F)(C_{in})/(cV) \qquad (4\text{-}1)$$

in which

C_{in} = Indoor concentration (units: mass/volume)

F_B = Fraction of outdoor concentration intercepted by the enclosure (dimensionless fraction)

F_d = Pollutant decay coefficient (1/time)

ν	=	Air exchange rate (1/time)
C_{out}	=	Outdoor concentration (mass/volume)
S	=	Indoor generation rate (mass/time)
cV	=	Effective indoor volume where c is a dimensionless fraction (volume)
m	=	Mixing factor (dimensionless fraction)
q	=	Flow rate through air-cleaning device (volume/time)
F	=	Efficiency of the air-cleaning device (dimensionless fraction)

As CO is a nonreactive pollutant, it is reasonable to assume 1) that the enclosure does not intercept any of the CO as it moves indoors, 2) that the CO does not decay once it enters the enclosure, and 3) that no CO is removed by air-filtration devices. Under these assumptions, the parameters F_B, F_d, and F in Equation 4-1 would be set equal to zero. If the additional assumptions are made that c and m are each equal to 1, the resulting differential equation is

$$dC_{in}/dt = (\nu)(C_{out}) + S/V - (\nu)(C_{in}) \qquad (4\text{-}2)$$

It can be shown that this equation has the following exact solution:

$$C_{in}(t) = k_1 C_{in}(t - \Delta t) + k_2 C_{out}(t - \Delta t) + k_3 \qquad (4\text{-}3)$$

where

$$k_1 = e^{-\nu\Delta t} \qquad (4\text{-}4)$$

$$k_2 = 1 - e^{-\nu\Delta t} \qquad (4\text{-}5)$$

$$k_3 = (S)(1 - e^{-\nu\Delta t})/(\nu V) \qquad (4\text{-}6)$$

and Δt is a fixed time interval. In Version 2.1 of pNEM/CO, Δt is either one hour or one minute, depending on the time resolution required by a particular modeling algorithm.

When Δt = 1 hour, the average indoor pollutant concentration of hour h [$CAVG_{in}(h)$] can be calculated by the expression

$$CAVG_{in}(h) = (a_1)[C_{in}(h - 1)] + (a_2)[CAVG_{out}(h)] + a_3 \tag{4-7}$$

where $C_{in}(h - 1)$ is the indoor concentration at the end of the preceding hour and $CAVG_{out}(h)$ is the average outdoor concentration during hour h. The other variables appearing in Equation 4-7 are defined by the following equations:

$$a_1 = z(h) \tag{4-8}$$

$$a_2 = 1 - z(h) \tag{4-9}$$

$$a_3 = (S)[1 - z(h)]/(\nu V) \tag{4-10}$$

$$z(h) = (1 - e^{-\nu})/\nu \tag{4-11}$$

The instantaneous indoor concentration at the end of a particular hour h [i.e., $C_{in}(h)$] is calculated by the equation

$$C_{in}(h) = k_1 C_{in}(h - 1) + k_2 CAVG_{out}(h) + k_3 \tag{4-12}$$

in which $C_{in}(h - 1)$ is the instantaneous indoor concentration at the end of hour h -1, $CAVG_{out}(h)$ is the average outdoor concentration during hour h, and

$$k_1 = e^{-\nu} \tag{4-13}$$

$$k_2 = 1 - e^{-\nu} \tag{4-14}$$

$$k_3 = (S)(1 - e^{-\nu})/(\nu V). \tag{4-15}$$

The same set of equations can be used for $\Delta t = 1$ minute, with each hourly index (h) replaced by a corresponding minute index (m).

To achieve reasonable run times, the hour version of the mass-balance model was used to estimate hour-by-hour CO concentrations in indoor microenvironments from sources other than environmental tobacco smoke (ETS). In addition, a special version of the hour mass-balance model was used to estimate hour-by-hour CO concentrations in restaurants and bars in areas which permit smoking. The minute version of the mass-balance model was used to estimate the minute-by-minute contribution of ETS in the indoors - residence microenvironment. It was also used to estimate total exposure in the automobile microenvironment. Section 4.2 describes these applications in more detail.

The majority of parameters included in each version of the mass-balance model were treated as probabilistic variables, in that the values for each parameter were randomly selected from appropriate distributions as they were required by the model. Table 4-1 indicates the selection frequency applied to each parameter (annual - i.e., one value per cohort; seasonal; daily; hourly; or by trip when in a vehicle). The parameters will be defined as they appear throughout this section.

4.2 Application of the Mass-balance Model to Specific Microenvironments

Table 2-5 lists the 15 microenvironments defined for Version 2.1 of pNEM/CO. As discussed above and in Section 2, the mass-balance model was used to estimate CO levels (partial or total) in 12 of these microenvironments. Subsections 4.2.1 through 4.2.6 describe the specific methodology used for each microenvironment.

4.2.1 Indoors - Residence

In simulating CO concentrations in this microenvironment, the hour version of the mass-balance model was used to estimate the hourly average contribution of CO from outdoor sources and from indoor gas stoves. The minute version of the mass-balance model was used to estimate a minute-by-minute contribution from ETS which was averaged over each exposure event in which passive smoking occurred. If more than

Table 4-1. Selection Frequencies for Probabilistic Parameters Used in Mass-balance Model.

Version of mass-balance model	Microenvironment	Probabilistic parameter	Frequency of Selection
Hour	Indoors - residence	Open window air exchange rate (AER)	Daily (function of window status)
		Closed window AER	Seasonal
		AC type (central, window, none)	Annual
		Window status (open/closed)	Daily
		Enclosed volume (V)	Annual
		Burner status (on/off)	Hourly
		Burner emission factor (EFBURN)	Annual
		Burner annual fuel use (AUB)	Annual
		Pilot light emission factor (EFPILOT)	Annual
		Pilot light annual fuel use (AUP)	Annual
		Pilot light status (yes/no)	Annual
	Restaurants and bars	Air exchange rate (ν)	Annual
		Cigarette emission rate ($CO_{cigarette}$)	Hourly
		Normalized ventilation rate (NVR)	Annual
	Other indoor ME's	Air exchange rate (ν)	Annual
	Mass transit vehicles	Air exchange rate (ν)	Daily
Minute	Indoor - residence (for ETS increment)	Cigarette emission rate ($CO_{cigarette}$)	Annual
		Air exchange rate (ν)	a
		Volume (V)	Annual
	Cars and trucks	Volume (V)	Annual
		$CO_{cigarette}$	Annual
		Air conditioning availability (Step 3 in Table 4-2)	Annual
		Vent status (Step 2 in Table 4-4)	Trip
		Speed (Step 3 in Table 4-4)	Trip
		Z value for AER (Step 4 in Table 4-4)	Trip

[a]Use same value as selected for hour mass-balance model.

one passive smoking event occurred in sequence, the minute mass-balance model was run for the entire time period during which passive smoking occurred. The CO contribution from passive smoking was assumed to be zero during all non-smoking periods, and the minute mass-balance model was not run during these periods. This approach, which significantly reduced model run-time, may produce estimates that are biased low, as it does not account for CO from smoking that lingers indoors after smoking stops. Analysts assumed that the effect was small enough to disregard.

In running the hour version of the mass-balance model, the value of $CAVG_{out}$ for a particular hour was set equal to the value for outdoor concentration determined for that hour by the algorithm described in Subsection 2.4.1. A value for air exchange rate (ν) was selected for each season from the lognormal distributions specified in Subsection 4.3. This same air exchange rate was also used in the minute mass-balance model when estimating the contribution of passive smoking, with the value expressed in air changes per minute rather than air changes per hour.

In applying the hour mass-balance model to residences, the S parameter was assumed to represent CO emissions from a single gas stove in the residence. In applying the minute mass-balance model, the S parameter represented CO emissions from passive smoking. In both versions, the V parameter was assumed to represent the total volume of the residence.

Cohorts with gas stoves were randomly identified as having stoves with either (1) continuously operating pilot lights or (2) electronic ignitions (i.e., no emissions from pilot lights), based on the estimated proportions of gas stove homes with and without electronic ignition in the Denver and Los Angeles study areas. Subsection 4.4.2 describes the methods used to simulate the CO contribution from continuously operating pilot lights.

The probabilistic algorithm described in Section 4.4.1 was used to simulate the operation of gas stove burners. Briefly, burner operation was assumed to occur in discrete "burner operation periods" (BOPs) of 60 minutes duration during normal dinner hours and of 30 minutes duration at other times. No more than one BOP was permitted to occur within a given clock hour, and each BOP began and ended with the same clock hour. A Monte Carlo process was used to randomly assign BOPs to clock hours throughout the year based on a table listing the probability of a BOP occurring within each hour of a typical day. This table was developed from an analysis of gas stove use patterns observed during the Denver Personal Monitoring Study (Johnson, 1984).

Other probabilistic algorithms were used to determine values of annual fuel usage, pilot light emission rate (if required), and burner emission rate for each cohort with gas stoves. Section 4.4.2 describes these algorithms. The simulated burner and pilot light emissions were summed for each clock hour and presented to the mass-balance model as an hourly average value for S. The residential volume (V) receiving the CO emissions was determined for each cohort by selecting values from a distribution representing the housing stock of Denver or Los Angeles, as appropriate.

The probabilistic algorithm described in Subsection 4.6.1 was used to estimate emission rate per cigarette during passive smoking events. The algorithm assumed that one smoker was present and that two cigarettes were smoked per hour.

4.2.2 Restaurants and Bars

Equation 4-7 was used to estimate hourly average values of CO for restaurants and bars in both study areas. ETS was considered to be the only potential indoor source of CO in these microenvironments. Consequently, the a_3 term in Equation 4-7 was used solely to account for the effect of passive smoking. Because smoking is prohibited in Los Angeles bars and restaurants, a_3 was set to zero when pNEM/CO was applied to Los Angeles. Passive smoking was assumed to occur continuously in Denver bars and restaurants, as local regulations permit smoking in these locations. In Denver applications, pNEM/CO calculated a_3 using an alternative to Equation 4-10 which better utilized existing databases. The alternative equation and applicable parameter distributions are presented in Subsection 4.6.3.

4.2.3 Other Indoor Microenvironments

The hour mass-balance model was used to estimate hourly average CO concentrations for each of these indoor microenvironments. In each case, analysts assumed that either (1) local regulations did not permit smoking in the microenvironments or (2) the CO contribution from passive smoking was insignificant. Analysts further assumed that these microenvironments contained no other significant indoor CO sources. Consequently, the indoor CO emission rate (S) was set at zero for each application. With S = 0, no value was required for enclosure volume (V). An air exchange value was selected for each combination of cohort and microenvironment from an appropriate distribution (see Subsection 4.3.2.2).

4.2.4 Automobiles and Trucks

Microenvironment No. 12 was defined as including automobiles and other non-truck passenger vehicles (vans, sport utility vehicles, etc.). Trucks were included in Microenvironment No. 13. In modeling these two microenvironments, the minute mass-balance model was used to estimate CO concentrations as a function of outside concentration, air exchange rate, vehicle volume, and ETS. The resulting one-minute CO values were averaged over the duration of each exposure event occurring in the microenvironment to determine the CO concentration to be applied to the event. The 14-step procedure presented in Table 4-2 was used to model the trip-related exposures associated with each cohort for the year-long exposure period. Tables 4-3, 4-4, and 4-5 describe the algorithms used to estimate the values of particular parameters required by the procedure.

According to this procedure, pNEM/CO determined vehicle volume, cigarette emission rate, and air conditioning availability on an annual basis. Vent status, speed, and air exchange rate were selected on a trip basis. Smoking status was determined on an event-by-event basis during each trip.

A memorandum by Cohen, Johnson, and Rosenbaum (1999) describes the derivation of the 14-step algorithm in detail. Briefly, analysts assumed that the outside concentration during each exposure event in a vehicle would be equal to the outdoor concentration associated with the motor vehicle for the clock hour containing the event. The passive smoking status would be determined by the diary entry for the event. A value for the emission rate of the cigarette would be randomly selected from a lognormal distribution with geometric mean = 71,400 µg and geometric standard deviation = 1.3 (see Section 4.6.1). The volume of the vehicle would be determined by

Table 4- 2. Algorithm Used to Model the Trip-related Exposures Associated with Each Cohort for the Year-long Exposure Period.

1. The volume of the vehicle is determined by the algorithm presented in Table 4-3. This value is held constant for all trips associated with the cohort.

2. The CO emission rate for cigarettes ($CO_{cigarette}$) smoked in the vehicle is determined by randomly selecting a value from a lognormal distribution with geometric mean = 71,400 µg and a geometric standard deviation of 1.3. The total emission rate from cigarettes is determined by the equation

$$S_{min} = (n_{smokers})(n_{cigs/smoker/hr})(CO_{cigarette})/60$$

in which n_{smoker} is the number of smokers and $n_{cigs/smoker/hr}$ is the number of cigarettes smoked by each smoker per hour. Assume $n_{smokers}$ = 1 and $n_{cigs/smoker/hr}$ = 2. The resulting value of S_{min} (expressed as µg CO min^{-1}) is held constant for all trips with smokers associated with the cohort.

3. Air Conditioner Availability. Select a random number (RN1) between zero and 1. If RN1 is 0.85 or below, then assume an air conditioner is available. Otherwise assume an air conditioner is unavailable (i.e., the vehicle does not have an air conditioner or the air conditioner is not functional). Apply this result to all trips associated with the cohort.

4. Parameters specific to the trip (vent status, speed, and air exchange rate) are determined by the algorithm presented in Table 4-4.

5. The inside CO concentration at the beginning of the first event of the trip is set equal to the outdoor concentration associated with the motor vehicle for the hour.

6. The outside CO concentration for the duration of the event is set equal to the outdoor concentration associated with the motor vehicle for the clock hour containing the event. (As exposure events do not cross clock hours, there is only one outside concentration associated with each event).

7. The smoking status of the event is determined by the entry for "smokers present (yes/no)" included in the CHAD database.

8. If smoking occurs during the event, the CO emission rate for ETS is set equal to the value determined in Step 2 above.

9. The air exchange rate for the event is set equal to the value determined by Step 4 above.

Continued

Table 4-2 (continued)

10.	The one-minute version of the mass-balance model is used to determine the average CO concentration for each minute and the instantaneous CO concentration for the end of each minute.
11.	The average CO concentration for the event is determined by averaging the minute-average CO concentrations for the event.
12.	The inside CO concentration at the beginning of the next event is set equal to the instantaneous CO concentration calculated in Step 10 for the end of the last minute of the preceding event.
13.	Repeat Steps 6 through 12 for each subsequent event in the trip sequence.
14.	Repeat Steps 4 through 13 for each subsequent trip.

Table 4-3. Algorithm for Estimating Enclosed Volumes of Cars and Trucks.

1. Randomly select value between zero and 1.

2. Compare selected value to following ranges[a].

   Microenvironment No. 12: Automobiles

   0.000 to 0.034: mini-compact (1.93 m^3)
   0.035 to 0.068: sub-compact (2.32 m^3)
   0.069 to 0.275: compact (2.58 m^3)
   0.276 to 0.862: mid-size (2.78 m^3)
   0.863 to 0.988: large (3.09 m^3)
   0.989 to 0.992: small wagon (3.48 m^3)
   0.993 to 0.996: mid-size wagon (3.82 m^3)
   0.997 to 1.000: large wagon (4.81 m^3)

   Microenvironment No. 13: Trucks

   0.00 to 0.31: curb weight < 3,500 lbs (1.52 m^3)
   0.32 to 0.62: 3,500 lbs $\leq$ curb weight $\leq$ 4,000 lbs (1.81 m^3)
   0.63 to 1.00: curb weight > 4,000 lbs (2.25 m^3)

3. Use indicated value in parentheses for vehicle volume.

[a]See Subsection 4.5 for derivation of ranges and associated volumes.

Table 4-4. Algorithms for Determining Trip-Specific Values of Parameters Used in the Mass-balance Model Applied to Cars and Trucks.

1. Other algorithms have determined the availability of air conditioning in the cohort's vehicle and the daily average temperature (DAT) for each day of the year. Use these values as necessary in determining the following values to be applied to each vehicle trip taken by the cohort. (Trips by cars and trucks are treated separately).

2. Vent Status. Apply the residential window status algorithm as described in Subsection 4.3.1. This algorithm determines window status based on AC system and the daily average temperature according to the probabilities listed in Table 4-9. For the current purpose, vehicles with functional air conditioners are equated to residences with central air conditioning systems, and vehicles with vents open are equated to residences with windows open:

   a) For each day, determine daily average temperature from step 1 and air conditioning (AC) system availability from step 2. Select RN2 between zero and 1.

   b) Assume step (a) specified 65 degrees and functioning AC. RN2 will be evaluated against percentage values listed in Table 4-9 for functional AC - medium temperature range (i.e., 35.6, 29.4, and 34.6).

   c) If RN2 $\leq$ 0.356, vents are always closed. AER value is determined by "vent closed" equation in Step 4a below.

   d) If 0.356 < RN2 $\leq$ 0.650, vents are always open. AER value is determined by "vent open" equation in Step 4a below.

   e) If 0.650 < RN2, vents are open for 58.2 percent of the time (see last column of Table 4-3) and therefore are closed 41.8 percent of the time. The AER is calculated as 0.582 x (AER for open windows) + 0.418 x (AER for closed windows) in which the AER values are determined by Step 4a below.

Continued on next page

3. Speed. Select a random number (RN4) between zero and 1. Use this random number to select a vehicle speed using the distribution given in Table 4-5.

   a) If RN4 $\leq$ 0.0462, speed = 0 mph.

   b) If 0.0462 < RN4 $\leq$ 0.1124, speed = 5 mph.

   c) If 0.1124 < RN4 $\leq$ 0.2400, speed = 10 mph.

   d) Etc. Final case is 0.9988 < RN4, speed = 60 mph.

4. Air Exchange Rate. Simulate AER from the appropriate log-normal distribution as indicated below. Vent status and speed were simulated in Steps 2 and 3.

   a) Compute mean (of the logarithms) using the formulae

      If vent is closed: $\mu = 3.37311 - 2.46213 + 0.03696 \times \text{speed}$

      If vent is open: $\mu = 3.37311 + 0.01798 \times \text{speed}$.

   b) Variance (of the logarithms) = σ^2 = 0.27323.

   c) Randomly select Z from a standard normal distribution. Values of Z are not permitted to fall below -1.645 or above 1.645.

   d) Hour AER = $\exp(\mu + \sigma Z)$.

   e) Divide AER by 60 to determine minute AER.

Table 4-5. Vehicle Speed Distribution.

Speed (mph)	Frequency (percent)	Cumulative percentage
0	4.62	4.62
5	6.62	11.24
10	12.76	24.00
15	21.75	45.75
20	21.52	67.27
25	16.12	83.39
30	7.57	90.96
35	4.10	95.06
40	2.18	97.24
45	1.46	98.70
50	0.91	99.61
55	0.27	99.88
60	0.12	100.00

[a]Reference: Table 4 of Cohen et al. (1999) -- see Appendix G of this report. Estimates were derived from data presented in Carlson and Austin (1997).

probabilistically assigning a size classification (e.g., subcompact automobile) to the vehicle and then assuming that the volume of the vehicle was equal to the average enclosed volume of the passenger compartment for vehicles in that classification (e.g., 2.32 m^3). Subsection 4.5.2 describes the methods which analysts used to estimate the distribution of size classifications and the average passenger volume assigned to each classification.

Analysts evaluated the sensitivity of the pNEM/CO mass-balance model to variations in air exchange rate and found that the model was not very sensitive to the exact rate value when the value exceeded about 10 hr^{-1}. A review of the literature identified a recent study (Rodes et al, 1998) funded by the California Air Resources Board (CARB) as the best existing source of air exchange data for passenger vehicles, although the data were limited to a few vehicles tested under a small number of driving scenarios (defined by speed, window status, and vent status). All air exchange rates measured while the vehicle vents were open (and the windows were either open or closed) exceeded 20 hr^{-1}. At very low speeds, air exchange rates as low as 2 hr^{-1} were measured when the vehicle vents were closed. Consistent with these findings, analysts developed a probabilistic algorithm in which air exchange rates for a given speed and vent status (open or closed) were randomly selected from specified log-normal distributions based on the CARB data (see Subsection 4.3.2.3). Vehicle speed was probabilistically determined by an algorithm based on data obtained from the Spokane-Baltimore-Atlanta instrumented vehicle study (Carlson and Austin, 1997). Vent status was determined probabilistically by the same pNEM/CO algorithm that simulates the opening and closing of windows in residences as a function of daily average temperature and availability of air conditioning. To complete the simulation, the probability of having a functioning air conditioner was estimated using the results of an EPA Office of Mobile Sources study (Koupal, 1998).

Passive smoking was assumed to occur whenever the activity diary data indicated the presence of smokers in the vehicle. The probabilistic algorithm described in Subsection 4.6.1 was used to estimate emission rate per cigarette during passive smoking events. The algorithm specified that one smoker was present during smoking events and that two cigarettes were smoked per hour. These assumptions were consistent with estimates of smoking rates provided by Repace et al. (1998).

4.2.5 Mass Transit Vehicles

Microenvironment No. 14 included buses, trains, subway trains, and other mass transit vehicles not included in Microenvironment Nos. 12 and 13. Analysts assumed that passive smoking did not occur in these vehicles. The hour mass-balance model was used to estimate hourly average CO concentrations inside each vehicle as a function of outside CO concentration and air exchange rate. Air exchange rates were selected from a uniform distribution with minimum equal to 1.8 hr^{-1} and maximum = 5.6 hr^{-1} as discussed in Subsection 4.3.2.3.

4.2.6 Estimation of Mass-balance Parameters

Subsections 4.3 through 4.6 provide descriptions of the algorithms and data bases used to determine the air exchange rates, burner operation probabilities, burner emission rates, pilot light emission rates, cigarette emission rates, and residential volumes used in the mass-balance model. Many of these algorithms require that values be selected at random from normal or lognormal distributions. This selection was performed by first defining the distribution of interest by one of the following expressions:

Normal: $$X = AM + (ASD)(z) \qquad (4\text{-}16)$$

Lognormal: $$X = (GM)(GSD)^{Z} \qquad (4\text{-}17)$$

In these expressions, AM is the arithmetic mean, ASD is the arithmetic standard deviation, GM is the geometric mean, and GSD is the geometric standard deviation. The distribution type (normal vs. lognormal) and the corresponding values for the mean and standard deviation were determined by fitting distributions to representative data sets. A value for X was selected from a particular distribution by randomly selecting a value for Z from the unit normal distribution [N(0, 1)] and substituting it into the appropriate equation. Tables 4-6, 4-7, and 4-8 list the distribution types and parameter values for the majority of random variables used in the mass-balance model.

Table 4-6. Distributions of Parameter Values Used in the Application of the pNEM/CO Mass-Balance Model to Denver.

Parameter	Distribution of parameter	Reference
Air exchange rate, exchanges/h: residence - windows closed	Lognormal distributions by season ***Season 1*** ○ Geometric mean = 0.450 ○ Geometric standard deviation = 1.960 ○ Lower bound = 0.120 ○ Upper bound = 1.683 ***Season 2*** ○ Geometric mean = 0.308 ○ Geometric standard deviation = 2.241 ○ Lower bound = 0.063 ○ Upper bound = 1.498 ***Season 3*** ○ Geometric mean = 0.653 ○ Geometric standard deviation = 2.010 ○ Lower bound = 0.166 ○ Upper bound = 2.566 ***Season 4*** ○ Geometric mean = 0.309 ○ Geometric standard deviation = 1.716 ○ Lower bound = 0.107 ○ Upper bound = 0.890	Johnson, Memorandum No. 1, 1998 Murray and Burmaster, 1995
Air exchange rate, exchanges/h: residence - windows open	Lognormal distribution ○ Geometric mean = 1.34 ○ Geometric standard deviation = 1.55 ○ Lower bound = 0.57 ○ Upper bound = 3.16	Johnson, Memorandum No. 1, 1998 Johnson, Weaver, Mozier, et al., 1998
Air exchange rate, exchanges/h: nonresidential, enclosed microenvironments, including motor vehicles	See Table 4-8	See Table 4-8
Annual gas usage by burners, kilojoules	Lognormal distribution ○ Geometric mean = 2.11×10^6 ○ Geometric standard deviation = 1.48 ○ Lower bound = 0.98×10^6 ○ Upper bound = 4.55×10^6	Menkedick et al., 1993
Annual gas usage by pilot lights, kilojoules	Lognormal distribution ○ Geometric mean = 3.37×10^6 ○ Geometric standard deviation = 1.84 ○ Lower bound = 1.02×10^6 ○ Upper bound = 11.13×10^6	Menkedick et al., 1993
Burner emission factor, mg/kilojoule	Lognormal distribution ○ Geometric mean = 0.0294 ○ Geometric standard deviation = 2.77 ○ Lower bound = 0 ○ Upper bound = 0.400	Davidson et al., 1987
Residential volume, cubic meters	Lognormal distribution ○ Geometric mean = 436 ○ Geometric standard deviation = 1.62 ○ Lower bound = 169 ○ Upper bound = 1122	Bureau of Census, 1995

Table 4-7. Distributions of Parameter Values Used in Application of the pNEM/CO Mass-Balance Model to Los Angeles.

Parameter	Distribution of parameter	Reference
Air exchange rate, exchanges/h: residence - windows closed	Lognormal distributions by season ***Season 1*** ○ Geometric mean = 0.507 ○ Geometric standard deviation = 1.910 ○ Lower bound = 0.143 ○ Upper bound = 1.802 ***Season 2*** ○ Geometric mean = 0.619 ○ Geometric standard deviation = 1.950 ○ Lower bound = 0.167 ○ Upper bound = 2.292 ***Season 3*** ○ Geometric mean = 1.054 ○ Geometric standard deviation = 2.489 ○ Lower bound = 0.176 ○ Upper bound = 6.296 ***Season 4*** ○ Geometric mean = 0.607 ○ Geometric standard deviation = 2.034 ○ Lower bound = 0.151 ○ Upper bound = 2.441	Johnson, Memorandum No. 2, 1999 (see Appendix I) Murray and Burmaster, 1995
Air exchange rate, exchanges/h: residence - windows open	Lognormal distribution ○ Geometric mean = 1.34 ○ Geometric standard deviation = 1.55 ○ Lower bound = 0.57 ○ Upper bound = 3.16	Johnson, Memorandum No. 1, 1998 Johnson, Weaver, Mozier, et al., 1998
Air exchange rate, exchanges/h: nonresidential, enclosed microenvironments, including motor vehicles	See Table 4-8	See Table 4-8
Annual gas usage by burners, kilojoules	Lognormal distribution ○ Geometric mean = 1.73×10^6 ○ Geometric standard deviation = 1.48 ○ Lower bound = 0.80×10^6 ○ Upper bound = 3.73×10^6	Menkedick et al., 1993
Annual gas usage by pilot lights, kilojoules	Lognormal distribution ○ Geometric mean = 2.76×10^6 ○ Geometric standard deviation = 1.84 ○ Lower bound = 0.84×10^6 ○ Upper bound = 9.12×10^6	Menkedick et al., 1993
Burner emission factor, mg/kilojoule	Lognormal distribution ○ Geometric mean = 0.0294 ○ Geometric standard deviation = 2.77 ○ Lower bound = 0 ○ Upper bound = 0.400	Davidson et al., 1987
Residential volume, cubic meters	Lognormal distribution ○ Geometric mean = 363 ○ Geometric standard deviation = 1.64 ○ Lower bound = 138 ○ Upper bound = 957	Bureau of Census, 1995

Table 4-8. Distributions for Air Exchange Rate (ν) for Enclosed, Nonresidential Microenvironments

Microenvironment			Activity diary locations included in microenvironment	Distribution of Air Exchange Rate (ν)					
				Distribution type	Lognormal Parameters		Bounds		Source of data
Code	General location	Specific location			GM	GSD	Lower	Upper	
2	Indoors	Nonresidence A	Service station or auto repair	Lognormal	1.24	1.93	0.34	4.50	a
3	Indoors	Nonresidence B	Other repair shop Shopping mall	Lognormal	1.24	1.93	0.34	4.50	a
4	Indoors	Nonresidence C	Restaurant	See Table 4-21	--	--	--	--	--
5	Indoors	Nonresidence D	Bar	See Table 4-21	--	--	--	--	--
6	Indoors	Nonresidence E	Other indoor location Auditorium	Lognormal	1.24	1.93	0.34	4.50	a
7	Indoors	Nonresidence F	Store Office Other public building	Lognormal	1.24	1.93	0.34	4.50	a
8	Indoors	Nonresidence G	Health care facility School Church Manufacturing facility	Lognormal	1.36	1.91	0.38	4.83	b
9	Indoors	Residential garage	Residential garage	Lognormal	1.24	1.93	0.34	4.50	a

Microenvironment			Activity diary locations included in microenvironment	Distribution of Air Exchange Rate (ν)					
				Distribution type	Lognormal Parameters		Bounds		Source of data
Code	General location	Specific location			GM	GSD	Lower	Upper	
12	Vehicle	Automobile	Automobile	See Table 4-4	--	--	--	--	c
13	Vehicle	Truck	Truck	See Table 4-4	--	--	--	--	c
14	Vehicle	Mass transit vehicle	Bus Train/subway Other vehicle	Uniform	--	--	1.8	5.6	c

[a]Data set containing all non-school AER values provided by Turk et al. (1989) and CEC (Lagus Applied Technology, 1995).
[b]Data set containing all AER values provided by Turk et al. (1989) and CEC (Lagus Applied Technology, Inc., 1995).
[c]Rodes et al. (1998).

4.3 Estimation of Air Exchange Rate

4.3.1 The Air Exchange Algorithms

A probabilistic algorithm was used to estimate an air exchange rate (AER) value for each enclosed microenvironment (i.e., buildings and vehicles). In most cases, the estimation procedure consisted of randomly selecting an AER value for the cohort from a distribution specific to the microenvironment. These distributions are presented in Tables 4-4, 4-8, and 4-21.

A more sophisticated methodology was used for the indoor - residence microenvironment which distinguished between air exchange when windows were open and when windows were closed. The window status was conditioned on the air conditioning (AC) system assigned to the cohort's residence and the outdoor temperature. A probabilistic algorithm assigned one of three potential residential AC systems to each cohort (central, window units, or none). A window status algorithm was then used to probabilistically determine window status (closed or open). Based on this determination, a value of AER was selected from either the closed window distribution or the open window distribution. The closed window distribution varied with season; a single distribution was used to represent open window conditions.

The AC algorithm required that the user specify the proportion of residences in the study area that had central AC, window units, and no AC. According to the 1995 American Housing Survey for Denver (Bureau of the Census, 1995), the breakdown for Denver was 25.3 percent central, 14.3 percent window, and 60.4 percent none. Analysts estimated the corresponding statistics for the Los Angeles study area to be 32 percent central, 21 percent window, and 47 percent none, based on data for the Los Angeles - Long Beach Standard Metropolitan Statistical Area provided by the American Housing Survey (Bureau of the Census, 1995).

The application of the AC algorithm to Denver can be described as follows:

1. For each day, select a random number (RN) between zero and 1.
2. If RN $\leq$ 0.253, the AC system is "central."
3. If 0.253 < RN $\leq$ 0.396, the AC system is "window units."
4. If 0.396 < RN, the AC system is "none."

The same procedure with appropriate parameter substitutions was applied to Los Angeles.

The window status algorithm was originally developed for applications of pNEM/O3 and has been described by Johnson et al. (1990). This algorithm determines window status based on AC system and the daily average temperature according to the probabilities listed in Table 4-9. Version 2.1 of pNEM/CO combines the window status algorithm and AER algorithm as follows.

1. The AC algorithm determines the AC system for the cohort.

2. Go to the first/next day. The average temperature for the day is obtained from a supplementary temperature file. Select RN between zero and 1.

3. Find the row in Table 4-9 that corresponds to the specified AC system and daily average temperature. Evaluate RN against the percentage values listed in this row consistent with the following example.

   a. Assume Steps 1 and 2 specified AC system = central AC and average daily temperature = 65 degrees. RN will be evaluated against the percentage values listed in Table 4-9 for central AC - medium temperature range (i.e., 35.6, 29.4, and 34.6).

   b. If RN $\leq$ 0.356, windows are closed all day. AER value is selected from the "windows closed" AER distribution.

   c. If 0.356 < RN $\leq$ 0.650, windows are open all day. AER value is selected from the "windows open" AER distribution.

   d. If 0.650 < RN, windows are open for 58.2 percent of the day (see last column). AER is determined by the expression

   $$AER = (0.582)(\text{open AER}) + (0.418)(\text{closed AER}) \qquad (4\text{-}18)$$

   where open AER is selected from the open window AER distribution and closed AER is selected from the closed window AER distribution.

4. If last day, end. Otherwise, go to Step 2.

A special version of the mass-balance model was applied to restaurants and bars. This model characterized air exchange as normalized ventilation rate (NVR), expressed as volume of air changed per person per hour. Subsection 4.6.3 describes the model and provides a method for estimating NVR.

4.3.2 Air Exchange Rate Distributions

A review of scientific literature was conducted to identify references relating to air exchange rates (AERs). Of the references identified, only a few were found to contain sufficient data to construct a distribution of AERs relating to a particular building type such as residence or office. The three most useful studies were conducted by Murray and Burmaster (1995), Turk et al. (1989), and Lagus Applied Technology (1995).

Table 4-9. Percentage of Person-Days With Indicated Window Ratio by Air Conditioning System and Temperature Range

Air conditioning system	Temperature range[a]	Percentage of person-days with indicated window ratio[b]			Mean of ratios not equal to 0 or 1
		Ratio = 0	Ratio = 1	0 < Ratio = <1	
Central	Low	86.0	0.8	13.2	0.260
	Medium	35.6	29.4	34.6	0.582
	High	62.1	12.9	25.0	0.503
Room units	Low	73.2	2.0	24.7	0.316
	Medium	12.0	44.2	43.8	0.618
	High	17.1	34.3	48.6	0.521
No air conditioning	Low	80.0	1.0	19.0	0.276
	Medium	4.7	59.1	36.2	0.716
	High	1.4	70.8	27.8	0.774

[a] Low: 31° to 62°F.
Medium: 63° to 75°F.
High: 76°F and above.

[b] Ratio = (minutes windows open)/(minutes spent in residence).

4.3.2.1 Indoors - Residence

An article by Murray and Burmaster (1995) described their analysis of residential air exchange rate data compiled by the Brookhaven National Laboratory (BNL). The BNL data included AERs for 2,844 residences in the United States, classified according to four geographic regions and the four seasons. The data for Denver were included in Region 2. The BNL data for Region 2 includes a large number of AER values for winter and spring, but small sample sizes for summer and autumn (n = 2 and 23, respectively). Statistical methods were used to estimate the geometric mean and standard deviation for the seasons with limited data (Johnson, Memorandum No. 1, 1998). The resulting seasonal AER distributions for Region 2 (which includes Denver) are included in Table

4-6. The lower and upper bounds of the distributions are based on the 2.5th and 97.5th percentile of the distributions.

A similar approach was used to develop seasonal distributions of air exchange rate for Los Angeles when windows were open. In this case, the BNL data for Region 4 were assumed to represent Los Angeles. A memorandum by Johnson (No. 2, 1999) describes how analysts applied statistical methods to the these data to develop the seasonal distributions listed for Los Angeles in Table 4-7.

It should be noted that the estimates for Regions 2 and 4 presented by Murray and Burmaster were based solely on data derived from the BNL database. Pandian et al. (1998) recently identified errors in a version of the BNL database previously used by Pandian, Ott, and Behar (1993) and provided corrected estimates of AER for various geographic regions. In evaluating other researcher's use of the BNL database, Pandian et al. concluded that the errors they identified did not affect the AER statistics presented by Murray and Burmaster. This conclusion is supported by the corrected statistics presented by Pandian et al. (1998) for a region containing Denver which are consistent with the statistics presented by Murray and Burmaster (1995) for Region 2.

For residences with windows open, the AER distribution in Version 2.1 of pNEM/CO is based on a study of a single residence. The American Petroleum Institute (API) conducted a study of a typical suburban house over a 24-hour time period (Johnson et al., 1998). In that study, researchers altered the ventilation characteristics of the house each hour according to a prepared script, and measured the resulting hourly average AER. Analysts determined that the data for hours when windows were open could be characterized by a lognormal distribution with a geometric mean of 1.34 air changes per hour, and a geometric standard deviation of 1.55 (Johnson, Memorandum No. 1, 1998 -- see Appendix H). The upper and lower bounds of the distribution have been set at 0.57 and 3.16, which correspond to the 2.5th and 97.5th percentiles, respectively. The distribution was applied to both Denver and Los Angeles.

Although a wealth of air exchange data currently exist for commercial and residential buildings with closed windows, there is a shortage of data representing buildings with open windows. Perhaps the best existing source of open-window data prior to 1998 is a study reported by Wallace and Ott (1996) in which researchers measured air exchange rates in a detached house in Redwood City, California. A continuous monitor (Bruel & Kjaer Model 1302) was used to track the decay of sulfur hexaflouride (SF_6) under a variety of conditions over a period of 16 months. The majority of measurements (88 of 101) were made with all external doors and windows closed. Nine measurements were made under maximum air exchange conditions in which all windows and one or two doors were open. The most useful data were obtained from 27 measurements in which one or two windows were opened to varying widths in a single room (the den). The measured air exchange rates varied from 0.35 to 5.6 h^{-1}, with half the rates between 0.59 and 2.75 h^{-1}. Linear regression analyses indicated that the air exchange rate increased by about 0.12 h^{-1} for every inch that the window was opened. Analysts judged the results of this study to be generally consistent with those of the Johnson et al. (1998) study cited above.

Wallace and Ott (1996) also provide a useful survey of other studies which have measured air exchange rates. In most cases, the available data represent buildings with closed windows or buildings for which the window status is unknown.

4.3.2.2 Microenvironment Nos. 2 through 8

This group of microenvironments includes all nonresidential, indoor microenvironments. Two AER distributions are used in pNEM/CO to represent buildings in these microenvironments. Microenvironment Nos. 2 through 7 are represented by a lognormal distribution with geometric mean = 1.24 and geometric standard deviation = 1.93. Microenvironment No. 8 is represented by a lognormal distribution with geometric mean = 1.36 and geometric standard deviation = 1.91. These distributions were developed from statistical analyses of AER data provided by two studies. The first study, conducted by Turk et al. (1989), measured AERs in 40 public buildings identified as schools (n = 7), offices (n = 25), libraries (n = 3), and multipurpose buildings (n = 5). The second study was conducted by the California Energy Commission (Lagus Applied Technology, Inc., 1995), and included 49 public buildings identified as schools (15), offices (22), and retail stores (13).

Microenvironment Nos. 2 through 7 are similar in that each includes various types of public buildings but omits schools. To determine a representative distribution of AER for these microenvironments, analysts combined all non-school data from the

Turk and CEC studies into a single data set containing 68 values. These values could be well-fit by a lognormal distribution with geometric mean of 1.24 air changes per hour and a geometric standard deviation of 1.93. As indicated in Table 4-8, AER values for Microenvironments Nos. 2, 3, 6, and 7 were randomly selected from this distribution. Values were not permitted to fall below 0.34 or exceed 4.50, corresponding to the 2.5th and 97.5th percentiles of the distribution.

Microenvironment No. 8 differs from the microenvironments discussed above in that it includes school and non-school buildings. Consequently, analysts used the complete set of AER values from the Turk and CEC studies to represent this microenvironment. The resulting data set could be well fit by a lognormal distribution with geometric mean = 1.36 air changes per hour and geometric standard deviation = 1.91. AER values for Microenvironment No. 8 were randomly selected from this distribution. Values were not permitted to fall below 0.38 or exceed 4.83, corresponding to the 2.5th and 97.5th percentiles of the distribution.

An alternative to air exchange rate was used in calculating the a_3 term when Equation 4-7 was applied to Microenvironments No. 4 (restaurants) and No. 5 (bars). This parameter -- normalized ventilation rate (NVR) -- is defined as the volume of air exchanged per hour per person and is expressed as m^3/hr/person. Section 4.6.3 provides distributions for the parameter and discusses its use in estimating the contribution of passive smoking to CO concentrations in restaurants and bars.

4.3.2.3 Passenger and Mass Transit Vehicles

Table 4-2 presents the 14-step method used to estimate the CO concentration associated with each exposure event in Microenvironment Nos. 12 (automobiles) and 13 (trucks). In Step 4, the algorithm presented in Table 4-4 is used to determine the air exchange rate for the exposure event. The algorithm determines air conditioning status with an 85 percent probability of having AC; vent status according to AC status and temperature; and speed. Air exchange rate is then determined probabilistically as a function of these three parameters.

In developing the algorithm summarized in Table 4-4, analysts considered three sources of data for estimating the distribution of air exchange rates in vehicles: Hayes

(1991); Ott, Switzer, and Willis (1994); and Rodes et al. (1998). Hayes (1991) provided a point estimate of 36 air changes per hour based on his analysis of data presented by Peterson and Sabersky (1975). This estimate was used for all vehicle-related microenvironments in the 1992 version of pNEM/CO. In a study reported by Ott, Switzer, and Willis (1994), researchers measured an AER value of 13.1 air changes per hour in a car moving at 20 mph with windows closed. AER values of 67 to 120 air changes per hour were measured in the car at the same speed with windows open.

During a study funded by the California Air Resources Board, Rodes et al. (1998) measured 11 AER values under test conditions which varied the ventilation setting, vehicle speed, and vehicle type (Table 4-10). (The draft version of the CARB report shows that multiple measurements were made for some vehicle/vent combinations - the analysis presented here used the average values given in the final CARB report). Three of the 11 values were obtained from a 91 Caprice which was tested under all three ventilation conditions. Unfortunately, this vehicle was tested at only one speed (55 mph). The 97 Taurus was tested at two ventilation settings and one speed (55 mph). The 97 Explorer was tested at the same two ventilation settings and at all three speeds. Note that the none of Taurus and Explorer values represent conditions with windows open. There is only one value for windows open -- the 91 Caprice driven at 55 mph. For the statistical analysis, analysts grouped this special case of vent open and windows (partially) open with the other cases of vent open and windows closed to produce data classified by only two ventilation conditions (open or closed).

The CARB data better represent AER under varying speeds and vent conditions than the point estimate provided by Hayes (1991) or the data provided by Ott, Switzer, and Willis (1994). Consequently, analysts used the CARB data as the basis for constructing the algorithm presented in Table 4-4. A memorandum by Cohen, Johnson, and Rosenbaum (1999) describes the methodology in more detail and provides justifications for the parameter values presented in Table 4-4. This memorandum can be found in Appendix G of this report.

Briefly, researchers began the process of constructing the algorithm by performing a sensitivity analysis of the mass-balance model used in pNEM/CO to determine whether it was sensitive to air exchange rates in the range associated with motor vehicles. The analysis showed that the mass-balance model was not very

Table 4-10. Air Exchange Rates Measured by Rodes et al. (1998) Under Varying Conditions.

Test conditions		Air exchange rate (hr^{-1})		
Ventilation settings	Vehicle speed, mph[a]	1991 Caprice	1997 Taurus	1997 Explorer
Vent closed, low fan speed	55	39	14	13.5
	35			5.6
	0			1.8
Vent open, low fan speed	55	98	76	55.5
	35			35.7
	0			20.7
Vent open, low fan speed, front windows 1/3 open	55	160		

[a]The vehicle speed was constantly maintained throughout the AER measurement.

sensitive to the exact value of the AER when AER exceeded 10 hr^{-1}. The data obtained from CARB (Table 4-10) indicated that air exchange rate tended to exceed 20 hr^{-1} when vehicle vents were open (and the windows were open or closed). Furthermore, AER could be as low as 2 hr^{-1} when the vehicle vents were closed (at very low speeds). These results suggested that the AER algorithm should realistically simulate the opening and closing of vents.

Cohen, Johnson, and Rosenbaum (1999) used the CARB data to develop an algorithm that selected AER values from a lognormal distribution whose parameters varied according speed, vent status (open or closed), and air conditioning status (present or absent). The <u>speed</u> value was simulated using speed distributions (Table 4-5) developed from the Spokane-Baltimore-Atlanta instrumented vehicle study (Carlson and Austin, 1997). The algorithm determined <u>window status</u> using the same probabilistic procedure used elsewhere in pNEM/CO to determine window status in residences (see Subsection 4.3.1). The probabilities used in this procedure are a function of daily average temperature and the availability of an air conditioner.

Researchers acknowledged that behavior patterns for opening windows in residences may not be the same as those for opening vents in vehicles, but were unable to find good data which were directly applicable for vehicles. Air conditioning status was estimated using the results of an EPA Office of Mobile Sources study (Koupal, 1998).

Researchers were unable to obtain specific measured data on air exchange rates for mass transit vehicles. A reasonable approximation was obtained from the 1997 Ford Explorer data provided by Rodes et al (1998) study and tabulated in Table 4-10. Preference was given to the first set of data listed in the table (vent closed, low fan speed) which was considered to be more representative of mass transit vehicles. Under these conditions, the measured air exchange rates were 1.8 per hour at 0 mph, 5.6 per hour at 35 mph, and 13.5 per hour at 55 mph. As mass transit vehicles typically travel at relatively low speeds, researchers selected the air exchange rates measured at 0 and 35 mph and assumed a uniform distribution over that range. Consequently, air exchange rates for mass transit vehicles were selected from a uniform distribution with minimum value equal to 1.8 hr^{-1} and maximum value equal to 5.6 hr^{-1}.

4.4 Simulation of Gas Stove Operation

4.4.1 Probability of Stove Use

The operation of gas stove burners in residences is simulated in the mass-balance model by specifying when the burners are on, the emission rate of the burners during operation, and the volume of the residence where it is located.

As discussed in Subsection 4.2.1, burner operation was assumed to occur in discrete BOPs such that use always began and ended within a single clock hour. BOP duration was assigned a value of either 30 or 60 minutes, depending on the time of day. These values were based on responses to a questionnaire administered by GEOMET to 4312 survey participants. Each participant provided data on the type of cooking facilities in the home, frequency of cooking, and average time spent in meal preparation (Koontz et al., 1992).

Table 4-11 presents a summary of data from this survey by type of meal (break-fast, lunch, and dinner). The values listed for average weekly time spent cooking break-fast, lunch, and dinner are 66, 71, and 288 minutes, respectively. The total time for all three meals is 425 minutes per week. The average daily cooking time based on this weekly value is 425/7 or 61 minutes.

Table 4-11. Statistics on Gas Stove Use Obtained from a Survey by Koontz et al. (1992)

Data item	Breakfast	Lunch	Dinner	Sum
Weekly duration of gas stove use, minutes	66	71	288	425
Weekly frequency of gas stove use	2.5	2.2	5.0	9.7
Average duration of use, minutes	26	32	58	

In addition to duration, the data in Table 4-11 provide an indication as to the frequency that a gas stove is used to prepare meals in the typical residence. In one week, the stove will be used to prepare 2.5 breakfasts, 2.2 lunches, and 5.0 dinners -- a total of 9.7 meals per week. On an average day, the number of meals prepared on a gas stove is 9.7/7 or 1.4.

Dividing the weekly cooking time associated with each meal type by the average frequency of the meal yields average BOPs for breakfast, lunch, and dinner of 26, 32, and 58 minutes, respectively. Based on these results, pNEM/CO uses a value of 60 minutes for BOPs that occur during normal dinner hours and 30 minutes for BOPs that occur at other times.

In pNEM/CO, stove operation is determined on an hourly basis by comparing a randomly selected number between 0 and 1 with AP(h), the probability of a gas stove being operated during the indicated clock hour h (h = 1, 2, ..., 24). If the random number is less than AP(h), the stove is "on" for a duration of M(h) minutes, where M(h) is either 30 or 60 minutes, depending on the value of h. If the random number is greater than or equal to AP(h), the gas stove is "off" for the entire hour.

Table 4-12 lists the values of AP(h) and M(h) used in the pNEM/CO analysis by clock hour. These values were developed to (1) reflect diurnal patterns in gas stove usage specific to Denver, (2) yield an average daily duration for stove use of approximately 61 minutes, and (3) yield an average daily frequency of stove use of approximately 1.4.

Table 4-12. Probability of Gas Stove Use by Clock Hour and Assumed Burner Operation Period

Clock hour	AP(h): probability of gas stove operation	M(h): assumed burner operation period, minutes	Product of AP(h) and M(h), minutes
1	0.025	30	0.76
2	0.023	30	0.68
3	0.023	30	0.69
4	0.023	30	0.70
5	0.023	30	0.70
6	0.026	30	0.77
7	0.049	30	1.46
8	0.058	30	1.73
9	0.081	30	2.43
10	0.073	30	2.20
11	0.062	30	1.86
12	0.075	30	2.25
13	0.085	30	2.54
14	0.071	30	2.14
15	0.067	60	4.01
16	0.064	60	3.86
17	0.107	60	6.41
18	0.130	60	7.80
19	0.091	60	5.49
20	0.058	60	3.45
21	0.052	60	3.11
22	0.047	60	2.79
23	0.040	30	1.21
24	0.035	30	1.04
Total	1.386		60.04

Diurnal patterns in stove use were determined through an analysis of data from the Denver Personal Monitoring Study (Johnson, 1984). In this analysis, the diary entries and background questionnaire provided by each study subject were used to determine (1) when the subject was in a residence having a gas stove and (2) whether the stove was on. As working subjects would not always be present when other family members were operating a gas stove, it was assumed that workers would tend to under-report stove use in their residences. It was further assumed that nonworkers would use gas stoves more than the average person and that the diaries of nonworkers would tend to over-represent typical gas stove use. Consequently, the decision was made to average the worker and nonworker data and then adjust these results so that the adjusted P(h) values would yield 1.4 hours of stove use "events" per day, on average.

Table 4-13 presents the relevant data. For each clock hour, the table lists values of p(h) for workers and nonworkers calculated as

$$P(h) = [N(\text{stove on, GSR})]/[N(\text{GSR})] \qquad (4\text{-}19)$$

where N(stove on, GSR) is the number of diary entries indicating the subject was in a gas stove residence when the stove was on and N(GSR) is the total number of diary entries indicating the subject was in a gas stove residence. In calculating these values, a stove was considered on during a particular clock hour if the subject's activity diary indicated at least 1 minute of use during the hour.

The column labeled "average P(h)" lists the arithmetic mean of the worker and nonworker P(h) values. These probabilities sum to 4.2 over 24 hours. It is desirable that the probabilities sum to 1.4, as this will produce an average of 1.4 BOPs per day. The values labeled "AP(h): adjusted P(h)" were calculated by multiplying the average values by 0.333 (1.4/4.2). The adjusted values sum to 1.4.

The AP(h) values are listed also in Table 4-12. To the right of each AP(h) value is the assumed value of M(h); that is, the number of minutes the stove will be assumed to operate if the stove is determined to be "on" during the hour. The product of AP(h) and M(h) is listed in the far right column. Summing these values over all 24 hours provides an estimate of the average number of minutes per day that a gas stove will be

Table 4-13. Proportion of PEM Values in Gas Stove Residences with Stove in Operation by Clock Hour and Work Status

Clock hour	Nonworkers		Workers		Average P(h)	AP(h): adjusted P(h)
	n	P(h)	n	P(h)		
1	63	0.111	149	0.041	0.076	0.025
2	59	0.085	139	0.051	0.068	0.023
3	5	0.086	136	0.052	0.069	0.023
4	58	0.086	134	0.053	0.070	0.023
5	58	0.086	133	0.053	0.070	0.023
6	62	0.097	141	0.057	0.077	0.026
7	67	0.119	175	0.173	0.146	0.049
8	84	0.179	151	0.167	0.173	0.058
9	119	0.269	134	0.216	0.243	0.081
10	87	0.230	86	0.209	0.220	0.073
11	80	0.200	70	0.171	0.186	0.062
12	76	0.253	76	0.197	0.225	0.075
13	72	0.296	70	0.214	0.255	0.085
14	62	0.213	80	0.215	0.214	0.071
15	51	0.216	59	0.186	0.201	0.067
16	64	0.266	75	0.120	0.193	0.064
17	96	0.396	122	0.246	0.321	0.107
18	103	0.456	174	0.326	0.391	0.130
19	151	0.251	244	0.299	0.275	0.091
20	148	0.149	341	0.196	0.173	0.058
21	102	0.147	236	0.165	0.156	0.052
22	82	0.183	176	0.097	0.140	0.047
23	82	0.159	193	0.083	0.121	0.040
24	75	0.133	148	0.075	0.104	0.035
				Sum:	4.167	1.386

operated according to the algorithm. The sum is approximately 60 minutes, a value very close to the desired value of 61 minutes.

4.4.2 Gas Stove Emission Rates

Version 2.1 of pNEM/CO differentiates between gas stoves with and without electronic ignitions. The Monte Carlo algorithm described in Subsection 4.4.4 was used to randomly determine pilot light status for each cohort defined as having gas stoves. Gas stoves without electronic pilot ignition were assumed to have continuously burning pilot lights. The mass of CO emitted by gas stove with a pilot light during a particular hour (h) was estimated by the equation

$$MASSCO(h) = (ERBURN)[M(h)]/60 + (ERPILOT)(1\ hr) \qquad (4\text{-}20)$$

where MASSCO(h) is expressed in mg, ERBURN is the hourly burn emission rate in mg per hour, and ERPILOT is the hourly pilot light emission rate in mg per hour. M(h) is the duration of burner use during hour h expressed in minutes. The pilot light is assumed to on continuously during the one hour period.

The mass of CO emitted by gas stove with electronic ignition was estimated by the equation

$$MASSCO(h) = (ERBURN)[M(h)]/60; \qquad (4\text{-}21)$$

i.e., the ERPILOT term in Equation 4-20 was set equal to zero.

In both equations, M(h) is zero for each hour in which the algorithm assigns the stove a status of "off." If the stove status is "on" for a particular hour, M(h) is assigned a value of 30 or 60 minutes according to Table 4-12.

ERBURN was determined by the equation

$$ERBURN = (AUB/365.2)(EFBURN)(Y') \qquad (4\text{-}22)$$

where AUB is the annual fuel usage of the burners in kilojoules, 365.2 is the number of hours per year that the burners are operated assuming 60 minutes of use per day

(Table 4-11), EFBURN is the burner emission factor in mg of CO per kilojoule, and Y' is an adjustment factor which varies sinusoidally throughout the year. The values of AUB, EFBURN, and Y' are specific to cohort.

Subsections 4.4.2.1 and 4.4.2.2 provide estimates for the parameter values in Equations 4-20 through 4-22 specific to Denver and Los Angeles, respectively. The development of Denver parameter values is discussed first, as many of the Los Angeles values were derived from the corresponding Denver values through the use of an adjustment factor.

4.4.2.1 Denver Estimates

Values of AUB for Denver were randomly selected from a lognormal distribution with geometric mean = 2.11 million kilojoules and geometric standard deviation = 1.48. This distribution is based on the distribution of annual burner gas use measured by the Northern Illinois Gas Company (NIGAS) in 57 homes (Menkedick et al., 1993). The value of AUB was not permitted to exceed 4.55 million kilojoules. This value represents the 97.5^{th} percentile of the distribution.

The seasonal adjustment factor (Y') was determined by the equation

$$Y'(j) = 1.00 - (0.190)\{\sin[-1.616 + (2\pi)(j)/365]\}. \tag{4-23}$$

in which j is the Julian date. This equation was derived by Johnson (Memorandum No. 1, 1998) from a sinusoidal pattern observed in a study conducted by NIGAS (Wilkes and Koontz, 1995). The NIGAS data indicate that gas use in the winter is approxi-mately 46 percent higher than in the summer.

Values of EFBURN were randomly selected from a lognormal distribution with geometric mean = 0.0294 mg/kilojoule and geometric standard deviation = 2.77. Values of EFBURN were not permitted to exceed 0.400 mg/kilojoule. These values are based on the results of an analysis of data reported by Davidson et al. (1987) and represent a well-adjusted stove. As such, the assumed geometric mean is probably low with respect to the overall population of gas stoves.

Consistent with the above discussion, the following algorithm was used to estimate a value of ERBURN for each 24-hour period.

1. Randomly select a value for AUB from a lognormal distribution with geometric mean = 2.11 million kilojoules per year and geometric standard deviation = 1.48.

2. Randomly select a value of EFBURN from a lognormal distribution with geometric mean = 0.0294 mg/kilojoule and geometric standard deviation = 2.77.

3. Go to the next day of the current sequence. The Julian date of this day is j.

4. Use Equation 4-23 to calculate Y′(j).

5. ERBURN = (EFBURN)(AUB)(Y′)/365.2 for all hours of the day.

6. Go to Step 3. Repeat for all days of the year.

The resulting daily values of ERBURN were inserted into Equation 4-21 as required.

The ERPILOT value in Equation 4-20 was determined by the equation

$$\text{ERPILOT} = (\text{AUP}/8760)(\text{EFPILOT}) \qquad (4\text{-}24)$$

where AUP is the annual fuel usage by all pilot lights in kilojoules, 8760 is the number of hours per year that the pilot lights are in operation, and EFPILOT is the pilot light emission factor in mg of CO per kilojoule. The value of AUP was held constant over the entire year and was randomly selected from a specified lognormal distribution. The value of EFPILOT was assumed to be constant over the entire year and was set equal to the value determined for EFBURN in Equation 4-22.

The distribution for gas usage by pilot lights (AUP) was based on data from the NIGAS study discussed previously. The total gas usage (burners plus pilot lights) for 33 stoves had an arithmetic mean of 57.1 therms and a standard deviation of 18.3 therms. Total gas use was also measured for 57 stoves that did not have pilot lights; the arithmetic mean gas use for stoves without pilot lights was 21.8 therms. The difference between the two samples, 57.1 - 21.8 = 35.3 therms, provided an estimate of the mean fuel usage for pilot lights only. The square root of the differences in variances, $(18.3^2 - 8.9^2)^{1/2}$ = 16.0 therms, provided an estimate of the standard deviation. Consequently, AUP was assumed to have an arithmetic mean of 35.3 therms (3,500 ft^3) and an arithmetic standard deviation of 16.0 therms (1,600 ft^3).

The ratio of standard deviation to mean is 0.45, indicating that the distribution is skewed. Consequently, analysts assumed that the underlying distribution was lognormal. The corresponding geometric mean and geometric standard deviation for this distribution were 3,215 ft^3 = 3.37 million kilojoules per year and 1.84 (dimensionless), respectively. Values of AUP were randomly selected from this distribution as needed. Values of AUP were not permitted to fall below 1.02 million kilojoules per year or above 11.13 million kilojoules per year. These bounds correspond to the 2.5th and 97.5th percentiles, respectively, of the specified lognormal distribution.

The value of MASSCO(h) as determined by Equation 4-20 or 4-21 was used as the value of S for hour h in Equations 4-10 and 4-15, regardless of the value of M(h). This approach permitted the use of the hourly average exact solution (Equation 4-7) to the mass-balance equation (Equation 4-2). The practical result of this simplification was a slight smoothing in the simulated hour-to-hour variation in indoor CO concentrations with respect to the pattern which would be simulated by a model with finer time resolution.

4.4.2.2 Los Angeles Estimates

As discussed above, a study conducted by NIGAS was the principal source of the AUB and AUP distributions developed for Denver. Analysts obtained gas stove data specific to Los Angeles which provided a basis for adjusting the NIGAS-derived values for application to Los Angeles. Table 4-14 lists data for six utility districts provided by the Demand Analysis Office of the California Energy Commission (CEC, 1998). Three of the districts span the Los Angeles study area (LADWP, BDG, and SCE). The average gas use per stove in these three districts ranges from 45.0 to 49.2 therms with 47 therms representing a reasonable overall estimate. Note that these values specify total gas use by the stove; the CEC did not provide separate estimates for burners and pilot lights.

Table 4-14. Gas Stove Data Provided by Demand Analysis Office of the California Energy Commission.

Utility district	Approximate geographic area	Percent cooking w/gas	Number of gas stoves	Therms used by all stoves (millions)	Therms per stove[a]
Pacific Gas and Electric (PG&E)	northwest of Los Angeles	33.0	1,399,887	67.8	48.4
Sacramento Municipal Utility Division (SMUD)	Sacramento	30.5	130,319	6.2	47.6
Southern California Edison (SCE)	South coast outside downtown Los Angeles	68.6	2,772,522	131	47.3
Los Angeles Department of Water and Power (LADWP)	Los Angeles	78.6	982,891	48.4	49.2
San Diego Gas and Electric (SDG&E)	San Diego	46.5	486,537	20.5	42.1
Combined Municipal Districts of Burbank, Glendale, and Pasadena (BDG)	Burbank, Glendale, Pasadena	78.4	131,111	5.9	45.0

[a]Calculated by Ted Johnson.
[b]Source: California Energy Commission (1998).

As previously discussed, the NIGAS study reported an average of total gas usage of 57.1 therms per stove based on 33 stoves. Based on the assumption that Los Angeles residents use less gas per stove than the population sampled by NIGAS (47 therms vs. 57.1 therms), analysts calculated an appropriate adjustment ratio by the expression

$$\text{Adjustment ratio} = (47 \text{ therms})/(57.1 \text{ therms}) = 0.82. \qquad (4\text{-}25)$$

The adjusted GM for annual burner use (AUB) in Los Angeles was 2.11 million kilojoules x 0.82 = 1.73 million kilojoules. The corresponding GSD of 1.48 was unchanged, as this is a dimensionless quantity.

Using the same adjustment approach, the GM for annual pilot light use (AUP) was estimated as 3.37 million kilojoules x 0.82 = 2.76 million kilojoules. Again, the GSD remained unchanged at 1.84. It should be noted that the application of the adjustment factor to the NIGAS pilot light data assumes that pilot light use is proportionally lower in Los Angeles, an assumption which cannot be currently verified.

Analysts assumed that the Denver estimates for EFBURN and EFPILOT could be applied to Los Angeles. Consistent with the Denver approach, Equations 4-20 and 4-21 were used to estimate MASSCO(h) values for Los Angeles gas stoves with and without pilot lights. The values of ERBURN and ERPILOT in this equation were similarly estimated by Equations 4-22 and 4-24, respectively. Equation 4-23 provided the estimate of $Y'(j)$ for Equation 4-22.

4.4.3 Gas Stove Prevalence Rates

The equations used to estimate cohort populations require an estimate of F(h,f), defined as the fraction of homes in Home district h that use cooking fuel f. Analysts estimated that F(h,f) = 19.6 percent for the Denver study area based on data obtained from the Bureau of Census (1992). The demographic data listed in Table 4-14 was used to estimate F(h,f) = 79 percent for the Los Angeles study area. The data were compiled from three reports (Bureau of Census, 1996a, 1996b, 1997) listing statistics obtained from American Housing Survey (AHS). The area labeled Los Angeles in Table 4-15 includes the Los Angeles - Long Beach PMSA (i.e., Los Angeles County), a region which contains most of the census tracts included in the study area defined for Los Angeles pNEM/CO analysis. The remaining census tracts are located just outside Los Angeles County in Orange County or in Riverside County. Because of their similar demographics and close proximity to Los Angeles County, analysts assumed that these bordering census tracts were likely to be better represented by the prevalence rate of Los Angeles County (79.8 percent) than by rates listed for Orange County (61.9 percent) or Riverside County (77.4 percent).

The 79.8 percent prevalence rate for Los Angeles County obtained from the AHS is consistent with the gas stove use rates listed in Table 4-14 for LADWP (78.6 percent) and BDG (78.4 percent). Taken together, the three estimates support an estimate of about 79 percent for the gas stove prevalence rate.

4.4.4 Probability of Gas Stove Having Electronic Ignition

A Monte Carlo algorithm was used to randomly determine the pilot light status (pilot light or electronic ignition) for each cohort defined as having gas stoves. This approach required estimates of prevalence rates for pilot lights in Denver and Los Angeles. The CO CD (USEPA, 2000, p. 3-46) provided two sources of such data:

1. Koontz, Mehegan, and Nagda. Distribution and Use of Cooking Appliances that can Affect Indoor Air Quality: Topical Report. 1992.

2. Wilson, Colome, Tian. California Residential Indoor Air Quality Study, Volume 1, Methodology and Descriptive Statistics, Appendix. 1993.

Based on a national sample of homes, Koontz et al. (1992) estimated that the fraction of U. S. gas stoves with electronic ignition was 20 percent in 1985 and 27 percent in 1991. Wilson et al. (1993) surveyed 293 households in California during 1991 and identified 142 homes as having gas stoves. Of the gas stove homes, 70 (49 percent) had electronic ignition. Note that the Wilson et al. estimate for California (49 percent) is significantly higher than the Koontz et al. estimate for the nation (27 percent in 1991). Unable to find data specific to Denver, analysts decided to use the California value (49 percent) for Los Angeles and the national value (27 percent) for Denver.

Table 4-15. Fuel Use Statistics from the American Housing Survey (1996).

Statistics	Anaheim (1994)[a]	Los Angeles (1995)[b]	Riverside (1994)[c]
Total Housing Units (HU)	918,000	3,276,000	1,121,400
Total HU w/cooking fuel	915,500	3,165,200	1,101,900
Total HU w/natural gas cooking fuel	568,700	2,614,000	867,500
Prevalence of HU w/gas cooking fuel[d]	61.9 percent	79.8 percent	77.4 percent

[a]Anaheim = Orange County PMSA (includes all of Orange County).
[b]Los Angeles = Los Angeles - Long Beach PMSA (includes all of Los Angeles County.
[c]Riverside = Riverside-San Bernardino PMSA (Includes all of Riverside and San Bernardino Counties).
[d]Prevalence rate = 100 x (total HU w/natural gas cooking fuel)/(total housing units).

These estimates were incorporated into a probabilistic algorithm for determining the pilot light status. The algorithm randomly selected a number between 0 and 1 for each cohort identified as having gas stoves. The selected number was compared to a city-specific value of X (0.49 for Los Angeles and 0.27 for Denver). If the selected number was X or less, the cohort was assumed to have gas stoves with electronic ignitions. Otherwise, the cohort was assumed to have gas stoves with pilot lights which burned continuously. Whenever a cohort was assigned to the electronic ignition category, the value for “annual fuel use by gas stove pilot light” was set equal to zero in the gas stove emission algorithm (see Subsection 4.4.2).

4.5 Enclosed Volumes

4.5.1 Residences

Table 4-16 presents data obtained from the American Housing Survey (Bureau of Census, 1995) representing the distribution for square footage of occupied units in Denver and Los Angeles. Plots of these statistics indicate that the data can be closely fit by lognormal distributions with the following values for geometric mean and geometric standard deviation.

Table 4-16. Statistics on Square Footage of Occupied Units in Denver and Los Angeles (Bureau of the Census, 1995).

Range of square footage for occupied units	Denver		Los Angeles	
	Number in thousands	Cumulative percent	Number in thousands	Cumulative percent
less than 500	1.0	0.2	20.7	1.7
500 to 749	9.3	2.5	37.0	4.7
750 to 999	34.1	10.6	104.9	13.2
1,000 to 1,499	75.6	28.6	354.8	42.0
1,500 to 1,999	86.0	49.2	326.1	68.5
2,000 to 2,499	86.7	69.8	199.6	84.7
2,500 to 2,999	49.8	81.7	66.8	90.1
3,000 to 3,999	53.4	94.5	77.1	96.3
4,000+	23.2	100.00	45.1	100.0
Total[a]	419.1	--	1232.1	--

[a] Omits 38,500 units which did not report square footage values.

		Geometric mean	Geometric std. dev.	Median
Square footage:	Denver	1926	1.62	2020
	Los Angeles	1604	1.64	1651

The values listed under "median" were provided in the American Housing Survey listings and agree closely with the estimated geometric means. (The geometric mean of a "perfect" lognormal distribution is equal to its median).

Assuming an eight-foot ceiling and using 1 cubic meter = 35.315 cubic feet, the residential volumes can be modeled by lognormal distributions with the following parameters.

		Geometric mean	Geometric std. dev.
Volume, m^3:	Denver	436	1.62
	Los Angeles	363	1.64

Version 2.1 of pNEM/CO selects residential volumes from these distributions. To prevent the occurrence of unrealistic values, volumes are not permitted to fall outside the 2.5th and 97.5th percentiles of each lognormal distribution. These values are listed below.

		Lower bound	Upper bound
Volume, m^3:	Denver	169	1,122
	Los Angeles	138	957

4.5.2 Passenger Vehicles

The volume of the passenger compartment is determined by the algorithm presented in Table 4-3. For the specified microenvironment (automobiles or trucks), this algorithm randomly determines the vehicle type according to the estimated distribution of registered passenger vehicles and then assigns the vehicle the average volume for that vehicle type.

The distribution for automobiles by vehicle type was based on an analysis of the data listed in Table 4-17. The left-hand section of the table provides a breakdown of 1998 automobile sales by segment. The right-hand section provides values for average enclosed volume by vehicle type. Because data on enclosed volume were not available for the specified market segments (or vice versa), analysts made a series of assumptions as to how market segments could be allocated to vehicle types. Table 4-18 documents these assumptions and presents the resulting allocation of market share to each vehicle type.

Table 4-19 lists interior volume data for pickup trucks acquired from various industry sources. The trucks are classified according to the three weight classes for which 1995 sales data are available: less than 3,500 lbs (31 percent), 3,500 to 4,000 lbs (31 percent), and greater than 4,000 lbs (38 percent).

Analysts made the assumption that the average interior volume for each weight classification in Table 4-19 was equal to the average of interior volumes of the trucks listed for the classification. These average volumes are listed below together with the corresponding ranges of individual values (in parentheses).

Weight classification	Percentage of sales	Average interior volume (m^3)
less than 3,500 lbs	31	1.52 (1.49 - 1.59)
3,500 to 4,000 lbs	31	1.81 (1.49 - 2.35)
greater than 4,000 lbs	38	2.25 (1.49 - 3.15)

These results were the basis for the algorithm used to estimate truck volume (see Table 4-3.

Table 4-17. 1998 Automobile Sales by Segment and Enclosed Volume by Vehicle Type.

1998 Automobile Sales by Segment[a]		Enclosed volume by vehicle type[b]	
Segment	Percent of market	Vehicle type	Average volume, m^3
Budget	3.0	Mini-compact	1.93
Small	18.7	Sub-compact	2.32
Lower mid-size	17.5	Compact	2.58
Mid-size	29.5	Mid-size	2.78
Upper mid-size	11.5	Large	3.09
Near luxury	5.4	Small wagon	3.48[c]
Luxury	7.1	Mid-size wagon	3.82[c]
Sporty	5.6	Large wagon	4.81[c]
Specialty	1.3	--	--

[a]Source: "1998 U.S. Car Sales by Segment," **Automotive News Market Data Book Supplement**, p. 33, May 1999.
[b]Source: Average volumes by EPA class as listed in new car buying pages on Yahoo!
[c]Includes luggage space.

Table 4-18. Allocation of Market Segments to Vehicle Types.

Vehicle type (average passenger compartment volume, m^3)	Assigned market segment	Percent of market in segment (see Table 4-17)	Fraction of segment allocated to vehicle type	Resulting percent of market in vehicle type
Mini-compact (1.93)	Sporty	5.6	0.33	3.4[a]
	Budget	3.0	0.50	
Sub-compact (2.32)	Sporty	5.6	0.33	3.4
	Budget	3.0	0.50	
Compact (2.58)	Sporty	5.6	0.33	20.7
	Small	18.7	1.00	
Mid-size (2.78)	Lower mid-size	17.5	1.00	58.7
	Mid-size	29.5	1.00	
	Upper mid-size	11.5	1.00	
Large (3.09)	Near luxury	5.4	1.00	12.6
	Luxury	7.1	1.00	
Small wagon (3.48)	Specialty	1.3	0.33	0.4
Mid-size wagon (3.82)	Specialty	1.3	0.33	0.4
Large wagon (4.81)	Specialty	1.3	0.33	0.4
			Total	100.0

[a]Sample calculation: (5.6% x 0.33) + (3.0% x 0.50) = 3.4%.

Table 4-19. Interior Volumes for Selected Pickup Trucks Classified by Curb Weight.

Curb weight category, lbs	Percentage of 1995 pickup sales[a]	Model	Curb weight, lbs	Interior volume		Source of volume data
				ft^3	m^3	
Less than 3,500	31	Dodge Dakota reg. cab	3378 - 3581	56.3	1.59	b
		Mazda 4x2 reg. cab	3356 - 3431	52.5	1.49	c
		Ford Ranger reg. cab	3429 - 3518	52.5	1.49	c
3,500 to 4,000	31	Dodge Dakota ext. cab	3611+	82.9	2.35	b
		Mazda supercab 2dr	3580	65.2	1.85	c
		Ford Ranger supercab 2dr	3576 - 3618	65.2	1.85	c
		Ford Ranger 4x4 reg. cab	3784	52.5	1.49	c
		Mazda 4x4 reg. cab	3862	52.5	1.49	c
Greater than 4,000	38	Dodge RAM reg. cab	4150+	62.8	1.78	b
		Dodge RAM ext. cab	4704+	111.2	3.15	b
		Ford F150	4247+	61.8	1.75	c
		Ford Ranger Elec	4427+	52.5	1.49	c
		Ford F150 supercab	4621+	106.9	3.03	c
		Ford F250 reg. cab	4957+	61.8	1.75	c
		Ford F250 supercab	5130+	106.9	3.03	c
		Maxda 4x4 supercab	4055	65.2	1.85	c
		Ford Ranger 4x4 supercab	4017 - 4057	65.2	1.85	c
		Ford F150 4x4 reg. cab	4615 - 4747	61.8	1.75	c
		Ford F150 4x4 supercab	5222 - 5364	106.9	3.03	c
		Ford F250 4x4 reg. cab	5426 - 5468	61.8	1.75	c
		Ford F250 4x4 supercab	5627 - 5642	106.9	3.03	c

[a]Insurance Institute of Highway Safety, EPM Communications, Copyright 1998. In: “Utility Vehicles Overtake Passenger Vehicles,” Research Alert, Vol. 16, No. 7, p. 7 (April 3, 1998).
[b]Personal communication from Mr. Chuck Paterka (248-576-5465), Daimler-Chrysler.
[c]Spread sheet provided by Mr. Neil Whitbeck (313-322-9329), Fuel Economy and Quality, Environmental and Safety Engineering, Ford Motor Company.
[d]Steve Cadle of General Motors stated that the cab volumes of GM pickups typically range from 60 to 70 ft^3 (1.70 to 1.98 m^3). Personal communication (November 4, 1999).

4.6 Simulation of Passive Smoking

This subsection begins with a description of the method used to estimate CO emission rate from cigarettes in Version 2.1 of pNEM/CO. It then shows how this estimate is converted into CO levels in selected microenvironments.

4.6.1 Estimation of CO Emission Rate from Passive Smoking

Subsection 2.4.1 presented an overview of the methods used to estimate CO concentration in each microenvironment. Passive smoking was considered to be a significant source of CO in the following indoor and vehicle microenvironments: No. 1: indoors - residence, No. 4: restaurants (when permitted), No. 5: bars (when permitted), No. 12: automobiles, and No. 13: trucks. Subsections 4.6.2 through 4.6.4 describe the algorithms used to estimate the contribution of passive smoking in each of these microenvironments. Each of these algorithms requires an estimate of CO emission rate from smokers present in the microenvironment. This estimate was obtained from the equation

$$S = (n_{smokers})(n_{cigs/smoker/hr})(CO_{cigarette}) \tag{4-26}$$

in which S is the emission rate in μg/hr, $n_{smokers}$ is the number of smokers present, $n_{cigs/smoker/hr}$ is the number of cigarettes smoked per hour per smoker, and $CO_{cigarette}$ is the mass of CO emitted per cigarette. The values used for $n_{smokers}$ and $n_{cigs/smoker/hr}$ are presented by microenvironment in Subsections 4.6.2 through 4.6.4.

The values used for $CO_{cigarette}$ were randomly selected from a lognormal distribution with geometric mean equal to 71,400 μg/cigarette and geometric standard deviation equal to 1.3. This distribution was developed by Traynor et al. (1989) based on data from six studies published between 1982 and 1988. The distribution appears to be generally consistent with other research in the scientific literature.

The 5th and 95th percentiles of the Traynor distribution cited above are 46,400 and 109,900 μg/cigarette. This range is generally consistent with the range of estimates reported in most studies cited in the Criteria Document (EPA, 2000). Values selected for $CO_{cigarette}$ from the Traynor distribution were not permitted to fall outside these bounds.

4.6.2 Residential Locations

Version 2.1 of pNEM/CO treats CO from ETS in the residence as an incremental addition to the CO concentration obtained from the one-hour mass-balance model. The incremental CO concentration is determined through the use of a one-minute mass-balance model that accounts for air exchange rate, residential volume, and CO emission rate. This mass-balance model determines the average CO concentration for each minute of the event. These average one-minute CO values are then averaged over the duration of the event to determine the incremental CO concentration from ETS for the event.

As previously discussed in Subsection 4.1, the instantaneous indoor CO concentration at the end of minute m can be calculated as

$$C_{in}(m) = k_1 C_{in}(m - 1) + k_2 CAVG_{out}(m) + k_3 \qquad (4\text{-}27)$$

where

$$k_1 = e^{-\nu} \qquad (4\text{-}28)$$

$$k_2 = 1 - e^{-\nu} \qquad (4\text{-}29)$$

$$k_3 = (S)(1 - e^{-\nu})/(\nu V) \qquad (4\text{-}30)$$

The average indoor CO concentration for minute m can be calculated as

$$CAVG_{in}(m) = a_1 C_{in}(m - 1) + a_2 CAVG_{out}(m) + a_3 \qquad (4\text{-}31)$$

$C_{in}(m - 1)$ is the instantaneous indoor concentration at the end of the preceding minute and $CAVG_{out}(m)$ is the average outdoor concentration during minute m. The other variables appearing in Equation 4-31 are defined by the following equations:

$$a_1 = z(m) \tag{4-32}$$

$$a_2 = 1 - z(m) \tag{4-33}$$

$$a_3 = (S)[1 - z(m)]/(\nu V) \tag{4-34}$$

$$z(m) = (1 - e^{-\nu})/\nu \tag{4-35}$$

Equations 4-27 and 4-31 can be used to construct a sequence of minute-average values for the duration of a particular exposure event.

With appropriate simplifications, this model was applied to each continuous sequence of exposure events in the residence in which each event indicated the occurrence of passive smoking. The CO from ETS was assumed to equal zero prior to the beginning of sequence. Thus the term $C_{in}(m - 1)$ in Equation 4-27 was zero for the first minute of the first event in the sequence. As the calculation was limited to the incremental effects of CO emitted within the residence, the outdoor term $CAVG_{out}(m)$ in Equations 4-27 and 4-31 was also set equal to zero. Consequently, Equation 4-27 simplified to

$$C_{in}(m) = k_1 C_{in}(m - 1) + k_3 \tag{4-36}$$

and Equation 4-31 simplified to

$$CAVG_{in}(m) = a_1 C_{in}(m - 1) + a_{3.}. \tag{4-37}$$

To reduce computational time, analysts also assumed that all CO dissipated immediately after the end of the last smoking event in a sequence of smoking events; i.e., there was no residual CO from smoking during non-smoking exposure events.

Consistent with this assumption, the one-minute mass-balance model was not run during non-smoking events. This approach tended to slightly under-estimate the total incremental CO contribution of passive smoking.

The following eight-step procedure was used to model each continuous sequence of smoking events within a residence.

1. The volume of the residence is determined for the cohort by an existing algorithm within pNEM/CO (see Subsection 4.5.1). This volume is held constant for all smoking events associated with the cohort.

2. The air exchange rate for the event is the value assigned to the hour containing the event by an existing algorithm (see Subsection 4.3.2.1) within pNEM/CO.

3. The smoking status of the event is determined by an existing code in the diary data base.

4. If smoking occurs during the event, the CO emission rate for ETS is determined by the algorithm in Table 4-20.   This value is used for all passive smoking events associated with the cohort.

5. Equations 4-36 and 4-37 are used to determine the instantaneous CO concentration for the end of each minute and the average CO concentration for each minute, respectively.

6. The average CO concentration for the event is determined by averaging the minute-average CO concentrations for the event.

7. The inside CO concentration at the beginning of the next event is set equal to the instantaneous CO concentration calculated in Step 5 for the end of the last minute of the first event.

8. Repeat Steps 2 through 7 for each subsequent event in the sequence.

The one-minute CO concentrations determined by this algorithm were averaged by exposure event and added to the CO concentration estimated by the one-hour mass-balance model for the exposure event.

The algorithm for estimating CO emission rate incorporates the assumptions that there is only one smoker present during a passive smoking event, that the smoker consumes two cigarettes per hour, and that the CO emitted per hour per cigarette is characterized by a lognormal distribution with geometric mean = 71,400 μg and geometric standard deviation = 1.3. The assumptions concerning smoking prevalence and smoking rate are based on estimates presented by Repace et al. (1998). These researchers estimated that chain smokers smoke approximately 6 cigarettes per hour and that average smokers smoke approximately 2 cigarettes. Repace et al. (1998) also estimated that roughly 25 percent of Americans smoke tobacco products.

Table 4-20. Algorithm for Estimating CO Emission Rate from Passive Smoking in the Residential Microenvironment.

1. If smoking status algorithm indicates that smoking occurs during exposure event, go to Step 2. Otherwise, CO emission rate from tobacco products is set at zero for exposure event.

2. Assume there is one smoker in residence (n_{smoker} = 1).

3. Assume that the smoker consumes two cigarettes per hour ($n_{cigs/smoker/hr}$ = 2).

4. Determine CO emitted per hour from each cigarette by randomly selecting a value from a lognormal distribution with geometric mean = 71,400 μg and geometric standard deviation = 1.3.

5. The hour emission rate (μg/hr) is calculated by the equation

$$S_{hr} = (n_{smokers})(n_{cigs/smoker/hr})(CO_{cigarette}).$$

6. Convert S_{hr} value obtained in Step 5 to minute emission rate (μg/min) by the equation

$$S_{min} = (S_{hr})/60.$$

4.6.3 Restaurants and Bars

The hour mass-balance model (Equation 4-7) was used estimate CO concentrations in restaurants and bars in both study areas. As discussed in Subsection 4.2.2, ETS was considered to be the only potential indoor source of CO in these microenvironments. Consequently, the a_3 term in Equation 4-7 was used solely to account for the effect of passive smoking. Because smoking is prohibited in Los Angeles bars and restaurants, a_3 was set to zero when pNEM/CO was applied to Los

Angeles. Passive smoking was assumed to occur continuously in Denver bars and restaurants, however, as local regulations permit smoking in these locations. In Denver applications, pNEM/CO calculated a_3 using an alternative to Equation 4-10 which better utilized existing databases.   This subsection describes the derivation of this alternaitve equation. The approach is similar to one employed by the California Air Resources Board in estimating pollution increments from ETS in public buildings (Miller et al., 1998).

The complete hour mass-balance model is described in Subsection 4.1. Equation 4-7 provides estimates of the average indoor pollutant concentration of hour h. The CO contribution of indoor sources such as ETS is represented by an emission rate variable (S) which appears in the a_3 term (see Equation 4-10). In estimating the CO levels in bars and restaurants, analysts assumed that cigarette smoke was the only potential source of CO and estimated the emission rate from passive smoking by the expression

$$S_{hr} = (n_{smokers})(n_{cigs/smoker/hr})(CO_{cigarette}). \tag{4-38}$$

in which $n_{smokers}$ is the number of smokers present, $n_{cigs/smoker/hr}$ is the average number of cigarettes smoked per hour by each smoker, and $CO_{cigarette}$ is the average CO emission rate of the smoked cigarettes.

Ordinarily, the a_3 term would be calculated as

$$a_3 = (S)[1 - z(h)]/(\nu V) \tag{4-39}$$

in which

$$z(h) = (1 - e^{-\nu})/\nu \tag{4-40}$$

and S is determined by Equation 4-38. This approach requires estimates for both the number of smokers ($n_{smokers}$) and the volume of the facility (V). Analysts were not able to identify reliable data for estimating these parameters specific to bars and restaurants.

Following the example of Miller et al. (1998), analysts implemented an alternative approach in which both the numerator and denominator of the a_3 term were divided by the number of occupants of the facility. Thus, the S term in the numerator of the a_3 term was calculated as

$$S_{hr} = (Fr)(n_{cigs/smoker/hr})(CO_{cigarette}), \tag{4-41}$$

in which Fr is the fraction of occupants who are smokers. The Fr parameter was estimated according to existing data on the prevalence rate of smokers in study area (Denver or Los Angeles). In the denominator of the a_3 term, the product of the variables ν and V (m^3/hr) was replaced by the normalized ventilation rate (m^3/hr/occupant), hereafter denoted by NVR. NVR can be estimated from local building codes which specify average ventilation rate per occupant according to business type. With these substitutions, the a_3 term can be expressed as

$$a_3 = (Fr)(n_{cigs/smoker/hr})(CO_{cigarette})[1 - z(h)]/(NVR). \tag{4-42}$$

Consistent with this approach, the k_3 term in Equation 4-12 would be expressed as

$$k_3 = (Fr)(n_{cigs/smoker/hr})(CO_{cigarette})(1 - e^{-\nu})/(NVR). \tag{4-43}$$

Los Angeles does not permit smoking in restaurants and bars. Consequently, a_3 is set equal to zero for Los Angeles. Denver, which permits smoking in restaurants and bars, requires that these businesses meet the following 1989 ASHRAE ventilation standards.

Restaurant:	20 cfm/person (34 m^3/hour/person)
Bar:	30 cfm/person (51 m^3/hour/person)

Analysts considered two methods for using this information. In Method A, analysts would use 34 and 51 m^3/hour/person as point estimates for NVR when applying the special mass-balance model to Microenvironent No. 4 (restaurants) and No. 5 (bars), respectively. In Method B, analysts would treat these values as the geometric means of lognormal distributions. Each distribution would have a geometric mean of 1.81. Values of NVR would be selected from these distributions as required.

In developing Method B, analysts noted that the ASHRAE standard for restaurants (34 m^3/hr/person) was consistent with the geometric mean derived by CARB from the Persily (1989) study of 14 office buildings (36.9 m^3/hr/person). The geometric standard deviation for this data set was 1.81. In Method B, analysts assumed that restaurants had a lower geometric mean (34 m^3/hr/person) but the same geometric standard deviation (1.81). Similarly, bars were assumed to have a higher geometric mean (51 m^3/hr/person) but the same geometric standard deviation.

Consistent with EPA's goal of using probabilistic elements to represent the majority of parameters affecting exposure, analysts selected the distributional alternative (Method B) for the pNEM/CO analyses described in this report.

The CDC's Morbidity and Mortality Weekly Report of November 6, 1998 (Vol. 47, No. 43) indicates that the 1997 adult smoking prevalence rate for Colorado was 22.6 percent. Based on this value, analysts set Fr equal to 0.226 for Denver restaurants and bars.

To maintain consistency between the NVR value in the a_3 and k_3 terms and the air exchange rate (ν) used elsewhere in hour mass-balance algorithm (i.e., the NVR should be relatively high when the air exchange rate is relatively high), the same distribution percentile was used in determining both values. For example, the 30th percentile of the NVR distribution was used when the 30th percentile of the air exchange rate distribution was selected. Table 4-21 presents the algorithm used to estimate the modified variables for the a_3 and k_3 terms of the hourly mass-balance algorithm for bars and restaurants in Denver.

4.6.4 Passenger Vehicles

The one-minute mass-balance model was used to estimate the combined minute-by-minute contribution of outdoor CO and in-vehicle ETS to CO levels in Microenvironments Nos. 12 (automobiles) and 13 (trucks). The model was implemented according to the 14-step procedure presented in Table 4-2. The equation in Step 2 of the algorithm provided an estimate of the CO emission rate from passive smoking in the vehicle. The equation assumes that the vehicle was occupied by only one smoker during each passive smoking event, the smoker consumed two cigarettes per hour on average, and the CO emission rate could be characterized by a lognormal distribution with geometric mean = 71,400 μg/hr and geometric standard deviation = 1.3.

Table 4-21. Algorithm for Estimating CO Emission Rate from Passive Smoking in Restaurants and Bars (Method B in Text).

1. Assume the fraction of people in the bar/restaurant at any time is the same as the adult prevalence rate of smoking in Colorado for the year of simulation (Fr = 0.226).

2. Assume that each smoker consumes two cigarettes per hour ($n_{cigs/smoker/hr}$ = 2).

3. Determine the CO emitted per hour from each cigarette by randomly selecting a value from a lognormal distribution with mean = 71,400 μg and geometric standard deviation = 1.3. Note percentile (P) of selected value.

4. The hour emission rate per occupant (μg/hr/occupant) is calculated by the equation

$$S_{hr} = (Fr)\,(n_{cigs/smoker/hr})(CO_{cigarette}).$$

5. Determine the hour normalized ventilation rate (m^3/hr/occupant) as the value corresponding to percentile = P of a lognormal distribution with geometric standard deviation = 1.81 and geometric mean indicated below. P is the value previously determined in Step 3.

   Restaurant: 34 m^3/hr/person

   Bar: 51 m^3/hr/person

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SECTION 5
ESTIMATION OF ALVEOLAR VENTILATION RATE

As discussed in Subsection 2.4.3, pNEM/CO includes an algorithm which estimates carboxyhemoglobin (COHb) levels in the blood as a function of alveolar ventilation rate, the CO concentration of the respired air, and various physiological variables such as blood volume and pulmonary CO diffusion rate. Version 2.1 of pNEM/CO estimates alveolar ventilation rate as a function of oxygen uptake rate, which in turn is estimated as a function of energy expenditure rate. This section provides a brief summary of the algorithm used to estimate alveolar ventilation rate together with the distributions and estimating equations used in determining the value of each parameter in the algorithm. The section also discusses the rationale behind the decision not to explicitly account for the potential effects of angina in the algorithm. The section begins with a brief discussion of the physiological principles incorporated into the new algorithm.

5.1 The Metabolic Equivalence Concept

McCurdy (2000) has recommended that measures of human ventilation (respiration) rate be estimated as functions of energy expenditure rate. The energy expended by an individual during a particular activity can be expressed as

$$EE = (MET)(RMR) \tag{5-1}$$

in which EE is the average energy expenditure rate (kcal min^{-1}) during the activity and RMR is the resting metabolic rate of the individual expressed in terms of number of energy units expended per unit of time (kcal min^{-1}). MET (the “metabolic equivalent of work”) is a ratio specific to the activity and is dimensionless. If RMR is specified for an individual, then Equation 5-1 requires only an activity-specific estimate of MET to produce an estimate of the energy expenditure rate for a given activity. EPA has recently developed the Consolidated Human Activity Database (CHAD) which contains 24-hour sequences of activity-specific values of MET indexed by gender, age, and other useful descriptors. As discussed below, equations for estimating RMR as a function of body mass (BM) can be obtained from the literature for the demographic groups of interest to a particular exposure assessment.

The MET concept provides a means for estimating the alveolar ventilation rate associated with each activity. For convenience, let $EE_a(i,j,k)$ indicate the energy expenditure rate associated with the i-th activity of day j for person k. Equation 5-1 can now be expressed as

$$EE_a(i,j,k) = [MET(i,j,k)][RMR(k)] \tag{5-2}$$

in which RMR(k) is the average value for resting metabolic rate specific to person k. Note that MET(i,j,k) is specific to a particular activity performed by person k.

5.2 Oxygen Requirements for Energy Expenditure

Energy expenditure requires oxygen which is supplied by ventilation (respiration). Let ECF(k) indicate an energy conversion factor defined as the volume of oxygen required to produce one kilocalorie of energy in person k. The oxygen uptake rate (VO_2) associated with a particular activity can be expressed as

$$VO_2(i,j,k) = [ECF(k)][EE_a(i,j,k)], \tag{5-3}$$

in which $VO_2(i,j,k)$ has units of liters oxygen min^{-1}, ECF(k) has units of liters oxygen $kcal^{-1}$, and EE(i,j,k) has units of kcal min^{-1}. The value of $VO_2(i,j,k)$ can now be determined from MET(i,j,k) by substituting Equation 5-2 into Equation 5-3 to produce the relationship

$$VO_2(i,j,k) = [ECF(k)][MET(i,j,k)][RMR(k)]. \tag{5-4}$$

The analyst must provide values of ECF(k) and RMR(k) for person k.   Methods for estimating these values are provided in Section 5.4.

5.3 Estimating Alveolar Ventilation Rate from Oxygen Uptake Rate

Alveolar ventilation (V_A) represents the portion of the minute ventilation that is involved in gaseous exchange with the blood. VO_2 is the oxygen uptake that occurs during this exchange. The absolute value of V_A is known to be affected by total lung volume, lung dead space, and respiration frequency -- parameters which vary according to person and/or exercise rate. However, it is reasonable to assume that the ratio of V_A to VO_2 is relatively constant regardless of a person's physiological characteristics or energy expenditure rate. Consistent with this assumption, Version 2.1 of pNEM/CO converted each estimate of VO_2(i,j,k) to an estimate of V_A(i,j,k) by the proportional relationship

$$V_A(i,j,k) = (19.63)[VO_2(i,j,k)] \tag{5-5}$$

in which both V_A and VO_2 are expressed in units of liters min^{-1}.   This relationship was obtained from an article by Joumard et al. (1981), who based it on research by Galetti (1959). Equation 5-5 was applied to all cohorts under all energy expenditure rates.

The V_A algorithm included a method for identifying "impossible" values which were occasionally generated by the estimation process. This method determined a maximum VO_2 value for each exposure event which accounted for the duration of the activity and for the age, weight, and gender of the person. No estimate of VO_2 (and the corresponding estimate of V_A) was permitted to exceed this limit.   Subsection 5.4 provides a more detailed description of this procedure.

In summary, Equation 5-4 was used to convert event-specific values of MET to corresponding values of VO_2. Equation 5-5 was then used to convert the VO_2 value to a value of V_A. Section 5.4 describes two tests for reasonableness that were performed on the VO_2 estimates prior to converting them to V_A values. Section 5.5 presents a step-by-step description of the algorithm that was used to probabilistically determine the various parameter values required by Equations 5-4 and 5-5.

5.4 Tests to Identify Unrealistic Values of Oxygen Uptake Rate

A person's maximum alveolar ventilation rate is determined by his or her maximum oxygen uptake rate (VO_{2max}) and the V_A/VO_2 ratio in effect under maximum oxygen uptake conditions. As work increases, energy is provided primarily by aerobic (oxygen-based) processes up to the point of VO_{2max}, referred to as the point of maximal aerobic power (MAP). The additional energy required for higher work rates is provided primarily by anaerobic processes. Consequently, the work rate where VO_{2max} is reached is less than a person's maximum work rate.

Astrand and Rodahl (1977) state that most individuals cannot maintain a work rate equal to 100 percent of MAP (i.e., a work rate where VO_2 equals VO_{2max}) for more than about five minutes. As the duration of work increases, there is a progressive decrease in the <u>average</u> VO_2 level that can be maintained. Astrand and Rodahl also state that a VO_2 level equal to 50 percent of VO_{2max} cannot be maintained for a whole working day.

Erb (1981) has developed estimates of the percentage of "maximum work capacity" that can be maintained by young and middle-aged adults for durations of one to nine hours (Table 5-1). These values -- which apply to normally active, non-trained adults -- appear to be functionally equivalent to the percentage of VO_{2max} (designated $PCTVO_{2max}$) that can be maintained for the indicated time period and are so labeled in Table 5-1. According to Erb, a person can maintain 64 percent of VO_{2max} for one hour and 33 percent of VO_{2max} for nine hours without straining.

The following expression provides a close fit to values Erb proposed for durations of one to nine hours:

$$PCTVO_{2max}(t) = 121.2 - (14.0)[\ln(t)]. \tag{5-6}$$

Note that t is duration in minutes and ln indicates the natural (base e) logarithm. Equation 5-6 provides an estimate of approximately 100 percent for t = 5 minutes, consistent with the statement by Astrand and Rodahl that 100 percent of VO_{2max} can be maintained for up to 5 minutes. These findings suggest that it is reasonable to assume that (1) $PCTVO_{2max}$ should not exceed 100 percent for events with durations between 0 and 5 minutes, (2) Equation 5-6 can be used to determine the upper limit of $PCTVO_{2max}$ for events of durations between 5 minutes and 540 minutes (9 hours), and (3) the $PCTVO_{2max}$ values in Table 5-1 can be used as upper limits for VO_2 averaged over multi-hour periods from one to nine hours in duration. A conservative assumption (i.e., one which may permit unrealistically high VO_2 values) is that the value for nine hours (33 percent) applies to longer time periods.

Table 5-1.   Values of the Upper Limit of $PCTVO_{2max}$ for Specified Averaging Times.

Averaging time (hours)	Upper limit of $PCTVO_{2max}$, percent
1	64
2	54
3	48
4	44
5	41
6	39
7	37
8	35
9	33
10 to 24	33[a]

[a]Conservative estimate based on nine-hour value proposed by Erb (1981). All other values in this column are identical to values proposed by Erb (1981).

The concepts discussed above were the basis of two tests applied to VO_2 estimates produced by Version 2.1 of pNEM/CO. The first test was applied to VO_2 values associated with individual exposure events. The second test was applied to running-average values of VO_2 with durations of 1 to 24 hours.

The first test was based on the assumption that the $PCTVO_{2max}$ value associated with an individual (event -specific) VO_2 value could not exceed an upper limit calculated by Equation 5-6. This test was carried out by comparing each event-specific VO_2 value generated for a cohort with a permitted upper limit (PUL) value obtained from the following equation.

$$\text{Permitted upper limit of } VO_2 = (\text{Upper limit of } PCTVO_{2max})(VO_{2max})/100. \qquad (5\text{-}7)$$

When the event duration ranged between 5 minutes and nine hours, the value for the upper limit of $PCTVO_{2max}$ in Equation 5-7 was obtained from Equation 5-6 using the value of VO_{2max} assigned to the cohort by the physiological profile generator. Outside this range, $PCTVO_{2max}$ was assumed to equal 100 percent for durations less than 5 minutes and to equal 33 percent for durations greater than nine hours. If the VO_2 value exceeded the PUL determined by Equation 5-7, the VO_2 value was set equal to the calcuated PUL. Otherwise, the value of VO_2 was not affected by Test 1.

The second test assumed that "running-average" VO_2 values (expressed as a percentage of the VO_{2max} value) could not exceed the values specified by Erb in Table 5-1. This test was implemented by first averaging the event-specific VO_2 values generated for a cohort by clock hour to produce 24 one-hour VO_2 values. Running-average VO_2 values for all possible sequential periods of 1 to 24 hours in duration were then calculated from these one-hour values. Each running-average VO_2 value was used to calculate the value

$$\text{Test Ratio} = (\text{running average } VO_2)/(\text{permitted upper limit of } VO_2) \qquad (5\text{-}8)$$

in which the "permitted upper limit" (PUL) is a value specific to the indicated averaging time. If any test ratio exceeded 1.0, then all event-specific VO_2 values for the person-day were proportionally reduced so that the largest test ratio equaled exactly 1.0.

Equation 5-7 was used to determine PULs for running-average VO_2 values. In this application, the upper limit of $PCTVO_{2max}$ was obtained from Table 5-1 according to the period of the running average.

The value for VO_{2max} required by the two tests was determined by the physiological profile generator using the equation

$$VO_{2max} = (NVO_{2max})(BM), \qquad (5\text{-}9)$$

in which BM was body mass in kg and NVO_{2max} was maximum oxygen uptake rate per kg of body mass. As discussed in the next section, values of NVO_{2max} and BM were randomly sampled from distributions specific to the age and gender of the cohort.

5.5 The Probabilistic Algorithm

Table 5-2 presents a probabilistic algorithm for estimating alveolar ventilation rate which incorporates the physiological principles discussed above. This algorithm was programmed into Version 2.1 of pNEM/CO. Table 5-3 lists the parameters appearing in the algorithm and indicates the functional form and source of data for each parameter.

To run the model, the algorithm requires distributions for BM, NVO_{2max}, and ECF specific to age and gender. Table 5-3 lists distributions for BM by gender for adults 18 to 74 years of age based on articles by Brainard and Burmaster (1992). Table 5-4 lists distributions for NVO_{2max} obtained through a review of the literature. Table 5-5 lists distributions of ECF based on data provided by Esmail, Bhambhani, and Brintnell (1995). Analysts reviewed these data and selected the most appropriate distribution for each parameter for each combination of gender and age (0 < age < 100 years). These distributions (listed in Appendix C) were incorporated into the ventilation rate algorithm.

The ventilation rate algorithm also requires an equation for estimating RMR for each combination of age and gender. Analysts reviewed a list of equations previously compiled by McCurdy (1998) and determined that a set of equations developed by Schofield (1985) provided good coverage of all age and gender combinations. These equations were determined through regression analyses and have the functional form

$$RMR = a + (b)(BM) + e, \qquad (5\text{-}10)$$

in which e is assumed to be normally distributed with mean = zero and standard deviation = σ_e. Table 5-6 lists Schofield's values of a, b, and σ_e for 12 age/gender combinations. These values are the basis of the RMR equations listed in the Appendix C which have been incorporated into the ventilation rate algorithm.

Table 5-2. Algorithm Used in Version 2.1 of pNEM/CO to Estimate Alveolar Ventilation Rates as a Function of Energy Expenditure Rate.

1. Go to first/next cohort. Cohort = k.

2. Obtain age, gender, and height of cohort k from physiological profile generator.

3. Obtain appropriate values of $NVO_{2max}(k)$, BM(k), and ECF(k) for Cohort k by randomly selecting values from appropriate distributions according to age and gender determined in Step 2.

4. Substitute BM(k) value in appropriate equation to determine RMR(k).

5. Calculate

$$VO_{2max}(k) = [NVO_{2max}(k)][BM(k)].$$

6. Go to first/next day. Day = j.

7. Go to first/next exposure event. Event = i. Note activity classification of exposure event. Select MET value from distribution assigned to activity classification. This value is denoted MET(i,j,k).

8. Convert the MET(i,j,k) value to a corresponding $VO_2(i,j,k)$ value by Equation 5-4, i.e.,

$$VO_2(i,j,k) = [ECF(k)][MET(i,j,k)][RMR(k)].$$

9. Determine upper limit of $PCTVO_{2max}(i,j,k)$ by Equation 5-6. If duration is less than 5 minutes, upper limit of $PCTVO_{2max}(i,j,k)$ equals 100 percent. If duration is greater than 540 minutes (9 hours), upper limit of $PCTVO_{2max}(i,j,k)$ equals 33 percent.

10. Test 1: Determine the permitted upper limit for VO_2 by Equation 5-7 using the value of $PCTVO_{2max}(i,j,k)$ determined in Step 9. If VO_2 for event exceeds upper limit, set VO_2 equal to the upper limit.

11. If last exposure event of day, go to Step 12. Otherwise, go to Step 7.

12. Test 2: Average event-specific VO_2 values for day by clock hour to produce 24 one-hour VO_2 values. Calculate running-average VO_2 values for all possible sequences of 1 to 24 hours in duration from these one-hour values. Obtain $PCTVO_{2max}$ value for each duration from Table 5-1. Use Equation 5-7 to calculate permitted upper limit of VO_2 for each duration. Use Equation 5-8 to determine test ratio for each running-average VO_2 value. If any test ratio exceeds 1.0, reduce all event-specific VO_2 values proportionally so that largest test ratio of resulting adjusted VO_2 values equals exactly 1.0.

13. Following completion of Test 2 (Step 12), use Equation 5-5 to convert each event-specific VO_2 value of day to a corresponding V_A value.

14. If last day, go to Step 15. Otherwise, go to Step 6.

15. If last cohort, end. Otherwise, go to Step 1.

Table 5-3. Parameters Used in Probabilistic Algorithm for Estimating Alveolar Ventilation Rates in Version 2.1 of pNEM/CO.

Parameter	Abbreviation	Functional Form	Source of Data
Body mass	BM	Lognormal distribution[a] Males (18 - 74): GM = 76.7 kg GSD = 1.19 Females (18 - 74): GM = 64.7 kg GSD = 1.22	Brainard and Burmaster
Energy Conversion Factor	ECF	Uniform distribution Lower limit = 0.20 Upper limit = 0.22	Esmail et al., 1995 (see Table 5-5)
Metabolic Equivalence	MET	Distribution specified in CHAD Database	McCurdy, 1998 (see Appendix A)
Resting metabolic rate	RMR	Regression equations specific to age and gender	Schofield, 1985, as compiled by McCurdy, 1998 (see Table 5-6)
Normalized oxygen uptake rate	NVO_{2max}	Normal distribution	Research summarized in Table 5-4

[a]GM = geometric mean, GSD = geometric standard deviation

Table 5-4. Descriptive Statistics for VO_2 and NVO_2 Measured at Maximal Exertion by Various Researchers.

Population group	n	VO_{2max}, liters/min$_X$			NVO_{2max}, ml/min per kg			Source
		Mean	S.D.	C.V.[a]	Mean	S.D.	C.V.	
Females, 20-29	8	2.23	0.26	0.12	39.9	4.7	0.12	Åstrand (1960)
Females, 30-39	12	2.13	0.28	0.13	37.3	5.2	0.14	
Females, 40-49	8	2.01	0.19	0.09	32.5	2.7	0.08	
Females, 50-65	16	1.85	0.25	0.14	28.4	2.7	0.10	
Females, 20-25	32	2.88	0.24	0.08	48.4	2.8	0.06	
Males, 20-29	4	4.19	NR	NR	52.2	NR	NR	
Males, 30-39	13	3.01	0.54	0.18	39.8	7.3	0.18	
Males, 40-49	9	2.99	0.32	0.11	39.2	5.5	0.14	
Males, 50-59	66	2.54	0.36	0.14	33.1	4.9	0.15	
Males, 60-69	8	2.23	0.29	0.13	31.4	5.3	0.17	
Males, 20-33	29	4.16	0.39	0.09	58.6	4.5	0.08	
Males, 21-27	13	3.91	0.52	0.13	54.5	7.61	0.14	Katch and Park (1975)
Males and Females, 20-29	80	3.09	0.83	0.27	45.3	7.54	0.17	Heil et. al. (1995)
Males and Females, 30-39	81	3.19	0.86	0.27	43.8	8.15	0.19	
Males and Females, 40-49	79	3.13	0.92	0.29	42.9	9.04	0.21	Heil et al. (1995)
Males and Females, 50-59	78	2.84	0.91	0.32	36.8	8.93	0.24	
Males and Females, 60-69	74	2.31	0.72	0.31	30.7	7.98	0.26	
Males and Females, 70-79	47	1.91	0.56	0.29	27.2	5.67	0.21	
Males, 20-79	210	3.54	0.71	0.20	44.0	9.42	0.21	
Females, 20-79	229	2.14	0.51	0.24	33.8	8.65	0.26	
Males, 18-72	15	NR	NR	NR	45.7	16.7	0.37	Merrier et al. (1993)
Females, 21-72	16	NR	NR	NR	32.2	8.9	0.28	
Male, 23-33	20	NR	NR	NR	48.3	4.9	0.10	Rowland et. al. (1987)

[a]C.V. = (std. dev.)/(mean), dimensionless.

Table 5-5. Estimates of the Energy Conversion Factor (ECF) Based on Data in Esmail, Bhambhani, and Brintnell (1995).

Group	Number of subjects	Test	Mean VO_2, liters min^{-1}	Mean GEC[a], kcal min^{-1}	Ratio of means[b]
Women	20	wheel-turn	0.81	4.1	0.198
		push-pull	0.80	4.0	0.200
		overhead-reach	0.87	4.4	0.198
Men	Not reported	wheel-turn	1.13	5.7	0.198
		push-pull	1.16	5.6	0.207
		overhead-reach	1.13	5.7	0.198

[a]GEC: gross energy cost.
[b]Data were not available for calculating the mean of subject-specific ratios.

Table 5-6. Regression Equations for Predicting Basal Metabolic Rate in Adults Provided by Schofield (1985) as Compiled by McCurdy (1998).

Gender	Age, years	Regression coefficients[a]		
		a	b	σ_e
Female	18 - 29.9	2.036	0.062	0.50
Female	30 - 59.9	3.538	0.034	0.47
Female	≥ 60	2.755	0.038	0.45
Male	18 - 29.9	2.896	0.063	0.64
Male	30 - 59.9	3.653	0.048	0.70
Male	≥ 60	2.459	0.049	0.69

[a]Regression equation: BMR(MJ/day) = a + (b)(BM) + e, σ_e = standard deviation of e.
Basal metabolic rate (BMR) is assumed to be equivalent to resting metabolic rate (RMR).

5.6 Effect of Cardiovascular Disease on Exertion Levels

As discussed in Section 2.5.2, analysts assumed the exercise patterns of people with IHD were similar to those of the general population. To determine the validity of this assumption, Cohen, Nikiforov, and Rosenbaum (1999) analyzed activity/exertion data from the National Human Activity Pattern Survey (NHAPS) representing subjects with and without heart disease. Subjects were classified as having heart disease if they reported that a doctor had told them they had angina. The NHAPS database provided a 24-hour sequence of activities for each subject as reported in a recall-style diary (Robinson and Blair, 1995). A Monte Carlo algorithm based on the METS principle described in Section 5.1 was applied 100 times to each 24-hour sequence. In each application (iteration), the algorithm generated an energy expenditure rate (EE) in kcal min^{-1} for each activity in the sequence. The resulting distributions of EE values were statistically analyzed to determine whether they differed according to the health status of the associated NHAPS subjects. Researchers also analyzed differences in time spent in outdoor and in-vehicle microenvironments.

Cohen, Nikiforov, and Rosenbaum (1999) provide detailed results for the following activity/exertion indicators: average and 95th percentile of the maximum daily 8-hour EE value; percentage of time spent outdoors or in a vehicle; average percentage of time at light, moderate, and heavy exertion; and occurrence of moderate or high EE values. Tables 5-9 and 5-10 are illustrative of the general results of the analysis. The tables provide means and standard deviations for each indicator stratified by gender and age. The T test is used to test for differences in means; the F test for differences in standard deviations. The non-parametric Wilcoxon test is used to compare the central tendencies of the angina and non-angina distributions without the normality assumption required by the T test. The Kolmogorov-Smirnov test compares the overall distributions of each group.

Although the results in Tables 5-7 and 5-8 suggest that mean values for the various indicators tend to be lower for angina subjects in each age and gender group than for corresponding non-angina subjects, there are exceptions to this pattern. For example, the tables show that angina subjects tend to have lower mean values for the average maximum 8-hour exertion than the non-angina subjects. However, the mean is

Table 5-7. Results of Statistical Tests Performed on CHAD Data Evaluating the Association Between Angina and Various Variables Representing Physical Exertion and Time Spent in Selected Microenvironments (Data for Males Only).

Variable	Age group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test p-value	Kolmogorov-Smirnov Test p-value
		Mean		p-value	Standard deviation		p-value		
		Angina	Non-angina		Angina	Non-angina			
Average maximum 8 hr exertion (Mcal)	0 - 54	1.85	1.59	0.00	0.49	0.55	0.34	0.02	0.02
	55 - 64	1.48	1.77	0.00	0.48	0.48	0.86	0.01	0.02
	65 - 74	1.39	1.49	0.36	0.47	0.48	0.96	0.41	0.82
	75+	1.27	1.20	0.52	0.44	0.42	0.65	0.51	0.95
95^{th} percentile of maximum 8 hr exertion (Mcal)	0 - 54	2.94	2.68	0.17	1.06	1.30	0.13	0.22	0.06
	55 - 64	2.40	2.90	0.04	1.21	1.14	0.61	0.02	0.03
	65 - 74	1.91	2.17	0.14	0.78	0.94	0.31	0.26	0.63
	75+	1.73	1.67	0.71	0.69	0.76	0.68	0.55	0.88
Percentage of time spent outdoors	0 - 54	16.9	8.9	0.02	19.2	13.8	0.00	0.01	0.01
	55 - 64	9.3	10.0	0.79	14.3	13.9	0.78	0.65	1.00
	65 - 74	6.4	10.4	0.13	11.4	14.3	0.20	0.12	0.13
	75+	8.2	7.1	0.72	12.6	10.1	0.16	0.58	0.66
Percentage of time spent in vehicle	0 - 54	6.0	6.1	0.92	7.6	8.1	0.63	0.89	0.52
	55 - 64	4.0	6.9	0.00	3.8	9.6	0.00	0.18	0.19

Variable	Age group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test p-value	Kolmogorov-Smirnov Test p-value
		Mean		p-value	Standard deviation		p-value		
		Angina	Non-angina		Angina	Non-angina			
Percentage of time spent in vehicle (cont.)	65 - 74	7.2	5.9	0.51	9.0	7.8	0.29	0.82	0.93
	75+	2.3	3.3	0.14	2.5	3.9	0.05	0.44	0.54
Percentage of time spent outdoors or in vehicle	0 - 54	22.8	14.9	0.02	19.3	15.5	0.05	0.02	0.02
	55 - 64	13.3	16.9	0.24	15.3	16.2	0.76	0.17	0.22
	65 - 74	13.6	16.3	0.45	15.9	15.9	1.00	0.19	0.29
	75+	10.5	10.4	0.98	12.9	10.4	0.19	0.69	0.41
Average percentage of time with exertion above 2.39 kcal/min = 0.010MJ/min (light)	0 - 54	34.8	27.8	0.00	13.3	15.2	0.34	0.02	0.05
	55 - 64	24.6	30.1	0.06	14.5	12.0	0.14	0.06	0.14
	65 - 74	21.9	23.3	0.63	13.2	12.5	0.64	0.67	0.84
	75+	18.2	15.9	0.41	11.1	10.4	0.63	0.39	0.74
Average percentage of time with exertion above 5.97 kcal/min = 0.025MJ/min (moderate)	0 - 54	6.6	4.5	0.05	6.4	4.3	0.00	0.02	0.01
	55 - 64	3.4	5.4	0.01	3.6	4.4	0.17	0.01	0.01
	65 - 74	2.3	3.3	0.08	2.5	3.5	0.06	0.20	0.40
	75+	2.0	1.6	0.53	2.4	2.4	0.92	0.43	0.59

Variable	Age group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test p-value	Kolmogorov-Smirnov Test p-value
		Mean		p-value	Standard deviation		p-value		
		Angina	Non-angina		Angina	Non-angina			
Average percentage of time with exertion above 9.55 kcal/min = 0.040MJ/min (heavy)	0 - 54	0.66	0.74	0.59	0.79	0.99	0.11	0.55	0.15
	55 - 64	0.57	0.85	0.19	1.07	1.22	0.40	0.05	0.17
	65 - 74	0.16	0.39	0.01	0.36	0.72	0.00	0.06	0.04
	75+	0.13	0.16	0.79	0.33	0.51	0.05	0.55	0.96

Table 5-8. Results of Statistical Tests Performed on CHAD Data Evaluating the Association Between Angina and Various Variables Representing Physical Exertion and Time Spent in Selected Microenvironments (Data for Females Only).

Variable	Age group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test p-value	Kolmogorov-Smirnov Test p-value
		Mean		p-value	Standard deviation		p-value		
		Angina	Non-angina		Angina	Non-angina			
Average maximum 8 hr exertion (Mcal)	0 - 54	1.30	1.27	0.69	0.31	0.38	0.34	0.72	0.73
	55 - 64	1.21	1.27	0.33	0.32	0.33	1.00	0.56	0.22
	65 - 74	1.05	1.10	0.29	0.30	0.31	0.94	0.31	0.44
	75+	0.96	0.98	0.63	0.33	0.30	0.34	0.44	0.66
95^{th} percentile of maximum 8 hr exertion (Mcal)	0 - 54	1.98	2.01	0.86	0.82	0.91	0.69	0.99	0.86
	55 - 64	1.79	1.92	0.41	0.80	0.77	0.68	0.33	0.28
	65 - 74	1.42	1.51	0.26	0.53	0.57	0.57	0.31	0.62
	75+	1.27	1.31	0.59	0.56	0.52	0.43	0.43	0.47
Percentage of time spent outdoors	0 - 54	3.6	5.1	0.42	7.3	9.6	0.20	0.43	0.91
	55 - 64	4.3	4.6	0.88	9.5	8.2	0.23	0.23	0.63
	65 - 74	2.8	4.1	0.14	5.5	7.3	0.02	0.49	0.53
	75+	3.8	2.3	0.40	12.0	4.6	0.00	0.76	1.00
Percentage of time spent in vehicle	0 - 54	4.5	5.4	0.55	5.5	6.0	0.72	0.40	0.35
	55 - 64	4.2	5.6	0.35	7.5	7.2	0.71	0.06	0.12

Variable	Age group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test p-value	Kolmogorov-Smirnov Test p-value
		Mean		p-value	Standard deviation		p-value		
		Angina	Non-angina		Angina	Non-angina			
Percentage of time spent in vehicle (cont.)	65 - 74	5.3	4.2	0.23	5.9	6.2	0.77	0.15	0.19
	75+	2.8	2.9	0.86	4.4	4.3	0.91	0.72	0.96
Percentage of time spent outdoors or in vehicle	0 - 54	8.2	10.5	0.36	9.9	11.3	0.57	0.18	0.27
	55 - 64	8.5	10.2	0.48	12.2	10.4	0.22	0.04	0.05
	65 - 74	8.1	8.3	0.88	8.2	9.4	0.26	0.99	0.86
	75+	6.6	5.2	0.45	12.4	6.3	0.00	0.77	0.97
Average percentage of time with exertion above 2.39 kcal/min = 0.010MJ/min (light)	0 - 54	23.5	21.4	0.49	12.3	12.2	0.86	0.41	0.69
	55 - 64	19.0	21.0	0.33	10.3	10.5	1.00	0.51	0.54
	65 - 74	14.0	15.5	0.26	8.5	9.5	0.31	0.43	0.76
	75+	11.3	11.8	0.73	9.8	8.6	0.24	0.51	0.89
Average percentage of time with exertion above 5.97 kcal/min = 0.025MJ/min (moderate)	0 - 54	1.44	1.59	0.71	1.66	1.97	0.44	0.73	0.74
	55 - 64	0.79	1.31	0.05	1.27	2.07	0.00	0.04	0.06
	65 - 74	0.65	0.68	0.87	1.35	1.56	0.22	0.51	0.88
	75+	0.75	0.43	0.23	1.73	1.31	0.01	0.84	0.67

Variable	Age group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test p-value	Kolmogorov-Smirnov Test p-value
		Mean		p-value	Standard deviation		p-value		
		Angina	Non-angina		Angina	Non-angina			
Average percentage of time with exertion above 9.55 kcal/min = 0.040MJ/min (heavy)	0 - 54	0.10	0.18	0.06	0.17	0.32	0.00	0.63	0.80
	55 - 64	0.10	0.09	0.96	0.28	0.20	0.01	0.67	1.00
	65 - 74	0.03	0.03	0.89	0.08	0.11	0.00	0.85	0.99
	75+	0.03	0.02	0.44	0.08	0.08	0.90	0.28	0.83

actually higher for angina subjects aged 0 - 54 years of either gender and for males 75 years or older. The mean average maximum 8-hour exertions are consistently higher for males of all age groups, with or without angina, compared to females. Similar patterns are found for the 95^{th} percentile of the maximum 8-hour exertion.

The comparisons of the percentages of time spent outdoors or in a vehicle also vary across age and gender subgroups. The largest, and most surprising, angina vs. non-angina difference is for the mean percentage of time spent outdoors by males aged 0 - 54 years: angina subjects have a mean of 17% compared to the mean of 9% for non-angina subjects. However the angina subjects in the 55 - 64 and 65 - 74 age groups of either gender spend less time outdoors, on average, than non-angina subjects.

The comparisons in Tables 5-7 and 5-8 of the mean percentages of time above the light, moderate or high exertion levels show a variety of patterns for different age groups, genders, and exertion levels. Overall, age and gender were found to have very significant effects on the summary statistics under evaluation. As angina patients tend to be much older and tend to include more females than the general population, researchers performed additional analyses in which the results were adjusted for gender and age by stratification (comparing subjects in a given age/gender subgroup), or by fitting a general linear model (with separate terms for age, gender, and angina effects and their interactions). These analyses showed that, overall, angina subjects tended to have less extreme exertion levels. More specifically, the maximum 8-hour exertion energies tended to be lower, as did the percentages of time above moderate or high exertion rate thresholds. The differences between angina and non-angina subjects in percentages of time spent outdoors or in a vehicle were not generally statistically significant.

The large sample of NHAPS subjects produced, in many cases, statistically significant differences in the exertion rate summaries between angina and non-angina subjects. However, those differences were generally numerically small compared to the mean values. EPA has concluded that the differences in activity and exertion between angina and non-angina subjects, although statistically significant, are not large enough to warrant adjusting the pNEM/CO modeling approach to account for an angina/non-angina difference.

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SECTION 6
ESTIMATION OF COMMUTING PATTERNS

In applying the previous (1992) version of pNEM/CO to Denver, analysts used an iterative algorithm described by Johnson, Capel, and Byrne (1991) to develop an “origin-destination” table indicating the pattern of commuting trips made by working cohorts among the defined exposure districts. Version 2.1 of pNEM/CO required similar origin-destination tables for the Denver and Los Angeles study areas. Researchers identified a special commuting database developed by the Bureau of Census (1994) as a promising alternative to the commuting algorithm for creating this table. This section describes the method used to develop origin-destination tables for Denver and Los Angeles using the Bureau of Census (BOC) database.

6.1 The Bureau of Census Commuting Database

Table 6-1 presents the format of the BOC database. The following two data items were used in the analyses which follow.

- WF: weighted count of workers in specified flow.

- WA: weighted count of workers allocated to this tract of work.

WF is the total number of workers estimated by BOC to commute (“flow”) from the indicated residence census tract to the indicated work census tract. Each value of WF is a weighted estimate based on responses to the 1990 census “long form.” The estimate includes both (1) people who explicitly indicated they lived and worked in the indicated census tracts and (2) other people who the BOC allocated to the flow based on supplemental information. WA indicates only the number of people who fall into the second category. As WA increases as a percentage of WF, confidence in the value of WF is reduced.

Table 6-1. Format of Commuting Database Obtained from the Bureau of Census.

Bytes	Data item	Explanation of codes
1 - 2	FIPS state code of place of work	01 - 56 = Alabama - Wyoming 99 = did not work in U.S.
3 - 5	FIPS county code of place of work	000 = did not work in U.S. NNN = county code
6 - 11	Census tract/BNA code of place of work	000000 = did not work in U.S. 000100...999999 = legal tract code range
12 - 14	Census MCD code of place of work	000 = did not work in New England state NNN = MCD code in New England (FIPS State = 09, 23, 25, 33, 44, 50)
15 - 18	Census place code of place of work	0000 = did not work in U.S. 0001...9998 = census place code 9999 = did not work in a place
19	Blank	
20 - 21	FIPS state code of residence	01 - 56 = Alabama - Wyoming 99 = did not work in U.S.
22 - 24	FIPS county code of residence	NNN = county code
25 - 30	Census tract/BNA code of residence	000100...999999 = legal tract code range
31 - 33	Census MCD code of place of residence	000 = did not live in New England state NNN = MCD code in New England (FIPS State = 09, 23, 25, 33, 44, 50)
34 - 37	Census place code of residence	0001...9998 = census place code 9999 = did not live in a place
38	Blank	
39 - 44	Weighted count of workers in this flow, including all place of work allocation (everyone forced into a tract of work)	
45 - 50	Weighted count of workers allocated to this tract of work	
51 - 56	Weighted count of workers allocated to this place of work	
57 - 62	Weighted count of workers allocated to this county or MCD (in 6 New England states) of work	

To develop an origin-destination table for a particular study area, analysts first identify the census tracts included within each exposure district defined within the study area. Next, the flows among the individual census tracts in each district are combined to determine flows among the districts. Each district-to-district flow originating in a particular district is then converted to a fraction of the total workers commuting from the district. These fractions are organized by home and work districts to create the required origin-destination table. Section 6.2 describes the application of this approach to the exposure districts defined for the application of Version 2.1 of pNEM/CO to Denver. Section 6.3 provides a similar description for Los Angeles.

6.2 Denver Commuting Patterns

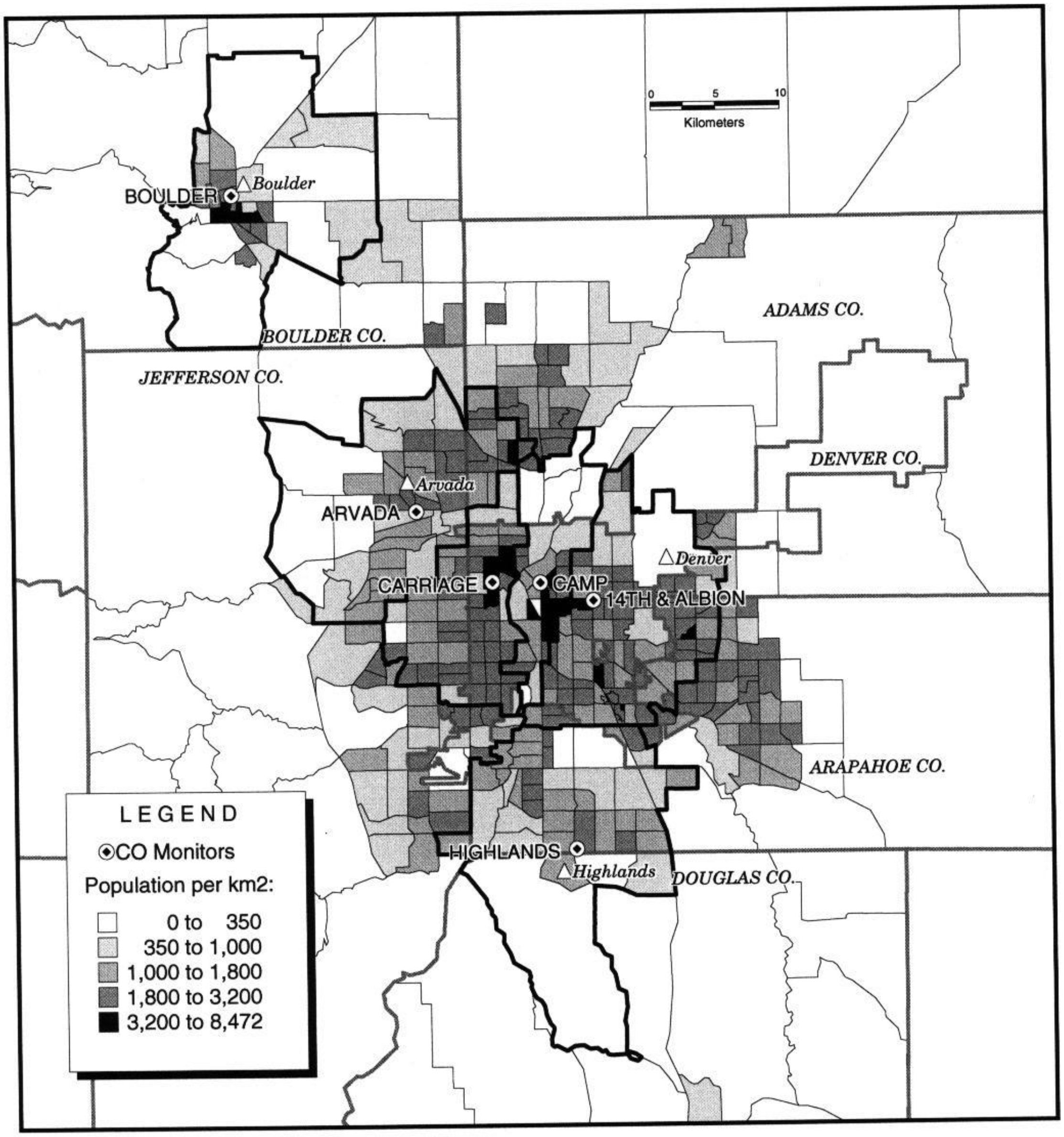
6.2.1 The Denver Exposure Districts

As described in Section 2.1, analysts defined six exposure districts for application of the Version 2.1 of pNEM/CO to the Denver study area. Five of the districts are centered on individual fixed-site CO monitors in the Denver metropolitan area. The sixth district is centered on a point midway between two monitors located in Boulder, CO. Figure 6-1 shows the locations of these seven fixed-site monitors. Table 6-2 identifies the monitor(s) associated with each district.

Each district was defined as a collection of census tracts as delineated by the BOC for the 1990 decennial census. The census tracts were drawn from a comprehensive listing of the census tracts located in the following nine counties:

Adams	Clear Creek	Gilpin
Arapahoe	Denver	Jefferson
Boulder	Douglas	Weld.

In developing the districts, analysts assigned each census tract located within 10 km of one or more district centers to the nearest district. People residing in the remaining census tracts were excluded from the pNEM/CO analysis, based on the assumption



CO Monitors and Population Density in the Denver Study Area

Figure 6-1. Fixed-Site CO Monitoring Sites Used to Define Denver Exposure Districts.

Table 6-2. Exposure Districts Defined for Denver pNEM/CO Analysis.

District no.	Monitor(s) included in district			Number of census tracts assigned to district
	AIRS ID	City	Address	
1	005-0002	Littleton	8100 So. University Blvd. (Highlands)	47
2	031-0002	Denver	2105 Broadway (CAMP)	44
3	031-0013	Denver	14th and Albion St. (NJHE)	116
4	031-0014	Denver	23rd and Julian (Carriage)	61
5	059-0002	Arvada	W. 57th Ave. and Garrison	55
6	013-0010 013-1001	Boulder	2150 28th Street 2320 Marine Street	28
19	Remaining census tracts in nine county region			242

that pNEM/CO could not accurately estimate the exposures of people who lived more than 10 km from a monitoring station.

Table 6-2 lists the number of census tracts assigned to each of the six exposure districts and the number of remaining census tracts (designated “District 19”). Among the home districts (1 through 6), the number of census tracts contained within a district ranges from 28 (No. 6: Boulder) to 116 (No. 3: 14th and Albion). The six home districts account for 351 (59 percent) of the 593 census tracts in the nine-county area.

6.2.2 Origin-Destination Table for Denver

Analysts defined six “home” exposure districts and seven “work” exposure districts. The six home districts were the six monitor-derived exposure districts listed in Table 6-2. The seven “work” districts included the six districts in Table 6-2 and a seventh district (District 19) containing all areas not included in the six home districts. Each flow value in the BOC database was assigned to the appropriate combination of home and work districts according to the residence and work census tracts listed for the

Table 6-3. Number and Fraction of Denver Commuters Associated with Each Combination of Home and Work District.

Home district	Statistic	Work District: Districts containing CO monitors 1	2	3	4	5	6	District 19[a]	Totals by Home District
1	Commuters	35,045	15,334	14,929	3,974	1,499	470	18,288	89,539
	Fraction[b]	0.391	0.171	0.167	0.044	0.017	0.005	0.204	1.000
2	Commuters	2,184	27,440	8,649	3,457	1,789	669	4,511	48,699
	Fraction	0.045	0.563	0.178	0.071	0.037	0.014	0.093	1.000
3	Commuters	12,804	42,602	64,969	7,844	2,651	1,434	22,028	154,332
	Fraction	0.083	0.276	0.421	0.051	0.017	0.009	0.143	1.000
4	Commuters	5,207	26,728	13,773	28,053	9,283	898	14,563	98,505
	Fraction	0.053	0.271	0.140	0.285	0.094	0.009	0.148	1.000
5	Commuters	2,811	22,282	11,666	14,765	39,110	3,428	19,675	113,737
	Fraction	0.025	0.196	0.103	0.130	0.344	0.030	0.173	1.000
6	Commuters	814	4,149	1,771	766	1,305	44,630	6,839	60,274
	Fraction	0.014	0.069	0.029	0.013	0.022	0.740	0.113	1.000
Totals by Work District		58,865	138,535	115,757	58,859	55,637	51,529	85,904	565,086

[a] District 19 includes all census tracts in the nine-county area that are not located in Districts 1 through 6.

[b] Fraction = $(Com_{ij})/(Com_i)$

Com_{ij} = number of workers commuting from home district i to work district j

Com_i = total number of workers commuting from home district i to all work districts (including District 19)

flow. Table 6-3 lists the sums of the flows assigned to each combination of home and work district. It also presents each sum as a fraction of the total flow originating at the indicated home district. For example, the flow from Home District No. 1 to Work District No. 2 is 15,334. Listed under this value is the fraction 0.171, calculated by dividing 15,334 by the total flow (89,539) from Home District No. 1 to all districts.

Home District No. 3, the district containing the largest number of census tracts, is associated with the largest number of commuters (154,332). Home District No. 2 has the smallest number of commuters (48,699). Work District No. 2 is associated with the largest number of commuters (138,535); Work District No. 6 (Boulder) has the smallest number of commuters (51,529). Note that these values include only those commuters which move among the home and work districts listed in Table 6-2.

Table 6-3 accounts for the commuting patterns of 565,086 workers. Of these, 85,904 workers (15 percent) reside in one of the six home districts but work in District 19 (i.e., at a location more than 10 km from the nearest fixed-site monitor). People working in District 19 were excluded from the pNEM/CO analysis of Denver, based on the assumption that pNEM/CO could not accurately estimate the exposures of people who worked more than 10 km from a monitoring station. Consequently, the working cohorts are limited to people with residential and work locations within Districts 1 through 6.

6.2.3 Denver Data Quality

It should be noted that the BOC Commuting Database is not a perfect representation of the commuting patterns of Denver residents. The data were acquired from the census “long form” which the BOC administered to about one-sixth of the Denver residents. The BOC extrapolated the data from this subset of the population to the remainder of the population using various assumptions and supplemental information.

Analysts defined WR as the ratio of WA (number of workers allocated to a particular home-work combination by indirect methods) to WF (total number of workers associated with the home-work combination); i.e.,

$$WR = (WA)/(WF) \tag{6-1}$$

WR provided a crude indication of the uncertainty associated with each WF value in the database.

Table 6-4 presents the population-weighted mean value of WR (expressed as a percentage) for each of the 42 combinations of home and work district. The 42 WR values range from 10.28 percent (Home District No. 6, Work District No. 3) to 43.90 percent (Home District No. 1, Work District No. 5). The largest values (indicating the highest degree of uncertainty) are associated with Work Districts Nos. 5 and 19.

Table 6-4 also provides an aggregate WR value for all flows originating in each home district. The six values range from 22.14 percent (Home District No. 1) to 28.59 percent (Home District No. 2). Aggregate WR values for all flows ending in each work district can also be found in Table 4. The values range from 18.46 percent (Work District No. 1) to 35.27 percent (Work District No. 19).

The overall aggregate value of WR is 23.98 percent. In general, this analysis indicates that less than 25 percent of the commute trips were estimated indirectly using supplemental data.

6.3 Los Angeles Commuting Patterns

6.3.1 The Los Angeles Exposure Districts

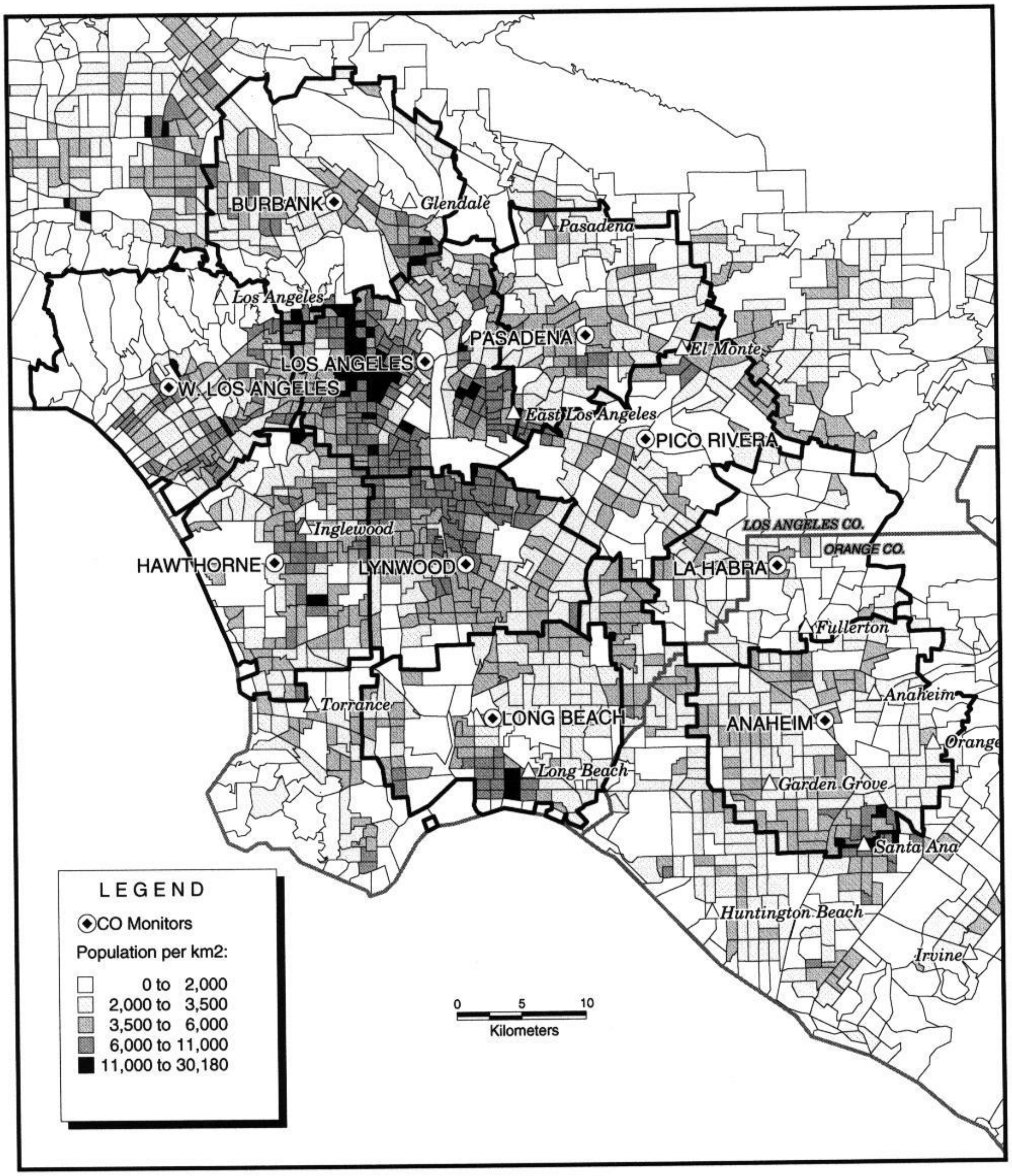
As described in Subsection 2.1, analysts defined 10 exposure districts for application of Version 2.1 of pNEM/CO to the Los Angeles study area. All 10 districts were centered on individual fixed-site CO monitors in the central Los Angeles metropolitan area. Figure 6-2 shows the locations of these 10 fixed-site monitors. Table 6-5 identifies the monitor(s) associated with each district.

Each district was defined as a collection of census tracts as defined by the Bureau of Census for the 1990 decennial census. The census tracts were drawn from a comprehensive listing of the census tracts located in the three California counties (Los Angeles, Orange, and San Bernardino).

Table 6-4. Percentage of Denver Commuters (WR) Assigned by Bureau of Census to Each Home-Work Combination Based on Supplemental Data.

Home District	Work District							All work districts
	Districts containing CO monitor(s)						19	
	1	2	3	4	5	6		
1	15.21	18.47	23.93	23.70	43.90[a]	21.70	34.93[a]	22.14
2	23.99	30.09[a]	22.68	22.36	29.29[a]	22.87	38.40[a]	28.59[a]
3	19.31	22.87	16.21	32.66[a]	35.16[a]	24.48	35.28[a]	22.27
4	30.44[a]	22.96	35.05[a]	14.95	33.14[a]	35.63[a]	36.14[a]	25.79[a]
5	24.55	17.72	25.12[a]	21.38	25.73[a]	33.07[a]	24.18	24.18
6	32.56[a]	21.43	10.28	11.49	31.34[a]	22.47	38.60[a]	24.06
All home districts	18.46	22.96	20.74	19.91	26.93[a]	22.97	35.27[a]	23.98

[a] Value exceeds 25 percent.



CO Monitors and Population Density in the Los Angeles Study Area

Figure 6-2. Fixed-Site CO Monitoring Sites Used to Define Los Angeles Exposure Districts.

Table 6-5. Exposure Districts Defined for Los Angeles pNEM/CO Analysis.

District no.	Monitor(s) included in district			Number of census tracts assigned to district
	AIRS ID	City	Address	
1	37-0113	West LA	VA Hospital	141
2	37-1002	Burbank	228 W. Palm Avenue	113
3	37-1103	Los Angeles	1630 N. Main Street	238
4	37-1301	Lynwood	11220 Long Beach Road	141
5	37-1601	Pico Rivera	3713 San Gabriel River	72
6	37-2005	Pasadena	752 S. Wilson Avenue	113
7	37-4002	Long Beach	3648 N. Long Beach Blvd.	125
8	37-5001	Hawthorne	5234 W. 120th Street	142
9	59-0001	Anaheim	1610 S. Harbor Blvd.	161
10	59-5001	La Habra	621 W. Lambert	79
19	Remaining census tracts in three county region			985

In developing the districts, analysts assigned each census tract located within 10 km of one or more district centers to the nearest district. People residing in the remaining census tracts were excluded from the pNEM/CO analysis, based on the assumption that pNEM/CO could not accurately estimate the exposures of people who lived more than 10 km from a monitoring station.

Table 6-5 lists the number of census tracts assigned to each of the 10 exposure districts and the number of remaining census tracts (designated "District 19"). Among the home districts (1 through 10), the smallest is No. 5 (72 census tracts) and the largest is No. 3 (238 census tracts). The 10 home districts account for 1,325 (57 percent) of the 2,310 census tracts in the three-county area.

6.3.2 Origin-Destination Table for Los Angeles

Analysts defined 10 "home" exposure districts and 11 "work" exposure districts for the Los Angeles pNEM/CO analysis. The 10 home districts were the 10 monitor-derived exposure districts listed in Table 6-5. The 11 "work" districts included the 10 districts in Table 6-5 and an eleventh district (District 19) containing all areas not included in the 10 home districts. Each flow value in the BOC database was assigned to the appropriate combination of home and work districts according to the residence and work census tracts listed for the flow. Table 6-6 lists the sums of the flows assigned to each combination of home and work district. It also presents each sum as a fraction of the total flow originating at the indicated home district. For example, the flow from Home District No. 1 to Work District No. 2 is 15,515. Listed under this value is the fraction 0.046, calculated by dividing 15,515 by the total flow from Home District No. 1 to all districts (338,913).

Home District No. 3, the home district containing the largest number of census tracts, is associated with the largest number of commuters (518,833). The smallest home district (No. 5) has the smallest number of commuters (186,862). Work District No. 19 is associated with the largest number of commuters (612,520) followed by Work District No. 3, which has 580,604 commuters. Work District No. 10 has the smallest number of commuters (112,128). Note that these values include only those commuters which move among the home and work districts listed in Table 6-6.

Table 6-6. Number and Fraction of Los Angeles Commuters Associated with Each Combination of Home and Work District.

Home district	Statistic	Work District											Totals by Home District
		Districts containing CO monitors										District 19[a]	
		1	2	3	4	5	6	7	8	9	10		
1	Commuters	182,334	15,515	58,564	4,906	3,261	3,778	4,847	23,424	882	378	41,024	338,913
	Fraction[b]	0.538	0.046	0.173	0.014	0.010	0.011	0.014	0.069	0.003	0.001	0.121	1.000
2	Commuters	33,435	118,466	58,901	3,870	3,536	9,589	4,751	6,769	893	803	62,036	303,049
	Fraction	0.110	0.391	0.194	0.013	0.012	0.032	0.016	0.022	0.003	0.003	0.205	1.000
3	Commuters	71,728	40,429	233,933	17,820	16,671	19,980	14,254	23,024	2,061	2,969	75,964	518,833
	Fraction	0.138	0.078	0.451	0.034	0.032	0.039	0.027	0.044	0.004	0.006	0.146	1.000
4	Commuters	14,640	7,466	62,067	93,713	23,801	5,410	31,357	24,668	4,646	5,692	40,462	313,942
	Fraction	0.047	0.024	0.198	0.299	0.076	0.017	0.100	0.79	0.015	0.018	0.129	1.000
5	Commuters	5,457	4,133	24,976	11,340	65,007	17,367	7,001	3,912	4,241	12,571	30,857	186,862
	Fraction	0.029	0.022	0.134	0.061	0.348	0.093	0.037	0.021	0.023	0.067	0.165	1.000
6	Commuters	12,295	13,105	57,102	6,995	21,705	107,091	5,553	5,299	2,141	3,348	41,037	275,671
	Fraction	0.045	0.048	0.207	0.025	0.079	0.388	0.020	0.019	0.008	0.012	0.149	1.000
7	Commuters	7,329	3,541	17,459	24,904	8,067	3,132	137,187	23,980	10,108	4,582	69,583	309,872
	Fraction	0.024	0.011	0.056	0.080	0.026	0.010	0.443	0.077	0.033	0.015	0.225	1.000
8	Commuters	41,321	7,919	49,329	19,621	5,634	4,110	17,422	140,234	1,691	1,100	59,031	347,412
	Fraction	0.119	0.023	0.142	0.056	0.016	0.012	0.050	0.404	0.005	0.003	0.170	1.000
9	Commuters	1,837	1,168	5,326	5,227	6,238	1,498	15,886	3,926	180,861	26,804	153,263	402,034
	Fraction	0.005	0.003	0.013	0.013	0.016	0.004	0.040	0.010	0.450	0.067	0.381	1.000
10	Commuters	2,447	1,824	12,927	7,948	24,863	5,483	8,215	3,278	29,743	53,881	39,263	189,872
	Fraction	0.013	0.010	0.068	0.042	0.131	0.029	0.043	0.017	0.157	0.284	0.207	1.000
Totals by Work District		372,823	213,566	580,604	196,344	178,783	177,438	246,473	258,514	237,267	112,128	612,520	3,186,460

[a] District 19 includes all census tracts in the three-county area that are not located in Districts 1 through 10. [b] Fraction = $(Com_{ij})/(Com_i)$. Com_{ij} = number of workers commuting from home district i to work district j. Com_i = total number of workers commuting from home district i to all work districts (including District 19).

6.3.3 Los Angeles Data Quality

The BOC Commuting Database for Los Angeles was developed by extrapolating census data obtained from about one-sixth of the Los Angeles residents to the remainder of the population. Consistent with the approach described in Subsection 6.2.3, analysts used the ratio WR = (WA)/(WF) as a crude indication of the uncertainty associated with each WF value in the database. Table 6-7 presents the population-weighted mean value of WR (expressed as a percentage) for each of the 110 combinations of home and work district. The 110 WR values range from 19.58 percent (Home District No. 1, Work District No. 10) to 75.60 percent (Home District No. 3, Work District No. 19). WR values exceeding 50 percent tend to occur most frequently when the home district is No. 3 and/or when the work district is No. 1, No. 2, No. 7, or No. 19.

Table 6-7 also provides an aggregate WR value for all flows originating in each home district. The 10 values range from 31.26 percent (Home District No. 1) to 48.10 percent (Home District No. 3). Aggregate WR values for all flows ending in each work district can also be found in Table 6-7. The values range from 33.54 percent (Work District No. 1) to 51.03 percent (Work District No. 19).

The overall aggregate value of WR is 38.80 percent. In general, the results show that less than 39 percent of the commute trips were estimated indirectly using supplemental data.

In developing the commuting data base for Denver, analysts calculated an overall aggregate value for WR of 24.0 percent (see Subsection 6.2.3). The higher WR value for Los Angeles (38.8 percent) may be the result of the relatively large number of possible work destinations associated with each Los Angeles home census tract. Uncommon home-work combinations may not appear in the BOC “long form” census data because of the limited sample population available for analysis. In such cases, the BOC would likely estimate the relatively small flow values using supplemental information, increasing the aggregate value of WR.

Table 6-7. Percentage of Los Angeles Commuters (WR) Assigned by BOC to Each Home-Work Combination Based on Supplemental Data.

Home District	Work District											All work districts
	Districts containing CO monitor(s)											
	1	2	3	4	5	6	7	8	9	10	19	
1	20.16	44.15	37.49	38.24	47.81	36.61	51.68[a]	32.30	42.97	19.58	61.02[a]	31.26
2	40.32	24.89	34.73	42.66	46.52	31.73	73.23[a]	50.60[a]	40.20	47.70	42.61	34.26
3	51.22[a]	51.91[a]	36.68	44.00	46.42	42.67	72.37[a]	50.41[a]	55.70[a]	48.23	75.60[a]	48.10
4	57.66[a]	66.44[a]	43.34	39.26	45.46	42.74	44.22	45.73	45.07	45.47	62.22[a]	46.26
5	55.23[a]	46.67	28.48	33.09	37.51	43.74	47.97	41.77	45.39	44.20	55.74[a]	41.46
6	50.09[a]	37.69	20.37	34.01	39.80	32.85	49.60	40.82	38.58	39.64	49.84	34.99
7	50.28[a]	51.62[a]	37.15	39.07	32.39	36.08	30.70	34.07	41.47	26.87	39.61	35.09
8	35.15	63.62[a]	42.27	32.17	52.17[a]	39.27	42.78	30.16	49.38	41.73	46.74	37.39
9	58.79[a]	50.60[a]	32.99	36.81	38.62	40.25	36.25	35.89	34.37	37.20	44.81	38.89
10	47.45	37.66	21.09	27.60	33.28	33.63	39.16	29.35	33.10	27.75	43.25	33.10
All home districts	33.54	36.19	35.43	37.92	39.73	35.64	38.47	35.01	35.31	33.86	51.03[a]	38.80

[a] Value exceeds 50 percent.

6.4 References for Section 6

Bureau of the Census. 1994. "STP154: Census Tract of Work by Census Tract of Residence." Journey-to-Work and Migration Statistics Branch, Population Division, U. S. Bureau of the Census.

Johnson, Ted R., J. E. Capel, and D. M. Byrne. 1991. "The Estimation of Commuting Patterns in Applications of the Hazardous Air Pollutant Model (HAPEM)." Paper No. 91-172.6. Presented at the 84th Annual meeting of the Air and Waste Management Association, Vancouver, British Columbia, June 16 - 21.

SECTION 7

EXPOSURE ESTIMATES FOR DENVER AND LOS ANGELES RESIDENTS WITH ISCHEMIC HEART DISEASE

This section provides estimates of CO exposure and resulting COHb levels for residents of the Denver and Los Angeles study areas with ischemic heart disease. It also presents the results of a sensitivity analysis evaluating the effects of window position on CO exposures occurring in motor vehicles during episodes of passive smoking. The section concludes with a comparison of average CO exposure by microenvironment.

7.1 Exposure Estimates Obtained from Version 2.1 of pNEM/CO

As discussed in Section 2, the pNEM/CO methodology was used to develop estimates of CO exposure and resulting COHb levels within a population-of-interest (POI) defined as "all adults with ischemic heart disease (IHD) who reside and work within the specified study area." Adults were defined as persons 18 years and older. The Denver and Los Angeles study areas were defined as aggregations of exposure districts as specified in Section 2.1. The POI's in the Denver and Los Angeles study areas contained approximately 48,000 and 258,00 persons, respectively.

Tables 7-1 through 7-12 present exposure estimates for six scenarios:

1. Denver - existing conditions - internal sources "on"
2. Denver - existing conditions - internal sources "off"
3. Los Angeles - existing conditions - internal sources "on"
4. Los Angeles - existing conditions - internal sources "off"
5. Los Angeles - attainment - internal sources "on"
6. Los Angeles - attainment - internal sources "off."

Table 7-1. Number of Person-Days Under Existing Conditions[a] in Which Denver Adults with Ischemic Heart Disease Were Estimated to Experience a 1-Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration.

CO concen-tration, ppm	Internal sources on							Internal sources off						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
60	3.94E1	3.26E1	2.70	1.31E2	b	b	b	0	0	0	0	0	0	0
50	2.20E2	1.38E2	7.31E1	7.53E2	b	b	b	0	0	0	0	0	0	0
45	3.21E2	2.51E2	1.33E2	9.02E2	b	b	0.01	2.50	0	0	2.21E1	b	0	b
40	5.71E2	5.22E2	2.64E2	1.15E3	b	b	0.01	1.21E1	1.30	0	7.00E1	b	0	b
35	1.37E3	1.21E3	8.06E2	2.25E3	0.01	b	0.01	2.92E1	1.18E1	0	1.24E2	b	0	b
30	3.24E3	3.28E3	2.03E3	4.26E3	0.02	0.01	0.02	3.00E2	1.45E2	2.82E1	1.56E3	b	b	0.01
25	7.82E3	7.95E3	5.52E3	9.95E3	0.04	0.03	0.06	1.15E3	6.78E2	4.11E2	3.89E3	0.01	b	0.02
20	2.00E4	2.09E4	1.32E4	2.41E4	0.11	0.07	0.14	4.43E3	4.12E3	2.31E3	8.41E3	0.03	0.01	0.05
15	6.28E4	6.33E4	5.16E4	7.05E4	0.35	0.29	0.40	2.44E4	2.35E4	2.00E4	3.46E4	0.14	0.11	0.2
10	2.63E5	2.58E5	2.49E5	2.96E5	1.49	1.41	1.67	1.73E5	1.69E5	1.53E5	2.05E5	0.98	0.87	1.16
0	1.77E7	1.77E7	1.77E7	1.77E7	100	100	100	1.77E7	1.77E7	1.77E7	1.77E7	100	100	100

[a]Existing conditions: Denver CO conditions during 1995. Second non-overlapping eight-hour maximum CO concentration (design value) = 9.5 ppm.
[b]Less than 0.005 percent.

Table 7-2. Number of Person-Days Under Existing Conditions[a] in Which Denver Adults with Ischemic Heart Disease Were Estimated to Experience an 8-Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration.

CO concen-tration, ppm	Internal sources on							Internal sources off						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
25	2.04E3	2.07E3	9.27E2	3.20E3	0.01	0.01	0.02	0	0	0	0	0	0	0
20	4.52E3	4.84E3	2.86E3	5.68E3	0.03	0.02	0.03	8.90	0	0	7.03E1	b	0	b
15	9.52E3	9.64E3	5.95E3	1.16E4	0.05	0.03	0.07	1.20E2	2.89E1	3.40	8.57E2	b	b	b
12	1.54E4	1.52E4	1.16E4	1.98E4	0.09	0.07	0.11	4.50E2	2.85E2	1.03E2	1.77E3	b	b	0.01
9	2.88E4	2.81E4	2.38E4	3.40E4	0.16	0.13	0.19	3.58E3	3.33E3	2.29E3	6.63E3	0.02	0.01	0.04
6	1.02E5	1.02E5	9.08E4	1.15E5	0.58	0.51	0.65	5.50E4	5.19E4	4.77E4	7.00E4	0.31	0.27	0.40
0	1.77E7	1.77E7	1.77E7	1.77E7	100	100	100	1.77E7	1.77E7	1.77E7	1.77E7	100	100	100

[a]Existing conditions: Denver CO conditions during 1995. Second non-overlapping eight-hour maximum CO concentration (design value) = 9.5 ppm.
[b]Less than 0.005 percent.

Table 7-3. Cumulative Number of Denver Adults with Ischemic Heart Disease Estimated to Experience a Daily Maximum End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage Under Existing Conditions[a].

COHb, percent	Internal sources on							Internal sources off						
	Number of people				Percentage			Number of people				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	8.14E1	7.40E1	3.30	1.95E2	0.17	0.01	0.40	0	0	0	0	0	0	0
5.0	2.96E2	2.65E2	1.02E2	8.36E2	0.61	0.21	1.72	0	0	0	0	0	0	0
4.0	7.58E2	7.36E2	3.89E2	1.33E3	1.56	0.80	2.75	0	0	0	0	0	0	0
3.0	2.67E3	2.78E3	1.50E3	4.29E3	5.51	3.1	8.86	2.00	0	0	1.70E1	b	0	0.04
2.9	3.21E3	3.38E3	2.06E3	4.69E3	6.62	4.26	9.68	7.20E1	0	0	6.99E2	0.15	0	1.44
2.8	3.42E3	3.47E3	2.34E3	4.78E3	7.06	4.83	9.85	7.21E1	0	0	6.99E2	0.15	0	1.44
2.7	3.73E3	3.83E3	2.48E3	5.76E3	7.70	5.12	11.88	7.68E1	0.80	0	7.38E2	0.16	0	1.52
2.6	4.30E3	4.46E3	2.74E3	5.85E3	8.88	5.65	12.07	7.70E1	1.60	0	7.38E2	0.16	0	1.52
2.5	5.02E3	5.05E3	2.94E3	6.24E3	10.35	6.06	12.87	8.63E1	6.10	0	7.38E2	0.18	0	1.52
2.4	5.60E3	5.52E3	3.69E3	7.00E3	11.56	7.62	14.45	9.68E1	1.75E1	0	7.42E2	0.20	0	1.53
2.3	6.65E3	6.44E3	4.63E3	9.33E3	13.72	9.56	19.26	1.03E2	1.99E1	1.50	7.42E2	0.21	b	1.53
2.2	7.58E3	7.37E3	6.16E3	1.02E4	15.64	12.71	21.02	1.22E2	2.39E1	2.30	7.47E2	0.25	b	1.54
2.1	8.72E3	8.27E3	6.70E3	1.06E4	18.00	13.82	21.79	1.62E2	3.87E1	3.60	8.20E2	0.33	0.01	1.69
2.0	9.65E3	9.46E3	7.20E3	1.18E4	19.92	14.85	24.42	2.36E2	1.46E2	2.17E1	8.28E2	0.49	0.04	1.71
1.5	1.82E4	1.82E4	1.46E4	2.17E4	37.64	30.09	44.83	3.25E3	3.37E3	1.96E3	4.73E3	6.71	4.04	9.77
1.0	4.03E4	4.03E4	3.81E4	4.30E4	83.16	78.71	88.78	3.15E4	3.18E4	2.81E4	3.35E4	64.98	57.98	69.07
0.5	4.84E4	4.85E4	4.84E4	4.85E4	99.98	99.84	100	4.84E4	4.85E4	4.84E4	4.85E4	99.98	99.84	100
0	4.85E4	4.85E4	4.85E4	4.85E4	100	100	100	4.85E4	4.85E4	4.85E4	4.85E4	100	100	100

[a]Existing conditions: Denver CO conditions during 1995. Second non-overlapping eight-hour maximum CO concentration (design value) = 9.5 ppm.
[b]Less than 0.005 percent.

Table 7-4. Cumulative Number of Person-Hours Under Existing Conditions[a] in Which Denver Adults with Ischemic Heart Disease Were Estimated to Experience an End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage.

COHb, percent	Internal sources on							Internal sources off						
	Number of person-hours				Percentage			Number of person-hours				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	5.07E2	2.47E2	1.83E1	1.68E3	b	b	b	0	0	0	0	0	0	0
5.0	1.54E3	1.34E3	6.19E2	3.04E3	b	b	b	0	0	0	0	0	0	0
4.0	4.27E3	3.98E3	1.81E3	6.81E3	b	b	b	0	0	0	0	0	0	0
3.0	1.57E4	1.37E4	8.48E3	2.31E4	b	b	0.01	4.00	0	0	3.40E1	b	0	b
2.9	1.83E4	1.68E4	1.07E4	2.58E4	b	b	0.01	7.61E1	0	0	6.99E2	b	0	b
2.8	2.10E4	1.89E4	1.26E4	3.04E4	b	b	0.01	7.62E1	0	0	6.99E2	b	0	b
2.7	2.42E4	2.38E4	1.44E4	3.52E4	0.01	b	0.01	2.32E2	1.50	0	2.21E3	b	0	b
2.6	2.79E4	2.77E4	1.63E4	3.81E4	0.01	b	0.01	3.12E2	2.80	0	2.99E3	b	0	b
2.5	3.28E4	3.26E4	1.96E4	4.56E4	0.01	b	0.01	3.27E2	1.80E1	0	3.03E3	b	0	b
2.4	3.81E4	3.72E4	2.27E4	4.90E4	0.01	0.01	0.01	4.20E2	3.95E1	0	3.77E3	b	0	b
2.3	4.56E4	4.36E4	2.80E4	5.81E4	0.01	0.01	0.01	5.31E2	4.34E1	3.00	4.52E3	b	b	b
2.2	5.31E4	5.10E4	3.38E4	6.67E4	0.01	0.01	0.02	7.06E2	8.39E1	5.30	5.27E3	b	b	b
2.1	6.34E4	6.17E4	4.13E4	7.93E4	0.01	0.01	0.02	1.20E3	1.94E2	8.20	7.51E3	b	b	b
2.0	7.58E4	7.21E4	4.98E4	9.51E4	0.02	0.01	0.02	1.66E3	3.77E2	4.00E1	8.39E3	b	b	b
1.5	3.65E5	3.02E5	2.12E5	6.18E5	0.08	0.05	0.15	1.42E5	6.65E4	1.13E4	3.53E5	0.03	b	0.08
1.0	9.97E6	9.98E6	7.39E6	1.27E7	2.35	1.74	2.99	8.86E6	8.97E6	6.35E6	1.15E7	2.09	1.5	2.71
0.5	2.64E8	2.66E8	2.37E8	2.84E8	62.08	55.78	66.91	2.56E8	2.59E8	2.29E8	2.78E8	60.30	53.85	65.40
0	4.24E8	4.24E8	4.24E8	4.24E8	100	100	100	4.24E8	4.24E8	4.24E8	4.24E8	100	100	100

[a]Existing conditions: Denver CO conditions during 1995. Second non-overlapping eight-hour maximum CO concentration (design value) = 9.5 ppm.
[b]Less than 0.005 percent.

Table 7-5. Number of Person-Days Under Existing Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience a 1-Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration.

CO concen-tration, ppm	Internal sources on							Internal sources off						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
60	4.12E2	8.61E1	2.29E1	3.02E3	b	b	b	0	0	0	0	0	0	0
50	9.20E2	5.72E2	2.04E2	3.10E3	b	b	b	0	0	0	0	0	0	0
45	1.96E3	1.29E3	3.94E2	5.46E3	b	b	0.01	5.70	0	0	5.61E1	b	0	b
40	3.11E3	2.22E3	1.58E3	6.33E3	b	b	0.01	2.51E2	1.30	0	2.38E3	b	0	b
35	6.18E3	6.63E3	3.32E3	9.30E3	0.01	b	0.01	2.85E2	5.45E1	2.50	2.40E3	b	b	b
30	1.50E4	1.48E4	6.80E3	2.29E4	0.02	0.01	0.02	1.96E3	1.55E3	3.62E1	4.52E3	b	b	b
25	3.59E4	3.71E4	2.45E4	4.64E4	0.04	0.03	0.05	8.23E3	7.38E3	5.47E3	1.20E4	0.01	0.01	0.01
20	9.89E4	9.77E4	8.04E4	1.09E5	0.10	0.09	0.12	3.83E4	3.88E4	2.76E4	4.86E4	0.04	0.03	0.05
15	3.56E5	3.57E5	3.08E5	3.96E5	0.38	0.33	0.42	2.16E5	2.18E5	1.77E5	2.41E5	0.23	0.19	0.26
10	1.80E6	1.78E6	1.70E6	1.93E6	1.91	1.80	2.04	1.50E6	1.47E6	1.38E6	1.62E6	1.59	1.46	1.72
0	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[b]Less than 0.005 percent.

Table 7-6. Number of Person-Days Under Existing Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience an 8-Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration.

CO concen-tration, ppm	Internal sources on							Internal sources off						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
25	9.87E3	8.81E3	1.89E3	2.06E4	0.01	b	0.02	0	0	0	0	0	0	0
20	1.69E4	1.46E4	8.26E3	3.06E4	0.02	0.01	0.03	4.00	0	0	2.89E1	b	0	b
15	3.90E4	4.12E4	2.22E4	5.41E4	0.04	0.02	0.06	1.14E3	8.60E2	6.03E1	3.95E3	b	b	b
12	6.49E4	6.39E4	5.14E4	8.03E4	0.07	0.05	0.09	7.40E3	7.63E3	2.93E3	1.24E4	0.01	b	0.01
9	1.62E5	1.60E5	1.34E5	2.05E5	0.17	0.14	0.22	6.20E4	5.83E4	3.96E4	9.01E4	0.07	0.04	0.10
6	1.03E6	1.00E6	8.84E5	1.22E6	1.09	0.94	1.30	8.23E5	7.93E5	6.84E5	1.01E6	0.87	0.73	1.07
0	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[b]Less than 0.005 percent.

Table 7-7. Cumulative Number of Los Angeles Adults with Ischemic Heart Disease Estimated to Experience a Daily Maximum End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage Under Existing Conditions[a].

COHb, percent	Internal sources on							Internal sources off						
	Number of people				Percentage			Number of people				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	8.69E2	4.14E2	1.13E2	3.13E3	0.34	0.04	1.21	0	0	0	0	0	0	0
5.0	2.41E3	1.49E3	6.71E2	5.65E3	0.93	0.26	2.19	0	0	0	0	0	0	0
4.0	5.87E3	6.13E3	1.31E3	1.12E4	2.28	0.51	4.32	0.30	0	0	2.90	b	0	b
3.0	1.51E4	1.28E4	7.31E3	3.06E4	5.84	2.83	11.85	5.69E1	3.99E1	0.50	1.71E2	0.02	b	0.07
2.9	1.74E4	1.62E4	1.03E4	3.14E4	6.75	4.00	12.17	8.13E1	5.84E1	1.10	1.83E2	0.03	b	0.07
2.8	1.94E4	1.82E4	1.21E4	3.17E4	7.50	4.71	12.29	1.81E2	8.38E1	2.20	8.45E2	0.07	b	0.33
2.7	2.09E4	1.93E4	1.40E4	3.49E4	8.10	5.43	13.53	5.53E2	2.72E2	2.27E1	2.41E3	0.21	0.01	0.93
2.6	2.44E4	2.16E4	1.62E4	3.82E4	9.44	6.29	14.79	6.92E2	4.35E2	5.70E1	2.41E3	0.27	0.02	0.93
2.5	2.72E4	2.59E4	1.90E4	3.97E4	10.52	7.38	15.38	1.37E3	1.03E3	2.88E2	4.08E3	0.53	0.11	1.58
2.4	3.23E4	3.09E4	2.39E4	4.46E4	12.52	9.26	17.26	1.68E3	1.81E3	3.18E2	4.12E3	0.65	0.12	1.60
2.3	3.75E4	3.62E4	2.64E4	4.94E4	14.54	10.21	19.15	2.39E3	2.14E3	5.78E2	6.88E3	0.93	0.22	2.67
2.2	4.19E4	4.00E4	3.08E4	5.52E4	16.22	11.92	21.37	3.96E3	3.24E3	2.12E3	7.59E3	1.53	0.82	2.94
2.1	4.80E4	4.63E4	3.99E4	6.19E4	18.61	15.47	23.96	5.97E3	5.07E3	3.06E3	1.05E4	2.31	1.18	4.05
2.0	5.40E4	5.45E5	4.60E4	6.44E4	20.92	17.83	24.95	7.84E3	7.55E3	3.47E3	1.20E4	3.04	1.34	4.67
1.5	1.25E5	1.25E5	1.15E5	1.38E5	48.35	44.61	53.60	6.03E4	6.34E4	4.25E4	7.49E4	23.35	16.48	29.01
1.0	2.43E5	2.44E5	2.33E5	2.47E5	93.97	90.30	95.58	2.25E5	2.27E5	2.04E5	2.35E5	87.22	79.17	90.98
0.5	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100
0	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[b]Less than 0.005 percent.

Table 7-8. Cumulative Number of Person-Hours Under Existing Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience an End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage.

COHb, percent	Internal sources on							Internal sources off						
	Number of person-hours				Percentage			Number of person-hours				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	4.73E3	2.46E3	3.80E2	2.01E4	b	b	b	0	0	0	0	0	0	0
5.0	1.22E4	7.47E3	3.00E3	3.24E4	b	b	b	0	0	0	0	0	0	0
4.0	3.18E4	3.05E4	7.91E3	6.11E4	b	b	b	0.30	0	0	2.90	b	0	b
3.0	9.05E4	9.02E4	4.08E4	1.64E5	b	b	0.01	9.66E1	9.24E1	0.50	3.23E2	b	b	b
2.9	1.02E5	9.87E4	5.35E4	1.75E5	b	b	0.01	1.33E2	1.28E2	2.40	3.41E2	b	b	b
2.8	1.14E5	1.11E5	6.86E4	1.86E5	0.01	b	0.01	3.53E2	1.93E2	4.00	1.86E3	b	b	b
2.7	1.29E5	1.24E5	7.69E4	2.09E5	0.01	b	0.01	8.12E2	3.62E2	3.58E1	3.01E3	b	b	b
2.6	1.49E5	1.46E5	9.53E4	2.36E5	0.01	b	0.01	1.09E3	5.88E2	7.75E1	4.24E3	b	b	b
2.5	1.68E5	1.65E5	1.07E5	2.49E5	0.01	b	0.01	2.45E3	1.54E3	7.70E2	1.06E4	b	b	b
2.4	1.92E5	1.91E5	1.30E5	2.82E5	0.01	0.01	0.01	3.29E3	2.54E3	1.13E3	1.18E4	b	b	b
2.3	2.26E5	2.25E5	1.56E5	3.22E5	0.01	0.01	0.01	6.09E3	5.08E3	1.84E3	1.78E4	b	b	b
2.2	2.66E5	2.61E5	1.80E5	3.68E5	0.01	0.01	0.02	1.27E4	9.17E3	4.84E3	3.16E4	b	b	b
2.1	3.27E5	3.19E5	2.27E5	4.52E5	0.01	0.01	0.02	3.30E4	1.42E4	7.27E3	1.13E5	b	b	b
2.0	4.32E5	3.88E5	2.68E5	7.37E5	0.02	0.01	0.03	8.47E4	3.15E4	1.46E4	2.95E5	b	b	0.01
1.5	3.23E6	1.94E6	1.07E6	1.18E7	0.14	0.05	0.52	2.40E6	1.20E6	3.08E5	1.07E7	0.11	0.01	0.47
1.0	4.65E7	4.28E7	2.84E7	7.38E7	2.06	1.26	3.26	4.30E7	3.96E7	2.54E7	6.98E7	1.9	1.12	3.08
0.5	1.07E9	1.07E9	9.77E8	1.14E9	47.28	43.19	50.37	1.05E9	1.05E9	9.54E8	1.12E9	46.26	42.16	49.42
0	2.26E9	2.26E9	2.26E9	2.26E9	100	100	100	2.26E9	2.26E9	2.26E9	2.26E9	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[b]Less than 0.005 percent.

Table 7-9. Number of Person-Days Under Attainment Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience a 1-Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration.

CO concen-tration, ppm	Internal sources on							Internal sources off						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
60	4.06E2	8.54E1	2.26E1	3.02E3	b	b	b	0	0	0	0	0	0	0
50	7.24E2	5.66E2	9.37E1	3.09E3	b	b	b	0	0	0	0	0	0	0
45	1.48E3	8.92E2	2.75E2	5.29E3	b	b	0.01	0	0	0	0	0	0	0
40	2.68E3	1.85E3	1.04E3	6.22E3	b	b	0.01	0	0	0	0	0	0	0
35	5.15E3	5.90E3	1.53E3	8.92E3	0.01	b	0.01	5.70	0	0	5.61E1	b	0	b
30	1.10E4	1.01E4	5.29E3	2.01E4	0.01	0.01	0.02	2.49E2	1.30	0	2.38E3	b	0	b
25	2.17E4	2.04E4	1.50E4	3.46E4	0.02	0.02	0.04	6.15E2	1.25E2	3.10	2.53E3	b	b	b
20	5.55E4	5.62E4	4.33E4	6.28E4	0.06	0.05	0.07	4.96E3	4.79E3	2.07E3	8.80E3	0.01	b	0.01
15	1.57E5	1.57E5	1.38E5	1.72E5	0.17	0.15	0.18	4.06E4	4.10E4	2.94E4	4.95E4	0.04	0.03	0.05
10	7.15E5	7.16E5	6.60E5	7.84E5	0.76	0.70	0.83	4.43E5	4.44E5	3.91E5	4.89E5	0.47	0.41	0.52
0	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100

[a]Attainment Conditions: CO levels adjusted to simulate conditions when second non-overlapping eight-hour maximum CO concentration at design value site equals 9.4 ppm.
[b]Less than 0.005 percent.

Table 7-10. Number of Person-Days Under Attainment Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience an 8-Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration.

CO concen-tration, ppm	Internal sources on							Internal sources off						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
25	8.88E3	8.68E3	1.70E3	1.93E4	0.01	b	0.02	0	0	0	0	0	0	0
20	1.53E4	1.33E4	7.93E3	2.94E4	0.02	0.01	0.03	0	0	0	0	0	0	0
15	3.35E4	3.42E4	1.88E4	4.65E4	0.04	0.02	0.05	7.40	0	0	6.21E1	b	0	b
12	5.02E4	5.00E4	3.89E4	5.91E4	0.05	0.04	0.06	4.36E2	2.01E2	3.37E1	1.45E3	b	b	b
9	9.24E4	9.22E4	7.69E4	1.02E5	0.10	0.08	0.11	8.26E3	8.46E3	3.29E3	1.31E4	0.01	b	0.01
6	3.23E5	3.17E5	2.74E5	3.70E5	0.34	0.29	0.39	1.55E5	1.44E5	1.04E5	2.00E5	0.16	0.11	0.21
0	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100

[a]Attainment Conditions: CO levels adjusted to simulate conditions when second non-overlapping eight-hour maximum CO concentration at design value site equals 9.4 ppm.
[b]Less than 0.005 percent.

Table 7-11. Cumulative Number of Los Angeles Adults with Ischemic Heart Disease Estimated to Experience a Daily Maximum End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage Under Attainment Conditions[a].

COHb, percent	Internal sources on							Internal sources off						
	Number of people				Percentage			Number of people				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	6.58E2	3.70E2	1.13E2	3.13E3	0.25	0.04	1.21	0	0	0	0	0	0	0
5.0	2.17E3	1.23E3	6.63E2	5.56E3	0.85	0.26	2.15	0	0	0	0	0	0	0
4.0	5.62E3	5.87E3	1.25E3	1.09E4	2.18	0.48	4.24	0	0	0	0	0	0	0
3.0	1.32E4	1.18E4	5.89E3	2.86E4	5.11	2.28	11.08	0.30	0	0	2.90	b	0	b
2.9	1.46E4	1.22E4	9.37E3	2.99E4	5.64	3.63	11.57	0.30	0	0	2.90	b	0	b
2.8	1.67E4	1.59E4	1.02E4	3.12E4	6.45	3.93	12.08	0.40	0	0	2.90	b	0	b
2.7	1.85E4	1.72E4	1.02E4	3.17E4	7.17	3.96	12.27	0.50	0	0	2.90	b	0	b
2.6	2.13E4	1.93E4	1.38E4	3.49E4	8.24	5.34	13.53	5.70	0.50	0	5.12E1	b	0	0.02
2.5	2.32E4	2.13E4	1.48E4	3.75E4	8.98	5.72	14.53	2.57E1	0.50	0	1.55E2	0.01	0	0.06
2.4	2.54E4	2.52E4	1.72E4	3.80E4	9.83	6.66	14.73	5.25E1	3.89E1	0.50	1.65E2	0.02	b	0.06
2.3	3.10E4	3.03E4	2.29E4	4.25E4	12.01	8.88	16.47	9.92E1	5.33E1	0.50	4.10E2	0.04	b	0.16
2.2	3.38E4	3.22E4	2.61E4	4.35E4	13.11	10.11	16.85	1.71E2	1.05E2	2.20	5.94E2	0.07	b	0.23
2.1	3.85E4	3.62E4	2.93E4	5.26E4	14.9	11.35	20.37	8.36E2	3.42E2	6.93E1	5.01E3	0.32	0.03	1.94
2.0	4.34E4	4.06E4	3.46E4	5.60E4	16.81	13.37	21.71	1.27E3	8.33E2	1.48E2	5.04E3	0.49	0.06	1.95
1.5	8.34E4	8.26E4	7.54E4	1.03E5	32.32	29.19	39.72	1.34E4	1.22E4	8.24E3	2.07E4	5.18	3.19	8.01
1.0	2.04E5	2.05E5	1.86E5	2.20E5	78.98	71.97	85.20	1.50E5	1.43E5	1.36E5	1.78E5	58.06	52.66	69.03
0.5	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100
0	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100

[a]Attainment Conditions: CO levels adjusted to simulate conditions when second non-overlapping eight-hour maximum CO concentration at design value site equals 9.4 ppm.
[b]Less than 0.005 percent.

Table 7-12. Cumulative Number of Person-Hours Under Attainment Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience an End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage.

COHb, percent	Internal sources on							Internal sources off						
	Number of person-hours				Percentage			Number of person-hours				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	3.78E3	2.09E3	3.48E2	2.01E4	b	b	b	0	0	0	0	0	0	0
5.0	1.10E4	6.30E3	2.63E3	3.21E4	b	b	b	0	0	0	0	0	0	0
4.0	2.91E4	2.63E4	7.14E3	5.69E4	b	b	b	0	0	0	0	0	0	0
3.0	7.96E4	8.13E4	3.27E4	1.43E5	b	b	0.01	0.40	0	0	2.90	b	0	b
2.9	8.90E4	8.85E4	4.07E4	1.64E5	b	b	0.01	0.40	0	0	2.90	b	0	b
2.8	9.96E4	9.81E4	5.33E4	1.76E5	b	b	0.01	0.40	0	0	2.90	b	0	b
2.7	1.12E5	1.11E5	5.94E4	1.87E5	b	b	0.01	0.60	0	0	2.90	b	0	b
2.6	1.29E5	1.27E5	8.01E4	2.10E5	0.01	b	0.01	8.10	0.80	0	7.30E1	b	0	b
2.5	1.48E5	1.45E5	9.06E4	2.37E5	0.01	b	0.01	3.27E1	0.90	0	1.57E2	b	0	b
2.4	1.64E5	1.63E5	1.00E5	2.47E5	0.01	b	0.01	8.06E1	3.99E1	0.50	3.21E2	b	b	b
2.3	1.89E5	1.89E5	1.16E5	2.89E5	0.01	0.01	0.01	1.41E2	1.06E2	1.40	4.10E2	b	b	b
2.2	2.17E5	2.12E5	1.39E5	3.25E5	0.01	0.01	0.01	9.88E2	2.53E2	3.60	7.56E3	b	b	b
2.1	2.57E5	2.42E5	1.63E5	3.64E5	0.01	0.01	0.02	4.74E3	5.75E2	1.47E2	3.35E4	b	b	b
2.0	3.10E5	3.04E5	1.86E5	4.20E5	0.01	0.01	0.02	1.97E4	1.53E3	3.07E2	1.48E5	b	b	0.01
1.5	2.13E6	8.19E5	6.59E5	9.65E6	0.09	0.03	0.43	1.45E6	2.46E5	4.81E4	8.77E6	0.06	b	0.39
1.0	2.50E7	2.42E7	1.21E7	4.52E7	1.1	0.53	2.00	2.23E7	2.19E7	9.86E6	4.23E7	0.99	0.44	1.87
0.5	8.20E8	8.26E8	7.25E8	9.05E8	36.25	32.05	40.01	7.96E8	8.03E8	7.02E8	8.82E8	35.2	31.02	39.00
0	2.26E9	2.26E9	2.26E9	2.26E9	100	100	100	2.26E9	2.26E9	2.26E9	2.26E9	100	100	100

[a]Attainment Conditions: CO levels adjusted to simulate conditions when second non-overlapping eight-hour maximum CO concentration at design value site equals 9.4 ppm.
[b]Less than 0.005 percent.

In these descriptions, the qualifier “existing conditions” refers to the air quality conditions reported by the Denver fixed-site monitors during 1995 or by the Los Angeles fixed-site monitors during 1997. “Attainment” is a simulated condition in which air quality in the study area has been adjusted to meet the current 8-hour NAAQS for CO, which states that the second highest non-overlapping eight-hour average CO concentration shall not exceed 9 ppm. The term “internal sources” refers to gas stoves and passive smoking only. Internal sources “on” indicates pNEM/CO was run in the standard mode in which CO contributions from gas stoves and passive smoking are treated according to the procedures described in Section 2. Internal sources “off” indicates that pNEM/CO was run with the CO contribution from these sources set equal to zero.

Note that each listed exposure statistic is the arithmetic mean of statistics obtained from 10 runs of pNEM/CO. Because pNEM/CO contains a variety of stochastic (probabilistic) factors, each run of the model produces a different set of exposure estimates. Consequently, the means and medians presented in Tables 7-1 through 7-12 provide an indication of the central tendency of each exposure statistic. The tables also provide the range of values observed for each statistic over the 10 runs.

Table 7-1 presents estimates of the number of person-days in which members of the Denver POI experienced a 1-hour daily maximum CO exposure at or above each of the indicated CO concentrations. Table 7-2 is similar in format; it presents estimates of the number of person-days in which members of the Denver POI experienced an 8-hour daily maximum exposure at or above each indicated CO concentration. The maximum possible value in each of these tables is about 17.7 million (denoted 1.77E7 in the tables) -- the product of the number of persons in the Denver POI (approximately 48,500) and the number of days in the exposure period (365).

Table 7-3 presents estimates of the number of people in the Denver POI who experienced a daily maximum end-of-hour COHb level at or above each of the indicated levels. The maximum possible value in this table is the number of people in the POI (48,500), as each person can be counted no more than once in determining the value of each statistic.

Table 7-4 presents estimates of the number of person-hours in which members of the Denver POI experienced an end-of-hour COHb level at or above each of the indicated levels. The maximum possible value in this table is about 424 million

(4.24E08) - the product of the number of persons in the POI (48,457) and the number of hours in the exposure period (8760).

Tables 7-1 through 7-4 present results for Denver under existing or “as is” conditions. Each table provides results for the “internal source on” and “internal source off” scenarios. As expected, the values of the various exposure indicators tend to be larger for the “sources on” scenarios than for the corresponding “sources off” scenarios.

Tables 7-5 through 7-8 present corresponding exposure estimates for existing conditions in the Los Angeles study area. Tables 7-6 through 7-12 provide Los Angeles exposure estimates for attainment conditions. The Los Angeles results are consistent with expectations in that the estimates for attainment conditions tend to be lower than the corresponding estimates for existing conditions.

Cohen and Rosenbaum (2000) performed a statistical analysis comparing the results of pNEM/CO simulations for the “as-is” and “attainment” scenarios in Los Angeles. The comparison was based on 10 pairs of simulations, using matched random number seeds, so that the observed differences between the as-is and attainment results in each simulation pair were solely the result of the corresponding differences in the fixed-site outdoor concentrations. By definition, the exposure estimated from pNEM/CO for a simulation of the “as-is” scenario is at least as large as for the matched simulation of the “attainment” scenario. The statistical analysis showed that at most concentration and COHb levels, the differences between the two scenarios were large enough to have been detected at the five percent significance level from the 10 simulations (using a one-sided t-test). However at the higher levels, where the number of exposures were considerably smaller and more variable, the mean differences for the 10 simulations were not statistically significantly greater for the “as-is” scenario, so that more simulations would be needed for the difference to be detected with 95% confidence by the statistical test. The differences were consistently more likely to be detected at higher CO and COHb levels when internal sources were included. The results of the statistical analyses are briefly summarized below. For full details, see the memorandum by Cohen and Rosenbaum (2000) included as Appendix K to this report.

The paired t-test comparisons from the 10 simulations were statistically significant at the (one-sided) five percent level for cumulative person-days at 1-hour daily maximum CO exposure concentrations above levels from 0 to 35 ppm with internal sources included, and above levels from 0 to 30 ppm with internal sources omitted. For 8-hour daily maximum CO exposures, the differences were statistically significant for levels from 0 to 20 ppm with internal sources included, and for levels from 0 to 15 ppm with internal sources omitted. For numbers of persons above selected 1-hour daily maximum COHb percentage levels, the differences were statistically significant for levels from 0 to 4% with internal sources included, and for levels from 0 to 3% with internal sources omitted. Finally, for numbers of person-hours above selected 1-hour daily maximum COHb percentage levels, the differences were statistically significant for levels from 0 to 5% with internal sources included, and for levels from 0 to 3% with internal sources omitted.

7.2 Sensitivity of Exposure Estimates to Model Assumptions Concerning Vehicle Window Position During Passive Smoking Episodes

Analysts examined the exposure estimates for “sources on” conditions and found that the highest estimated CO exposures tended to occur in motor vehicles when smokers were present and windows were closed. In the pNEM/CO mass-balance model for motor vehicles, a probabilistic algorithm generates lower air exchange rates when windows are closed, tending to increase the CO contribution of passive smoking to exposure. Window position is treated as being unaffected by the presence of smokers. This may be an unrealistic assumption, as non-smokers would be expected to open windows more frequently when traveling with a smoker. However, researchers were not able to find experimental data that could be used to establish a probabilistic relationship between window position and passive smoking.

A sensitivity analysis was conducted to determine the degree to which the exposure results are influenced by the assumption that window position and passive smoking are independent. Tables 7-13 through 7-16 present results obtained from a special version of pNEM/CO in which the mass-balance model was altered to open windows whenever passive smoking occurs in motor vehicles. For comparison purposes, these tables also provide the corresponding estimates obtained from the standard version of pNEM/CO (previously included in Tables 7-5 through 7-8) in which vehicle windows are operated according to the algorithm described in Subsection 4.3. This algorithm is based on the assumption that window position and passive smoking are independent. In all cases, the estimates in Tables 7-13 through 7-16 represent existing conditions in Los Angeles with internal sources on.

As expected, the special version yielded lower estimates of CO exposure and resulting COHb levels, particularly at the upper end of the ranges tabulated in each table. For example, the special version produced significantly lower estimates for the number of person-days in which 1-hour daily maximum exposure CO equaled or exceeded 35 ppm (Table 7-13). The 10-run mean was approximately 2,930 person-days for the special version -- less than half of the corresponding value obtained from the standard version (6,180 person-days). A similar pattern is apparent in the estimates for 8-hour daily maximum exposures in Table 7-14, although the differences between the special and standard model estimates do not tend to be as great as for the 1-hour daily maximum exposures. For example, the special version produced a 10-run mean of approximately 28,200 for the number of person-days in which the 8-hour daily maximum exposure equaled or exceeded 15 ppm. The corresponding estimate obtained from the standard version was 38 percent higher (approximately 39,000).

The frequency of COHb levels above 2 percent was also found to be relatively sensitive to the method used to determine vehicle window position. As indicated by Table 7-15, the number of persons with end-of-hour COHb levels at or above 2 percent was approximately 35,000 for the special version of pNEM/CO versus 54,000 for the standard version. In Table 7-16, the special version produced an estimate of approximately 29,300 for the number of person-hours in which end-of-hour COHb was at or above 2 percent; the corresponding estimate obtained from the standard version was 47 percent higher (approximately 43,200).

Overall, the results of this sensitivity analysis demonstrate that estimates of CO exposure and resulting COHb levels are significantly influenced in the upper ranges by the method used to model the relationship between vehicle window position and passive smoking. The results suggest that Version 2.1 of pNEM/CO is likely to over-estimate the contribution of passive smoking in motor vehicles to CO exposure because

Table 7-13. Number of Person-Days Under Existing Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience a 1-

Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration. <u>Sensitivity Analysis</u>: Comparison of Estimates Obtained from Special and Standard Versions of pNEM/CO.

CO concen-tration, ppm	Internal sources on — Special Version of pNEM/CO[c]							Internal sources on — Standard Version of pNEM/CO[d]						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
60	2.81E2	5.90E0	0	2.68E3	b	0	b	4.12E2	8.61E1	2.29E1	3.02E3	b	b	b
50	4.40E2	2.29E1	7.00E-1	2.69E3	b	b	b	9.20E2	5.72E2	2.04E2	3.10E3	b	b	b
45	1.10E3	9.67E1	7.90E0	4.21E3	b	b	b	1.96E3	1.29E3	3.94E2	5.46E3	b	b	0.01
40	1.45E3	6.80E2	5.68E1	4.22E3	b	b	b	3.11E3	2.22E3	1.58E3	6.33E3	b	b	0.01
35	2.92E3	2.71E3	1.51E2	6.31E3	b	b	0.01	6.18E3	6.63E3	3.32E3	9.30E3	0.01	b	0.01
30	7.16E3	6.67E3	1.07E3	1.46E4	0.01	b	0.02	1.50E4	1.48E4	6.80E3	2.29E4	0.02	0.01	0.02
25	1.85E4	1.88E4	9.85E3	2.59E4	0.02	0.01	0.03	3.59E4	3.71E4	2.45E4	4.64E4	0.04	0.03	0.05
20	5.93E4	6.17E4	4.12E4	6.94E4	0.06	0.04	0.07	9.89E4	9.77E4	8.04E4	1.09E5	0.10	0.09	0.12
15	2.64E5	2.71E5	2.14E5	3.09E5	0.28	0.23	0.33	3.56E5	3.57E5	3.08E5	3.96E5	0.38	0.33	0.42
10	1.60E6	1.58E6	1.49E6	1.72E6	1.7	1.58	1.82	1.80E6	1.78E6	1.70E6	1.93E6	1.91	1.80	2.04
0	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[a]Less than 0.005 percent.
[c]Special Version: windows in motor vehicles are always open when passive smoking occurs.
[d]Standard Version: windows in motor vehicle operate according to algorithm described in Subsection 4.3.

Table 7-14. Number of Person-Days Under Existing Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience an 8-Hour Daily Maximum Carbon Monoxide Exposure At or Above the Specified Concentration. Sensitivity Analysis: Comparison of Estimates Obtained from Special and Standard Versions of pNEM/CO.

CO concen-tration, ppm	Internal sources on — Special Version of pNEM/CO[c]							Internal sources on — Standard Version of pNEM/CO[d]						
	Number of person-days				Percentage			Number of person-days				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
25	6.62E3	4.67E3	2.08E1	1.59E4	0.01	b	0.02	9.87E3	8.81E3	1.89E3	2.06E4	0.01	b	0.02
20	1.15E4	1.03E4	3.36E3	2.32E4	0.01	b	0.02	1.69E4	1.46E4	8.26E3	3.06E4	0.02	0.01	0.03
15	2.82E4	3.05E4	1.17E4	4.15E4	0.03	0.01	0.04	3.90E4	4.12E4	2.22E4	5.41E4	0.04	0.02	0.06
12	4.67E4	4.55E4	3.56E4	6.34E4	0.05	0.04	0.07	6.49E4	6.39E4	5.14E4	8.03E4	0.07	0.05	0.09
9	1.26E5	1.27E5	9.30E4	1.72E5	0.13	0.10	0.18	1.62E5	1.60E5	1.34E5	2.05E5	0.17	0.14	0.22
6	9.46E5	9.17E5	7.93E5	1.14E6	1.00	0.84	1.20	1.03E6	1.00E6	8.84E5	1.22E6	1.09	0.94	1.30
0	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100	9.42E7	9.42E7	9.42E7	9.42E7	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[a]Less than 0.005 percent.
[b]Special Version: windows in motor vehicles are always open when passive smoking occurs.
[c]Standard Version: windows in motor vehicle operate according to algorithm described in Subsection 4.3.

Table 7-15. Cumulative Number of Los Angeles Adults with Ischemic Heart Disease Estimated to Experience a Daily Maximum End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage Under Existing Conditions[a]. Sensitivity Analysis: Comparison of Estimates Obtained from Special and Standard Versions of pNEM/CO.

COHb, percent	Internal sources on — Special Version of pNEM/CO[b]							Internal sources on — Standard Version of pNEM/CO[c]						
	Number of people				Percentage			Number of people				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	4.76E2	2.26E1	2.00E-1	2.68E3	0.18	b	1.04	8.69E2	4.14E2	1.13E2	3.13E3	0.34	0.04	1.21
5.0	1.31E3	5.77E2	4.30E0	4.21E3	0.51	b	1.63	2.41E3	1.49E3	6.71E2	5.65E3	0.93	0.26	2.19
4.0	3.42E3	3.48E3	2.20E1	9.52E3	1.32	0.01	3.69	5.87E3	6.13E3	1.31E3	1.12E4	2.28	0.51	4.32
3.0	9.04E3	7.60E3	6.79E2	1.82E4	3.50	0.26	7.05	1.51E4	1.28E4	7.31E3	3.06E4	5.84	2.83	11.85
2.9	1.03E4	8.56E3	3.60E3	1.86E4	4.00	1.40	7.19	1.74E4	1.62E4	1.03E4	3.14E4	6.75	4.00	12.17
2.8	1.17E4	1.03E4	3.86E3	1.86E4	4.52	1.49	7.20	1.94E4	1.82E4	1.21E4	3.17E4	7.50	4.71	12.29
2.7	1.24E4	1.05E4	3.95E3	2.14E4	4.79	1.53	8.27	2.09E4	1.93E4	1.40E4	3.49E4	8.10	5.43	13.53
2.6	1.46E4	1.25E4	7.28E3	2.38E4	5.67	2.82	9.21	2.44E4	2.16E4	1.62E4	3.82E4	9.44	6.29	14.79
2.5	1.58E4	1.47E4	7.30E3	2.46E4	6.13	2.83	9.53	2.72E4	2.59E4	1.90E4	3.97E4	10.52	7.38	15.38
2.4	1.97E4	1.96E4	1.26E4	2.89E4	7.65	4.89	11.2	3.23E4	3.09E4	2.39E4	4.46E4	12.52	9.26	17.26
2.3	2.34E4	2.32E4	1.28E4	3.65E4	9.05	4.96	13.7	3.75E4	3.62E4	2.64E4	4.94E4	14.54	10.21	19.15
2.2	2.68E4	2.67E4	1.67E4	4.04E4	10.4	6.49	15.7	4.19E4	4.00E4	3.08E4	5.52E4	16.22	11.92	21.37
2.1	3.10E4	3.07E4	2.18E4	4.61E4	12.0	8.46	17.9	4.80E4	4.63E4	3.99E4	6.19E4	18.61	15.47	23.96
2.0	3.50E4	3.48E4	2.51E4	4.82E4	13.6	9.73	18.7	5.40E4	5.45E5	4.60E4	6.44E4	20.92	17.83	24.95
1.5	9.75E4	9.71E4	8.31E4	1.16E5	37.8	32.2	44.8	1.25E5	1.25E5	1.15E5	1.38E5	48.35	44.61	53.60
1.0	2.36E5	2.36E5	2.27E5	2.43E5	91.5	88.1	94.2	2.43E5	2.44E5	2.33E5	2.47E5	93.97	90.30	95.58
0.5	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100
0	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100	2.58E5	2.58E5	2.58E5	2.58E5	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[b]Less than 0.005 percent. [c]Special Version: windows in motor vehicles are always open when passive smoking occurs.

[d]Standard Version: windows in motor vehicle operate according to algorithm described in Subsection 4.3.

Table 7-16. Cumulative Number of Person-Hours Under Existing Conditions[a] in Which Los Angeles Adults with Ischemic Heart Disease Were Estimated to Experience an End-of-Hour Carboxyhemoglobin (COHb) Level At or Above the Specified Percentage. Sensitivity Analysis: Comparison of Estimates Obtained from Special and Standard Versions of pNEM/CO.

COHb, percent	Internal sources on — Special Version of pNEM/CO[b]							Internal sources on — Standard Version of pNEM/CO[c]						
	Number of person-hours				Percentage			Number of person-hours				Percentage		
	mean	median	min	max	mean	min	max	mean	median	min	max	mean	min	max
6.0	2.02E3	3.58E1	5.00E-1	1.61E4	b	b	b	4.73E3	2.46E3	3.80E2	2.01E4	b	b	b
5.0	6.12E3	2.55E3	1.37E1	2.15E4	b	b	b	1.22E4	7.47E3	3.00E3	3.24E4	b	b	b
4.0	1.59E4	1.38E4	6.31E1	3.63E4	b	b	b	3.18E4	3.05E4	7.91E3	6.11E4	b	b	b
3.0	5.17E4	4.85E4	5.04E3	1.08E5	b	b	b	9.05E4	9.02E4	4.08E4	1.64E5	b	b	0.01
2.9	5.81E4	5.23E4	1.08E4	1.11E5	b	b	b	1.02E5	9.87E4	5.35E4	1.75E5	b	b	0.01
2.8	6.52E4	5.90E4	1.39E4	1.18E5	b	b	0.01	1.14E5	1.11E5	6.86E4	1.86E5	0.01	b	0.01
2.7	7.33E4	6.72E4	1.41E4	1.31E5	b	b	0.01	1.29E5	1.24E5	7.69E4	2.09E5	0.01	b	0.01
2.6	8.64E4	8.21E4	2.54E4	1.51E5	b	b	0.01	1.49E5	1.46E5	9.53E4	2.36E5	0.01	b	0.01
2.5	9.63E4	9.14E4	3.12E4	1.58E5	b	b	0.01	1.68E5	1.65E5	1.07E5	2.49E5	0.01	b	0.01
2.4	1.11E5	1.09E5	4.37E4	1.82E5	b	b	0.01	1.92E5	1.91E5	1.30E5	2.82E5	0.01	0.01	0.01
2.3	1.35E5	1.33E5	5.82E4	2.16E5	0.01	b	0.01	2.26E5	2.25E5	1.56E5	3.22E5	0.01	0.01	0.01
2.2	1.61E5	1.60E5	9.89E4	2.41E5	0.01	b	0.01	2.66E5	2.61E5	1.80E5	3.68E5	0.01	0.01	0.02
2.1	2.06E5	2.07E5	1.35E5	3.12E5	0.01	0.01	0.01	3.27E5	3.19E5	2.27E5	4.52E5	0.01	0.01	0.02
2.0	2.93E5	2.68E5	1.57E5	5.80E5	0.01	0.01	0.03	4.32E5	3.88E5	2.68E5	7.37E5	0.02	0.01	0.03
1.5	2.88E6	1.62E6	7.18E5	1.14E7	0.13	0.03	0.50	3.23E6	1.94E6	1.07E6	1.18E7	0.14	0.05	0.52
1.0	4.54E7	4.18E7	2.73E7	7.27E7	2.01	1.21	3.21	4.65E7	4.28E7	2.84E7	7.38E7	2.06	1.26	3.26
0.5	1.07E9	1.07E9	9.75E8	1.14E9	47.2	43.1	50.3	1.07E9	1.07E9	9.77E8	1.14E9	47.28	43.19	50.37
0	2.26E9	2.26E9	2.26E9	2.26E9	100	100	100	2.26E9	2.26E9	2.26E9	2.26E9	100	100	100

[a]Existing conditions: Los Angeles CO conditions during 1997. Second non-overlapping eight-hour maximum CO concentration (design value) = 15.0 ppm.
[b]Less than 0.005 percent. [c]Special Version: windows in motor vehicles are always open when passive smoking occurs.
[d]Standard Version: windows in motor vehicles operate according to algorithm described in Subsection 4.3.

it treats ventilation and passive smoking as being independent. Researchers can refine the pNEM/CO model for this relationship as new data become available.

Cohen and Rosenbaum (2000) performed a statistical analysis comparing exposure estimates obtained from the standard and special versions of pNEM/CO as applied to “as is” conditions in Los Angeles, with internal sources included in both cases. (As discussed above, the mass-balance model in the special version was altered to open windows whenever passive smoking occurs in motor vehicles.) The comparison was based on 10 pairs of simulations, using matched random number seeds, so that the observed differences between the standard and special results in each simulation pair were solely the result of having windows opened rather than closed in vehicles during some smoking events. By definition, the exposure estimated by the standard version of pNEM/CO is at least as large as the corresponding matched exposure estimate obtained from the special version. The statistical analysis showed that at all levels analyzed, the differences between the two scenarios were large enough to have been detected at the one percent significance level with the 10 simulations, using a one-sided t-test. Additional details concerning this analysis can be found in Appendix K.

7.3 Distribution of One-Minute Exposures in Individual Microenvironments

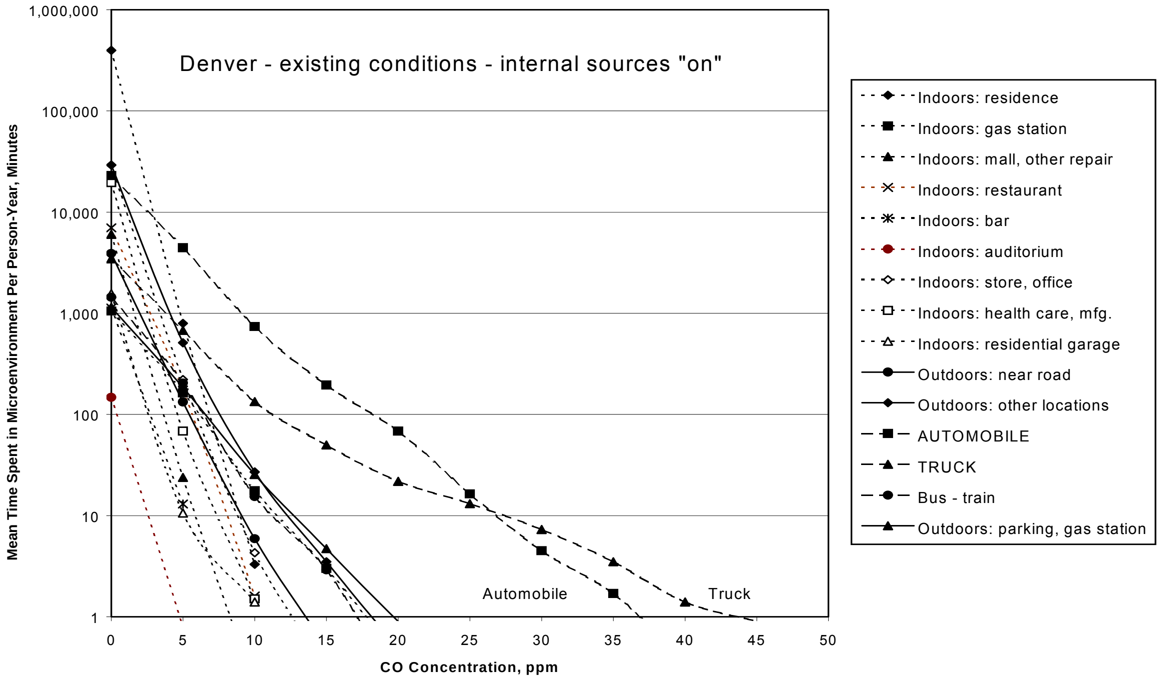
Version 2.1 of pNEM/CO assigns a CO concentration to each exposure event associated with a particular cohort. As each event is also characterized by a microenvironment and a duration expressed in minutes, analysts were able to determine the distribution of one-minute CO exposures in each microenvironment as experienced by each cohort over the specified one-year exposure period. Appropriate population-weights were applied to these one-minute exposures, and the results were averaged over the entire population-of-interest in each study area. This procedure produced the following six graphs, one for each of the six scenarios previously considered in Subsection 7.1.

Figure 7-1: Denver - existing conditions - internal sources “on”
Denver - existing conditions - internal sources “off”

Figure 7-2: Los Angeles - existing conditions - internal sources “on”
Los Angeles - existing conditions - internal sources “off”
Figure 7-3: Los Angeles - attainment - internal sources “on”
Los Angeles - attainment - internal sources “off.”

Each graph shows the average number of minutes per person-year that occurred at or above the indicated CO concentration in the specified microenvironment. Note that the vertical scale (minutes) on each graph is logarithmic. Although the scale extends to 1,000,000 minutes, the maximum possible value for time spent in a microenvironment is 525,600 minutes (the number of minutes in one year).

In each of the six scenarios, one-minute CO exposures at or above 10 ppm are most likely to occur in the automobile and truck microenvironments. The effect is more pronounced for the scenarios with internal sources on, as these scenarios account for the effects of passive smoking in motor vehicles. In general, these results are consistent with the sensitivity analysis discussed in Subsection 7.2 which found that high (i.e, greater than 30 ppm) CO exposures tended to occur in motor vehicles during periods of passive smoking, particularly when windows were closed.



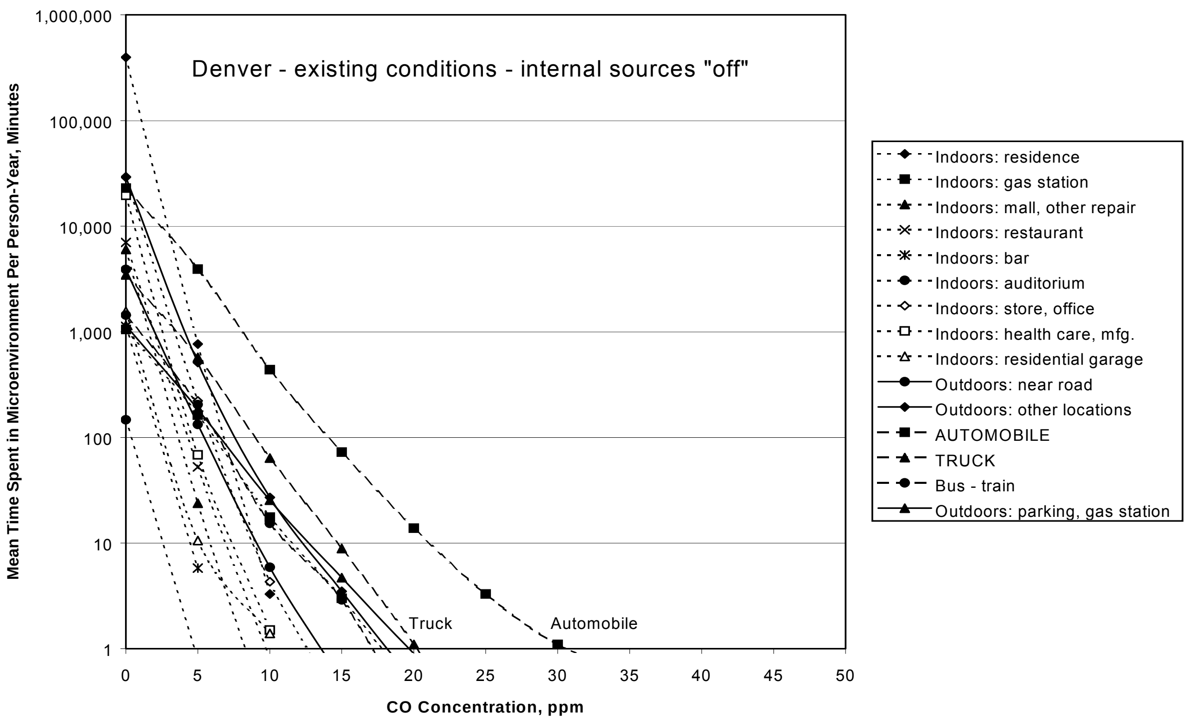
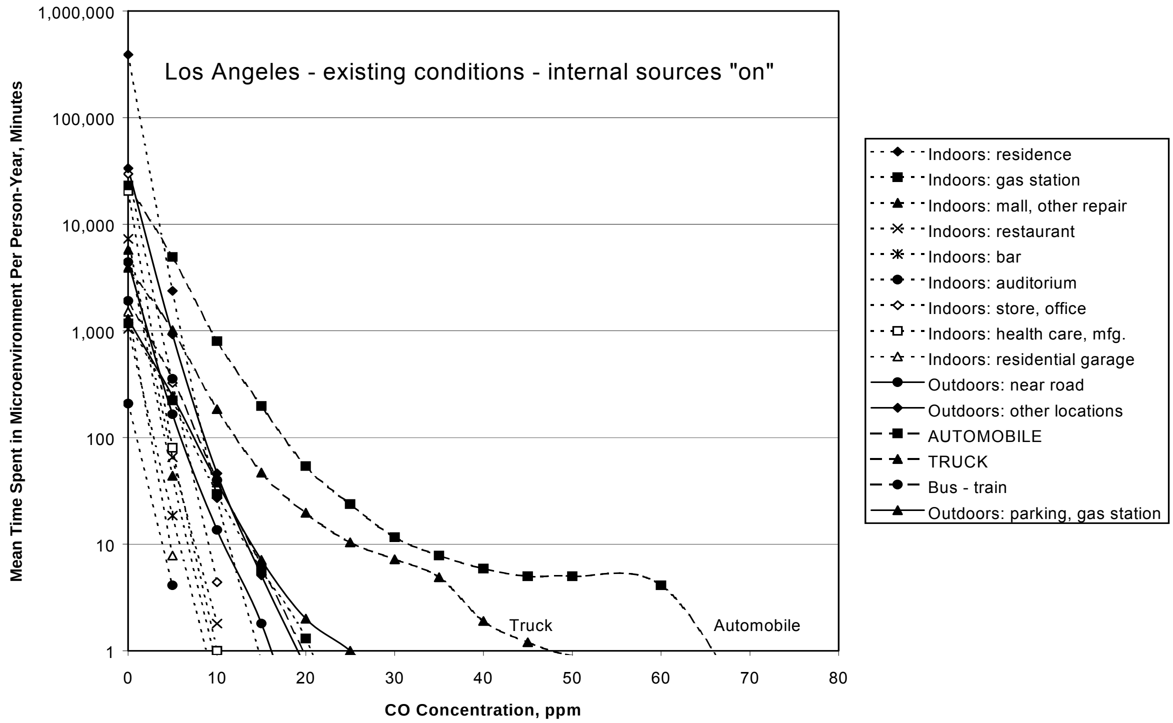


Figure 7-1. Average Number of Minutes Spent in Specified Microenvironment Per Person-Year During Which Carbon Monoxide Exposure Equaled or Exceeded Indicated Concentration. Scenarios: Denver - Existing Conditions - Internal Sources “On” (Top) and “Off” (Bottom).



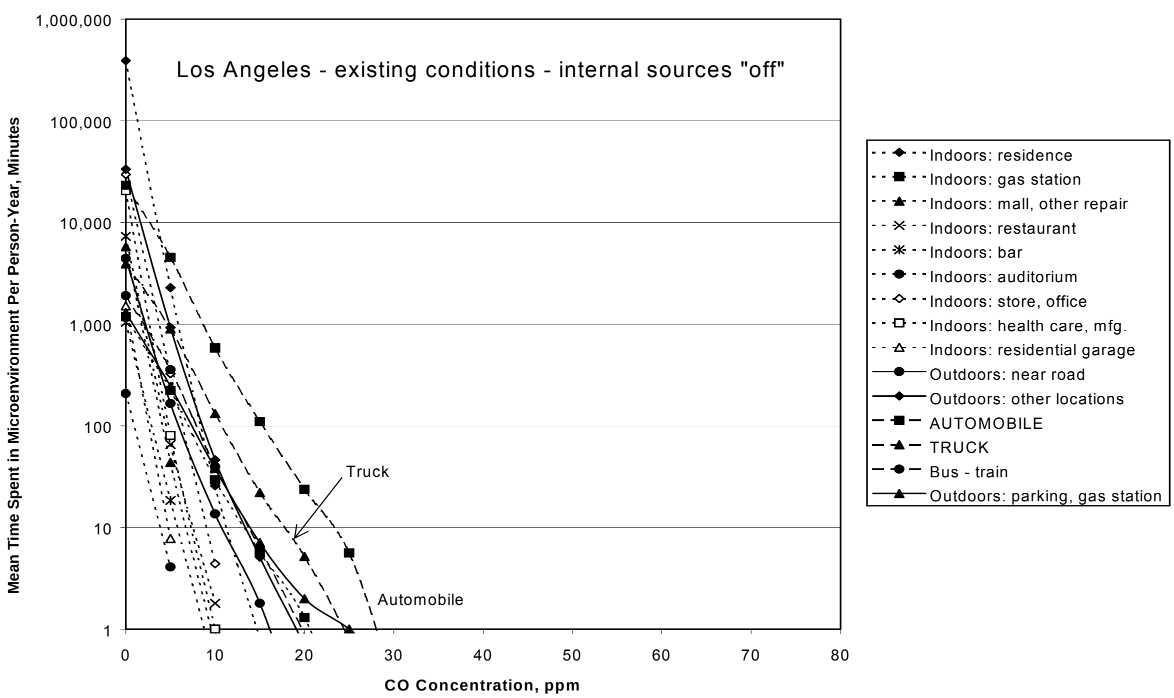
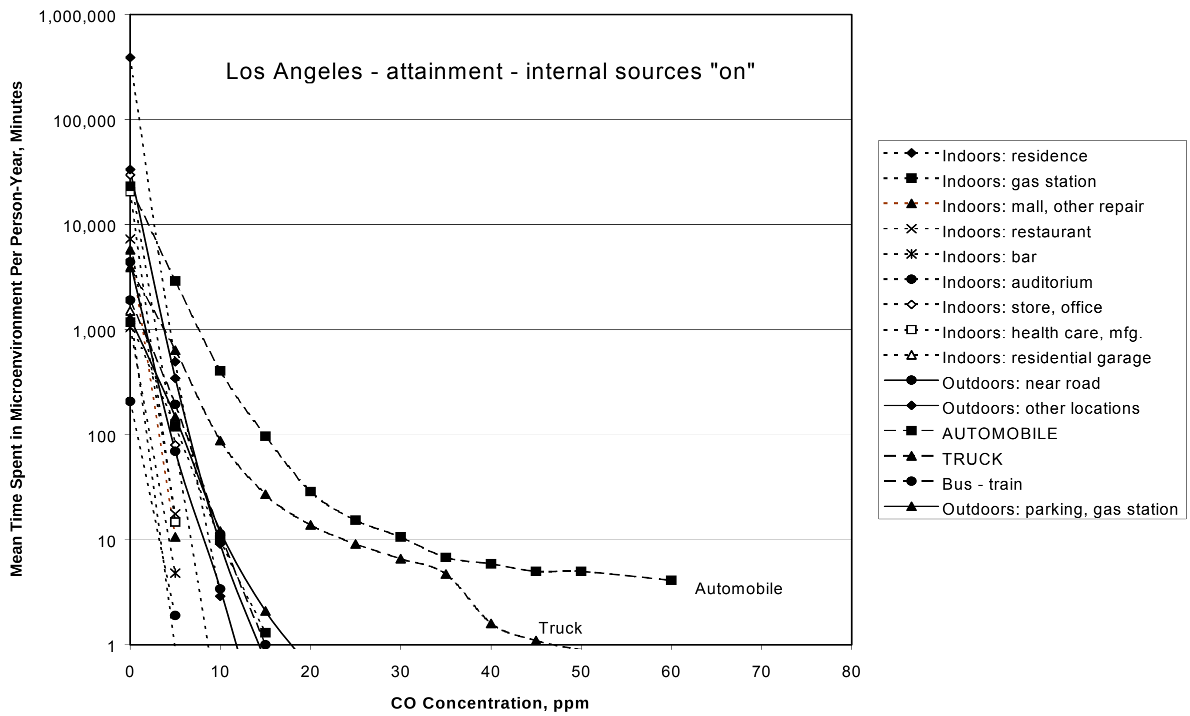


Figure 7-2. Average Number of Minutes Spent in Specified Microenvironment Per Person-Year During Which Carbon Monoxide Exposure Equaled or Exceeded Indicated Concentration. Scenarios: Los Angeles - Existing Conditions - Internal Sources “On” (Top) and “Off” (Bottom).



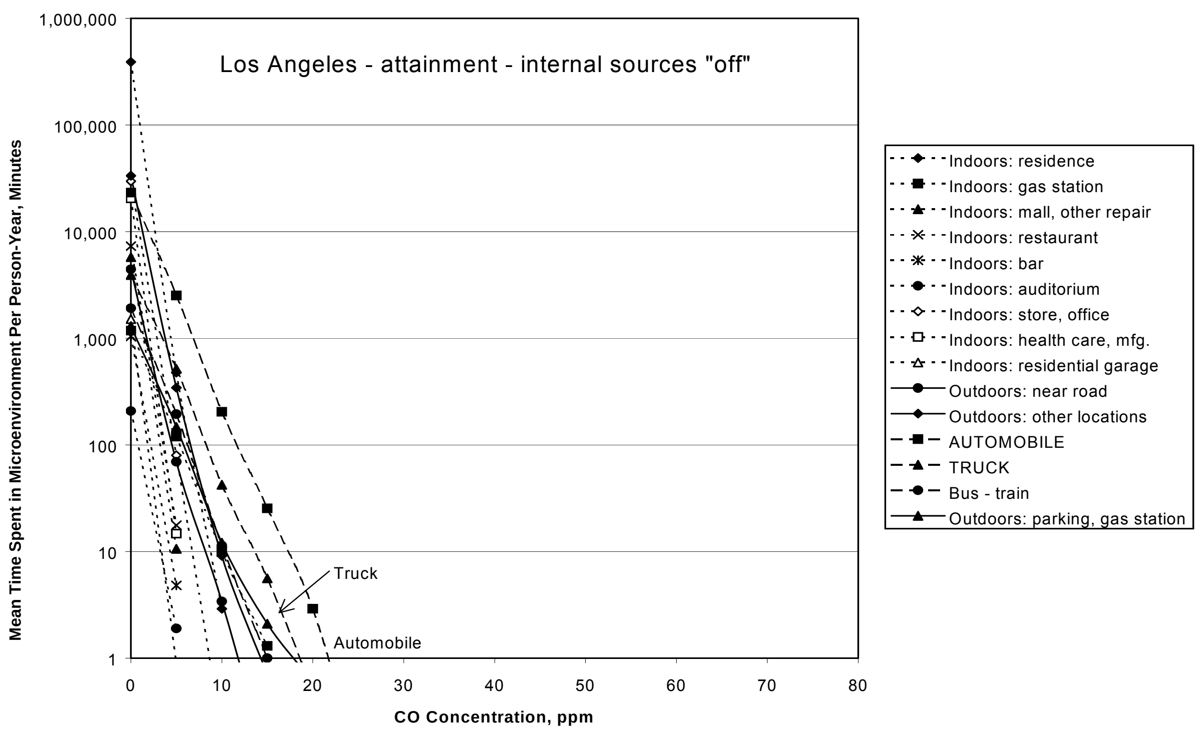


Figure 7-3. Average Number of Minutes Spent in Specified Microenvironment Per Person-Year During Which Carbon Monoxide Exposure Equaled or Exceeded Indicated Concentration. Scenarios: Los Angeles - Attainment - Internal Sources “On” (Top) and “Off” (Bottom).

SECTION 8

PRINCIPAL LIMITATIONS OF THE pNEM/CO METHODOLOGY

The pNEM/CO methodology was developed specifically to meet the requirements of OAQPS for a computer-based model capable of simulating the CO exposures and resulting COHb levels of specific population groups under alternative NAAQS. In addition to meeting these needs, the designers of pNEM/CO have attempted to create a model which is flexible in application and easy to upgrade. The model was deliberately constructed as a collection of stand-alone algorithms organized within a modular framework. For this reason, analysts can revise individual algorithms without the need to make major changes to other parts of the model.

The structure of each algorithm in pNEM/CO is largely determined by the characteristics of the available input data. For example, the algorithm used to construct a season-long exposure event sequence for each cohort is constrained by the fact that none of the available time/activity studies provides more than three days of diary data for any one subject. To make maximum use of the available diary data, the pNEM/CO sequencing algorithm constructs each exposure event sequence by sampling data from more than one subject. The other pNEM/CO algorithms are similarly designed to make best use of available data bases.

The exposure and COHb estimates presented in this report represent estimates based on the current Version 2.1 methodology. An earlier draft version of this report provided estimates obtained from Version 2.0 of pNEM/CO. Version 2.1 incorporates a number of revisions and enhancements to Version 2.0 based on newly available data and comments received from EPA reviewers, the Clean Air Scientific Advisory Committee, and the general public.

This section presents a brief discussion of the principal limitations in the pNEM/CO methodology as applied to adults in Denver and Los Angeles with IHD. These limitations are usually the result of limitations in the input data bases. The available data were typically collected for purposes other than use in a population exposure model. Consequently, these data frequently represent special sets of conditions which differ from those assumed by pNEM/CO. In these situations, analysts must exercise a certain degree of judgment in adapting the data for use in pNEM/CO. The limitations are organized according to six major components of the model: time/activity patterns, outdoor concentrations, indoor and in-vehicle concentrations, alveolar ventilation rates, the COHb algorithm, and cohort populations.

8.1 Time/Activity Patterns

In the general pNEM/CO methodology, the exposure-related activities of each cohort are represented by a multi-day exposure event sequence which spans a specified time period (typically a calendar year). Each sequence is constructed by an algorithm which selects 24-hour (midnight-to-midnight) activity patterns from a specially prepared data file. This time/activity data file was derived from CHAD, a database developed by EPA which combines data from a variety of diary studies and telephone surveys in which subjects reported their daily activities.

In the application of pNEM/CO to residents of Denver and Los Angeles with IHD, the special data file consisted of diary data from CHAD subjects identified as adults. As these data were obtained primarily from healthy subjects, the data should adequately characterize the spectrum of activity patterns associated with the general adult population. However, the time/activity data may be somewhat unrepresentative of adults with IHD, the sensitive population group under analysis. To determine whether the data misrepresent the target group, researchers conducted the analysis described in Section 5.6. EPA has concluded that the differences in activity and exertion between angina and non-angina subjects, although statistically significant, do not appear to be large enough to significantly impact the validity of pNEM/CO modeling results which do not adjust for an angina/non-angina difference.

Section 7 presents pNEM/CO results for Denver and Los Angeles. The majority of time/activity data used in these model runs were obtained from locations other than Denver and Los Angeles. Although the algorithm which constructs exposure event sequences attempts to account for effects of local climate on activity, it is unlikely that this adjustment corrects for all inter-city differences in people’s activities. Time/activity patterns are likely to be affected by a variety of local factors, including topography, land-use, traffic patterns, mass transit systems, and recreational opportunities.

The average subject in the CHAD-derived database provided less than two days of diary data. For this reason, the construction of each year-long exposure event sequence required either the repetition of data from one subject or the use of data from multiple subjects. The latter approach was used in the pNEM/CO analyses described in this report to better represent the variability of exposure expected to occur among the adults in each cohort. The principal deficiency of this approach is that it may not adequately account for the day-to-day repetition of activities common to individual adults. Using activities from different subjects may underestimate multiple occurrences of high exposure situations (e.g., long commutes) for segments of the population who engage in highly repetitive activities.

8.2 Outdoor Concentrations

Version 2.1 of pNEM/CO requires estimates of outdoor CO concentration for each indoor, vehicle, and outdoor microenvironment. For the pNEM/CO applications described in this report, outdoor concentrations were derived from fixed-site monitoring data through a Monte Carlo process (Equation 2-3). This process varied the relationship between the outdoor CO concentration and the simultaneous fixed-site concentration according to the identity of the microenvironment, the geographic location of the microenvironment, and the time of day. Researchers evaluated a number of potential "outdoor models" before selecting Equation 2-3 as the candidate which best balanced model simplicity with its ability to represent the most important patterns in the available data. Most of the model development was based on a comparison of hourly averages of 10-minute concentrations measured outside residences in California with hourly averages measured at the nearest fixed site monitor. This effort produced a model which was completely specified by four parameters. Researchers were unable to identify any single data set that could be used to estimate values for all four parameters simultaneously. Consequently, values for three of these parameters were estimated by analyzing data obtained from the California residential study, whereas the fourth parameter (specific to microenvironment) was estimated by an analysis of data provided by the Denver Personal Monitoring Study. These California and Denver-based parameter estimates were subsequently combined into a single set of parameter values which were used in applying the model to Denver and Los Angeles.

Researchers conducted a series of sensitivity analyses to evaluate the potential effects on parameter estimates of variations in (1) region and (2) scale of the fixed-site monitor. Equation 2-3 was fitted to a series of data subsets defined by region (Los Angeles or San Diego) or by the scale of the fixed monitor (micro, middle, neighborhood, or urban). The fitted parameter values were very similar across the different subsets, supporting the assumption that these parameters are relatively unaffected by residential location (within Southern California) and monitoring scales. It is not known whether the parameter values are affected by large geographical differences (e.g., Denver vs. Los Angeles). However, the model was found to produce reasonable estimates of outdoor CO concentration when applied to monitoring data obtained from the Denver Broadway station, the site reporting Denver's highest CO concentrations.

The model uses hourly-average CO concentrations measured by a relatively small number of fixed-site monitors in each study area (six individual sites plus one composite site in Denver, 10 sites in Los Angeles). These monitoring networks are unlikely to fully represent the geographically variability of outdoor CO concentrations in the Denver and Los Angeles study areas. In addition, some of these sites may be affected by specific CO sources which are not typical of general CO emission patterns. (However, there are no known major CO point sources near any of the fixed-site monitors used in this exposure analysis.) These potential deficiencies in the fixed-site data may be somewhat mitigated by the use of probabilistic relationships in pNEM/CO to estimate outdoor CO concentrations for the mass-balance model. The relationships are based on outdoor monitoring data representing 156 residential locations within the Los Angeles study area.

Section 7 presents exposure estimates for Los Angeles and Denver representing "existing" conditions. In these pNEM/CO runs, no adjustments were applied to the fixed-site monitoring data used in estimating outdoor CO concentrations. Section 7 also presents exposure estimates for Los Angeles under "attainment" conditions. In this case, Equation 3-1 was used to adjust the one-hour CO concentrations representing existing conditions in order to simulate the one-hour concentrations expected to occur when the "worst-case" monitor exactly meets the current 8-hour NAAQS for CO. Equation 3-1 was based on the assumption that CO concentrations measured by fixed-site monitors could be partitioned into two parts: a constant component representing the background CO concentration and a varying component which is proportional to the CO emissions that are permitted under a specified regulatory scenario. The same proportionality factor was applied to one-hour CO concentrations for all hours at all monitors, based on the simplifying assumptions that (1) CO emissions under attainment conditions would be reduced by the same proportion at all times and locations and (2) meteorological conditions would be same under both existing and attainment conditions. The approach is consistent with statistics reported in Subsection 3.4.3 of the CD (EPA, 2000) that show the general shape of the distributions of ambient CO concentrations measured at fixed-site monitors have remained the same as CO have decreased.

8.3 Indoor and In-Vehicle Concentrations

The pNEM/CO methodology uses the mass-balance model described in Section 4 to estimate CO concentrations in various enclosure types. The mass-balance model provides average CO concentrations by hour or minute for each enclosure category as a function of outdoor CO concentration, air exchange rate (AER), and internal emissions of CO from gas stoves and passive smoking. The pNEM/CO model is based on the generalized mass-balance model presented by Nagda, Rector, and Koontz (1987) with the reasonable simplifying assumptions that 1) the enclosure does not intercept any of the CO as it moves indoors, 2) the CO does not decay once it enters the enclosure, and 3) no CO is removed by air-filtration devices. In addition, the pNEM/CO mass-balance model assumes that effective indoor volume is equal to the actual indoor volume (i.e., $c = 1$) and that perfect (uniform) mixing occurs (i.e., $m = 1$).

The assumption of uniform mixing may not be reasonable for all exposure situations simulated by pNEM/CO, particularly when internal emission rates are high and air exchange rates are low. When mixing is not uniform, some areas within the enclosure will have higher CO concentrations than estimated by the mass-balance model while others will have lower CO concentrations. It should also be noted that

Mage and Ott (1996) have questioned the use of a single factor (m) to characterize mixing in the equation proposed by Nagda, Rector, and Koontz. Mage and Ott propose the use of an alternative conceptual model that divides an indoor emission episode into three distinct time periods (τ_α = source is emitting, τ_β = source is not emitting but mixing is nonuniform, and τ_γ = source is not emitting and mixing is uniform). They also define criteria based on this model that can be used to identify situations in which it is reasonable to assume uniform mixing has occurred. Analysts judged that existing data were inadequate to incorporate this level of sophistication into the current version of pNEM/CO.

The AER values for residential buildings with closed windows were obtained from lognormal distributions fit to seasonal AER data collected by Brookhaven National Laboratory (BNL). The BNL data for the region containing Denver included a large number of AER values for winter and spring, but exhibited small sample sizes for summer and winter. Similarly, the BNL data for the region containing Los Angeles included a large number of AER values for three seasons (winter, spring, and summer) but few values for fall. Analysts were required to use statistical methods to estimate the geometric mean and standard deviation for the seasons with limited data.

The AER distribution for residences with windows open is based on data collected in a single test residence in North Carolina over a single 24-hour period. These data may not be representative of residences in Denver or Los Angeles with open windows. However, the resulting distribution used in pNEM/CO is consistent with open-window data obtained by Wallace and Ott (1996) in Redwood City, California. The pNEM/CO AER distribution for residential open windows has a geometric mean of 1.34 hr^{-1} and ranges from 0.57 to 3.16 hr^{-1}. Wallace and Ott report open windows AER values raging from 0.35 to 5.6 hr^{-1}, with half the values falling between 0.59 and 2.75 hr^{-1}.

AER distributions for non-residential buildings are based on statistical analysis of data for 89 buildings. Many of these buildings were located in California; consequently, researchers assumed that the resulting distributions would be fairly representative of the Los Angeles study area. As none of the buildings was located in Denver, the distributions may not accurately represent non-residential buildings in Denver.

AER values for vehicles are estimated by an algorithm which considers vehicle speed and vent/window status (open or closed). The assumed relationship is based on 11 AER values (Table 4-10) measured in three vehicles by Rodes et al. (1998). As only two of these values represent speeds under 35 mph, the resulting algorithm may not accurately estimate AER values for low speeds. This deficiency may significantly affect estimates for in-vehicle exposures when passive smoking occurs, as the contribution of ETS to CO exposure is likely to be greatest at slow speeds when AER is low.

The mass-balance model simulates the operation of gas stove burners in residences by specifying when the burners are on, the emission rate of the burners during operation, and the volume of the residence where it is located. The probabilistic burner use patterns used in pNEM/CO are considered relatively reliable, as they are based on survey data for 4312 users and on diaries completed by several hundred subjects of the Denver personal monitoring study. Burner emission rates for Denver are based on fuel use patterns observed by NIGAS in 57 Illinois homes and emission factors representing a well-adjusted stove. It is not known whether Denver fuel use patterns differ significantly from those of Illinois residents. Using gas stove data specific to Los Angeles, analysts adjusted the Illinois NIGAS data to obtain burner emission rates applicable to the Los Angeles study area. The validity of this approach is uncertain.

Residential volumes are randomly selected from lognormal distributions based on square footage data for Denver and Los Angeles obtained from the 1995 American Housing Survey. These data are considered to be relatively reliable.

Version 2.1 of pNEM/CO does not directly account for certain indoor sources (e.g., kerosene heaters, wood stoves, fireplaces, charcoal grills and hibachis used in the living area of homes, or motor vehicle operation in attached garages) which are likely to produce some high-end CO personal exposures. However, it should be noted that these situations are not directly related to the CO contribution from the ambient air. The model also does not capture high-end CO exposures that are due to malfunction-ing gas stoves, ovens, or other gas appliances or the improper use of these gas appliances. The fact that some of these potentially high-end CO exposure scenarios are not considered within pNEM/CO may partially explain why past comparisons of the model predictions with actual personal exposure data collected in Denver showed the model under-predicting the upper tail of the CO exposure distribution for the population (Law et al., 1997, Johnson et al., 1992).

Section 6 of the report by Johnson et al. (1992) describes 52 high-exposure situations (defined as 8-hr daily maximum CO concentrations at or above 10 ppm) that were identified in data obtained from personal exposure monitors (PEMs) carried by the subjects of the Denver personal monitoring study (Johnson, 1984). The following excerpt from the report discusses patterns observed in these high-exposure situations.

> A total of 52 person-days were identified as being associated with 8-hour daily maximum exposures at or above 10 ppm. In most of these cases, the PEM data indicated an extended period of CO exposures ranging between 10 ppm and 30 ppm had occurred rather than a short-term exposure at a much higher level.
>
> In 18 cases, the subject spent most of the 8-hour period in the indoors-residence microenvironment. A gas stove was in operation in the residence for an extended period of time (more than two hours) in five of these cases. Smokers were present in the residence in two of these cases. Multiple potential sources of CO were present in the residence in 11 cases.
>
> In five of the fifty-two cases, the subject spent an extended period of time in a motor vehicle. The subject stayed in a service station or public garage for an extended time period in three cases. One or two of the 52 cases were associated with each of the following exposure situations: 1) working in an office with or without smokers, 2) riding in a truck with or without smokers, 3) visiting or working in restaurant, 4) shopping, 5) working in a store, 6) working in a hospital, 7) riding a bus, and 8) attending school.
>
> In nine cases, the subject moved through a variety of microenvironments in which high exposures were recorded. In four other cases, the situation associated with a high 8-hour exposure could not be adequately characterized because of missing or unreliable data.
>
> A detailed review of the PEM data associated with these cases suggested that high 8-hour daily maximum exposures often arise from an extended series of short-term exposures that exhibit a high degree of autocorrelation over time. Although many of the existing pNEM/CO algorithms incorporate some degree of autocorrelation, it appears that additional autocorrelation is required if the model is to adequately represent the upper end of the distribution of 8-hour daily maximum CO exposures. In particular, autocorrelation should be increased in the algorithms that determine the sequence of outdoor CO concentrations for each microenvironment and that determine the sequence of on/off periods for gas stoves. In addition, it may be necessary to provide pNEM/CO with special

algorithms to simulate certain extended, high exposure situations, such as working in a service station, parking garage, or restaurant.

Note that these comments apply to the 1992 version of pNEM/CO. Researchers have attempted to address many of the model deficiencies noted above through the use of improved computational algorithms and expanded time/activity databases. For example, Version 2.1 of pNEM/CO contains improved algorithms for estimating outdoor CO concentrations, for estimating the contribution of environmental tobacco smoke to CO concentrations in buildings and vehicles, for simulating the operation of gas stoves with and without pilot lights, and for representing repetitive activities. However, it is likely that Version 2.1 does not fully account for all sources of autocorrelation in CO exposure. In addition, Version 2.1 does not account for all potential indoor CO emission sources or provide special algorithms for simulating specific high-exposure occupational situations.

As there has not been a large-scale personal monitoring study conducted during the 1990's, researchers have not attempted to validate Version 2.1 through the use of personal monitoring data. Personal monitoring data from the 1982/83 Denver study are considered to be unrepresentative of current exposure conditions.

8.4 Alveolar Ventilation Rate

One of the advanced features of pNEM/CO is its ability to probabilistically estimate a value for alveolar ventilation rate (V_A) value for each exposure event, where V_A is expressed as liters of air respired per minute (liters min^{-1}). The algorithm used to estimate V_A was developed specifically for Version 2.1 of pNEM/CO and has not been used previously in pNEM analyses. As described in Section 5, the exposure event sequence for each cohort provides an activity descriptor (e.g., “raking”) for each event. Analysts provide a distribution of possible MET values for each activity descriptor type. The alveolar ventilation rate algorithm selects a value of MET for each exposure event from the appropriate distribution and converts it to a corresponding energy expenditure rate according to a resting metabolic rate assigned to the cohort.

The algorithm next converts each energy expenditure rate to a corresponding oxygen uptake rate (VO_2). Finally, the algorithm converts the resulting VO_2 value to V_A through the use of a proportionality factor which is applied to all cohorts under all levels of exertion. In essence, the algorithm determines the quantity of air that must reach the alveoli of the lung so that a person will obtain the oxygen needed to burn the calories required by the activity associated with each exposure event.

Most of the steps in converting an activity descriptor for an event to a V_A value for the event employ equations and parameter values which are relatively well-supported by clinical data (see Section 5). Perhaps the weakest link in the algorithm is the step which requires the analyst to provide a distribution of possible MET values for each event descriptor. These distributions are currently based on distributions provided by the developers of CHAD. Because there were often insufficient data available to accurately define a distribution for each activity descriptor, the developers tended to follow a conservative approach and over-estimate the variability of each distribution. Consequently, the V_A values produced by the ventilation rate algorithm may exhibit an excessive degree of variability. To prevent the occurrence of "impossible" values arising from this variability, the alveolar ventilation rate algorithm includes test routines which identify and adjust VO_2 values that exceed limits based on activity duration and the physiological characteristics of the cohort.

The alveolar ventilation rate estimated for a particular exposure event is not explicitly affected by the ventilation rates estimated for preceding events. Consequently, the algorithm may not adequately account for excess post-exercise oxygen consumption (EPOC), a condition experienced when individuals are engaged in strenuous exertion that results in an oxygen debt that impacts oxygen uptake and ventilation rates after cessation of the strenuous exercise. EPA is considering adding an adjustment approach to account for EPOC in future versions of pNEM.

Finally, healthy subjects provided most of the clinical data used to estimate the parameters of the alveolar ventilation rate algorithm. These data may not be entirely representative of adults with IHD, the sensitive population group included in this exposure analysis.

8.5 COHb Algorithm

This algorithm provides an estimate of the COHb level at the end of each exposure event. The algorithm is based on a differential equation proposed by Coburn, Foster, and Kane (1963). EPA's updated CD (EPA, 2000, p. 5 - 37) states that the nonlinear CFK equation is the most widely used predictive model of COHb formation, and it is still considered the best all-around model for COHb prediction. Various tests of the CFK equation indicate that the model predicts COHb levels accurately, unless one is dealing with very high CO exposures of short duration (e.g., hundreds of ppm CO in a few minutes).

A special algorithm within pNEM/CO probabilistically generates a value for each parameter of the CFK equation (collectively referred to as a "physiological profile"). The algorithm ensures that the functional relationships among the various parameters are maintained. A report by Richmond and Johnson (Appendix E of this report) discusses the limitations of data used to estimate the distributions and predictive equations associated with each of the parameters appearing in the CFK equation.

8.6 Cohort Populations

Subsection 2.5.1 of this report describes the procedure used to estimate cohort populations for the general population of each study area. Each cohort is defined by demographic group, cooking fuel, and work location. Ideally, the population of each cohort would be estimated from census data specific to the specified values of these factors. In actuality, census data are available for each factor separately. Consequently, the population-estimation routines within pNEM/CO assume that the factors are independent in developing cohort estimates. However, it is likely that some factors are correlated. For example, pNEM/CO applies the same commuting pattern to all working demographic groups residing in a particular district because commuting data specific to the pNEM/CO demographic groups are not available from BOC. This assumption ignores the probable correlations between gender and work location.

Version 2.1 of pNEM/CO marks the first use of a new commuting database provided by the BOC. Although an improvement over earlier sources of commuting data, the BOC commuting database is not a perfect representation of the commuting patterns of Denver and Los Angeles residents. The data were acquired from the census "long form" which the BOC administered to about one-sixth of the U.S. residents. The BOC extrapolated the data from this subset of the population to the remainder of the population using various assumptions and supplemental information.

Section 2.5.2 describes the method used to estimate cohort populations for the sensitive population defined as persons with diagnosed and undiagnosed IHD. The method used the procedure applied to the general population with an additional step which accounted for the fraction of each demographic group who had IHD (diagnosed and undiagnosed). Table 2-8 lists estimates of these fractions. The estimates for <u>diagnosed</u> IHD are considered relatively reliable on a national scale, as they were obtained from data disaggregated by age and gender obtained from the National Health Interview Survey. According to the National Health Interview Survey, approximately 8.0 million individuals are estimated to have diagnosed IHD in the civilian, non-institutionalized population. These estimates do not include individuals in the military or individuals in nursing homes or other institutions. There is likely to be some geographic variation in the fraction of persons with IHD, but there is insufficient information available to account for this variation in this exposure analysis.

The estimates of <u>undiagnosed</u> IHD are considered less certain. These estimates are based on two assumptions: (1) there are 3.5 million persons in the U.S. with undiagnosed IHD and (2) persons with undiagnosed IHD are distributed by age and gender within the population in the same proportions as persons with diagnosed IHD. The 3.5 million statistic is based on an estimate by the American Heart Association (1990) that there are between three and four million persons with undiagnosed IHD.

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ESTIMATION OF CARBON MONOXIDE EXPOSURES AND ASSOCIATED CARBOXYHEMOGLOBIN LEVELS FOR RESIDENTS OF DENVER AND LOS ANGELES USING pNEM/CO (VERSION 2.1)

APPENDICES

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CONTENTS

Appendix A

Distribution of Energy Expenditure Rates
Associated with CHAD Location Descriptors

Distributions for Energy Expenditure Rates By Activity Code, Age, and Occupation (if applicable).

Notes:

1. Activities coded as 10... are activities with codes beginning with 10.
2. OCC: occupational categories.
3. DN: distribution number
4. DL: distribution type (T = triangular, N = normal, U = uniform, E = exponential, P = point)
5. Activities starting with 17... are calculated based on age.
   Age = 1 if respondent < 25 years
   Age = 2 if respondent 25 - 39 years
   Age = 3 if respondent > 40 years

ACTIV-ITY	AGE	OCC	DN	DL	MEAN	MED	SD	MIN	MAX	FLAG	LEFT	RIGHT
10...	X	ADMIN	4	L	1.7	1.7	0.3	1.4	2.7	0	0.16	0.01
10...	X	PROF	5	T	2.9	2.7	1	1.2	5.6	0	0	0
10...	X	ADMSUP	4	L	1.7	1.7	0.3	1.4	2.7	0	0.16	0.01
10...	X	TECH	5	T	3.3	3.3	0.4	2.5	4.5	1	0	0
10...	X	TRANS	4	L	3.3	3	1.5	1.3	8.4	1	0.03	0.01
10...	X	SALE	5	T	2.9	2.7	1	1.2	5.6	0	0	0
10...	X	SERV	5	T	5.2	5.3	1.4	1.6	8.4	1	0	0
10...	X	HSHLD	4	L	3.6	3.5	0.8	2.5	6	1	0.07	0.01
10...	X	PROTECT	5	T	2.9	2.7	1	1.2	5.6	0	0	0
10...	X	PREC	5	T	3.3	3.3	0.4	2.5	4.5	1	0	0
10...	X	MACH	2	U	5.3	5.3	0.7	4	6.5	1	0	0
10...	X	FARM	4	L	7.5	7	3	3.6	17	1	0.04	0.01
10...	X	LABOR	5	T	8.5	8.4	2.1	3.6	13.8	1	0	0
17100	1	X	4	L	5.7	5	3	1.4	16	1	0.01	0.01
17100	2	X	1	N	5	5	2	1	9	1	0.02	0.02
17100	3	X	1	N	4.5	4.5	1.4	1.7	7.3	1	0.02	0.02
17110	1	X	4	L	3.6	3.2	1.9	1.4	10	1	0.05	0.01
17110	2	X	4	L	3.6	3.2	1.9	1.4	10	1	0.05	0.01
17110	3	X	4	L	3.4	3	1.7	1.4	9	1	0.05	0.01
17111	1	X	1	N	5.6	5.6	2.1	1.4	9.8	1	0.02	0.02
17111	2	X	1	N	5.8	5.8	2.4	1	10.6	1	0.02	0.02
17111	3	X	1	N	4.7	4.7	1.8	1.1	8.3	1	0.02	0.02
17112	1	X	2	U	3.8	3.8	1	2	5.5	1	0	0
17112	2	X	2	U	3.8	3.8	1	2	5.5	1	0	0
17112	3	X	2	U	3.5	3.5	0.9	2	5	1	0	0
17120	1	X	4	L	4.2	3.9	1.5	2	9	1	0.03	0.01
17120	2	X	4	L	4.2	3.9	1.5	2	9	1	0.03	0.01
17120	3	X	6	P	3.5	3.5	.	.	.	1	.	.
17121	1	X	4	L	4.2	3.9	1.5	2	9	1	0.03	0.01
17121	2	X	4	L	4.2	3.9	1.5	2	9	1	0.03	0.01
17121	3	X	6	P	3.5	3.5	.	.	.	1	.	.
17130	1	X	4	L	5.8	5.5	1.8	1.8	11.3	1	0	0.01
17130	2	X	1	N	5.7	5.7	1.8	2.1	9.3	1	0.02	0.02
17130	3	X	1	N	4.7	4.7	1.2	2.3	7.1	1	0.02	0.02
17131	1	X	4	L	5.8	5.5	1.8	1.8	11.3	1	0	0.01
17131	2	X	1	N	5.7	5.7	1.8	2.1	9.3	1	0.02	0.02
17131	3	X	1	N	4.7	4.7	1.2	2.3	7.1	1	0.02	0.02

ACTIV-ITY	AGE	OCC	DN	DL	MEAN	MED	SD	MIN	MAX	FLAG	LEFT	RIGHT
17140	1	X	1	N	5.3	5.3	1.8	1.7	8.9	1	0.02	0.02
17140	2	X	1	N	5.2	5.2	1.7	1.7	8.9	1	0.02	0.01
17140	3	X	1	N	3.8	3.8	1	1.8	5.8	1	0.02	0.02
17144	1	X	1	N	5.3	5.3	1.8	1.7	8.9	1	0.02	0.02
17144	2	X	1	N	5.2	5.2	1.7	1.7	8.9	1	0.02	0.01
17144	3	X	1	N	3.8	3.8	1	1.8	5.8	1	0.02	0.02
17180	1	X	4	L	6.6	5.9	3.2	2	17.4	1	0.01	0.01
17180	2	X	1	N	6	6	2	2	10	1	0.02	0.02
17180	3	X	1	N	4.8	4.8	1.4	2	7.6	1	0.02	0.02
10200	X	X	2	U	1.8	1.8	0.4	1	2.5	0	0	0
10300	X	X	2	U	1.8	1.8	0.4	1	2.5	0	0	0
11000	X	X	5	T	4.7	4.6	1.3	1.5	8	1	0	0
11100	X	X	4	L	2.6	2.5	0.5	2	4	0	0.13	0.01
11110	X	X	3	E	2.8	2.5	0.9	1.9	4	0	0	0.02
11200	X	X	3	E	3.4	3	1.4	2	5	1	0	0.01
11210	X	X	2	U	2.5	2.5	0.1	2.3	2.7	0	0	0
11220	X	X	3	E	4.1	3.5	1.9	2.2	5	1	0	0.01
11300	X	X	1	N	5	5	1	2	7	1	0	0.02
11310	X	X	3	E	5.3	4.5	2.7	2.6	6	1	0	0
11400	X	X	3	E	2.2	2	0.7	1.5	4	0	0	0.02
11410	X	X	6	P	2	2	.	.	.	0	.	.
11500	X	X	6	P	2	2	.	.	.	0	.	.
11600	X	X	1	N	4.5	4.5	1.5	2	8	1	0.05	0.01
11610	X	X	6	P	4.5	4.5	.	.	.	1	.	.
11620	X	X	3	E	4.9	4.5	1.4	3.5	6	1	0	0
11630	X	X	5	T	3.5	3.4	0.4	3	4.5	1	0	0
11640	X	X	3	E	4.7	4.5	0.7	4	6	1	0	0
11650	X	X	2	U	4.5	4.5	1.4	2	7	1	0	0
11700	X	X	2	U	3.5	3.5	0.9	2	5	1	0	0
11800	X	X	2	U	3.3	3.3	0.1	3	3.5	1	0	0
11900	X	X	3	E	6.6	5.5	3.6	3	9	1	0	0
12000	X	X	4	L	3.1	3	0.7	2.5	5	1	0.2	0.01
12100	X	X	2	U	3.3	3.3	0.1	3	3.5	1	0	0
12200	X	X	2	U	3.3	3.3	0.1	3	3.5	1	0	0
12300	X	X	2	U	2.8	2.8	0.1	2.5	3	0	0	0
12400	X	X	2	U	2.8	2.8	0.1	2.5	3	0	0	0
12500	X	X	2	U	2.8	2.8	0.1	2.5	3	0	0	0
12600	X	X	2	U	4.5	4.5	0.3	4	5	1	0	0
12700	X	X	2	U	3.2	3.2	0.1	3	3.3	1	0	0
12800	X	X	2	U	3	3	0.3	2.5	3.5	1	0	0
13000	X	X	5	T	3.8	3.7	0.8	2	6	1	0	0
13100	X	X	2	U	3.3	3.3	0.4	2.5	4	1	0	0
13200	X	X	5	T	3.7	3.6	0.8	2	6	1	0	0
13210	X	X	5	T	3.9	3.8	0.8	2.2	6	1	0	0
13220	X	X	2	U	3.4	3.4	0.6	2.3	4.5	1	0	0
13230	X	X	2	U	3.5	3.5	0.6	2.5	4.5	1	0	0
13300	X	X	2	U	3.5	3.5	0.6	2.5	4.5	1	0	0
13400	X	X	2	U	3.5	3.5	0.6	2.5	4.5	1	0	0
13500	X	X	2	U	3.5	3.5	0.6	2.5	4.5	1	0	0
13600	X	X	2	U	3.5	3.5	0.6	2.5	4.5	1	0	0

ACTIV-ITY	AGE	OCC	DN	DL	MEAN	MED	SD	MIN	MAX	FLAG	LEFT	RIGHT
13700	X	X	2	U	3.5	3.5	0.6	2.5	4.5	1	0	0
13800	X	X	2	U	3.5	3.5	0.6	2.5	4.5	1	0	0
14000	X	X	2	U	2	2	0.6	1	3	0	0	0
14100	X	X	1	N	2	2	0.3	1	4	0	0	0
14110	X	X	2	U	3	3	0.6	2	4	1	0	0
14120	X	X	2	U	1.8	1.8	0.4	1	2.5	0	0	0
14200	X	X	2	U	1.8	1.8	0.4	1	2.5	0	0	0
14300	X	X	4	L	3.1	3	0.7	2.5	5	1	0.2	0.01
14400	X	X	2	U	1.8	1.8	0.1	1.5	2	0	0	0
14500	X	X	4	L	0.9	0.9	0.1	0.8	1.1	0	0.09	0.01
14600	X	X	6	P	2.5	2.5	.	.	.	0	.	.
14700	X	X	5	T	2	2	0.4	1	2.9	0	0	0
15000	X	X	4	L	1.9	1.8	0.7	1.4	4	0	0.23	0.01
15100	X	X	2	U	2.1	2.1	0.4	1.4	2.8	0	0	0
15110	X	X	2	U	2.3	2.3	0.4	1.5	3	0	0	0
15120	X	X	2	U	2.1	2.1	0.4	1.4	2.8	0	0	0
15130	X	X	2	U	2	2	0.3	1.4	2.5	0	0	0
15140	X	X	2	U	1.8	1.8	0.2	1.4	2.2	0	0	0
15200	X	X	2	U	2.2	2.2	0.5	1.4	3	0	0	0
15300	X	X	6	P	1.8	1.8	.	.	.	0	.	.
15400	X	X	2	U	2.3	2.3	0.4	1.5	3	0	0	0
15500	X	X	2	U	2.8	2.8	0.7	1.5	4	0	0	0
16000	X	X	4	L	2.2	2	1.1	1	6	0	0.07	0.01
16100	X	X	2	U	2.7	2.7	0.8	1.4	4	0	0	0
16200	X	X	2	U	1.7	1.7	0.2	1.4	2	0	0	0
16210	X	X	2	U	1.7	1.7	0.2	1.4	2	0	0	0
16300	X	X	2	U	1.3	1.3	0.2	1	1.6	0	0	0
16400	X	X	2	U	1.7	1.7	0.4	1	2.3	0	0	0
16500	X	X	2	U	2.5	2.5	0.3	2	2.9	0	0	0
16600	X	X	2	U	1.5	1.5	0.3	1	1.9	0	0	0
16700	X	X	4	L	3.3	3	1.4	1.5	8	1	0.05	0.01
16800	X	X	4	L	3.3	3	1.4	1.5	8	1	0.05	0.01
16900	X	X	2	U	3.8	3.8	1.3	1.5	6	1	0	0
17113	X	X	2	U	3	3	0.6	2	4	1	0	0
17114	X	X	5	T	3.1	3.2	0.6	1.4	4	1	0	0
17122	X	X	2	U	1.5	1.5	0.2	1.2	1.8	0	0	0
17141	X	X	5	T	2.8	2.7	0.8	1.5	5	0	0	0
17142	X	X	5	T	2	1.9	0.4	1.5	3	0	0	0
17143	X	X	2	U	2.5	2.5	0.3	2	3	0	0	0
17150	X	X	5	T	3.3	3.2	0.6	2.4	5	1	0	0
17160	X	X	2	U	1.6	1.6	0.2	1.2	2	0	0	0
17170	X	X	2	U	5	5	1.7	2	8	1	0	0
17200	X	X	4	L	1.3	1.3	0.3	1	2.3	0	0.14	0.01
17210	X	X	2	U	1.5	1.5	0.2	1.2	1.8	0	0	0
17211	X	X	2	U	.	.	.	1.2	.	0	0	.
17212	X	X	2	U	.	.	.	1.2	.	0	0	.
17213	X	X	2	U	.	.	.	1.2	.	0	0	.
17214	X	X	2	U	.	.	.	1.2	.	0	0	.
17215	X	X	2	U	.	.	.	1.2	.	0	0	.
17216	X	X	2	U	2.7	2.7	0.8	1.4	4	0	0	0

ACTIV-ITY	AGE	OCC	DN	DL	MEAN	MED	SD	MIN	MAX	FLAG	LEFT	RIGHT
17220	X	X	4	L	1.2	1.2	0.4	0.9	2.3	0	0.15	0.01
17221	X	X	2	U	1.2	1.2	0.1	1	1.3	0	0	0
17222	X	X	2	U	1.9	1.9	0.2	1.5	2.3	0	0	0
17223	X	X	6	P	1	1	.	.	.	0	.	.
17230	X	X	2	U	1.3	1.3	0.2	1	1.6	0	0	0
17231	X	X	2	U	1.3	1.3	0.2	1	1.6	0	0	0
17232	X	X	2	U	1.3	1.3	0.2	1	1.6	0	0	0
17233	X	X	2	U	1.3	1.3	0.2	1	1.6	0	0	0
17240	X	X	2	U	1.4	1.4	0.2	1	1.8	0	0	0
17241	X	X	2	U	1.4	1.4	0.2	1	1.8	0	0	0
17242	X	X	2	U	1.4	1.4	0.2	1	1.8	0	0	0
17250	X	X	2	U	1.2	1.2	0.1	1	1.3	0	0	0
17260	X	X	2	U	1.9	1.9	0.2	1.5	2.3	0	0	0
17300	X	X	2	U	1.5	1.5	0.2	1.2	1.8	0	0	0
18000	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18100	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18200	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18300	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18400	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18500	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18600	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18700	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18800	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18900	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18910	X	X	4	L	2.3	2	1.3	1	7	0	0.1	0.01
18920	X	X	4	L	2.3	2	1.3	1.8	7	0	0.42	0.01

CHAD Activity Codes

<10> Work and Other Income Producing Activities
10000: work and other income producing activities, general
10100: work, general
    10110: work, general, for organizational activities
        10111: work for professional/union organizations
        10112: work for special interest identity organizations
        10113: work for political party and civic participation
        10114: work for volunteer/ helping organizations
        10115: work of/ for religious groups
        10116: work for fraternal organizations
        10117: work for child/ youth/ family organizations
        10118: work for other organizations
    10120: work, income-related only
    10130: work, secondary (income-related)
10200: unemployment
10300: breaks
<11> Household Activities
11000: general household activities
11100: prepare food
    11110: prepare and clean-up food
11200: indoor chores
    11210: clean-up food
    11220: clean house
11300: outdoor chores
    11310: clean outdoors
11400: care of clothes
    11410: wash clothes
11500: build a fire
11600: repair, general
    11610: repair of boat
    11620: paint home/ room
    11630: repair/ maintain car
    11640: home repairs
    11650: other repairs
11700: care for plants
11800: care for pets/ animals
11900: other household
<12> Child Care
12000: child care, general
12100: care of baby
12200: care of child
12300: help/teach
12400: talk/read
12500: play indoors

12600: play outdoors
12700: medical care-child
12800: other child care
<13> Obtain Goods and Services
13000: obtain goods and services, general
13100: dry clean
13200: shop/ run errands, general
    13210: shop for food
    13220: shop for clothes or household goods
    13230: run errands
13300: obtain personal care service
13400: obtain medical service
13500: obtain government/ financial services
13600: obtain car service
13700: other repairs
13800: other services
<14> Personal Needs and Care
14000: personal needs and care, general
14100: shower, bathe, personal hygiene
    14110: shower, bathe
    14120: personal hygiene
14200: medical care
14300: help and care
14400: eat
14500: sleep or nap
14600: dress, groom
14700: other personal needs
<15> Education and Professional Training
15000: general education and professional training
15100: attend full-time school
    15110: attend day-care
    15120: attend K-12
    15130: attend college or trade school
    15140: attend adult education and special training
15200: attend other classes
15300: do homework
15400: use library
15500: other education
<16> Entertainment/ Social Activities
16000: general entertainment/ social activities
16100: attend sports events
16200: participate in social, political, or religious activities
    16210: practice religion
16300: view movie
16400: attend theater
16500: visit museums
16600: visit

16700: attend a party
16800: go to bar/ lounge
16900: other entertainment/ social events
<17> Leisure
17000: leisure, general
17100: participate in sports and active leisure
    17110: participate in sports
        17111: hunting, fishing, hiking
        17112: golf
        17113: bowling/ pool/ ping pong/ pinball
        17114: yoga
    17120: participate in outdoor leisure
        17121: play, unspecified
        17122: passive, sitting
    17130: exercise
        17131: walk, bike, or jog (not in transit)
    17140: create art, music, participate in hobbies
        17141: participate in hobbies
        17142: create domestic crafts
        17143: create art
        17144: perform music/ drama/ dance
    17150: play games
    17160: use of computer
    17170: participate in recess and physical education
    17180: other sports and active leisure
17200: participate in passive leisure
    17210: watch
        17211: watch adult at work
        17212: watch someone provide childcare
        17213: watch personal care
        17214: watch education
        17215: watch organizational activities
        17216: watch recreation
    17220: listen to radio/ listen to recorded music/ watch t.v.
        17221: listen to radio
        17222: listen to recorded music
        17223: watch t.v.
    17230: read, general
        17231: read books
        17232: read magazine/ not ascertained
        17233: read newspaper
    17240: converse/ write
        17241: converse
        17242: write for leisure/ pleasure/ paperwork
    17250: think and relax
    17260: other passive leisure
17300: other leisure

<18> Travel

18000: travel, general
18100: travel during work
18200: travel to/from work
18300: travel for child care
18400: travel for goods and services
18500: travel for personal care
18600: travel for education
18700: travel for organizational activity
18800: travel for event/ social activity
18900: travel for leisure
- 18910: travel for active leisure
- 18920: travel for passive leisure

Appendix B

Fixed-Site Monitors in Colorado and California Reporting CO Data to AIRS for One or More Years Between 1993 and 1997

0 CARBON MONOXIDE (42101) COLORADO UNITS: 007 PPM

SITE ID	POC	MT	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
008-001-3001	1	2		ADAMS CO	78TH AVE & STEELE ST - W	93	001	8632	9.0	8.2	0	6.6	4.9	0	054
08-001-3001	1	2		ADAMS CO	78TH AVE & STEELE ST - W	94	001	8687	9.0	8.8	0	6.4	6.3	0	054
08-001-3001	1	2		ADAMS CO	78TH AVE & STEELE ST - W	95	001	8681	8.5	8.1	0	5.7	5.1	0	054
08-001-3001	1	2		ADAMS CO	78TH AVE & STEELE ST - W	96	001	8712	6.2	6.2	0	3.9	3.9	0	054
08-001-3001	1	2		ADAMS CO	78TH AVE & STEELE ST - W	97	001	8661	8.3	6.6	0	5.0	4.3	0	054
08-001-7015	1	4	COMMERCE CITY	ADAMS CO	ROCKY MOUNTAIN ARSENAL	93	830	7919	7.7	6.6	0	4.3	4.0	0	054
08-001-7015	1	4	COMMERCE CITY	ADAMS CO	ROCKY MOUNTAIN ARSENAL	94	830	3595	3.2	2.5	0	1.2	1.1	0	054
08-005-0002	1	2	LITTLETON	ARAPAHOE CO	8100 SO UNIVERSITY BLVD-	93	001	8589	7.0	6.5	0	4.9	3.4	0	054
08-005-0002	1	2	LITTLETON	ARAPAHOE CO	8100 SO UNIVERSITY BLVD-	94	001	8705	4.6	4.2	0	2.9	2.2	0	054
08-005-0002	1	2	LITTLETON	ARAPAHOE CO	8100 SO UNIVERSITY BLVD-	95	001	8670	3.6	3.3	0	2.6	2.1	0	054
08-005-0002	1	2	LITTLETON	ARAPAHOE CO	8100 SO UNIVERSITY BLVD-	96	001	8677	4.3	4.1	0	2.9	2.6	0	054
08-005-0002	1	2	LITTLETON	ARAPAHOE CO	8100 SO UNIVERSITY BLVD-	97	001	8463	4.3	4.0	0	3.0	2.8	0	054
08-005-0003	1	2	ENGLEWOOD	ARAPAHOE CO	3300 S. HURON ST.	93	001	8717	11.5	10.9	0	8.4	6.2	0	054
08-005-0003	1	2	ENGLEWOOD	ARAPAHOE CO	3300 S. HURON ST.	94	001	7126	7.5	7.3	0	4.9	4.0	0	054
08-013-0009	1	2	LONGMONT	BOULDER CO	440 MAIN ST. LONGMONT	93	001	8701	9.5	9.0	0	7.0	6.4	0	054
08-013-0009	1	2	LONGMONT	BOULDER CO	440 MAIN ST. LONGMONT	94	001	8557	12.6	12.2	0	6.7	6.2	0	054
08-013-0009	1	2	LONGMONT	BOULDER CO	440 MAIN ST. LONGMONT	95	001	8690	14.0	8.8	0	5.6	4.7	0	054
08-013-0009	1	2	LONGMONT	BOULDER CO	440 MAIN ST. LONGMONT	96	001	8735	11.3	9.2	0	5.5	5.5	0	054
08-013-0009	1	2	LONGMONT	BOULDER CO	440 MAIN ST. LONGMONT	97	001	8617	9.6	9.1	0	5.7	5.4	0	054
08-013-0010	1	2	BOULDER	BOULDER CO	2150 28TH STREET	93	001	353	7.6	7.6	0	5.1	4.9	0	054
08-013-0010	1	2	BOULDER	BOULDER CO	2150 28TH STREET	94	001	8639	12.4	10.5	0	6.6	6.0	0	054
08-013-0010	1	2	BOULDER	BOULDER CO	2150 28TH STREET	95	001	8608	10.6	10.3	0	5.3	5.2	0	054
08-013-0010	1	2	BOULDER	BOULDER CO	2150 28TH STREET	96	001	8576	8.5	8.4	0	5.6	4.3	0	054
08-013-0010	1	2	BOULDER	BOULDER CO	2150 28TH STREET	97	001	8697	9.0	8.2	0	5.5	3.9	0	054
08-013-1001	1	2	BOULDER	BOULDER CO	2320 MARINE ST., BOULDER	93	001	8708	10.2	8.4	0	5.5	4.1	0	054
08-013-1001	1	2	BOULDER	BOULDER CO	2320 MARINE ST., BOULDER	94	001	8565	7.8	6.0	0	2.8	2.7	0	054
08-013-1001	1	2	BOULDER	BOULDER CO	2320 MARINE ST., BOULDER	95	001	8651	8.3	8.2	0	4.1	3.7	0	054
08-013-1001	1	2	BOULDER	BOULDER CO	2320 MARINE ST., BOULDER	96	001	8669	4.5	4.3	0	2.5	2.5	0	054
08-013-1001	1	2	BOULDER	BOULDER CO	2320 MARINE ST., BOULDER	97	001	8517	7.1	6.9	0	5.1	3.3	0	054
08-031-0002	2	1	DENVER	DENVER CO	2105 BROADWAY - CAMP	93	001	8687	19.4	18.2	0	10.4	10.4	2	054
08-031-0002	2	1	DENVER	DENVER CO	2105 BROADWAY - CAMP	94	001	8700	20.4	17.1	0	9.9	8.2	1	054
08-031-0002	2	1	DENVER	DENVER CO	2105 BROADWAY - CAMP	95	001	8697	24.5	16.4	0	11.0	9.5	2	054
08-031-0002	2	1	DENVER	DENVER CO	2105 BROADWAY - CAMP	96	001	8673	21.6	16.7	0	9.0	7.3	0	054
08-031-0002	2	1	DENVER	DENVER CO	2105 BROADWAY - CAMP	97	001	8687	11.4	10.0	0	5.7	5.5	0	054
08-031-0013	1	2	DENVER	DENVER CO	14TH AND ALBION ST. NJH-	93	001	8675	18.1	14.9	0	9.1	7.8	0	054
08-031-0013	1	2	DENVER	DENVER CO	14TH AND ALBION ST. NJH-	94	001	8665	12.4	12.2	0	8.0	7.6	0	054
08-031-0013	1	2	DENVER	DENVER CO	14TH AND ALBION ST. NJH-	95	001	8647	14.6	13.6	0	8.5	6.2	0	054
08-031-0013	1	2	DENVER	DENVER CO	14TH AND ALBION ST. NJH-	96	001	8516	14.6	9.4	0	5.6	5.2	0	054
08-031-0013	1	2	DENVER	DENVER CO	14TH AND ALBION ST. NJH-	97	001	8690	11.6	10.6	0	4.8	4.7	0	054
08-031-0014	1	1	DENVER	DENVER CO	23 RD AND JULIAN_(CARRIA	93	001	8676	14.1	12.1	0	8.5	8.2	0	054
08-031-0014	1	1	DENVER	DENVER CO	23 RD AND JULIAN_(CARRIA	94	001	8543	11.2	10.9	0	9.3	7.3	0	054
08-031-0014	1	1	DENVER	DENVER CO	23 RD AND JULIAN_(CARRIA	95	001	8701	10.4	9.9	0	7.3	5.9	0	054
08-031-0014	1	1	DENVER	DENVER CO	23 RD AND JULIAN_(CARRIA	96	001	8736	9.1	8.2	0	7.3	5.7	0	054
08-031-0014	1	1	DENVER	DENVER CO	23 RD AND JULIAN_(CARRIA	97	001	8677	9.5	8.4	0	7.0	6.2	0	054

0 CARBON MONOXIDE (42101) COLORADO UNITS: 007 PPM
0 P

SITE ID	O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
008-031-0018	1	3	DENVER	DENVER CO	BLAKE ST. SIDE OF SPEER	93	001	1021	16.2	15.3	0	10.4	7.7	1	051
08-031-0018	1	3	DENVER	DENVER CO	BLAKE ST. SIDE OF SPEER	94	001	1591	12.2	11.6	0	7.8	6.5	0	051
08-031-0019	1	2	DENVER	DENVER CO	SPEER SIDE OF SPEER & AU	93	001	997	16.2	16.1	0	10.4	7.7	1	051
08-031-0019	1	2	DENVER	DENVER CO	SPEER SIDE OF SPEER & AU	94	001	3049	13.9	13.4	0	9.0	8.2	0	051
08-031-0019	1	2	DENVER	DENVER CO	SPEER SIDE OF SPEER & AU	95	001	3658	15.0	14.0	0	9.7	7.1	1	000
08-031-0019	1	2	DENVER	DENVER CO	SPEER SIDE OF SPEER & AU	96	001	8694	15.7	12.5	0	9.2	7.0	0	054
08-031-0019	1	2	DENVER	DENVER CO	SPEER SIDE OF SPEER & AU	97	001	8354	11.2	11.2	0	6.6	6.4	0	054
08-031-0020	1	3	DENVER	DENVER CO	935 COLORADO BLVD., UCHS	94	001	1370	12.8	11.7	0	7.6	6.8	0	054
08-031-0020	1	3	DENVER	DENVER CO	935 COLORADO BLVD., UCHS	95	001	2141	11.9	10.3	0	7.4	6.0	0	054
08-041-0004	1	2	COLORADO SPRING	EL PASO CO	712 S TEJON ST	93	001	8716	11.7	10.7	0	5.6	5.0	0	054
08-041-0004	1	2	COLORADO SPRING	EL PASO CO	712 S TEJON ST	94	001	8716	12.5	10.9	0	4.4	4.2	0	054
08-041-0004	1	2	COLORADO SPRING	EL PASO CO	712 S TEJON ST	95	001	8698	10.4	9.6	0	5.2	4.7	0	054
08-041-0004	1	2	COLORADO SPRING	EL PASO CO	712 S TEJON ST	96	001	8688	10.7	9.1	0	4.7	3.8	0	054
08-041-0004	1	2	COLORADO SPRING	EL PASO CO	712 S TEJON ST	97	001	4658	10.4	8.2	0	4.7	3.9	0	054
08-041-0006	1	2	COLORADO SPRING	EL PASO CO	UINTAH & I-25	93	001	8660	13.6	11.6	0	6.1	5.7	0	054
08-041-0006	1	2	COLORADO SPRING	EL PASO CO	UINTAH & I-25	94	001	8578	11.7	11.4	0	5.4	4.9	0	054
08-041-0006	1	2	COLORADO SPRING	EL PASO CO	UINTAH & I-25	95	001	8716	10.8	10.3	0	7.2	5.5	0	054
08-041-0006	1	2	COLORADO SPRING	EL PASO CO	UINTAH & I-25	96	001	8746	11.3	11.3	0	7.6	5.0	0	054
08-041-0006	1	2	COLORADO SPRING	EL PASO CO	UINTAH & I-25	97	001	8577	13.1	10.6	0	5.9	4.9	0	054
08-041-6004	1	3	COLORADO SPRING	EL PASO CO	6000 PULPIT ROCK DRIVE.	93	026	8341	4.1	3.9	0	2.1	1.8	0	048
08-041-6004	1	3	COLORADO SPRING	EL PASO CO	6000 PULPIT ROCK DRIVE.	94	026	8709	4.0	3.9	0	2.3	2.2	0	000
08-041-6004	1	3	COLORADO SPRING	EL PASO CO	6000 PULPIT ROCK DRIVE.	95	026	8724	4.2	3.8	0	2.3	2.3	0	093
08-041-6004	1	3	COLORADO SPRING	EL PASO CO	6000 PULPIT ROCK DRIVE.	96	026	8544	3.8	3.4	0	2.1	2.0	0	093
08-041-6005	1	3		EL PASO CO	4940 S. HIGHWAY 85/87	93	026	8508	7.0	7.0	0	4.5	3.8	0	048
08-041-6005	1	3		EL PASO CO	4940 S. HIGHWAY 85/87	94	026	8655	6.8	6.2	0	4.6	4.5	0	000
08-041-6005	1	3		EL PASO CO	4940 S. HIGHWAY 85/87	95	026	8515	5.9	5.6	0	3.2	3.1	0	093
08-041-6005	1	3		EL PASO CO	4940 S. HIGHWAY 85/87	96	026	3064	6.1	5.6	0	3.0	2.9	0	093
08-041-6006	1	3		EL PASO CO	9400 CHIPITA PARK ROAD	93	026	8257	2.0	1.8	0	1.1	1.0	0	048
08-041-6006	1	3		EL PASO CO	9400 CHIPITA PARK ROAD	94	026	7620	2.0	1.9	0	1.2	.9	0	000
08-041-6006	1	3		EL PASO CO	9400 CHIPITA PARK ROAD	95	026	7793	3.0	2.9	0	2.4	1.9	0	093
08-041-6006	1	3		EL PASO CO	9400 CHIPITA PARK ROAD	96	026	4148	2.1	2.1	0	1.8	1.8	0	093
08-041-6009	1	3		EL PASO CO	R.D.NIXON POWER PLANT EX	93	026	6003	1.9	1.7	0	1.0	.8	0	048
08-041-6009	1	3		EL PASO CO	R.D.NIXON POWER PLANT EX	94	026	8702	2.2	1.9	0	1.3	1.1	0	000
08-041-6009	1	3		EL PASO CO	R.D.NIXON POWER PLANT EX	95	026	8707	2.4	2.2	0	1.3	1.1	0	093
08-041-6009	1	3		EL PASO CO	R.D.NIXON POWER PLANT EX	96	026	4328	1.5	1.4	0	.8	.8	0	093
08-041-6011	1	3	COLORADO SPRING	EL PASO CO	130 WEST CACHE LA POUDRE	93	026	8584	8.7	7.9	0	4.5	3.9	0	048
08-041-6011	1	3	COLORADO SPRING	EL PASO CO	130 WEST CACHE LA POUDRE	94	026	8318	7.9	6.8	0	3.3	3.2	0	000
08-041-6011	1	3	COLORADO SPRING	EL PASO CO	130 WEST CACHE LA POUDRE	95	026	8500	7.4	7.0	0	4.0	3.7	0	093
08-041-6011	1	3	COLORADO SPRING	EL PASO CO	130 WEST CACHE LA POUDRE	96	026	8469	8.1	8.1	0	4.9	3.7	0	093
08-041-6013	1	3	COLORADO SPRING	EL PASO CO	1699 S. CORONA AVE	93	026	8619	11.0	10.1	0	5.3	4.7	0	054
08-041-6013	1	3	COLORADO SPRING	EL PASO CO	1699 S. CORONA AVE	94	026	8703	10.8	9.3	0	4.6	4.5	0	054
08-041-6013	1	3	COLORADO SPRING	EL PASO CO	1699 S. CORONA AVE	95	026	8429	9.4	8.7	0	5.0	4.0	0	093
08-041-6013	1	3	COLORADO SPRING	EL PASO CO	1699 S. CORONA AVE	96	026	4310	11.9	9.6	0	5.4	3.8	0	093
08-041-6016	1	3	COLORADO SPRING	EL PASO CO	3730 MEADOWLAND BLVD.	93	026	8593	15.1	14.2	0	6.5	5.9	0	054

0 CARBON MONOXIDE (42101) COLORADO UNITS: 007 PPM
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SITE ID	P O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
008-041-6016	1	3	COLORADO SPRING	EL PASO CO	3730 MEADOWLAND BLVD.	94	026	8574	16.6	14.5	0	4.9	4.7	0	054
08-041-6016	1	3	COLORADO SPRING	EL PASO CO	3730 MEADOWLAND BLVD.	95	026	8477	15.0	12.4	0	4.9	4.5	0	093

08-041-6016	1	3	COLORADO SPRING	EL PASO CO	3730 MEADOWLAND BLVD.	96	026	8682	11.0	11.0	0	4.6	4.0	0	093
08-059-0002	1	2	ARVADA	JEFFERSON CO	W 57TH AVENUE AND GARRIS	93	001	8723	11.2	10.4	0	5.1	4.9	0	054
08-059-0002	1	2	ARVADA	JEFFERSON CO	W 57TH AVENUE AND GARRIS	94	001	8525	10.8	10.0	0	5.2	5.0	0	054
08-059-0002	1	2	ARVADA	JEFFERSON CO	W 57TH AVENUE AND GARRIS	95	001	8680	11.9	8.9	0	5.1	4.6	0	054
08-059-0002	1	2	ARVADA	JEFFERSON CO	W 57TH AVENUE AND GARRIS	96	001	8724	7.9	7.2	0	4.3	4.3	0	054
08-059-0002	1	2	ARVADA	JEFFERSON CO	W 57TH AVENUE AND GARRIS	97	001	8697	9.2	7.7	0	5.1	4.9	0	054
08-069-1004	1	2	FORT COLLINS	LARIMER CO	708 S. MASON FT COLLINS	93	001	8698	17.3	13.8	0	7.4	6.6	0	054
08-069-1004	1	2	FORT COLLINS	LARIMER CO	708 S. MASON FT COLLINS	94	001	8703	13.6	12.1	0	7.3	6.0	0	054
08-069-1004	1	2	FORT COLLINS	LARIMER CO	708 S. MASON FT COLLINS	95	001	8699	10.6	9.8	0	5.6	5.2	0	054
08-069-1004	1	2	FORT COLLINS	LARIMER CO	708 S. MASON FT COLLINS	96	001	8597	12.7	10.9	0	5.5	5.1	0	054
08-069-1004	1	2	FORT COLLINS	LARIMER CO	708 S. MASON FT COLLINS	97	001	8708	10.3	9.2	0	5.3	5.2	0	054
08-077-0014	1	2	GRAND JUNCTION	MESA CO	STOCKER STADIUM (12TH &	93	001	8383	12.0	11.2	0	6.9	6.1	0	054
08-077-0014	1	2	GRAND JUNCTION	MESA CO	STOCKER STADIUM (12TH &	94	001	8367	11.6	11.6	0	7.5	6.0	0	054
08-077-0014	1	2	GRAND JUNCTION	MESA CO	STOCKER STADIUM (12TH &	95	001	8209	10.0	8.7	0	5.4	5.4	0	054
08-077-0014	1	2	GRAND JUNCTION	MESA CO	STOCKER STADIUM (12TH &	96	001	8754	10.5	10.5	0	7.5	5.8	0	054
08-077-0014	1	2	GRAND JUNCTION	MESA CO	STOCKER STADIUM (12TH &	97	001	8550	8.5	7.8	0	6.4	5.4	0	054
08-123-0007	1	2	GREELEY	WELD CO	811 15TH ST - GREELEY	93	001	8688	10.9	10.2	0	6.1	5.8	0	054
08-123-0007	1	2	GREELEY	WELD CO	811 15TH ST - GREELEY	94	001	8707	11.3	11.1	0	6.4	5.2	0	054
08-123-0007	1	2	GREELEY	WELD CO	811 15TH ST - GREELEY	95	001	8703	10.3	9.6	0	5.7	5.3	0	054
08-123-0007	1	2	GREELEY	WELD CO	811 15TH ST - GREELEY	96	001	8739	12.3	10.7	0	7.5	7.0	0	054
08-123-0007	1	2	GREELEY	WELD CO	811 15TH ST - GREELEY	97	001	8717	9.6	8.6	0	5.3	4.8	0	054

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1DATE 98/06/25                            EPA AEROMETRIC INFORMATION RETRIEVAL SYSTEM (AIRS)                              PAGE     1
 AMP450                                                  AIR QUALITY SUBSYSTEM
                                                           QUICK LOOK REPORT
0                               CARBON MONOXIDE (42101)
-METHODS:            CODE         COLLECTION METHOD                      ANALYSIS METHOD
                     ====     ==============================     ===================================
0                     000     MULTIPLE METHODS                   MULTIPLE METHODS
                      048     INSTRUMENTAL                       NON DISPERSIVE INFRA-RED
                      051     INSTRUMENTAL                       NON DISPERSIVE INFRA-RED
                      054     INSTRUMENTAL                       NON DISPERSIVE INFRA-RED
                      093     INSTRUMENTAL                       GAS FILTER COORELATION CO ANALYZER
1DATE 98/06/25                            EPA AEROMETRIC INFORMATION RETRIEVAL SYSTEM (AIRS)                              PAGE     1
 AMP217P                                                AIR QUALITY SUBSYSTEM
                                                AQ CLEANUP PROCESSING SUMMARY SHEET
-
-                                                                                                              REPORT
0                            *  *  * PROGRAM AMP217 TERMINATED SUCCESSFULLY ON 98/06/25 AT 09:40:17  *  *  *
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0 CARBON MONOXIDE (42101) CALIFORNIA UNITS: 007 PPM

SITE ID	P O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
006-001-0003	1	2	LIVERMORE	ALAMEDA	2614 OLD 1ST ST., LIVERM	95	004	8638	5.0	4.1	0	2.3	2.3	0	054
06-001-0003	1	2	LIVERMORE	ALAMEDA	2614 OLD 1ST ST., LIVERM	96	004	8516	4.9	4.7	0	2.5	2.4	0	054
06-001-0003	1	2	LIVERMORE	ALAMEDA	2614 OLD 1ST ST., LIVERM	97	004	8257	4.6	4.4	0	2.5	2.3	0	054
06-001-0005	1	2	OAKLAND	ALAMEDA	822 ALICE ST., OAKLAND	95	004	8680	4.9	4.8	0	3.8	3.7	0	008
06-001-0005	1	2	OAKLAND	ALAMEDA	822 ALICE ST., OAKLAND	96	004	8285	6.9	5.5	0	3.9	3.8	0	008
06-001-0005	1	2	OAKLAND	ALAMEDA	822 ALICE ST., OAKLAND	97	004	8592	7.9	6.0	0	3.6	3.6	0	008
06-001-1001	1	1	FREMONT	ALAMEDA	40733 CHAPEL WAY., FREMO	95	004	8544	5.5	5.2	0	2.9	2.7	0	054
06-001-1001	1	1	FREMONT	ALAMEDA	40733 CHAPEL WAY., FREMO	96	004	8496	6.2	5.4	0	3.4	3.3	0	054
06-001-1001	1	1	FREMONT	ALAMEDA	40733 CHAPEL WAY., FREMO	97	004	8342	6.0	5.1	0	3.0	3.0	0	054
06-005-0002	1	2	JACKSON	AMADOR	201 CLINTON ROAD, JACKS	95	001	8311	9.3	3.0	0	2.6	2.2	0	067
06-005-0002	1	2	JACKSON	AMADOR	201 CLINTON ROAD, JACKS	96	001	8301	2.2	2.2	0	1.5	1.4	0	067
06-005-0002	1	2	JACKSON	AMADOR	201 CLINTON ROAD, JACKS	97	001	8352	2.8	2.7	0	1.4	1.4	0	067
06-007-0002	1	2	CHICO	BUTTE	468 MANZANITA AVE, CHICO	95	001	8247	5.8	5.5	0	3.7	3.5	0	067
06-007-0002	1	2	CHICO	BUTTE	468 MANZANITA AVE, CHICO	96	001	8318	5.3	5.1	0	3.4	3.4	0	067
06-007-0002	1	2	CHICO	BUTTE	468 MANZANITA AVE, CHICO	97	001	8335	6.8	6.1	0	3.8	3.5	0	067
06-007-0005	1	2	CHICO	BUTTE	101 SALEM ST, CHICO	95	001	8741	8.5	7.6	0	4.8	4.7	0	067
06-007-0005	1	2	CHICO	BUTTE	101 SALEM ST, CHICO	96	001	8767	8.7	7.8	0	6.1	5.3	0	067
06-007-0005	1	2	CHICO	BUTTE	101 SALEM ST, CHICO	97	001	8580	7.0	6.6	0	5.1	4.5	0	067
06-009-0001	1	2	SAN ANDREAS	CALAVERAS	501 GOLD STRIKE ROAD, SA	95	001	8230	2.1	2.1	0	1.8	1.0	0	067
06-009-0001	1	2	SAN ANDREAS	CALAVERAS	501 GOLD STRIKE ROAD, SA	96	001	8097	1.7	1.6	0	.9	.8	0	067
06-009-0001	1	2	SAN ANDREAS	CALAVERAS	501 GOLD STRIKE ROAD, SA	97	001	8108	2.1	2.0	0	1.7	1.0	0	067
06-013-0002	1	1	CONCORD	CONTRA COSTA	2975 TREAT BLVD, CONCORD	95	004	8663	5.5	4.7	0	2.9	2.7	0	054
06-013-0002	1	1	CONCORD	CONTRA COSTA	2975 TREAT BLVD, CONCORD	96	004	8608	5.6	5.4	0	2.9	2.7	0	054
06-013-0002	1	1	CONCORD	CONTRA COSTA	2975 TREAT BLVD, CONCORD	97	004	8359	5.7	5.5	0	3.0	3.0	0	054
06-013-0003	1	2	RICHMOND	CONTRA COSTA	1144 13TH ST., RICHMOND	95	004	8632	6.5	4.8	0	2.4	2.3	0	054
06-013-0003	1	2	RICHMOND	CONTRA COSTA	1144 13TH ST., RICHMOND	96	004	8676	5.0	4.8	0	2.6	2.6	0	054
06-013-0003	1	2	RICHMOND	CONTRA COSTA	1144 13TH ST., RICHMOND	97	004	2963	4.6	3.7	0	2.6	2.3	0	054
06-013-1002	1	2	BETHEL ISLAND	CONTRA COSTA	5551 BETHEL ISLAND RD, B	95	004	8484	2.8	2.2	0	1.7	1.6	0	054
06-013-1002	1	2	BETHEL ISLAND	CONTRA COSTA	5551 BETHEL ISLAND RD, B	96	004	8540	2.7	1.7	0	1.4	1.4	0	054
06-013-1002	1	2	BETHEL ISLAND	CONTRA COSTA	5551 BETHEL ISLAND RD, B	97	004	8360	1.9	1.8	0	1.4	1.4	0	054
06-013-1003	1	2	SAN PABLO	CONTRA COSTA	UNIT 759 EL PORTAL SHOPP	97	004	5586	3.8	2.8	0	2.3	1.8	0	054
06-013-3001	1	2	PITTSBURG	CONTRA COSTA	583 W. 10TH ST., PITTSBU	95	004	8639	5.8	5.4	0	2.8	2.7	0	054
06-013-3001	1	2	PITTSBURG	CONTRA COSTA	583 W. 10TH ST., PITTSBU	96	004	8750	6.8	5.9	0	2.9	2.6	0	054
06-013-3001	1	2	PITTSBURG	CONTRA COSTA	583 W. 10TH ST., PITTSBU	97	004	8360	5.5	4.8	0	3.2	3.1	0	054
06-017-0005	1	2	SOUTH LAKE TAHO	EL DORADO	STATELINE-4045 HWY 50, S	95	001	8205	9.3	8.7	0	6.3	5.3	0	067
06-017-0005	1	2	SOUTH LAKE TAHO	EL DORADO	STATELINE-4045 HWY 50, S	96	001	8124	10.4	7.4	0	5.1	4.8	0	067
06-017-0005	1	2	SOUTH LAKE TAHO	EL DORADO	STATELINE-4045 HWY 50, S	97	001	7946	7.7	7.0	0	3.8	3.6	0	067
06-017-0010	1	2	PLACERVILLE	EL DORADO	3111 GOLD NUGGET WAY, P	95	001	8258	1.6	1.5	0	1.0	1.0	0	067
06-017-0010	1	2	PLACERVILLE	EL DORADO	3111 GOLD NUGGET WAY, P	96	001	8056	1.3	1.3	0	.9	.8	0	067
06-017-0010	1	2	PLACERVILLE	EL DORADO	3111 GOLD NUGGET WAY, P	97	001	8221	1.6	1.4	0	.8	.8	0	067
06-017-0011	1	2	SOUTH LAKE TAHO	EL DORADO	3337 SANDY WAY, SOUTH L	95	001	8223	5.2	4.5	0	2.6	2.4	0	067
06-017-0011	1	2	SOUTH LAKE TAHO	EL DORADO	3337 SANDY WAY, SOUTH L	96	001	8341	4.2	4.1	0	2.4	2.3	0	067
06-017-0011	1	2	SOUTH LAKE TAHO	EL DORADO	3337 SANDY WAY, SOUTH L	97	001	7993	3.2	3.1	0	2.4	2.2	0	067
06-019-0007	1	2	FRESNO	FRESNO	4706 E. DRUMMOND ST., FR	95	069	8159	6.4	6.3	0	4.8	4.7	0	011

0 CARBON MONOXIDE (42101) CALIFORNIA UNITS: 007 PPM
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SITE ID	O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
006-019-0007	1	2	FRESNO	FRESNO	4706 E. DRUMMOND ST., FR	96	069	8278	6.0	5.4	0	4.4	3.6	0	054
06-019-0007	1	2	FRESNO	FRESNO	4706 E. DRUMMOND ST., FR	97	069	8185	6.3	6.1	0	3.9	3.8	0	054
06-019-0008	1	2	FRESNO	FRESNO	3425 N FIRST ST, FRESNO	95	001	8177	10.3	9.5	0	7.3	6.3	0	067
06-019-0008	1	2	FRESNO	FRESNO	3425 N FIRST ST, FRESNO	96	001	8178	10.0	9.8	0	6.8	6.7	0	067
06-019-0008	1	2	FRESNO	FRESNO	3425 N FIRST ST, FRESNO	97	001	8240	8.7	8.3	0	5.7	5.1	0	067
06-019-0009	1	3	FRESNO	FRESNO	1145 FISHER STREET, FRES	95	001	4709	12.0	11.4	0	9.1	8.3	0	067
06-019-0009	1	3	FRESNO	FRESNO	1145 FISHER STREET, FRES	96	001	3570	10.1	8.5	0	6.8	5.7	0	067
06-019-0009	1	3	FRESNO	FRESNO	1145 FISHER STREET, FRES	97	001	4076	9.9	9.7	0	7.5	7.1	0	067
06-019-0242	1	2	FRESNO	FRESNO	SIERRA SKYPARK#2-BLYTHE	95	069	8258	3.8	3.3	0	2.5	2.3	0	011
06-019-0242	1	2	FRESNO	FRESNO	SIERRA SKYPARK#2-BLYTHE	96	069	8294	4.3	4.1	0	3.7	2.8	0	054
06-019-0242	1	2	FRESNO	FRESNO	SIERRA SKYPARK#2-BLYTHE	97	069	8210	4.1	3.9	0	2.8	2.2	0	054
06-019-5001	1	2	CLOVIS	FRESNO	908 N VILLA AVE, CLOVIS	95	069	8200	8.0	5.8	0	3.9	3.6	0	011
06-019-5001	1	2	CLOVIS	FRESNO	908 N VILLA AVE, CLOVIS	96	069	8281	6.3	6.1	0	3.5	3.5	0	054
06-019-5001	1	2	CLOVIS	FRESNO	908 N VILLA AVE, CLOVIS	97	069	8154	6.1	6.1	0	2.9	2.9	0	054
06-025-0005	1	2	CALEXICO	IMPERIAL	1029 ETHEL ST, CALEXICO	95	001	8289	32.0	29.8	0	22.9	19.7	15	067
06-025-0005	1	2	CALEXICO	IMPERIAL	1029 ETHEL ST, CALEXICO	96	001	8106	27.0	26.2	0	22.1	14.1	9	067
06-025-0005	1	2	CALEXICO	IMPERIAL	1029 ETHEL ST, CALEXICO	97	001	8306	24.0	21.8	0	17.8	16.7	12	067
06-025-0006	1	2	CALEXICO	IMPERIAL	CALEXICO - EAST	96	001	4392	22.0	18.0	0	8.7	7.8	0	067
06-025-0006	1	2	CALEXICO	IMPERIAL	CALEXICO - EAST	97	001	7771	21.0	20.6	0	16.3	9.6	2	067
06-025-1003	1	2	EL CENTRO	IMPERIAL	150 9TH ST., EL CENTRO	96	001	8784	12.0	10.0	0	6.8	6.8	0	011
06-025-1003	1	2	EL CENTRO	IMPERIAL	150 9TH ST., EL CENTRO	97	001	8702	6.0	6.0	0	3.7	3.5	0	011
06-027-0015	1	2	BISHOP	INYO	157 SHORT STREET, BISHOP	95	001	2240	4.0	4.0	0	2.0	1.8	0	011
06-029-0010	1	2	BAKERSFIELD	KERN	1128 GOLDEN STATE HIGHWA	95	069	8250	7.4	7.0	0	4.6	3.6	0	011
06-029-0010	1	2	BAKERSFIELD	KERN	1128 GOLDEN STATE HIGHWA	96	069	8138	6.2	5.6	0	3.7	3.6	0	054
06-029-0010	1	2	BAKERSFIELD	KERN	1128 GOLDEN STATE HIGHWA	97	069	8189	6.1	4.3	0	2.9	2.7	0	054
06-029-0014	1	2	BAKERSFIELD	KERN	5558 CALIFORNIA AVE, BAK	95	001	8162	7.8	7.2	0	6.2	4.9	0	067
06-029-0014	1	2	BAKERSFIELD	KERN	5558 CALIFORNIA AVE, BAK	96	001	7967	8.7	8.5	0	7.7	5.6	0	067
06-029-0014	1	2	BAKERSFIELD	KERN	5558 CALIFORNIA AVE, BAK	97	001	8035	5.2	5.2	0	3.4	3.2	0	067
06-037-0002	1	2	AZUSA	LOS ANGELES	803 N. LOREN AVE., AZUSA	95	061	8300	8.1	7.3	0	6.2	6.2	0	067
06-037-0002	1	2	AZUSA	LOS ANGELES	803 N. LOREN AVE., AZUSA	96	061	8025	6.1	5.9	0	4.1	3.9	0	067
06-037-0002	1	2	AZUSA	LOS ANGELES	803 N. LOREN AVE., AZUSA	97	061	8007	8.4	5.5	0	4.3	4.2	0	067
06-037-0113	1	2	WEST LOS ANGELE	LOS ANGELES	VA HOSPITAL, WEST LOS AN	95	061	7774	7.8	7.4	0	5.7	5.6	0	067
06-037-0113	1	2	WEST LOS ANGELE	LOS ANGELES	VA HOSPITAL, WEST LOS AN	96	061	8057	7.0	6.7	0	4.3	4.3	0	067
06-037-0113	1	2	WEST LOS ANGELE	LOS ANGELES	VA HOSPITAL, WEST LOS AN	97	061	8360	7.3	6.4	0	4.2	4.1	0	067
06-037-0206	1	3	DIAMOND BAR	LOS ANGELES	21865 E. COPLEY DR., DIA	95	061	8357	6.9	6.1	0	5.5	4.9	0	067
06-037-0206	1	3	DIAMOND BAR	LOS ANGELES	21865 E. COPLEY DR., DIA	96	061	3073	5.5	5.4	0	4.3	3.9	0	067
06-037-1002	1	2	BURBANK	LOS ANGELES	228 W. PALM AVE., BURBAN	95	061	8291	12.5	12.5	0	11.8	11.0	5	067
06-037-1002	1	2	BURBANK	LOS ANGELES	228 W. PALM AVE., BURBAN	96	061	7696	11.6	11.0	0	9.2	8.5	0	067
06-037-1002	1	2	BURBANK	LOS ANGELES	228 W. PALM AVE., BURBAN	97	061	8025	8.8	8.6	0	7.3	7.2	0	067
06-037-1103	1	2	LOS ANGELES	LOS ANGELES	1630 N MAIN ST, LOS ANGE	95	061	8165	9.7	9.2	0	8.4	7.9	0	067
06-037-1103	1	2	LOS ANGELES	LOS ANGELES	1630 N MAIN ST, LOS ANGE	96	061	8390	10.3	10.1	0	8.4	7.5	0	067
06-037-1103	1	2	LOS ANGELES	LOS ANGELES	1630 N MAIN ST, LOS ANGE	97	061	8292	8.9	8.7	0	7.8	5.9	0	067
06-037-1201	1	2	RESEDA	LOS ANGELES	18330 GAULT ST., RESEDA	95	061	7670	13.0	11.8	0	10.3	9.4	1	067
06-037-1201	1	2	RESEDA	LOS ANGELES	18330 GAULT ST., RESEDA	96	061	8012	10.2	10.2	0	8.7	6.7	0	067

SITE ID	P O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
006-037-1201	1	2	RESEDA	LOS ANGELES	18330 GAULT ST., RESEDA	97	061	8245	11.7	11.1	0	9.5	7.7	1	067
06-037-1301	1	1	LYNWOOD	LOS ANGELES	11220 LONG BEACH BLVD.,	95	061	8290	16.8	16.5	0	13.8	11.6	14	067

06-037-1301	1	1	LYNWOOD	LOS ANGELES	11220 LONG BEACH BLVD.,	96	061	8326	22.5	21.3	0	17.5	14.5	22	067
06-037-1301	1	1	LYNWOOD	LOS ANGELES	11220 LONG BEACH BLVD.,	97	061	8302	19.2	18.8	0	17.1	15.0	12	067
06-037-1601	1	2	PICO RIVERA	LOS ANGELES	3713 SAN GABRIEL RIVER P	95	061	8372	9.6	9.3	0	7.7	7.6	0	067
06-037-1601	1	2	PICO RIVERA	LOS ANGELES	3713 SAN GABRIEL RIVER P	96	061	8303	9.8	9.1	0	8.1	6.5	0	067
06-037-1601	1	2	PICO RIVERA	LOS ANGELES	3713 SAN GABRIEL RIVER P	97	061	7881	9.2	7.9	0	6.1	6.1	0	067
06-037-1701	1	2	POMONA	LOS ANGELES	924 N. GAREY AVE., POMON	95	061	8307	8.1	7.7	0	6.1	6.0	0	067
06-037-1701	1	2	POMONA	LOS ANGELES	924 N. GAREY AVE., POMON	96	061	8290	8.1	8.1	0	4.8	4.7	0	067
06-037-1701	1	2	POMONA	LOS ANGELES	924 N. GAREY AVE., POMON	97	061	8350	7.9	7.1	0	5.0	4.9	0	067
06-037-2005	1	2	PASADENA	LOS ANGELES	752 S. WILSON AVE., PASA	95	061	8387	11.4	11.4	0	9.1	8.6	0	067
06-037-2005	1	2	PASADENA	LOS ANGELES	752 S. WILSON AVE., PASA	96	061	8282	10.7	9.9	0	7.1	6.9	0	067
06-037-2005	1	2	PASADENA	LOS ANGELES	752 S. WILSON AVE., PASA	97	061	8250	8.1	7.7	0	6.0	5.4	0	067
06-037-4002	1	2	LONG BEACH	LOS ANGELES	3648 N. LONG BEACH BLVD.	95	061	8326	9.1	8.1	0	6.7	6.2	0	067
06-037-4002	1	2	LONG BEACH	LOS ANGELES	3648 N. LONG BEACH BLVD.	96	061	6015	9.7	9.2	0	6.8	6.5	0	067
06-037-4002	1	2	LONG BEACH	LOS ANGELES	3648 N. LONG BEACH BLVD.	97	061	8347	9.0	8.6	0	6.6	6.4	0	067
06-037-5001	1	2	HAWTHORNE	LOS ANGELES	5234 W. 120TH ST., HAWTH	95	061	8241	11.4	11.1	0	8.8	8.7	0	067
06-037-5001	1	2	HAWTHORNE	LOS ANGELES	5234 W. 120TH ST., HAWTH	96	061	8258	12.5	12.3	0	11.5	10.5	5	067
06-037-5001	1	2	HAWTHORNE	LOS ANGELES	5234 W. 120TH ST., HAWTH	97	061	8125	12.4	12.3	0	10.3	7.9	1	067
06-037-6002	1	2	SANTA CLARITA	LOS ANGELES	SAN FERNANDO RD, SANTA C	95	061	8241	6.7	6.5	0	4.1	3.8	0	067
06-037-6002	1	2	SANTA CLARITA	LOS ANGELES	SAN FERNANDO RD, SANTA C	96	061	8413	7.0	6.3	0	3.9	3.9	0	067
06-037-6002	1	2	SANTA CLARITA	LOS ANGELES	SAN FERNANDO RD, SANTA C	97	061	8289	7.4	7.0	0	6.7	6.5	0	067
06-037-9002	1	2	LANCASTER	LOS ANGELES	315 W. PONDERA ST., LANC	95	061	8383	7.5	6.8	0	5.1	4.5	0	067
06-037-9002	1	2	LANCASTER	LOS ANGELES	315 W. PONDERA ST., LANC	96	061	8406	6.8	6.4	0	4.7	4.6	0	067
06-037-9002	1	2	LANCASTER	LOS ANGELES	315 W. PONDERA ST., LANC	97	061	7759	5.9	5.5	0	4.0	4.0	0	067
06-041-0001	1	2	SAN RAFAEL	MARIN	534 4TH ST., SAN RAFAEL	95	004	8598	6.1	5.7	0	3.2	2.9	0	054
06-041-0001	1	2	SAN RAFAEL	MARIN	534 4TH ST., SAN RAFAEL	96	004	8527	7.1	6.9	0	4.0	3.4	0	054
06-041-0001	1	2	SAN RAFAEL	MARIN	534 4TH ST., SAN RAFAEL	97	004	8266	6.0	5.6	0	2.6	2.6	0	054
06-045-0008	1	2	UKIAH	MENDOCINO	306 E. GOBBI STREET, UK	95	001	7236	5.4	5.2	0	3.2	3.2	0	011
06-045-0008	1	2	UKIAH	MENDOCINO	306 E. GOBBI STREET, UK	96	001	4052	4.8	4.2	0	2.7	2.4	0	011
06-045-0008	1	2	UKIAH	MENDOCINO	306 E. GOBBI STREET, UK	97	001	8117	4.6	4.3	0	3.2	2.8	0	011
06-045-0009	1	2	WILLITS	MENDOCINO	899 SO MAIN STREET, WIL	95	001	7861	2.5	2.3	0	1.8	1.6	0	011
06-045-0009	1	2	WILLITS	MENDOCINO	899 SO MAIN STREET, WIL	96	001	2537	3.0	3.0	0	1.5	1.5	0	011
06-045-0009	1	2	WILLITS	MENDOCINO	899 SO MAIN STREET, WIL	97	001	7955	7.4	4.2	0	3.0	2.8	0	011
06-051-0001	1	2	MAMMOTH LAKES	MONO	GATEWAY HC., MAMMOTH LAK	95	001	8450	10.0	7.0	0	5.4	3.9	0	011
06-051-0001	1	2	MAMMOTH LAKES	MONO	GATEWAY HC., MAMMOTH LAK	96	001	7854	6.0	6.0	0	3.0	3.0	0	011
06-051-0001	1	2	MAMMOTH LAKES	MONO	GATEWAY HC., MAMMOTH LAK	97	001	8181	8.2	7.5	0	3.4	3.3	0	067
06-053-1002	1	2	SALINAS	MONTEREY	II-1270 NATIVIDAD RD, SA	95	011	7906	3.2	3.0	0	1.8	1.7	0	011
06-053-1002	1	2	SALINAS	MONTEREY	II-1270 NATIVIDAD RD, SA	96	011	8610	5.5	4.5	0	2.6	2.4	0	051
06-053-1002	1	2	SALINAS	MONTEREY	II-1270 NATIVIDAD RD, SA	97	011	8490	4.4	3.7	0	1.8	1.7	0	051
06-055-0003	1	2	NAPA	NAPA	2552 JEFFERSON AVE., NAP	95	004	8483	7.6	6.3	0	3.5	3.3	0	054
06-055-0003	1	2	NAPA	NAPA	2552 JEFFERSON AVE., NAP	96	004	8338	5.6	5.3	0	3.8	3.8	0	054
06-055-0003	1	2	NAPA	NAPA	2552 JEFFERSON AVE., NAP	97	004	8319	5.7	5.3	0	3.9	3.9	0	054
06-059-0001	1	1	ANAHEIM	ORANGE	1610 S. HARBOR BLVD., AN	95	061	8259	9.9	9.8	0	8.0	7.3	0	067

1DATE 99/03/09 EPA AEROMETRIC INFORMATION RETRIEVAL SYSTEM (AIRS) PAGE 4
AMP450
AIR QUALITY SUBSYSTEM
QUICK LOOK REPORT
0 CARBON MONOXIDE (42101) CALIFORNIA UNITS: 007 PPM
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SITE ID	POC	MT	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
006-059-0001	1	1	ANAHEIM	ORANGE	1610 S. HARBOR BLVD., AN	96	061	8298	8.9	8.9	0	7.4	6.1	0	067
06-059-0001	1	1	ANAHEIM	ORANGE	1610 S. HARBOR BLVD., AN	97	061	8354	8.4	8.2	0	5.7	5.4	0	067
06-059-1003	1	2	COSTA MESA	ORANGE	2850 MESA VERDE DR EAST,	95	061	8213	7.9	7.5	0	6.5	5.3	0	067
06-059-1003	1	2	COSTA MESA	ORANGE	2850 MESA VERDE DR EAST,	96	061	8191	8.7	8.6	0	7.2	6.6	0	067
06-059-1003	1	2	COSTA MESA	ORANGE	2850 MESA VERDE DR EAST,	97	061	8325	7.3	7.1	0	5.9	5.0	0	067
06-059-2001	1	2	EL TORO	ORANGE	23022 EL TORO RD., EL TO	95	061	8321	6.2	6.0	0	4.0	3.9	0	067
06-059-2001	1	2	EL TORO	ORANGE	23022 EL TORO RD., EL TO	96	061	8400	6.2	6.0	0	4.1	4.0	0	067

06-059-2001	1	2	EL TORO	ORANGE	23022 EL TORO RD., EL TO	97	061	8385	5.5	4.6	0	3.8	3.0	0	067
06-059-5001	1	2	LA HABRA	ORANGE	621 W. LAMBERT, LA HABRA	95	061	8363	12.7	11.5	0	6.5	6.4	0	067
06-059-5001	1	2	LA HABRA	ORANGE	621 W. LAMBERT, LA HABRA	96	061	8345	12.9	12.0	0	6.9	6.3	0	067
06-059-5001	1	2	LA HABRA	ORANGE	621 W. LAMBERT, LA HABRA	97	061	8230	11.9	11.0	0	5.7	5.7	0	067
06-061-0005	1	2	TAHOE CITY	PLACER	165 RIVER ROAD, TAHOE C	95	001	4236	9.5	9.0	0	2.9	2.6	0	008
06-061-0006	1	2	ROSEVILLE	PLACER	151 NO SUNRISE BLVD, RO	95	001	8304	3.9	3.5	0	2.2	2.1	0	067
06-061-0006	1	2	ROSEVILLE	PLACER	151 NO SUNRISE BLVD, RO	96	001	8358	4.5	4.0	0	2.8	2.3	0	067
06-061-0006	1	2	ROSEVILLE	PLACER	151 NO SUNRISE BLVD, RO	97	001	8273	3.7	3.5	0	2.1	2.1	0	067
06-061-3001	1	2	ROCKLIN	PLACER	5000 ROCKLIN ROAD, ROCKL	95	001	8289	2.9	2.8	0	1.6	1.4	0	067
06-061-3001	1	2	ROCKLIN	PLACER	5000 ROCKLIN ROAD, ROCKL	96	001	3173	3.1	2.8	0	1.4	1.4	0	067
06-065-1003	1	1	RIVERSIDE	RIVERSIDE	7002 MAGNOLIA AVE., RIVE	95	061	8432	9.0	9.0	0	6.3	5.8	0	067
06-065-1003	1	1	RIVERSIDE	RIVERSIDE	7002 MAGNOLIA AVE., RIVE	96	061	8404	9.1	8.2	0	5.3	5.0	0	067
06-065-1003	1	1	RIVERSIDE	RIVERSIDE	7002 MAGNOLIA AVE., RIVE	97	061	8345	10.7	9.3	0	5.5	4.8	0	067
06-065-5001	1	2	PALM SPRINGS	RIVERSIDE	FS-590 RACQUET CLUB AVE,	95	061	8258	3.3	3.1	0	1.5	1.5	0	067
06-065-5001	1	2	PALM SPRINGS	RIVERSIDE	FS-590 RACQUET CLUB AVE,	96	061	8030	3.2	3.0	0	1.6	1.3	0	067
06-065-5001	1	2	PALM SPRINGS	RIVERSIDE	FS-590 RACQUET CLUB AVE,	97	061	8170	2.7	2.4	0	1.3	1.3	0	067
06-065-8001	1	2	RUBIDOUX	RIVERSIDE	5888 MISSION BLVD., RUBI	95	061	8374	6.8	6.7	0	5.7	5.2	0	067
06-065-8001	1	2	RUBIDOUX	RIVERSIDE	5888 MISSION BLVD., RUBI	96	061	8311	8.5	7.4	0	5.1	4.6	0	067
06-065-8001	1	2	RUBIDOUX	RIVERSIDE	5888 MISSION BLVD., RUBI	97	061	7057	6.6	6.2	0	5.6	5.1	0	067
06-067-0002	1	3	NORTH HIGHLANDS	SACRAMENTO	7823 BLACKFOOT WAY, NORT	95	001	8068	5.1	4.8	0	3.4	3.3	0	066
06-067-0002	1	3	NORTH HIGHLANDS	SACRAMENTO	7823 BLACKFOOT WAY, NORT	96	001	8254	5.2	4.8	0	3.3	3.2	0	066
06-067-0002	1	3	NORTH HIGHLANDS	SACRAMENTO	7823 BLACKFOOT WAY, NORT	97	001	7964	5.6	5.1	0	3.6	3.2	0	066
06-067-0006	1	2	SACRAMENTO	SACRAMENTO	DEL PASO-2701 AVALON DR,	95	001	8081	7.6	7.0	0	6.7	5.4	0	066
06-067-0006	1	2	SACRAMENTO	SACRAMENTO	DEL PASO-2701 AVALON DR,	96	001	8302	6.7	6.7	0	6.0	5.0	0	000
06-067-0006	1	2	SACRAMENTO	SACRAMENTO	DEL PASO-2701 AVALON DR,	97	001	8037	8.1	7.2	0	6.0	5.7	0	066
06-067-0007	1	1	SACRAMENTO	SACRAMENTO	3535 EL CAMINO & WATT, S	95	001	8692	8.0	7.7	0	7.4	6.5	0	011
06-067-0007	1	1	SACRAMENTO	SACRAMENTO	3535 EL CAMINO & WATT, S	96	001	8506	8.5	8.4	0	7.2	7.1	0	066
06-067-0007	1	1	SACRAMENTO	SACRAMENTO	3535 EL CAMINO & WATT, S	97	001	8577	9.5	9.0	0	7.2	6.7	0	066
06-067-0010	1	2	SACRAMENTO	SACRAMENTO	1309 T ST., SACRAMENTO,	95	001	8303	9.8	9.6	0	6.6	6.3	0	067
06-067-0010	1	2	SACRAMENTO	SACRAMENTO	1309 T ST., SACRAMENTO,	96	001	8350	8.7	8.1	0	6.8	6.8	0	067
06-067-0010	1	2	SACRAMENTO	SACRAMENTO	1309 T ST., SACRAMENTO,	97	001	8161	7.6	7.4	0	6.0	5.5	0	067
06-067-5002	1	2	SACRAMENTO	SACRAMENTO	7926 EARHART DR., SACRAM	95	001	7148	8.0	7.0	0	4.3	4.3	0	066
06-067-5002	1	2	SACRAMENTO	SACRAMENTO	7926 EARHART DR., SACRAM	96	001	8014	3.5	3.3	0	2.2	2.2	0	066
06-067-5002	1	2	SACRAMENTO	SACRAMENTO	7926 EARHART DR., SACRAM	97	001	6774	3.1	2.9	0	2.0	2.0	0	066
06-071-0001	1	2	BARSTOW	SAN BERNARDINO	200 E. BUENA VISTA, BARS	95	014	7114	6.1	3.1	0	2.1	2.1	0	011
06-071-0001	1	2	BARSTOW	SAN BERNARDINO	200 E. BUENA VISTA, BARS	96	014	8071	3.8	3.7	0	2.3	2.1	0	000
06-071-0001	1	2	BARSTOW	SAN BERNARDINO	200 E. BUENA VISTA, BARS	97	014	7712	2.8	2.5	0	1.6	1.5	0	093

0 CARBON MONOXIDE (42101) CALIFORNIA UNITS: 007 PPM

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SITE ID	P O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
006-071-0012	1	3	PHELAN	SAN BERNARDINO	BEEKLEY & PHELAN RDS, PH	95	001	6338	1.7	1.7	0	1.5	1.3	0	011
06-071-0012	1	3	PHELAN	SAN BERNARDINO	BEEKLEY & PHELAN RDS, PH	96	001	4543	2.9	1.5	0	1.3	1.0	0	041
06-071-0014	1	2	VICTORVILLE	SAN BERNARDINO	14029 AMARGOSA ROAD, VIC	95	014	2812	3.1	3.1	0	2.7	2.4	0	011
06-071-0014	1	2	VICTORVILLE	SAN BERNARDINO	14029 AMARGOSA ROAD, VIC	96	014	5686	8.4	8.2	0	7.5	6.6	0	000
06-071-0014	1	2	VICTORVILLE	SAN BERNARDINO	14029 AMARGOSA ROAD, VIC	97	014	8082	4.1	3.8	0	3.1	2.3	0	093
06-071-0017	1	2	TWENTYNINE PALM	SAN BERNARDINO	6136 ADOBE ROAD, TWENTY	95	014	2876	5.0	3.3	0	2.0	1.8	0	011
06-071-0017	1	2	TWENTYNINE PALM	SAN BERNARDINO	6136 ADOBE ROAD, TWENTY	96	014	7695	1.9	1.8	0	1.3	1.2	0	008
06-071-0017	1	2	TWENTYNINE PALM	SAN BERNARDINO	6136 ADOBE ROAD, TWENTY	97	014	2996	2.0	1.6	0	1.0	.9	0	008
06-071-0217	1	3	MOUNT BALDY	SAN BERNARDINO	6945 MT BALDY ROAD	97	001	1779	1.4	.8	0	.5	.3	0	067
06-071-4001	1	2	HESPERIA	SAN BERNARDINO	17288 OLIVE ST., HESPERI	95	014	8032	3.1	3.0	0	2.1	2.0	0	011
06-071-4001	1	2	HESPERIA	SAN BERNARDINO	17288 OLIVE ST., HESPERI	96	014	8265	3.9	3.5	0	2.2	2.1	0	041
06-071-4001	1	2	HESPERIA	SAN BERNARDINO	17288 OLIVE ST., HESPERI	97	014	8115	3.4	3.4	0	2.6	2.3	0	041

SITE ID	P O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
06-071-9004	1	1	SAN BERNARDINO	SAN BERNARDINO	24302 4TH ST., SAN BERNA	95	061	8322	7.7	7.4	0	6.3	5.9	0	067
06-071-9004	1	1	SAN BERNARDINO	SAN BERNARDINO	24302 4TH ST., SAN BERNA	96	061	8260	5.8	5.8	0	4.5	4.3	0	067
06-071-9004	1	1	SAN BERNARDINO	SAN BERNARDINO	24302 4TH ST., SAN BERNA	97	061	7312	7.6	7.0	0	5.9	5.4	0	067
06-073-0001	1	1	CHULA VISTA	SAN DIEGO	80 E. "J" ST., CHULA VIS	95	036	8473	5.4	5.0	0	3.8	3.3	0	066
06-073-0001	1	1	CHULA VISTA	SAN DIEGO	80 E. "J" ST., CHULA VIS	96	036	8273	5.7	5.5	0	3.4	3.4	0	066
06-073-0001	1	1	CHULA VISTA	SAN DIEGO	80 E. "J" ST., CHULA VIS	97	036	8297	5.4	5.3	0	3.8	2.8	0	066
06-073-0003	1	2	EL CAJON	SAN DIEGO	1155 REDWOOD AVE., EL CA	95	036	8283	6.1	5.4	0	3.4	3.4	0	066
06-073-0003	1	2	EL CAJON	SAN DIEGO	1155 REDWOOD AVE., EL CA	96	036	8273	6.3	5.9	0	4.0	3.9	0	066
06-073-0003	1	2	EL CAJON	SAN DIEGO	1155 REDWOOD AVE., EL CA	97	036	8173	5.6	5.5	0	4.3	3.9	0	066
06-073-0005	1	2	OCEANSIDE	SAN DIEGO	1701 MISSION AVE., OCEAN	95	036	8552	4.4	4.4	0	3.1	3.1	0	066
06-073-0005	1	2	OCEANSIDE	SAN DIEGO	1701 MISSION AVE., OCEAN	96	036	8592	4.0	3.6	0	2.6	2.5	0	066
06-073-0005	1	2	OCEANSIDE	SAN DIEGO	1701 MISSION AVE., OCEAN	97	036	8599	6.1	6.0	0	2.9	2.7	0	066
06-073-0006	1	2	SAN DIEGO	SAN DIEGO	5555 OVERLAND AVE., SAN	95	036	8356	4.8	4.5	0	3.5	3.5	0	066
06-073-0006	1	2	SAN DIEGO	SAN DIEGO	5555 OVERLAND AVE., SAN	96	036	7829	4.6	4.5	0	3.3	3.1	0	066
06-073-0006	1	2	SAN DIEGO	SAN DIEGO	5555 OVERLAND AVE., SAN	97	036	8531	5.8	5.0	0	3.0	2.8	0	066
06-073-0007	1	1	SAN DIEGO	SAN DIEGO	1133 UNION ST., SAN DIEG	95	036	7880	8.5	8.2	0	5.5	5.0	0	066
06-073-0007	1	1	SAN DIEGO	SAN DIEGO	1133 UNION ST., SAN DIEG	96	036	8685	10.0	9.7	0	6.3	6.0	0	066
06-073-0007	1	1	SAN DIEGO	SAN DIEGO	1133 UNION ST., SAN DIEG	97	036	8714	7.7	7.0	0	5.3	4.7	0	066
06-073-1002	1	2	ESCONDIDO	SAN DIEGO	600 E. VALLEY PKWY., ESC	95	036	8460	9.9	9.9	0	6.0	5.5	0	088
06-073-1002	1	2	ESCONDIDO	SAN DIEGO	600 E. VALLEY PKWY., ESC	96	036	8590	11.2	11.1	0	7.1	6.0	0	088
06-073-1002	1	2	ESCONDIDO	SAN DIEGO	600 E. VALLEY PKWY., ESC	97	036	8572	9.3	9.3	0	4.9	4.7	0	088
06-073-1007	1	2	SAN DIEGO	SAN DIEGO	330A 12TH AVE., SAN DIEG	95	036	8565	8.0	7.5	0	5.9	5.4	0	066
06-073-1007	1	2	SAN DIEGO	SAN DIEGO	330A 12TH AVE., SAN DIEG	96	036	8320	7.9	7.7	0	5.4	4.6	0	066
06-073-1007	1	2	SAN DIEGO	SAN DIEGO	330A 12TH AVE., SAN DIEG	97	036	8205	7.5	6.9	0	5.4	4.9	0	066
06-073-2007	1	2	OTAY MESA	SAN DIEGO	1100 PASEO INTERNATIONAL	95	036	8292	8.5	7.7	0	6.3	4.5	0	066
06-073-2007	1	2	OTAY MESA	SAN DIEGO	1100 PASEO INTERNATIONAL	96	036	8278	12.4	9.8	0	5.8	4.8	0	066
06-073-2007	1	2	OTAY MESA	SAN DIEGO	1100 PASEO INTERNATIONAL	97	036	8263	7.7	7.4	0	4.6	4.2	0	066
06-075-0003	1	1	SAN FRANCISCO	SAN FRANCISCO	939 ELLIS ST., SAN FRANC	95	004	8658	8.5	7.9	0	5.3	5.0	0	054
06-075-0003	1	1	SAN FRANCISCO	SAN FRANCISCO	939 ELLIS ST., SAN FRANC	96	004	8699	8.6	7.6	0	5.6	5.1	0	054
06-075-0003	1	1	SAN FRANCISCO	SAN FRANCISCO	939 ELLIS ST., SAN FRANC	97	004	8670	8.0	7.4	0	5.7	3.9	0	054
06-075-0005	1	2	SAN FRANCISCO	SAN FRANCISCO	10 ARKANSAS ST., SAN FRA	95	004	8640	5.3	5.2	0	4.4	3.2	0	054
06-075-0005	1	2	SAN FRANCISCO	SAN FRANCISCO	10 ARKANSAS ST., SAN FRA	96	004	8503	5.4	5.3	0	3.8	3.7	0	054

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SITE ID	P O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
006-075-0005	1	2	SAN FRANCISCO	SAN FRANCISCO	10 ARKANSAS ST., SAN FRA	97	004	8334	4.8	4.6	0	3.5	3.1	0	054
06-077-0008	1	3	STOCKTON	SAN JOAQUIN	4310 CLAREMONT, STOCKTON	95	001	8078	8.7	8.5	0	6.2	5.2	0	067
06-077-0008	1	3	STOCKTON	SAN JOAQUIN	4310 CLAREMONT, STOCKTON	96	001	7905	11.0	11.0	0	7.6	6.7	0	067
06-077-0008	1	3	STOCKTON	SAN JOAQUIN	4310 CLAREMONT, STOCKTON	97	001	7642	6.3	6.2	0	4.2	3.9	0	067
06-077-1002	1	2	STOCKTON	SAN JOAQUIN	HAZELTON-HD, STOCKTON	95	001	8228	10.3	9.6	0	4.5	4.4	0	054
06-077-1002	1	2	STOCKTON	SAN JOAQUIN	HAZELTON-HD, STOCKTON	96	001	8288	9.4	8.7	0	6.4	5.3	0	054
06-077-1002	1	2	STOCKTON	SAN JOAQUIN	HAZELTON-HD, STOCKTON	97	001	8046	7.7	6.1	0	3.6	3.4	0	054
06-079-2002	1	2	SAN LUIS OBISPO	SAN LUIS OBISPO	1160 MARSH ST., SAN LUIS	95	001	8363	5.7	5.7	0	3.1	2.4	0	067
06-079-2002	1	2	SAN LUIS OBISPO	SAN LUIS OBISPO	1160 MARSH ST., SAN LUIS	96	001	8385	5.0	4.9	0	2.9	2.3	0	067
06-079-2002	1	2	SAN LUIS OBISPO	SAN LUIS OBISPO	1160 MARSH ST., SAN LUIS	97	001	8362	6.4	6.3	0	2.6	2.3	0	067
06-081-1001	1	2	REDWOOD CITY	SAN MATEO	897 BARRON AVE., REDWOOD	95	004	8677	10.1	9.3	0	3.9	3.5	0	054
06-081-1001	1	2	REDWOOD CITY	SAN MATEO	897 BARRON AVE., REDWOOD	96	004	8485	8.6	7.5	0	3.6	3.4	0	054
06-081-1001	1	2	REDWOOD CITY	SAN MATEO	897 BARRON AVE., REDWOOD	97	004	8343	10.7	7.1	0	4.2	3.8	0	054
06-083-0010	1	2	SANTA BARBARA	SANTA BARBARA	3 W. CARRILLO ST., SANTA	95	001	8154	7.8	7.7	0	5.8	4.9	0	067
06-083-0010	1	2	SANTA BARBARA	SANTA BARBARA	3 W. CARRILLO ST., SANTA	96	001	8320	12.6	8.0	0	4.9	4.5	0	067
06-083-0010	1	2	SANTA BARBARA	SANTA BARBARA	3 W. CARRILLO ST., SANTA	97	001	8240	8.2	8.1	0	4.1	3.8	0	067
06-083-1025	1	4	CAPITAN	SANTA BARBARA	LFC #1-LAS FLORES CANYON	95	909	7823	1.0	1.0	0	1.0	.9	0	054

06-083-1025	1	4	CAPITAN	SANTA BARBARA	LFC #1-LAS FLORES CANYON	96	909	7893	1.3	1.2	0	.9	.8	0	054
06-083-1025	1	4	CAPITAN	SANTA BARBARA	LFC #1-LAS FLORES CANYON	97	909	8164	1.2	.9	0	.7	.7	0	054
06-083-2004	1	2	LOMPOC	SANTA BARBARA	128 S 'H' ST, LOMPOC	95	017	8296	3.7	3.4	0	1.7	1.4	0	051
06-083-2004	1	2	LOMPOC	SANTA BARBARA	128 S 'H' ST, LOMPOC	96	017	8240	3.6	3.4	0	1.9	1.5	0	000
06-083-2004	1	2	LOMPOC	SANTA BARBARA	128 S 'H' ST, LOMPOC	97	017	8201	3.6	3.4	0	2.0	1.5	0	054
06-083-2011	1	2	GOLETA	SANTA BARBARA	380 N FAIRVIEW AVENUE, G	95	017	8269	4.0	3.7	0	1.8	1.7	0	041
06-083-2011	1	2	GOLETA	SANTA BARBARA	380 N FAIRVIEW AVENUE, G	96	017	7612	3.4	3.0	0	1.6	1.5	0	041
06-083-2011	1	2	GOLETA	SANTA BARBARA	380 N FAIRVIEW AVENUE, G	97	017	8275	3.5	3.5	0	2.0	1.6	0	041
06-083-4003	1	4	VANDENBERG AFB	SANTA BARBARA	STS POWER PLANT, VANDENB	95	046	4804	2.4	1.6	0	1.2	1.2	0	067
06-083-4003	1	4	VANDENBERG AFB	SANTA BARBARA	STS POWER PLANT, VANDENB	96	046	8072	1.4	.9	0	.7	.6	0	067
06-083-4003	1	4	VANDENBERG AFB	SANTA BARBARA	STS POWER PLANT, VANDENB	97	046	7916	1.1	1.0	0	.5	.5	0	067
06-083-5001	1	4	VANDENBERG AFB	SANTA BARBARA	WATT RD, VANDENBERG AFB	95	046	5234	2.2	2.1	0	1.9	1.4	0	051
06-083-5001	1	4	VANDENBERG AFB	SANTA BARBARA	WATT RD, VANDENBERG AFB	96	046	8202	.7	.7	0	.6	.6	0	051
06-083-5001	1	4	VANDENBERG AFB	SANTA BARBARA	WATT RD, VANDENBERG AFB	97	046	1344	.8	.7	0	.7	.5	0	051
06-085-0002	1	2	GILROY	SANTA CLARA	9TH & PRINCEVILLE, GILRO	95	004	1753	3.6	3.5	0	2.0	1.9	0	054
06-085-0004	1	1	SAN JOSE	SANTA CLARA	120B N 4TH ST, SAN JOSE	95	004	8339	8.9	8.3	0	5.8	5.8	0	054
06-085-0004	1	1	SAN JOSE	SANTA CLARA	120B N 4TH ST, SAN JOSE	96	004	8366	8.8	8.6	0	7.0	5.8	0	054
06-085-0004	1	1	SAN JOSE	SANTA CLARA	120B N 4TH ST, SAN JOSE	97	004	8316	9.9	8.5	0	6.1	5.6	0	054
06-085-0004	2	2	SAN JOSE	SANTA CLARA	120B N 4TH ST, SAN JOSE	95	004	8154	8.6	8.0	0	5.4	5.4	0	054
06-085-0004	2	2	SAN JOSE	SANTA CLARA	120B N 4TH ST, SAN JOSE	96	004	8277	8.4	8.3	0	6.5	5.5	0	054
06-085-0004	2	2	SAN JOSE	SANTA CLARA	120B N 4TH ST, SAN JOSE	97	004	8309	9.1	8.1	0	5.8	5.1	0	054
06-085-2004	1	2	SAN JOSE	SANTA CLARA	1866 W SAN CARLOS ST, SA	95	004	2520	7.3	6.4	0	3.9	3.7	0	054
06-087-0003	1	3	DAVENPORT	SANTA CRUZ	FIRE DEPT, DAVENPORT	95	011	7744	1.4	1.1	0	.9	.8	0	011
06-087-0003	1	3	DAVENPORT	SANTA CRUZ	FIRE DEPT, DAVENPORT	96	011	8355	3.0	3.0	0	.9	.7	0	051
06-087-0003	1	3	DAVENPORT	SANTA CRUZ	FIRE DEPT, DAVENPORT	97	011	8329	.9	.8	0	.7	.7	0	051
06-095-0004	1	2	VALLEJO	SOLANO	304 TUOLUMNE ST., VALLEJ	95	004	8491	7.0	6.8	0	5.3	5.1	0	054
06-095-0004	1	2	VALLEJO	SOLANO	304 TUOLUMNE ST., VALLEJ	96	004	8435	6.4	6.2	0	4.9	4.5	0	054

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SITE ID	P O C	M T	CITY	COUNTY	ADDRESS	YR	REP ORG	#OBS	MAX 1-HR 1ST	MAX 1-HR 2ND	OBS> 35	MAX 8-HR 1ST	MAX 8-HR 2ND	OBS> 9	METH
006-095-0004	1	2	VALLEJO	SOLANO	304 TUOLUMNE ST., VALLEJ	97	004	8329	6.5	6.3	0	4.9	4.9	0	054
06-097-0003	1	2	SANTA ROSA	SONOMA	837 5TH ST., SANTA ROSA	95	004	8700	4.9	4.2	0	2.8	2.4	0	054
06-097-0003	1	2	SANTA ROSA	SONOMA	837 5TH ST., SANTA ROSA	96	004	8201	5.6	4.4	0	3.0	3.0	0	054
06-097-0003	1	2	SANTA ROSA	SONOMA	837 5TH ST., SANTA ROSA	97	004	8264	5.4	5.0	0	3.3	3.1	0	054
06-099-0005	1	2	MODESTO	STANISLAUS	814 14TH ST., MODESTO	95	001	8308	11.4	9.5	0	5.7	5.4	0	067
06-099-0005	1	2	MODESTO	STANISLAUS	814 14TH ST., MODESTO	96	001	8311	9.2	9.0	0	6.5	5.6	0	067
06-099-0005	1	2	MODESTO	STANISLAUS	814 14TH ST., MODESTO	97	001	8316	7.1	7.1	0	5.0	4.2	0	067
06-099-0006	1	2	TURLOCK	STANISLAUS	900 S MINARET STREET, T	95	069	8243	4.1	4.0	0	3.4	3.0	0	011
06-099-0006	1	2	TURLOCK	STANISLAUS	900 S MINARET STREET, T	96	069	8301	5.1	5.0	0	3.2	3.0	0	054
06-099-0006	1	2	TURLOCK	STANISLAUS	900 S MINARET STREET, T	97	069	7607	5.2	4.9	0	3.9	3.2	0	054
06-101-0003	1	2	YUBA CITY	SUTTER	773 ALMOND ST, YUBA CITY	95	001	8207	7.5	6.9	0	4.7	4.1	0	067
06-101-0003	1	2	YUBA CITY	SUTTER	773 ALMOND ST, YUBA CITY	96	001	8325	7.7	6.9	0	4.7	4.1	0	067
06-101-0003	1	2	YUBA CITY	SUTTER	773 ALMOND ST, YUBA CITY	97	001	8205	6.1	6.0	0	4.1	3.9	0	067
06-107-2002	1	2	VISALIA	TULARE	310 N CHURCH ST, VISALIA	95	001	8002	9.3	9.2	0	4.4	4.2	0	054
06-107-2002	1	2	VISALIA	TULARE	310 N CHURCH ST, VISALIA	96	001	8210	5.3	5.1	0	4.0	3.9	0	054
06-107-2002	1	2	VISALIA	TULARE	310 N CHURCH ST, VISALIA	97	001	8294	7.3	6.8	0	4.1	3.5	0	054
06-109-0005	1	2	SONORA	TUOLUMNE	251 S BARRETTA, SONORA,	95	001	8229	3.9	3.9	0	3.4	2.6	0	067
06-109-0005	1	2	SONORA	TUOLUMNE	251 S BARRETTA, SONORA,	96	001	8337	4.5	4.1	0	2.6	2.5	0	067
06-109-0005	1	2	SONORA	TUOLUMNE	251 S BARRETTA, SONORA,	97	001	8318	6.6	3.2	0	1.9	1.9	0	067
06-111-2002	1	2	SIMI VALLEY	VENTURA	5400 COCHRAN STREET, SIM	95	019	7766	8.9	7.5	0	4.3	3.9	0	067
06-111-2002	1	2	SIMI VALLEY	VENTURA	5400 COCHRAN STREET, SIM	96	019	8005	7.8	6.7	0	3.4	3.3	0	067
06-111-2002	1	2	SIMI VALLEY	VENTURA	5400 COCHRAN STREET, SIM	97	019	8114	7.4	7.1	0	3.8	3.2	0	000

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 06-111-3001 1 2 EL RIO        VENTURA        RIO MESA SCHOOL, EL RIO  95 019 7741   2.9     2.8       0   2.4     2.4        0   051
 06-111-3001 1 2 EL RIO        VENTURA        RIO MESA SCHOOL, EL RIO  96 019 8235   2.2     2.0       0   1.5     1.4        0   051
 06-111-3001 1 2 EL RIO        VENTURA        RIO MESA SCHOOL, EL RIO  97 019 8065   2.6     2.2       0   1.9     1.5        0   067
 06-113-0004 1 3 DAVIS         YOLO           UC DAVIS-CAMPUS, DAVIS   96 001 4908   2.4     2.2       0   1.8     1.3        0   067
 06-113-0004 1 3 DAVIS         YOLO           UC DAVIS-CAMPUS, DAVIS   97 001 8285   2.8     2.7       0   1.8     1.5        0   067
 06-113-0006 1 2 DAVIS         YOLO           23 RUSSEL BLVD, DAVIS    95 001 1416   5.3     5.3       0   3.1     2.9        0   011

1DATE 99/03/09                          EPA AEROMETRIC INFORMATION RETRIEVAL SYSTEM (AIRS)                          PAGE     1
 AMP450                                                AIR QUALITY SUBSYSTEM
                                                         QUICK LOOK REPORT
0                                 CARBON MONOXIDE (42101)
-METHODS:                  CODE       COLLECTION METHOD                          ANALYSIS METHOD
                           ====    ==============================    ===================================
0                           000    MULTIPLE METHODS                  MULTIPLE METHODS
                            008    INSTRUMENTAL                      NON DISPERSIVE INFRA-RED
                            011    INSTRUMENTAL                      NONDISPERSIVE INFRA-RED
                            041    INSTRUMENTAL                      NON DISPERSIVE INFRA-RED
                            051    INSTRUMENTAL                      NON DISPERSIVE INFRA-RED
                            054    INSTRUMENTAL                      NON DISPERSIVE INFRA-RED
                            066    INSTRUMENTAL                      NON DISPERSIVE INFRA-RED
                            067    INSTRUMENTAL                      NON DISPERSIVE INFRA-RED
                            088    INSTRUMENTAL                      NON-DISPERSIVE INFARED PHOTOMETRY
                            093    INSTRUMENTAL                      GAS FILTER COORELATION CO ANALYZER
1DATE 99/03/09                          EPA AEROMETRIC INFORMATION RETRIEVAL SYSTEM (AIRS)                          PAGE     1
 AMP217P                                              AIR QUALITY SUBSYSTEM
                                                AQ CLEANUP PROCESSING SUMMARY SHEET
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-                                                                                                  REPORT
                                     RECORD              USER          RECORD/REPORT       SELECT/REQUEST
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Appendix C

Distributions and Equations Used in the Ventilation Rate Algorithm

Each table in Appendix C is specific to parameter and gender (e.g., NVO_{2max} values for males). The tables which list distributions include the following data items

Age: age of person in years
Source: source of data (see Table C-1)
Distr: distribution of data [normal, lognormal (LN), or uniform]
Mean: arithmetic mean for normal distributions SD: arithmetic standard deviation
GM: geometric mean of lognormal distribution
GSD: geometric standard deviation of lognormal distribution
Lower bound: smallest value permitted
Upper bound: largest value permitted
Assumptions: special assumptions used in developing distribution parameters

The tables which provide equations for estimating RMR include the following data items

Age: age of person in years
Source: source of data (see Table C-1)
DV: dependent variable of regression equation
IV: independent variable of regression equation
Slope: slope of regression equation (estimate of “a” in Equation 5-10)
Interc: intercept of regression equation (estimate of “b” in Equation 5-10)
SE: standard error of regression residuals (estimate of σ_e in Equation 5-10)
Assumptions: special assumptions used in developing equation parameters

The codes listed under “source” are informal identification codes developed by analysts. The following table relates these codes to tables provided in Section 5.

Table C-1. Explanation of Codes Listed Under “Source” in Appendix C Tables.

Code Listed in “Source” Column of Table in Appendix C	Referenced Table in This Report	Original References
1	a	Astrand and Rodahl (1977), Mercier et al. (1991).
2	a	Astrand and Rodahl (1977), Astrand (1960).
3a	Table 5-4	Astrand (1960)
3c	Table 5-4	Katch and Park (1975)
3d	Table 5-4	Heil et al. (1995)
4	Table 5-5	Brainard and Burmaster (1992), Burmaster et al. (1994).
5	Table 5-5	Esmail, Bhambhani, and Brintnell (1995).
R47d - R47f, R47j - R47l	Table 5-6	Schofield (1985)

[a]Figure 9-13 of Astrand and Rodahl (1977) provides estimates of VO_{2max}-to-weight ratio that are specific to age and gender. The mean NVO_{2max} values for males and females aged 18 and 19 years listed in this appendix were based on these ratios. The standard deviation specified for males 18 and 19 (4.9 ml min^{-1} kg^{-1}) was estimated by assuming the coefficient of variation was equal to 0.099, a value derived from data presented by Mercier et al. (1991) for males aged 15 years. The standard deviation for females 18 and 19 (4.8 ml min^{-1} kg^{-1}) was estimated by assuming the coefficient of variation was equal to 0.118, a value derived from data presented by Astrand (1960) for females 20 to 29 years.

NVO$_{2max}$ - Males

Males (last revised 6-11-98)							
		NVO$_{2max}$ distribution					
Age	Source	Distr	Mean	SD	Lower	Upper	Assumptions
18	1	Normal	50.0	4.9	40.3	59.7	
19	1	Normal	50.0	4.9	40.3	59.7	
20	3a	Normal	58.6	4.5	49.8	67.4	
21	3c	Normal	54.5	7.6	39.6	69.4	
22	3c	Normal	54.5	7.6	39.6	69.4	
23	3c	Normal	54.5	7.6	39.6	69.4	
24	3c	Normal	54.5	7.6	39.6	69.4	
25	3c	Normal	54.5	7.6	39.6	69.4	
26	3c	Normal	54.5	7.6	39.6	69.4	
27	3c	Normal	54.5	7.6	39.6	69.4	
28	3a	Normal	58.6	4.5	49.8	67.4	
29	3a	Normal	58.6	4.5	49.8	67.4	
30	3a	Normal	39.8	7.3	25.5	54.1	
31	3a	Normal	39.8	7.3	25.5	54.1	
32	3a	Normal	39.8	7.3	25.5	54.1	
33	3a	Normal	39.8	7.3	25.5	54.1	
34	3a	Normal	39.8	7.3	25.5	54.1	
35	3a	Normal	39.8	7.3	25.5	54.1	
36	3a	Normal	39.8	7.3	25.5	54.1	
37	3a	Normal	39.8	7.3	25.5	54.1	
38	3a	Normal	39.8	7.3	25.5	54.1	
39	3a	Normal	39.8	7.3	25.5	54.1	
40	3a	Normal	39.2	5.5	28.4	50.0	
41	3a	Normal	39.2	5.5	28.4	50.0	
42	3a	Normal	39.2	5.5	28.4	50.0	
43	3a	Normal	39.2	5.5	28.4	50.0	
44	3a	Normal	39.2	5.5	28.4	50.0	
45	3a	Normal	39.2	5.5	28.4	50.0	
46	3a	Normal	39.2	5.5	28.4	50.0	
47	3a	Normal	39.2	5.5	28.4	50.0	
48	3a	Normal	39.2	5.5	28.4	50.0	
49	3a	Normal	39.2	5.5	28.4	50.0	
50	3a	Normal	33.1	4.9	23.5	42.7	
51	3a	Normal	33.1	4.9	23.5	42.7	
52	3a	Normal	33.1	4.9	23.5	42.7	
53	3a	Normal	33.1	4.9	23.5	42.7	
54	3a	Normal	33.1	4.9	23.5	42.7	
55	3a	Normal	33.1	4.9	23.5	42.7	
56	3a	Normal	33.1	4.9	23.5	42.7	
57	3a	Normal	33.1	4.9	23.5	42.7	
58	3a	Normal	33.1	4.9	23.5	42.7	
59	3a	Normal	33.1	4.9	23.5	42.7	
60	3a	Normal	31.4	5.3	21.0	41.8	
61	3a	Normal	31.4	5.3	21.0	41.8	
62	3a	Normal	31.4	5.3	21.0	41.8	

		NVO_{2max} distribution					
Age	Source	Distr	Mean	SD	Lower	Upper	Assumptions
63	3a	Normal	31.4	5.3	21.0	41.8	
64	3a	Normal	31.4	5.3	21.0	41.8	
65	3a	Normal	31.4	5.3	21.0	41.8	
66	3a	Normal	31.4	5.3	21.0	41.8	
67	3a	Normal	31.4	5.3	21.0	41.8	
68	3a	Normal	31.4	5.3	21.0	41.8	
69	3a	Normal	31.4	5.3	21.0	41.8	
70	3d	Normal	27.2	5.7	16.1	38.3	
71	3d	Normal	27.2	5.7	16.1	38.3	
72	3d	Normal	27.2	5.7	16.1	38.3	
73	3d	Normal	27.2	5.7	16.1	38.3	
74	3d	Normal	27.2	5.7	16.1	38.3	
75	3d	Normal	27.2	5.7	16.1	38.3	
76	3d	Normal	27.2	5.7	16.1	38.3	
77	3d	Normal	27.2	5.7	16.1	38.3	
78	3d	Normal	27.2	5.7	16.1	38.3	
79	3d	Normal	27.2	5.7	16.1	38.3	
80	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
81	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
82	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
83	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
84	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
85	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
86	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
87	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
88	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
89	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
90	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
91	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
92	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
93	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
94	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
95	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
96	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
97	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
98	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
99	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
100	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies

NVO_{2max} - Females

Females (last revised 6-11-98)							
		NVO_{2max} distribution					
Age	Source	Distr	Mean	SD	Lower	Upper	Assumptions
18	2	Normal	41.0	4.8	31.5	50.5	CV = 4.7/39.9
19	2	Normal	41.0	4.8	31.5	50.5	CV = 4.7/39.9
20	3a	Normal	39.9	4.7	30.7	49.1	
21	3a	Normal	39.9	4.7	30.7	49.1	
22	3a	Normal	39.9	4.7	30.7	49.1	
23	3a	Normal	39.9	4.7	30.7	49.1	
24	3a	Normal	39.9	4.7	30.7	49.1	
25	3a	Normal	39.9	4.7	30.7	49.1	
26	3a	Normal	39.9	4.7	30.7	49.1	
27	3a	Normal	39.9	4.7	30.7	49.1	
28	3a	Normal	39.9	4.7	30.7	49.1	
29	3a	Normal	39.9	4.7	30.7	49.1	
30	3a	Normal	37.3	5.2	27.1	47.5	
31	3a	Normal	37.3	5.2	27.1	47.5	
32	3a	Normal	37.3	5.2	27.1	47.5	
33	3a	Normal	37.3	5.2	27.1	47.5	
34	3a	Normal	37.3	5.2	27.1	47.5	
35	3a	Normal	37.3	5.2	27.1	47.5	
36	3a	Normal	37.3	5.2	27.1	47.5	
37	3a	Normal	37.3	5.2	27.1	47.5	
38	3a	Normal	37.3	5.2	27.1	47.5	
39	3a	Normal	37.3	5.2	27.1	47.5	
40	3a	Normal	32.5	2.7	27.2	37.8	
41	3a	Normal	32.5	2.7	27.2	37.8	
42	3a	Normal	32.5	2.7	27.2	37.8	
43	3a	Normal	32.5	2.7	27.2	37.8	
44	3a	Normal	32.5	2.7	27.2	37.8	
45	3a	Normal	32.5	2.7	27.2	37.8	
46	3a	Normal	32.5	2.7	27.2	37.8	
47	3a	Normal	32.5	2.7	27.2	37.8	
48	3a	Normal	32.5	2.7	27.2	37.8	
49	3a	Normal	32.5	2.7	27.2	37.8	
50	3a	Normal	28.4	2.7	23.1	33.7	
51	3a	Normal	28.4	2.7	23.1	33.7	
52	3a	Normal	28.4	2.7	23.1	33.7	
53	3a	Normal	28.4	2.7	23.1	33.7	
54	3a	Normal	28.4	2.7	23.1	33.7	
55	3a	Normal	28.4	2.7	23.1	33.7	
56	3a	Normal	28.4	2.7	23.1	33.7	
57	3a	Normal	28.4	2.7	23.1	33.7	
58	3a	Normal	28.4	2.7	23.1	33.7	
59	3a	Normal	28.4	2.7	23.1	33.7	
60	3a	Normal	30.7	8.0	15.1	46.3	
61	3a	Normal	30.7	8.0	15.1	46.3	
62	3a	Normal	30.7	8.0	15.1	46.3	
63	3a	Normal	30.7	8.0	15.1	46.3	

Age	Source	NVO_{2max} distribution					Assumptions
		Distr	Mean	SD	Lower	Upper	
64	3a	Normal	30.7	8.0	15.1	46.3	
65	3a	Normal	30.7	8.0	15.1	46.3	
66	3d	Normal	30.7	8.0	15.1	46.3	
67	3d	Normal	30.7	8.0	15.1	46.3	
68	3d	Normal	30.7	8.0	15.1	46.3	
69	3d	Normal	30.7	8.0	15.1	46.3	
70	3d	Normal	27.2	5.7	16.1	38.3	
71	3d	Normal	27.2	5.7	16.1	38.3	
72	3d	Normal	27.2	5.7	16.1	38.3	
73	3d	Normal	27.2	5.7	16.1	38.3	
74	3d	Normal	27.2	5.7	16.1	38.3	
75	3d	Normal	27.2	5.7	16.1	38.3	
76	3d	Normal	27.2	5.7	16.1	38.3	
77	3d	Normal	27.2	5.7	16.1	38.3	
78	3d	Normal	27.2	5.7	16.1	38.3	
79	3d	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
80	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
81	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
82	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
83	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
84	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
85	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
86	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
87	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
88	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
89	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
90	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
91	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
92	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
93	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
94	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
95	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
96	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
97	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
98	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
99	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies
100	(3d)	Normal	27.2	5.7	16.1	38.3	Assumes data for age 70-79 applies

Body Mass - Males

Males (last revised 6-11-98)

Age	Source	Body mass distribution, kg					Assumptions
		Distr	GM	GSD	Lower	Upper	
18	4	LN	70.1	1.172	51.4	95.7	
19	4	LN	70.8	1.166	52.4	95.7	
20	4	LN	76.7	1.190	54.5	107.9	
21	4	LN	76.7	1.190	54.5	107.9	
22	4	LN	76.7	1.190	54.5	107.9	
23	4	LN	76.7	1.190	54.5	107.9	
24	4	LN	76.7	1.190	54.5	107.9	
25	4	LN	76.7	1.190	54.5	107.9	
26	4	LN	76.7	1.190	54.5	107.9	
27	4	LN	76.7	1.190	54.5	107.9	
28	4	LN	76.7	1.190	54.5	107.9	
29	4	LN	76.7	1.190	54.5	107.9	
30	4	LN	76.7	1.190	54.5	107.9	
31	4	LN	76.7	1.190	54.5	107.9	
32	4	LN	76.7	1.190	54.5	107.9	
33	4	LN	76.7	1.190	54.5	107.9	
34	4	LN	76.7	1.190	54.5	107.9	
35	4	LN	76.7	1.190	54.5	107.9	
36	4	LN	76.7	1.190	54.5	107.9	
37	4	LN	76.7	1.190	54.5	107.9	
38	4	LN	76.7	1.190	54.5	107.9	
39	4	LN	76.7	1.190	54.5	107.9	
40	4	LN	76.7	1.190	54.5	107.9	
41	4	LN	76.7	1.190	54.5	107.9	
42	4	LN	76.7	1.190	54.5	107.9	
43	4	LN	76.7	1.190	54.5	107.9	
44	4	LN	76.7	1.190	54.5	107.9	
45	4	LN	76.7	1.190	54.5	107.9	
46	4	LN	76.7	1.190	54.5	107.9	
47	4	LN	76.7	1.190	54.5	107.9	
48	4	LN	76.7	1.190	54.5	107.9	
49	4	LN	76.7	1.190	54.5	107.9	
50	4	LN	76.7	1.190	54.5	107.9	
51	4	LN	76.7	1.190	54.5	107.9	
52	4	LN	76.7	1.190	54.5	107.9	
53	4	LN	76.7	1.190	54.5	107.9	
54	4	LN	76.7	1.190	54.5	107.9	
55	4	LN	76.7	1.190	54.5	107.9	
56	4	LN	76.7	1.190	54.5	107.9	
57	4	LN	76.7	1.190	54.5	107.9	
58	4	LN	76.7	1.190	54.5	107.9	
59	4	LN	76.7	1.190	54.5	107.9	
60	4	LN	76.7	1.190	54.5	107.9	
61	4	LN	76.7	1.190	54.5	107.9	
62	4	LN	76.7	1.190	54.5	107.9	
63	4	LN	76.7	1.190	54.5	107.9	
64	4	LN	76.7	1.190	54.5	107.9	

Age	Source	Body mass distribution, kg					Assumptions
		Distr	GM	GSD	Lower	Upper	
65	4	LN	76.7	1.190	54.5	107.9	
66	4	LN	76.7	1.190	54.5	107.9	
67	4	LN	76.7	1.190	54.5	107.9	
68	4	LN	76.7	1.190	54.5	107.9	
69	4	LN	76.7	1.190	54.5	107.9	
70	4	LN	76.7	1.190	54.5	107.9	
71	4	LN	76.7	1.190	54.5	107.9	
72	4	LN	76.7	1.190	54.5	107.9	
73	4	LN	76.7	1.190	54.5	107.9	
74	4	LN	76.7	1.190	54.5	107.9	
75	4	LN	76.7	1.190	54.5	107.9	
76	4	LN	76.7	1.190	54.5	107.9	
77	4	LN	76.7	1.190	54.5	107.9	
78	4	LN	76.7	1.190	54.5	107.9	
79	4	LN	76.7	1.190	54.5	107.9	
80	4	LN	76.7	1.190	54.5	107.9	
81	4	LN	76.7	1.190	54.5	107.9	
82	4	LN	76.7	1.190	54.5	107.9	
83	4	LN	76.7	1.190	54.5	107.9	
84	4	LN	76.7	1.190	54.5	107.9	
85	4	LN	76.7	1.190	54.5	107.9	
86	4	LN	76.7	1.190	54.5	107.9	
87	4	LN	76.7	1.190	54.5	107.9	
88	4	LN	76.7	1.190	54.5	107.9	
89	4	LN	76.7	1.190	54.5	107.9	
90	4	LN	76.7	1.190	54.5	107.9	
91	4	LN	76.7	1.190	54.5	107.9	
92	4	LN	76.7	1.190	54.5	107.9	
93	4	LN	76.7	1.190	54.5	107.9	
94	4	LN	76.7	1.190	54.5	107.9	
95	4	LN	76.7	1.190	54.5	107.9	
96	4	LN	76.7	1.190	54.5	107.9	
97	4	LN	76.7	1.190	54.5	107.9	
98	4	LN	76.7	1.190	54.5	107.9	
99	4	LN	76.7	1.190	54.5	107.9	
100	4	LN	76.7	1.190	54.5	107.9	

Body Mass - Females

Females (last revised 6-11-98)

Age	Source	Body mass distribution, kg					Assumptions
		Distr	GM	GSD	Lower	Upper	
18	4	LN	58.6	1.158	44.0	78.1	
19	4	LN	60.3	1.161	45.0	80.8	
20	4	LN	64.7	1.220	43.8	95.5	
21	4	LN	64.7	1.220	43.8	95.5	
22	4	LN	64.7	1.220	43.8	95.5	
23	4	LN	64.7	1.220	43.8	95.5	
24	4	LN	64.7	1.220	43.8	95.5	
25	4	LN	64.7	1.220	43.8	95.5	
26	4	LN	64.7	1.220	43.8	95.5	
27	4	LN	64.7	1.220	43.8	95.5	
28	4	LN	64.7	1.220	43.8	95.5	
29	4	LN	64.7	1.220	43.8	95.5	
30	4	LN	64.7	1.220	43.8	95.5	
31	4	LN	64.7	1.220	43.8	95.5	
32	4	LN	64.7	1.220	43.8	95.5	
33	4	LN	64.7	1.220	43.8	95.5	
34	4	LN	64.7	1.220	43.8	95.5	
35	4	LN	64.7	1.220	43.8	95.5	
36	4	LN	64.7	1.220	43.8	95.5	
37	4	LN	64.7	1.220	43.8	95.5	
38	4	LN	64.7	1.220	43.8	95.5	
39	4	LN	64.7	1.220	43.8	95.5	
40	4	LN	64.7	1.220	43.8	95.5	
41	4	LN	64.7	1.220	43.8	95.5	
42	4	LN	64.7	1.220	43.8	95.5	
43	4	LN	64.7	1.220	43.8	95.5	
44	4	LN	64.7	1.220	43.8	95.5	
45	4	LN	64.7	1.220	43.8	95.5	
46	4	LN	64.7	1.220	43.8	95.5	
47	4	LN	64.7	1.220	43.8	95.5	
48	4	LN	64.7	1.220	43.8	95.5	
49	4	LN	64.7	1.220	43.8	95.5	
50	4	LN	64.7	1.220	43.8	95.5	
51	4	LN	64.7	1.220	43.8	95.5	
52	4	LN	64.7	1.220	43.8	95.5	
53	4	LN	64.7	1.220	43.8	95.5	
54	4	LN	64.7	1.220	43.8	95.5	
55	4	LN	64.7	1.220	43.8	95.5	
56	4	LN	64.7	1.220	43.8	95.5	
57	4	LN	64.7	1.220	43.8	95.5	

Age	Source	Body mass distribution, kg					Assumptions
		Distr	GM	GSD	Lower	Upper	
58	4	LN	64.7	1.220	43.8	95.5	
59	4	LN	64.7	1.220	43.8	95.5	
60	4	LN	64.7	1.220	43.8	95.5	
61	4	LN	64.7	1.220	43.8	95.5	
62	4	LN	64.7	1.220	43.8	95.5	
63	4	LN	64.7	1.220	43.8	95.5	
64	4	LN	64.7	1.220	43.8	95.5	
65	4	LN	64.7	1.220	43.8	95.5	
66	4	LN	64.7	1.220	43.8	95.5	
67	4	LN	64.7	1.220	43.8	95.5	
68	4	LN	64.7	1.220	43.8	95.5	
69	4	LN	64.7	1.220	43.8	95.5	
70	4	LN	64.7	1.220	43.8	95.5	
71	4	LN	64.7	1.220	43.8	95.5	
72	4	LN	64.7	1.220	43.8	95.5	
73	4	LN	64.7	1.220	43.8	95.5	
74	4	LN	64.7	1.220	43.8	95.5	
75	4	LN	64.7	1.220	43.8	95.5	
76	4	LN	64.7	1.220	43.8	95.5	
77	4	LN	64.7	1.220	43.8	95.5	
78	4	LN	64.7	1.220	43.8	95.5	
79	4	LN	64.7	1.220	43.8	95.5	
80	4	LN	64.7	1.220	43.8	95.5	
81	4	LN	64.7	1.220	43.8	95.5	
82	4	LN	64.7	1.220	43.8	95.5	
83	4	LN	64.7	1.220	43.8	95.5	
84	4	LN	64.7	1.220	43.8	95.5	
85	4	LN	64.7	1.220	43.8	95.5	
86	4	LN	64.7	1.220	43.8	95.5	
87	4	LN	64.7	1.220	43.8	95.5	
88	4	LN	64.7	1.220	43.8	95.5	
89	4	LN	64.7	1.220	43.8	95.5	
90	4	LN	64.7	1.220	43.8	95.5	
91	4	LN	64.7	1.220	43.8	95.5	
92	4	LN	64.7	1.220	43.8	95.5	
93	4	LN	64.7	1.220	43.8	95.5	
94	4	LN	64.7	1.220	43.8	95.5	
95	4	LN	64.7	1.220	43.8	95.5	
96	4	LN	64.7	1.220	43.8	95.5	
97	4	LN	64.7	1.220	43.8	95.5	
98	4	LN	64.7	1.220	43.8	95.5	
99	4	LN	64.7	1.220	43.8	95.5	

Age	Source	Body mass distribution, kg					Assumptions
		Distr	GM	GSD	Lower	Upper	
100	4	LN	64.7	1.220	43.8	95.5	

ECF - Males

Males (last revised 6-11-98)

Age	Source	ECF Distr	ECF Lower	ECF Upper	Assumptions
18	5	Uniform	0.20	0.21	
19	5	Uniform	0.20	0.21	
20	5	Uniform	0.20	0.21	
21	5	Uniform	0.20	0.21	
22	5	Uniform	0.20	0.21	
23	5	Uniform	0.20	0.21	
24	5	Uniform	0.20	0.21	
25	5	Uniform	0.20	0.21	
26	5	Uniform	0.20	0.21	
27	5	Uniform	0.20	0.21	
28	5	Uniform	0.20	0.21	
29	5	Uniform	0.20	0.21	
30	5	Uniform	0.20	0.21	
31	5	Uniform	0.20	0.21	
32	5	Uniform	0.20	0.21	
33	5	Uniform	0.20	0.21	
34	5	Uniform	0.20	0.21	
35	5	Uniform	0.20	0.21	
36	5	Uniform	0.20	0.21	
37	5	Uniform	0.20	0.21	
38	5	Uniform	0.20	0.21	
39	5	Uniform	0.20	0.21	
40	5	Uniform	0.20	0.21	
41	5	Uniform	0.20	0.21	
42	5	Uniform	0.20	0.21	
43	5	Uniform	0.20	0.21	
44	5	Uniform	0.20	0.21	
45	5	Uniform	0.20	0.21	
46	5	Uniform	0.20	0.21	
47	5	Uniform	0.20	0.21	
48	5	Uniform	0.20	0.21	
49	5	Uniform	0.20	0.21	
50	5	Uniform	0.20	0.21	
51	5	Uniform	0.20	0.21	
52	5	Uniform	0.20	0.21	
53	5	Uniform	0.20	0.21	
54	5	Uniform	0.20	0.21	
55	5	Uniform	0.20	0.21	
56	5	Uniform	0.20	0.21	
57	5	Uniform	0.20	0.21	

Age	Source	ECF			Assumptions
		Distr	Lower	Upper	
58	5	Uniform	0.20	0.21	
59	5	Uniform	0.20	0.21	
60	5	Uniform	0.20	0.21	
61	5	Uniform	0.20	0.21	
62	5	Uniform	0.20	0.21	
63	5	Uniform	0.20	0.21	
64	5	Uniform	0.20	0.21	
65	5	Uniform	0.20	0.21	
66	5	Uniform	0.20	0.21	
67	5	Uniform	0.20	0.21	
68	5	Uniform	0.20	0.21	
69	5	Uniform	0.20	0.21	
70	5	Uniform	0.20	0.21	
71	5	Uniform	0.20	0.21	
72	5	Uniform	0.20	0.21	
73	5	Uniform	0.20	0.21	
74	5	Uniform	0.20	0.21	
75	5	Uniform	0.20	0.21	
76	5	Uniform	0.20	0.21	
77	5	Uniform	0.20	0.21	
78	5	Uniform	0.20	0.21	
79	5	Uniform	0.20	0.21	
80	5	Uniform	0.20	0.21	
81	5	Uniform	0.20	0.21	
82	5	Uniform	0.20	0.21	
83	5	Uniform	0.20	0.21	
84	5	Uniform	0.20	0.21	
85	5	Uniform	0.20	0.21	
86	5	Uniform	0.20	0.21	
87	5	Uniform	0.20	0.21	
88	5	Uniform	0.20	0.21	
89	5	Uniform	0.20	0.21	
90	5	Uniform	0.20	0.21	
91	5	Uniform	0.20	0.21	
92	5	Uniform	0.20	0.21	
93	5	Uniform	0.20	0.21	
94	5	Uniform	0.20	0.21	
95	5	Uniform	0.20	0.21	
96	5	Uniform	0.20	0.21	
97	5	Uniform	0.20	0.21	
98	5	Uniform	0.20	0.21	
99	5	Uniform	0.20	0.21	

Age	Source	ECF			Assumptions
		Distr	Lower	Upper	
100	5	Uniform	0.20	0.21	

ECF - Females

Females (last revised 6-11-98)					
		ECF			
Age	Source	Distr	Lower	Upper	Assumptions
18	5	Uniform	0.20	0.21	
19	5	Uniform	0.20	0.21	
20	5	Uniform	0.20	0.21	
21	5	Uniform	0.20	0.21	
22	5	Uniform	0.20	0.21	
23	5	Uniform	0.20	0.21	
24	5	Uniform	0.20	0.21	
25	5	Uniform	0.20	0.21	
26	5	Uniform	0.20	0.21	
27	5	Uniform	0.20	0.21	
28	5	Uniform	0.20	0.21	
29	5	Uniform	0.20	0.21	
30	5	Uniform	0.20	0.21	
31	5	Uniform	0.20	0.21	
32	5	Uniform	0.20	0.21	
33	5	Uniform	0.20	0.21	
34	5	Uniform	0.20	0.21	
35	5	Uniform	0.20	0.21	
36	5	Uniform	0.20	0.21	
37	5	Uniform	0.20	0.21	
38	5	Uniform	0.20	0.21	
39	5	Uniform	0.20	0.21	
40	5	Uniform	0.20	0.21	
41	5	Uniform	0.20	0.21	
42	5	Uniform	0.20	0.21	
43	5	Uniform	0.20	0.21	
44	5	Uniform	0.20	0.21	
45	5	Uniform	0.20	0.21	
46	5	Uniform	0.20	0.21	
47	5	Uniform	0.20	0.21	
48	5	Uniform	0.20	0.21	
49	5	Uniform	0.20	0.21	
50	5	Uniform	0.20	0.21	
51	5	Uniform	0.20	0.21	
52	5	Uniform	0.20	0.21	
53	5	Uniform	0.20	0.21	
54	5	Uniform	0.20	0.21	
55	5	Uniform	0.20	0.21	
56	5	Uniform	0.20	0.21	
57	5	Uniform	0.20	0.21	

Age	Source	ECF			Assumptions
		Distr	Lower	Upper	
58	5	Uniform	0.20	0.21	
59	5	Uniform	0.20	0.21	
60	5	Uniform	0.20	0.21	
61	5	Uniform	0.20	0.21	
62	5	Uniform	0.20	0.21	
63	5	Uniform	0.20	0.21	
64	5	Uniform	0.20	0.21	
65	5	Uniform	0.20	0.21	
66	5	Uniform	0.20	0.21	
67	5	Uniform	0.20	0.21	
68	5	Uniform	0.20	0.21	
69	5	Uniform	0.20	0.21	
70	5	Uniform	0.20	0.21	
71	5	Uniform	0.20	0.21	
72	5	Uniform	0.20	0.21	
73	5	Uniform	0.20	0.21	
74	5	Uniform	0.20	0.21	
75	5	Uniform	0.20	0.21	
76	5	Uniform	0.20	0.21	
77	5	Uniform	0.20	0.21	
78	5	Uniform	0.20	0.21	
79	5	Uniform	0.20	0.21	
80	5	Uniform	0.20	0.21	
81	5	Uniform	0.20	0.21	
82	5	Uniform	0.20	0.21	
83	5	Uniform	0.20	0.21	
84	5	Uniform	0.20	0.21	
85	5	Uniform	0.20	0.21	
86	5	Uniform	0.20	0.21	
87	5	Uniform	0.20	0.21	
88	5	Uniform	0.20	0.21	
89	5	Uniform	0.20	0.21	
90	5	Uniform	0.20	0.21	
91	5	Uniform	0.20	0.21	
92	5	Uniform	0.20	0.21	
93	5	Uniform	0.20	0.21	
94	5	Uniform	0.20	0.21	
95	5	Uniform	0.20	0.21	
96	5	Uniform	0.20	0.21	
97	5	Uniform	0.20	0.21	
98	5	Uniform	0.20	0.21	
99	5	Uniform	0.20	0.21	

Age	Source	ECF			Assumptions
		Distr	Lower	Upper	
100	5	Uniform	0.20	0.21	

Males (last revised 6-11-98)

Age	Source	Regression equation DV	IV	Slope	Interc	SE	Units	Estimate for median weight	Assumptions
18	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.3	
19	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.4	
20	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
21	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
22	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
23	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
24	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
25	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
26	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
27	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
28	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
29	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7	
30	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
31	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
32	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
33	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
34	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
35	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
36	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
37	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
38	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
39	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
40	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
41	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
42	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
43	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
44	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
45	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
46	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
47	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
48	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
49	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
50	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
51	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
52	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
53	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
54	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
55	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
56	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	

Age	Source	Regression equation						Estimate for median weight	Assumptions
		DV	IV	Slope	Interc	SE	Units		
57	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
58	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
59	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
60	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
61	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
62	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
63	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
64	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
65	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
66	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
67	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
68	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
69	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
70	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3	
71	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
72	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
73	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
74	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
75	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
76	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
77	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
78	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
79	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
80	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
81	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
82	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
83	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
84	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
85	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
86	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
87	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
88	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
89	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
90	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
91	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
92	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
93	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
94	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
95	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
96	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
97	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	

Age	Source	Regression equation						Estimate for median weight	Assumptions
		DV	IV	Slope	Interc	SE	Units		
98	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
99	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	
100	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2	

RMR - Females

Females (last revised 6-11-98)

Age	Source	Regression equation DV	IV	Slope	Interc	SE	Units	Estimate for median weight	Assumptions
18	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	5.7	
19	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	5.8	
20	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
21	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
22	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
23	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
24	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
25	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
26	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
27	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
28	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
29	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0	
30	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
31	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
32	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
33	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
34	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
35	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
36	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
37	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
38	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
39	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
40	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
41	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
42	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
43	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
44	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
45	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
46	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
47	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
48	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
49	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
50	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
51	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
52	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
53	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
54	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
55	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
56	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	

Age	Source	Regression equation DV	IV	Slope	Interc	SE	Units	Estimate for median weight	Assumptions
57	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
58	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
59	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7	
60	R47e	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
61	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
62	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
63	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
64	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
65	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
66	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
67	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
68	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
69	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
70	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
71	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
72	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
73	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
74	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
75	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
76	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
77	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
78	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
79	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
80	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
81	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
82	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
83	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
84	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
85	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
86	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
87	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
88	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
89	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
90	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
91	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
92	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
93	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
94	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
95	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
96	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
97	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	

Age	Source	Regression equation						Estimate for median weight	Assumptions
		DV	IV	Slope	Interc	SE	Units		
98	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
99	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	
100	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2	

Appendix D

Equations for Converting Weight to Height Proposed for the 1998 Version of pNEM/CO

Memorandum

To: Arlene Rosenbaum
Systems Applications International

From: Ted Johnson
TRJ Environmental, Inc.

Date: September 29, 1998 (Rev. 1.2)

Project: EPA Work Assignment 1-19

Memo No. 5: Equations for Converting Weight to Height Proposed for the 1998 Version of pNEM/CO

Work Assignment 1-19 of EPA Contract No. 68-D6-0064 directs the ICF project team to propose and implement modifications to the Probabilistic NAAQS Exposure Model for Carbon Monoxide (pNEM/CO). These modifications will include enhancements to the algorithm which provides a "physiological profile" for each person simulated by pNEM/CO. The enhanced algorithm will use probabilistic techniques to generate values for all physiological parameters required by two other pNEM/CO algorithms: (1) the algorithm that estimates ventilation (respiratory) rate and (2) the algorithm that estimates carboxyhemoglobin (COHb) level. This memorandum provides equations which can be incorporated into the physiological profile algorithm to estimate height given a predetermined value for weight.

Background

In the 1992 version of pNEM/CO (Johnson et al., 1992), the COHb algorithm estimates blood volume (V_b) as a function of weight and height by the following equations

Men: $$V_b = (20.4)(W) + (0.00683)(H^3) - 30 \qquad (1)$$

Women: $$V_b = (14.6)(W) + (0.00678)(H^3) - 30. \qquad (2)$$

W is weight in pounds, and H is height in inches. We propose to use this same method to determine blood volume in the 1998 version of pNEM/CO. Note that Equations 1 and 2 require estimates of weight and height specific to the simulated person.

In the 1992 version of pNEM/CO, height was selected from one of six normal distributions which varied according to age and gender (see Table 14 of Johnson et al. 1992). The value for weight was then determined by the equation

$$\text{weight} = A_0 + (A_1)(\text{height}) + (z)(\text{S.E.}) \qquad (3)$$

where the values for A_0, A_1, and S.E. were obtained from Table 14 of Johnson et al.

(1992) according to the gender and age group of the simulated person. The value of z was randomly selected from a unit normal distribution.

In the 1998 version of pNEM/CO, weight will be used in both the ventilation and COHb algorithms, whereas height will be used only in the COHb algorithm. As discussed in Memorandum No. 3, we have developed lognormal distributions of weight for all combinations of gender and age where age is given in one-year increments from zero to 100. For these reasons, we would prefer that the physiological profile algorithm first select a value of weight according to gender and age and then let that value determine a corresponding value of height. The 1998 version of pNEM/CO will initially be applied to adults in Denver, Colorado. Consequently, the physiological profile algorithm currently requires gender-specific probabilistic equations which predict height as a function of weight for people ages 18 years and older.

Equations for Estimating Height from Weight

As noted in Memorandum No. 3, the lognormal distributions proposed for weight were obtained from an article by Burmaster and Crouch (1997). In an article published five years earlier, Brainard and Burmaster (1992) provide a method for sampling weight and height simultaneously from a bivariate distribution based on data obtained from the second National Health and Nutrition Examination Survey (NHANES II). Although Brainard and Burmaster do not explicitly provide a method for estimating height given weight, statistical results presented in the article indirectly suggest that height could be determined from weight using a regression-derived equation of the form

$$\text{height} = a_0 + (a_1)[\ln(\text{weight})] + e \qquad (4)$$

in which e is a normally-distributed random term with mean = zero and standard deviation = σ_e. Ideally, the values of a_0, a_1, and σ_e would be specific to age and gender.

Table 1 is a facsimile of a table appearing in the article by Brainard and Burmaster (1992). This table lists the number of males (18 to 74 years) associated with each of 210 combinations of height (inches) and weight (lbs). The authors suggest that an analysis of weight vs. height based on these data be limited to the 132 cells that fall within the shaded “box” (13 height categories times 12 weight categories). Consequently, we set up a data file containing 132 records, each corresponding to one of the cells in the included in the box. Each record listed the indicated height value, the midpoint of the indicated weight range (e.g., 115 = midpoint of 110 to 119 range), and the number of males associated with the cell.

As indicated in Equation 4, Brainard and Burmaster recommend relating height to ln(weight). Consequently, we performed a weighted linear regression of the data file using height as the dependent variable, ln(weight) as the independent variable, and number of males as a weighting factor. The resulting regression equation for males (18 to 74 years) was

$$\text{height, inches} = 34.43 \text{ in} + (6.67)[\ln(\text{weight,lbs})] + e. \qquad (5)$$

The R^2 value was 0.1469.

To estimate σ_e, the standard deviation of e, we used the equation

$$\sigma_e = [\Sigma(O_{ij} - E_{ij})^2(M_{ij})/(\text{total males})]^{0.5} \qquad (6)$$

in which O_{ij} was the observed (listed) height associated with $cell_{ij}$, E_{ij} was the estimated height for $cell_{ij}$ based on the regression equation, M_{ij} was the number of males listed in Table 1 for $cell_{ij}$, and total males was the total number of males in all cells. Equation 6 produced the estimate σ_e = 2.38 inches.

To test the regression results, we performed a sample calculation using Equation 5 and σ_e = 2.38 inches. For weight = 175 lb, we obtained height = 68.88 ± 2.38 inches. Based on this estimate, we would expect Table 1 to show a mode (most frequent value) for 175 lbs near 68.88 inches, with approximately 68.3 percent of the values falling between 68.88 - 2.38 = 66.5 inches and 68.88 + 2.38 = 71.26 inches. Consistent with our estimate, Table 1 shows a mode of 69 inches in the height values listed for the weight range (170 to 179 lb) centered on 175 lbs. Furthermore, 68.7 percent of the males in the weight range have heights that fall between 67 and 71 inches.

We repeated the analysis using the data for females provided by Table 2 of Brainard and Burmaster (1992). Table 2 of this memo presents a facsimile of this table which lists the number of females (18 to 74 years) associated with each of 270 combinations of height and weight. Brainard and Burmaster suggest that an analysis of weight vs. height based on these data be limited to the 208 cells that fall within the shaded "box" (16 height categories times 13 weight categories). Consistent with the earlier analysis, we set up a data file containing these 208 records in which each record listed the indicated height value, the midpoint of the indicated weight range (e.g., 115 = midpoint of 110 to 119 range), and the number of females associated with the cell.

We performed a weighted linear regression of the resulting data file using height as the dependent variable, ln(weight) as the independent variable, and number of females as a weighting factor. The resulting regression equation for females (18 to 74 years) was

$$\text{height, in} = 48.07 \text{ in} + (3.07)[\ln(\text{weight,lb})] + e. \qquad (7)$$

The R^2 value for females was low (0.0477) relative to the value obtained above for males (0.1469), but was still statistically significant.

To estimate σ_e, the standard deviation of e, we used the equation

$$\sigma_e = [\Sigma(O_{ij} - E_{ij})^2(F_{ij})/(\text{total females})]^{0.5} \qquad (8)$$

in which O_{ij} was the observed (listed) height associated with $cell_{ij}$, E_{ij} was the estimated height for $cell_{ij}$ based on the regression equation, F_{ij} was the number of females listed in Table 2 for $cell_{ij}$, and total females is the total number of females in all cells. Equation 8 yielded an estimate of σ_e = 2.48 inches for females, a value consistent with the value of

2.38 inches obtained previously for males.

We performed a sample calculation to test the regression results. For weight = 145 lb, Equation 7 yielded an estimate of height = 63.35 in ± 2.48 in. Based on this estimate, we would expect Figure 2 to show a mode for 145 lb near 63.35 inches, with approximately 68.3 percent of the values falling between 63.35 - 2.48 = 60.87 inches and 63.35 + 2.48 = 65.83 inches. Figure 2 shows a height mode for the corresponding weight range (140 to 149 lb) at 63 in, with 75 percent of the females falling between 61 in and 66 in.

It should be noted that the regression analyses described above were performed using weighting factors (i.e., values of M_{ij} and F_{ij}) which pertained to <u>ranges</u> of weight values (e.g., 140 to 149 lbs) rather than to <u>individual</u> weight values. Although each weight range was represented by its midpoint in the regression analyses, the resulting estimates of σ_e are larger than the estimates we would have obtained from an analysis in which the values of M_{ij} and F_{ij} were determined for individual weights rather than for weight ranges. Consequently, the values of σ_e presented above should be considered conservative in the sense that they indicate an overly wide distribution of possible heights for a given weight.

In addition, it should be noted that the data used in the regression analyses (Figures 1 and 2) represent subjects 18 to 74 years of age. We intend to apply the regression results to all adult cohorts in 1998 pNEM/CO analyses. As these cohorts include simulated persons 18 to 100 years of age, we will occasionally apply the results to simulated people who fall outside the range of data used in the regression analyses.

Although we believe the proposed equations are adequate for use in pNEM/CO, we will continue to look for alternative estimation equations in the literature. To facilitate on-going model testing, Jim Capel has incorporated the proposed equations into the 1998 version of pNEM/CO. Table 3 presents a subroutine for performing the required calculations.

<u>Parameters To Be Generated by the Physiological Profile Algorithm</u>

At this stage in the developmental process, we need a “master list” of the components which make up the physiological profile. Table 4 lists all adult physiological parameters which are currently required by the COHb and ventilation rate algorithms in the 1998 version of pNEM/CO. This table may change as we revise these algorithms.

References

Brainard, J., and D. E. Burmaster. 1992. “Bivariate Distributions for Height and Weight of Men and Women in the United States,” **Risk Analysis**, Vol. 12, No. 2, pp. 267 - 275.

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Johnson, T., J. Capel, R. Paul, and L. Wijnberg. 1992. **Estimation of Carbon Monoxide Exposures and Associated Carboxyhemoglobin Levels in Denver Residents Using a Probabilistic Version of NEM**. Report prepared by International Technology Air Quality Services under EPA Contract No. 68-D0-0062. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Table 1. Number of Men 18-74 Years of Age by Weight and Height, 1976 - 1980 (Number of Persons in Thousands)[a].

Height, inches[c]	Weight, lbs[b]														
	< 110	110-119	120--129	130-139	140-149	150-159	160-169	170-179	180-189	190-199	200-209	210-219	220-229	≥ 230	True total
< 62	41	70	100	42	110	38	69	24	8	19		10	11		542
62	38	34	94	102	196	73	35	33	48		15				668
63	66	65	195	197	286	136	113	98	33	29		3			1221
64	33	110	237	381	376	413	181	231	106	62	7	8	30		2175
65	53	191	177	578	806	820	556	363	269	161	154	30	30	25	4213
66	50	131	457	555	843	910	986	547	515	252	105	58	43	83	5535
67	12	102	324	780	1087	1237	1174	1181	801	429	319	135	154	245	7980
68	29	77	319	743	1127	1351	1625	1328	1152	686	390	284	250	205	9566
69	7	11	322	488	960	1169	1547	1436	1286	747	750	390	155	310	9578
70	4	37	104	455	900	1041	1450	1313	1334	710	479	441	252	347	8867
71		32	22	242	453	911	818	1103	868	692	481	377	217	500	6716
72		9	19	67	217	392	716	831	765	696	436	216	251	404	5019
73				20	41	228	356	322	483	370	306	190	203	226	2745
74			7	42		76	73	203	270	243	.191	156	84	119	1464
≥ 75						47	24	245	168	121	173	58	121	306	1263
True total	333	869	2377	4692	7402	8842	9723	9258	8106	5217	3806	2356	1801	2770	67,552

[a]Source: Table I of Brainard and Burmaster (1992).
[b]Height without shoes.
[c]Weight with clothes, estimated as ranging from 0.20 - 0.62 lb.
[d]Number of cells scaled up to reflect sizie of population; only 9983 men actually examined.
[e]Shaded cells contain data used in statistical analysis described in text.

Table 2. Number of Women 18-74 Years of Age by Weight and Height, 1976 - 1980 (Number of Persons in Thousands)[b].

Height, in[b]	Weight, lbs[c]														
	< 90	90-99	100-109	110-119	120--129	130-139	140-149	150-159	160-169	170-179	180-189	190-199	200-209	210-219	≥ 230	True total
< 55		7	8	11	25		7	7	15							80
55			13		4	26	12	31	13	8						107
56	31	57	12	41	55	25	44	25				6				296
57	44	91	107	90	55	115	76	26	24		9	18		4	36	695
58	93	164	132	338	317	147	78	120	35	68	27	14	34	3	42	1612
59	50	196	262	552	342	365	297	201	123	116	69	46	30		31	2680
60	86	267	538	621	722	775	451	334	261	239	128	99	54	30	40	4645
61	12	368	754	1286	1355	1089	877	807	439	308	269	240	123	110	164	8201
62	14	258	938	1660	1899	1306	1117	728	583	448	305	227	130	117	218	9948
63	32	165	843	1729	1776	1600	1565	1006	817	655	477	357	277	151	283	11,733
64		30	531	1168	1653	1936	1475	950	741	513	404	274	117	198	280	10,270
65		64	283	873	1582	2162	1183	1201	693	396	455	269	156	109	516	9942
66		10	76	705	804	1365	902	696	509	255	193	213	116	84	253	6181
67			32	188	514	740	605	336	338	381	275	155	106	67	253	3990
68			10	85	213	488	369	336	193	41	99	95	82	14	106	2131
69			33		98	135	266	125	214	119	43	28			93	1154
70					6	38	56	52	19	46		25	3			245
≥ 71				16		16	55	42	30	28		15	4		51	257
True total	362	1677	4572	9363	11,420	12,328	9435	7023	5047	3621	2753	2081	1232	887	2366	74,167

[a]Source: Table II of Brainard and Burmaster (1992).
[b]Height without shoes.
[c]Weight with clothes, estimated as ranging from 0.20 - 0.62 lb.

[d]Number of cells scaled up to reflect sizie of population; only 10,339 women actually examined. [e]Shaded cells contain data used in statistical analysis described in text.

Table 3. Subroutine for Determining Adult Height Values in the Physiological Parameter Algorithm.

Estimation of Adult Height Given Weight (Version 1.0)
1. In previous steps, the "physiological profile" program has determined age and gender of simulated person and selected a value for weight in kilograms (wgt_kg) from the body mass distribution specified for the age and gender.
2. Convert wgt_kg to wgt_lb by equation: wgt_lb = (2.2046)(wgt_kg).
3. Select random value (z) from unit normal distribution with mean = 0 and standard deviation = 1.
4. If male: hgt_inches = 34.43 inches + (6.67)[ln(wgt_lb)] + (2.38 inches)(z).
5. If female: hgt_inches = 48.07 inches + (3.07)[ln(wgt_lb)] + (2.48 inches)(z).
6. If height in cm is required, convert hgt_inches to hgt_cm by equation: hgt_cm = (2.54)(hgt_inches).

Table 4. Physiological Parameters for Adults To Be Included in the 1998 Version of pNEM/CO.

Parameter	Algorithm(s) Containing Parameter	Other Parameters Required for Calculating Parameter
Age	COHb Ventilation rate	
Gender	COHb Ventilation rate	
Weight (body mass)	COHb Ventilation rate	Gender Age
Height	COHb	Weight Gender
Menstrual phase	COHb	Gender Age
Blood volume	COHb	Gender Weight Height
Total hemoglobin content of the blood	COHb	Gender Age
Pulmonary CO diffusion rate	COHb	Gender Height Age
Endogenous CO production rate	COhb	Gender Menstrual phase
Resting metabolic rate (RMR)	Ventilation rate	Gender Age Weight (body mass)
Energy conversion factor (ECF)	Ventilation rate	Gender
MAXRATIO: VER at VO_{2max}	Ventilation rate	Gender Age
SUBRATIO: VER at 65% of VO_{2max}	Ventilation rate	Gender Age MAXRATIO
VO_{2max}	Ventilation rate	NVO_{2max} Weight (body mass)
NVO_{2max}	Ventilation rate	Gender Age

Appendix E

Algorithm for Estimating Carboxyhemoglobin Levels

COHB MODULE FOR pNEM/CO

H. M. Richmond and T. R. Johnson

February 1999

This appendix describes the probabilistic COHb module and discusses its basis. The approach described here is based primarily on the COHb module described by Biller and Richmond in an Appendix to the 1992 version of pNEM/CO (Johnson et al., 1992).

I. THE BASE PHYSIOLOGICAL MODEL FOR COMPUTING COHb LEVELS

The COHB module in the original CO-NEM (Johnson and Paul, 1983) used as its basic model the differential equation derived by Coburn, Forster, and Kane (1965) which described the dynamic relationship between instantaneous blood levels of COHb, inspired CO, and other physiological variables. This model, which will be referred to here as the CFK model, continues to be the most widely-used method for estimating COHb and is the basic model for COHb computations in pNEM/CO. The CFK model is described in Section II.

The CFK model describes the rate of change of COHb blood levels as a function of the following quantities:

1. Inspired CO pressure
2. COHb level
3. Oxyhemoglobin (O_2Hb) level
4. Hemoglobin (Hb) content of blood
5. Blood volume
6. Alveolar ventilation rate
7. Endogenous CO production rate
8. Mean pulmonary capillary oxygen pressure
9. Pulmonary diffusion rate of CO
10. Haldane coefficient (M)
11. Barometric pressure
12. Vapor pressure of water at body temperature (47 torr)

If all of the listed quantities except COHb level are constant over some time interval, the CFK equation has a linear form over the interval and is readily integrated. The solution to the linear form gives reasonably accurate results for lower levels of COHb. However, CO and oxygen compete for the available hemoglobin and are, therefore, not independent of each other. If this dependency is taken into account, the resulting differential equation is no longer linear. Peterson and Stewart (1975) proposed a heuristic approach to account for with this dependency which assumed the linear form and then adjusted the O_2Hb level iteratively based on the assumption of a linear relationship between COHB and O_2Hb. This approach was used in the COHb module of the original CO-NEM. Alternatively, it is possible to determine COHb at any time by numerical integration of the nonlinear CFK equation (e.g. by use of the Runge-Kutta method) if one assumes a particular relationship between COHb and O_2Hb. Muller and Barton (1987) demonstrated that assuming a linear relationship between COHb and O_2Hb leads to a form of the CFK equation equivalent to the Michaelis-Menton kinetic model which is analytically integrable. However, the analytical solution in this case cannot be solved explicitly for COHb. Muller and Barton demonstrated a binary search method for determining the COHb value.

The COHb module for pNEM/CO employs a linear relationship between COHb and O_2Hb which is consistent with the basic assumptions of the CFK model but differs from the linear forms used by other modelers. The Muller and Barton (1987) solution is employed. However, instead of the simple binary search described in the Muller and Barton paper, a combination of the binary search and Newton-Raphson root finding methods was used to solve for COHb (Press et al., 1986). Using the Muller and Barton solution increased computation time compared to the Peterson-Stewart method but was shown to be faster than fourth order Runge-Kutta numerical integration.

II. The CFK Model For Estimation Of Carboxyhemoglobin

Table 1 defines the variables which appear in the equations of this section. Coburn, Forster, and Kane (1965) derived the following differential equation governing COHb levels in the blood upon exposure to CO.

(Eq. 1) $$\frac{d[COHb]}{dt} = \frac{\dot{\mathrm{V}}_{\mathrm{CO}}}{\mathrm{V}_{\mathrm{b}}} + \frac{P_{ICO}}{BV_b} - \frac{\overline{P}_{CO_2}[COHb]}{MBV_b[O_2Hb]}$$

where

(Eq. 2) $$B = \frac{1}{D_{LCO}} + \frac{(P_B - P_{H_2O})}{\dot{V}_A}$$

If the only quantity in this equation that can vary with time is [COHb], the CFK equation is linear and can be readily integrated. However, since oxygen (O_2) and CO compete for the available HB, [COHb] and [O_2Hb] must be related. Increasing [COHb] will result in decreasing [O_2Hb]. Thus the CFK equation is not linear and requires the relationship between the two quantities to be known if it is to be accurately integrated over a wide range of COHb levels.

Various linear relationships between [COHb] and [O_2Hb] have been used (See Marcus, 1980; McCartney, 1990; Muller and Barton, 1987; and Tikuisis et al., 1987). A relationship not previously used follows directly from the basic assumptions of the CFK model. The CFK model employs the Haldane coefficient, which is the equilibrium constant associated with the following reaction representing the replacement of O_2 in O_2Hb by CO:

(Eq. 3) $$CO + O_2Hb = O_2 + COHb$$

Table 1. Definitions Of CFK Model Variables

Variable	Definition
t	Time from start of an exposure event, min
$[COHb]$	Concentration of carboxyhemoglobin (COHb) in blood at time, t, ml CO per ml blood at STPD
$[O_2Hb]$	Concentration of oxyhemoglobin (O_2Hb) in blood at time t, ml O_2 per ml blood at STPD
$[RHb]$	Concentration of reduced hemoglobin in blood as equivalent ml CO per ml of blood at STPD
$[COHb]_o$	$[COHb]$ at $t = 0$
$[THb]_0$	$[RHb] + [COHb] + [O_2Hb]$
$\%[COHb]$	$[COHb]$ expressed as percent of $[RHb]_0$
$\%[O_2Hb]$	$[O_2Hb]$ expressed as percent of $[RHb]_0$
$\%[COHb]_0$	$\%[COHb]$ at $t = 0$
$\%[COHB]_\infty$	$\%[COHb]$ at $t = \infty$
P_{Ico}	Pressure of inspired CO in air saturated with water vapor at body temperature, torr
$\overline{P}C_{CO}$	Mean pulmonary capillary CO pressure, torr
$\overline{P}C_{O_2}$	Mean pulmonary capillary O2 pressure, torr
P_B	Barometric pressure, torr
P_{H_2O}	Vapor pressure of water at body temperature, torr (47 torr)
$\dot{V}_A$	Alveolar ventilation rate, ml/min STPD
$\dot{V}_{CO}$	Endogenous CO production rate, ml/min STPD

Table 1. Definitions Of CFK Model Variables (Continued)

Variable	Definition
$D_{L_{CO}}$	Pulmonary CO diffusion rate, ml/min/torr STPD
M	Haldane coefficient
k	Equilibrium constant for reaction O_2 + RHb = O_2Hb
V_b	Blood volume, ml
Hb	Total hemoglobin in blood, g/100ml
%MetHb	Methemoglobin as weight percent of Hb

The following equation, the Haldane relationship, applies approximately at equilibrium conditions.

(Eq. 4)
$$\frac{\overline{P}_{CO_2}[COHb]}{\overline{P}_{CO}[O_2Hb]} = M$$

The Haldane coefficient, M, is the chemical equilibrium constant for reaction (3)

The above reaction can also be viewed as the difference between two competing chemical reactions:

(Eq. 5) $CO + RHb = COHb$

(Eq. 6) $O_2 + RHb = O_2Hb$

Subtracting (6) from (5) yields (3). If (3) is in equilibrium, then (5) and (6) are in equilibrium. If k is the equilibrium constant for (6) then:

(Eq. 7)
$$\frac{[O_2Hb]}{\overline{P}_{CO_2}[RHb]} = k$$

It is known that an individual breathing air free of CO for an extended period will have about 97% of the reactive hemoglobin tied up as O_2Hb and the rest (3%) as RHb. It is also known that at one atmosphere barometric pressure the mean pulmonary capillary oxygen pressure is approximately 100 torr. Substituting into (7) yields 0.32 as the approximate value of k at body temperature. From mass balance considerations:

(Eq. 8) $[O_2Hb] + [COHb] + [RHb] = [THb]_o$

Eliminating [RHb] between (7) and (8) and solving for $[O_2Hb]$ yields:

(Eq. 9)
$$[O_2Hb] = \frac{k\overline{P}_{CO_2}}{1 + k\overline{P}_{CO_2}}\left([THb]_0 - [COHb]\right)$$

This equation is the desired linear relationship. It has the same form as a relationship given without explanation by McCartney (1990), but replaces the constant in the McCartney equation by the term in (9) involving the mean pulmonary capillary oxygen pressure and the equilibrium constant k. Substituting (9) into (1) yields a CFK equation free of $[O_2Hb]$ and <u>fully consistent</u> with Coburn, Forster, and Kane's original derivation.

(Eq. 10) $$\frac{d[COHb]}{dt} = \frac{\dot{V}_{CO}}{\dot{V}_b} + \frac{P_{I_{CO}}}{BV_b} - \frac{[COHb]}{[THb]_o - [COHb]} \frac{1 + k\bar{P}_{C_{O_2}}}{kMBV_b}$$

In working with the CFK model it is convenient to express COHb as a percent of $[RHb]_0$. Multiplying (10) by 100 and dividing by $[RHb]_0$:

(Eq.11) $$\frac{d\%[COHb]}{dt} = \frac{100}{[THb]_o}\left(\frac{\dot{V}_{CO}}{V_b} + \frac{P_{I_{CO}}}{BV_b}\right) - \frac{\%[COHb]}{100 - \%[COHb]} \frac{100\left(1 + k\bar{P}_{C_{O_2}}\right)}{k[RHb]_o MBV_b}$$

Equation (11) can be written in the form suggested by Muller and Barton (1987):

(Eq.12) $$\frac{d\%[COHb]}{dt} = C_o - C_1 \frac{\%[COHb]}{100 - \%[COHb]}$$

where

(Eq.13) $$C_o = \frac{100}{[THb]_o}\left(\frac{\dot{V}_{CO}}{V_b} + \frac{P_{I_{CO}}}{BV_b}\right)$$

(Eq.14) $$C_1 = \frac{100\left(1 + k\bar{P}_{c_{O_2}}\right)}{k[THb]_o MBV_b}$$

Given values for the atmospheric pressure and the physiological variables in equations (12) - (14), the value of %[COHb] at time t can be found by numerical integration using such techniques as the fourth order Runge-Kutta method (Press et al., 1986).

Muller and Barton (1987) demonstrated that an equation of the form of (12) is equivalent to a Michaelis-Menton kinetics model which is integrable. Integration yields:

(Eq.15) $$-(C_0 + C_1)t + \%[COHb] - \%[COHb]_0 - \left(100 - \%[COHb]_\infty\right)\ln\frac{\left(\%[COHb]_\infty - \%[COHb]\right)}{\%[COHb]_\infty - \%[COHb]_0} = 0$$

The equation for $\%[COHb]_\infty$ is obtained by setting equation (12) equal to zero and solving for %[COHb] which is now equal to $\%[COHb]_\infty$.

(Eq.16) $$\%[COHb]_{\infty} = \frac{100C_0}{(C_0 + C_1)}$$

Equation (15) cannot be solved explicitly for %[COHb]. The Muller and Barton paper suggests the binary search method as one way to find the value of %[COHb]. Press and coauthors (1986) contend a combination of the binary search and Newton-Raphson methods is faster on average.

III. Application of the Basic COHb Model in pNEM/CO

Description of pNEM/CO

pNEM/CO follows the daily activities over an extended period of a finite set of cohorts residing within a given geographic area. The period may be a single season or a calendar year. Each cohort is defined as a group of people with similar demographic and physiological characteristics who are likely to follow similar activity patterns. (Smokers are typically omitted from the cohorts included in pNEM/CO assessments, as cigarette smoking dominates their exposure to CO.) The exposure of each cohort is represented by a continuous sequence of exposure events which span the time period of interest. Each exposure event represents a time interval of 60 minutes or less during which the individual resides in a single environment and engages in a single activity. To permit calculation of hourly average exposures, exposure events are not permitted to fall in more than one clock hour. Consequently, the passage from one exposure event to the next is indicated by a change in microenvironment, activity, or clock hour. Algorithms within pNEM/CO calculates an average CO concentration for each exposure event according to the time, district, and microenvironment specified for the event. As the exposure events for a cohort are contiguous, the model can combine these concentrations to output distributions of one-hour and running eight-hour exposures for each cohort. The exposures calculated for individual cohorts can then be weighted according to their estimated populations to produce exposure distributions for larger population groups of particular interest.

To treat the daily behavior of cohorts probabilistically, each cohort is identified according to home district, work district, demographic group, and the use of cooking fuel in the residence. Currently seven demographic groups are used to distinguish cohorts by sex and age. A set of pools of 24-hour activity patterns is used based on activity data drawn from the Consolidated Human Activity Data Base (CHAD) which is described in Section 2.3 of this report. These patterns are twenty-four hour samplings of the behavior of real people. The patterns in each pool represent the same demographic cohort group, day type (weekday, weekend day), and ambient temperature range. Each pattern consists of a 24-hour set of contiguous exposure events defined by event start time, duration, microenvironment, and activity. For a given cohort a daily pattern is randomly sampled from the appropriate pool each day during the period of the computation.

From the description in the preceding paragraph, it is apparent that while the cohort represents a single demographic group, the activity pattern selected to represent each 24-hour period is obtained from a different member of the group. This feature has an impact on the design of the COHb module.

The COHb Module

The COHb module of pNEM/CO employs the Muller and Barton (1987) integration of the CFK model as represented by equations (12)-(14) to compute the COHb level of a cohort at the end of each exposure event. To perform this computation, the COHb module requires information on each of the quantities listed in the section describing the CFK model. In addition, the COHb level at the beginning of the exposure event must be known. This latter quantity is usually the COHb level computed at the end of the previous contiguous exposure event. To obtain the initial COHb at the start of the exposure period, the computation is started one day before the beginning of the period. The effect of the initial COHb value on the end value is negligible after about 15 hours. The program stores the COHb levels at the end of each clock hour and outputs distributions of COHb levels for the sensitive population.

Assignment of CFK Model Input Data for an Exposure Event

Section IV describes the equations and procedures used by the pNEM/CO COHb module to obtain the values of the input variables for equations (2) and (13) through (16). A brief overview is given here.

The actual inspired CO level can change significantly during an exposure event. The model supplies an average exposure concentration for the event, which is used as the CO input. The time constant for the change in COHb is sufficiently large that the use of concentrations based on averaging times up to one hour can be used in place of the instantaneous concentrations over the averaging time period with little loss of accuracy in estimating the COHb level at the end of the exposure event. Furthermore, applying the average concentrations to a contiguous sequence of exposure events does not cause an accumulation of error.

The COHb model presently used in pNEM/CO does not account for changing barometric pressure. It uses a constant barometric pressure which is a function of the average elevation of an area above sea level. The pressure at sea level is taken to be 760 torr.

The remaining input variables to the CFK model are all physiological parameters. While the Haldane coefficient, the equilibrium constant k, and average pulmonary capillary oxygen pressure are treated as having the same constant values for all cohorts, the remaining physiological input variables will vary among individuals. The next section describes the methods used to generate the various physiological input variables for each combination of cohort and calendar day processed by pNEM/CO.

IV. Computation of Input Data for the COHb Module

As discussed in the previous section and in Sections 2.43 and 2.44 of the main body of this report, the algorithms used to estimate V_E and COHb require values for various physiological parameters such as body mass, blood volume, and pulmonary diffusion rate. Table 2 provides a complete list of these parameters. A special algorithm within pNEM probabilistically generates a value for each parameter on the list (collectively referred to as a "physiological profile") for each combination of cohort and calender day processed by pNEM/CO. Figure 1 is a flow diagram showing the process by which each physiological profile was generated. Each of the generated physiological profiles is internally consistent, in that the functional relationships among the various parameters are maintained. For example, blood volume is determined as a function of weight and height, where height is estimated as a function of weight. Weight in turn is selected from a distribution specific to gender and age. Table 2 provides a brief summary of the method used to estimate values for each parameter in the application of pNEM/CO to Denver.

For each cohort, as defined above, pNEM/CO computes exposure for a contiguous sequence of exposure events spanning the total time period of the computation. This multi-day sequence of exposure events is determined by random sampling day-long event sequences from a set of pools of 24-hour activity patterns. An individual 24-hour pattern in one of these pools is referred to as a unit exposure sequence (UES). Each pool consists of a collection of UESs which are specific to the cohort demographic group, day type, and average daily temperature.

A UES is a contiguous set of exposure events spanning 24 hours. Each event is characterized by start time, duration in minutes, home/work status, microenvironment, and activity. All exposure events are constrained to occur entirely within a clock hour. The UESs start at 7:00 p.m. and end at 7:00 p.m. the following day.

The CFK model within the COHb module is called for each exposure event. For each event it requires the following data.

Time duration of event, min
Inspired CO partial pressure averaged over the event, torr
Percent COHb at the start of the event
Alveolar ventilation rate, ml/min STPD
Average pulmonary capillary oxygen pressure, torr
Haldane Coefficient
Equilibrium constant for the reaction of O_2
Atmospheric pressure, torr
Blood volume, ml
Total potential reduced hemoglobin content of blood, ml CO/ml STPD
Pulmonary CO diffusion rate, ml/min/torr STPD
Endogenous CO production rate, ml/min STPD

Given these data as inputs, the module computes the percent COHb at the end of the exposure event. This value is used by the module as the initial percent COHb for the next contiguous exposure event. The main program retains only those COHb values at the end of each clock hour.

Some of the above data do not change during a pNEM/CO computer run and, therefore, need to be supplied to the computer program only once at the start. Some of the data vary with the cohort and therefore need to be supplied at the beginning of each activity day. Other data tend to change with the exposure event and therefore need to be supplied for each new exposure event.

Table 2. Parameters Included in Physiological Profile for Adults in Version 2.0 of pNEM/CO.

Parameter	Algorithm(s) Containing Parameter	Other Parameters Required for Calculating Parameter	Method Used to Estimate Parameter Value
Age	COHb Ventilation rate	Demographic group	Randomly selected from population-weighted distribution specific to demographic group
Gender	COHb Ventilation rate	Demographic group	Randomly selected from population-weighted distribution specific to demographic group
Weight (body mass)	COHb Ventilation rate	Gender Age	Randomly selected from population-weighted distribution specific to age and gender based on Brainard and Burmaster (1992).
Height	COHb	Weight Gender	Estimated by the following equations: males: height = 34.43 inches + (6.67)[ln(weight)] + (2.38 inches)(z) females: height = 48.07 inches + (3.07)[ln(weight)] + (2.48 inches)(z) The z term was randomly selected from a unit normal [N(0,1)] distribution. Units: height (inches), weight (lbs). The estimation equations are based on the results of a statistical analysis by Johnson (1998) of height and weight data provided by Brainard and Burmaster (1992).
Menstrual phase	COHb	Gender Age	If gender = female, menstrual phase was randomly assigned in alternating 14-day cycles according to the following age-specific probabilities. Age < 12 or >50: 100% premenstrual Age 12 through 50: 50% premenstrual, 50% postmenstrual.

Parameter	Algorithm(s) Containing Parameter	Other Parameters Required for Calculating Parameter	Method Used to Estimate Parameter Value
Blood volume	COHb	Gender Weight Height	Blood volume (V_b) was determined according to gender by the following equations which are based on work by Allen et al. (1956) which was modified to accept the units used for height and weight. Men: $V_b = (20.4)(weight) + (0.00683)(H^3) - 30$ Women: $V_b = (14.6)(weight) + (0.00678)(H^3) - 30$ Units: blood volume (ml), weight (lbs), height (inches).
Hemoglobin content of the blood, Hb	COHb	Gender Age	Randomly selected from normal distribution with arithmetic mean (AM) and arithmetic standard deviation (ASD) determined by gender and age based on data obtained from the 1976-1980 NHANES study (USDHHS, 1982) as follows. Males, 18 - 44: AM = 15.3, ASD = 1.0 Males, 45 - 64: AM = 15.1, ASD = 1.2 Males, 65+: AM = 14.8, ASD = 1.4 Females, 18 - 44: AM = 13.3, ASD = 1.1 Females, 45 - 64: AM = 13.6, ASD = 1.2 Females, 65+: AM = 13.7, ASD = 1.2 Units: grams of Hb per deciliter of blood
Pulmonary CO diffusion rate, DL_{CO}	COHb	Gender Height Age	Pulmonary CO diffusion rate (DL) was determined according to gender, height, and age according to the following equations obtained from a paper by Salorinne (1976) and modified to conform to the units used in the COHb module. Males: $DL_{CO} = (0.361)(height) - (0.232)(age) + 16.3$ ml/min/torr Females: $DL_{CO} = (0.556)(height) - (0.115)(age) - 5.97$ ml/min/torr Units: DL_{CO} (ml/min/torr), height (inches), age (years).

Parameter	Algorithm(s) Containing Parameter	Other Parameters Required for Calculating Parameter	Method Used to Estimate Parameter Value
Endogenous CO production rate	COHb	Gender Age Menstrual phase	Endogenous CO production rate was randomly selected from a lognormal distribution with geometric mean (GM) and geometric standard deviation (GSD) determined according to the following equations specific to age, gender, and menstrual phase. Males, 18 - 64: GM = 0.473, GSD = 1.316 Males, 65+: GM = 0.473, GSD = 1.316 Females, 18 - 64, premenstrual: GM = 0.497, GSD = 1.459 Females, 18 - 64, postmenstrual: GM = 0.311, GSD = 1.459 Females, 65+: GM = 0.497, GSD = 1.459 Units: GM (ml/hr), GSD (dimensionless).
Resting metabolic rate (RMR)	Ventilation rate	Gender Age Weight (body mass)	See Section 5.4 of the main body of this report.
Energy conversion factor (ECF)	Ventilation rate	Gender	See Section 5.4 of the main body of this report.
NVO_{2max}	Ventilation rate	Gender Age	See Section 5.4 of the main body of this report.
VO_{2max}	Ventilation rate	NVO_{2max} Weight (body mass)	See Section 5.4 of the main body of this report.

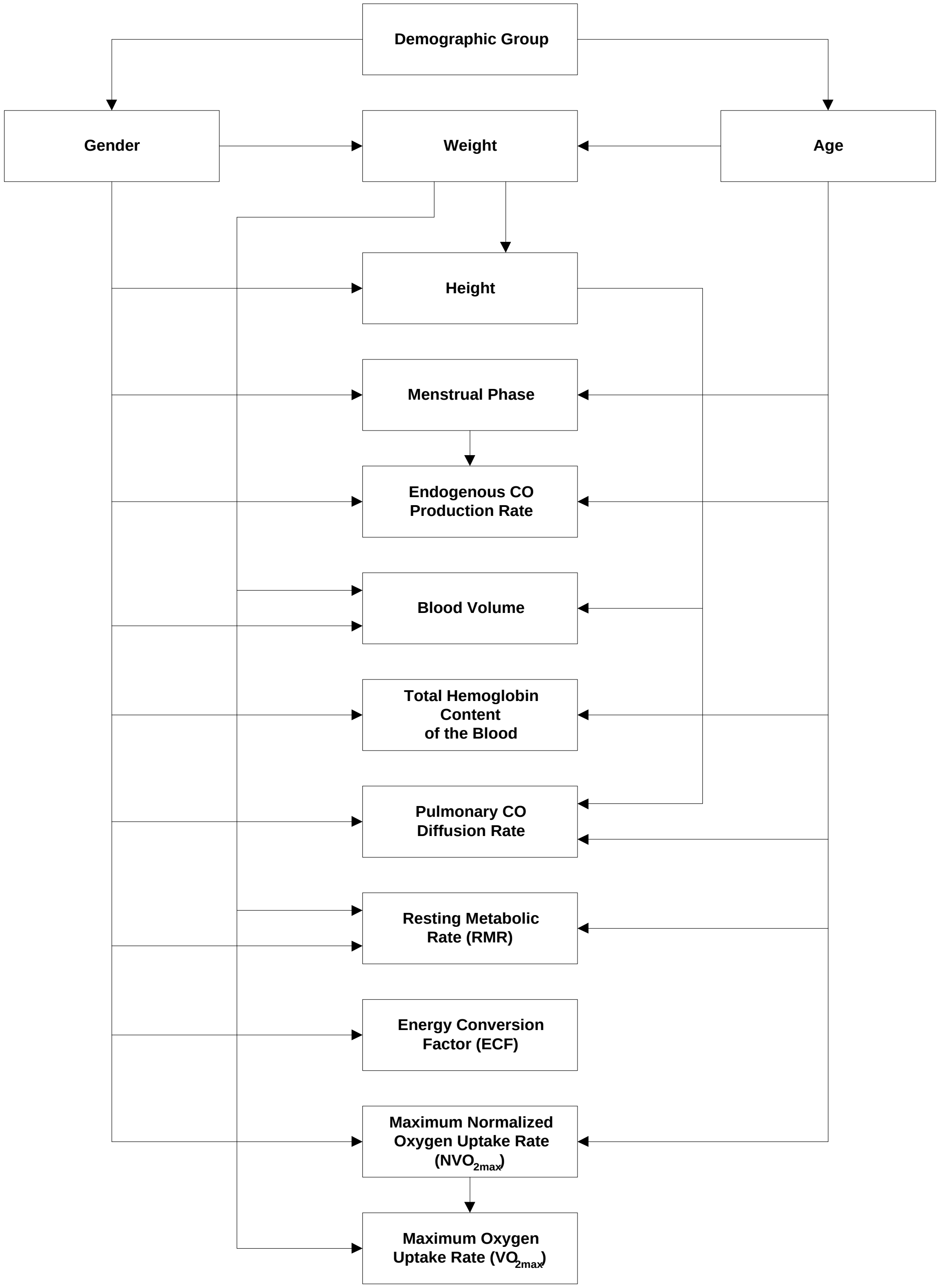

Figure 1. Flow Diagram for Physiological Profile Generator.
Input Data Supplied at Start of the pNEM/CO Computation

Barometric Pressure

A constant barometric pressure is assumed for the study area based on the average height above sea level:

(Eq. 17) $$P_B = 760 * \exp(-0.0000386 * Altitude)$$

where altitude is the average height (in feet) of the study area above sea level (USEPA, 1978). The altitude was set at 5183 feet for Denver and 328 feet for Los Angeles.

Average Pulmonary Capillary Oxygen Pressure

The equation employed is based on an approximation used by Peterson and Stewart (1975) in which the 49 torr is subtracted from the partial pressure of inspired oxygen. This leads to the following approximate relationship:

(Eq.18) $$\overline{P}_{C_{O_2}} = 0.209(P_B - 47) - 49$$

The constant 0.209 is the mole fraction of O_2 in dry air. The constant 47 is the vapor pressure of water at body temperature. This expression was used in an investigation of the CFK equation by Tikuisis et al. (1987). Modelers have tended to use the value 100 torr. Equation (18) gives the value 100 torr for a barometric pressure of 760 torr.

Haldane Coefficient

The value of 218 has been used for the Haldane coefficient. Measured values in the range 210 to 270 have been reported in the literature. Modelers have tended to use values in the range 210 to 240. In the early 1980's, the Clean Air Scientific Advisory Committee (CASAC) expressed the opinion to EPA (Friedlander, 1982) that the most careful work done in this area was that by Rodkey (1969), who determined a value of 218. This value was used in the COHb module of the earlier CO NEM version. Other modelers using values in the range 218 to 220 are Peterson and Stewart, 1970; Marcus, 1980; Collier and Goldsmith, 1983; Muller and Barton, 1987. As the value 218 falls within the range currently used by modelers, EPA analysts have decided to continue using value in pNEM/CO.

Equilibrium Constant for the Reaction of O_2 and RHb

This quantity was estimated in Section II to have the value 0.32 based on the observation that %[RHb] is about 3% in individuals breathing air which is free of CO and a value of 100 torr for $\overline{P}_{C_{O_2}}$.

Total Reduced Hemoglobin in the Absence of O_2 and CO

The quantity $[THb]_0$ is expressed as equivalent milliliters of O_2 or CO at STPD per milliliter of blood. Total Hb blood levels are customarily expressed as grams per deciliter of blood. The total Hb level in the absence of COHb and O_2Hb would consist principally of RHb which can react with O_2 or CO and MetHb which cannot. Total Hb blood levels also tend to be higher in people living at higher altitudes. To relate $[THb]_0$ to Hb, it is therefore necessary to correct for the MetHb present, adjust for the effect of altitude, and convert to equivalent milliliters of CO at STPD. The later conversion is based on the observation that a gram of reduced Hb can react with a maximum of 1.39 ml of O_2 or CO at STPD. The application of these three factors yields the equation:

(Eq. 23)
$$[THb]_0 = 1.39 * Hb(100 - \% \, MetHb) * \frac{(1 + HbAlt * Altitude)}{100}$$

where HbAlt is a regression constant. Hb in equation (23) is a sea level value. Hb level in a human population is normally distributed with the mean Hb and standard deviation both dependent on gender and age class (see entry in Table 2 for the distributions of Hb by age and gender). Given the hemoglobin content of the blood based on the distributions listed in Table 2, $[THb]_0$ is calculated using equation (23). The weight percent MetHB, %MetHB, is taken to be 0.5% of the weight of Hb (Muller and Barton, 1987).

The altitude correction factor, HbAlt, was developed by application of simple regression analyses to Hb data obtained in 17 U.S. cities (USEPA, 1973).

Men: 0.000161 S.E. = 0.000064
Women: 0.000115 S.E. = 0.000043

Two cities (Phoenix and Houston) were eliminated in the regression analysis because the measured Hb levels were substantially below that of the other cities. The altitude factor is small. It predicts about a 5% increase in Hb for residents of Denver over that for people living at sea level.

Determination of Weight

Body mass or weight (in kg) was determined by fitting lognormal distributions to data organized by age and gender based on work by Brainard and Burmaster (1992) and Burmaster et al. (1994). Table 5-5 in the main body of this report summarizes the parameters for the lognormal distributions obtained.

Determination of Height

The following equations were used to estimate height as a function of gender and weight.

(Eq. 24) males: height = 34.43 inches + (6.67)[ln(weight)] + (2.38 inches)(z)

(Eq. 25) females: height = 48.07 inches + (3.07)[ln(weight)] + (2.48 inches)(z)

The z term was randomly selected from a unit normal [N(0,1)] distribution.

Equations 24 and 25 are based on the results of a statistical analysis by Johnson (1998) of height and weight data provided by Brainard and Burmaster (1992).

Base Pulmonary Diffusion Rate of CO

A base lung diffusivity of CO for the cohort is calculated as follows:

(Eq. 26) Men: $$D_{L_{CO}} = 0.361 * height - 0.232 * age = 16.3$$

(Eq. 27) Women: $$D_{L_{CO}} = 0.556 * height - 0.115 * age - 5.97$$

where height is in inches and age is in years.

The regression equations were obtained from a paper by Salorinne (1976) and modified to conform to the units used in the COHb module. The Salorinne data were obtained for non-exercising individuals. Tikuisis et al. (1992), working with eleven male subjects at various exercise levels, showed significant increase in lung diffusivity of CO with increasing alveolar ventilation rate. Regression analyses of data provided by Tikuisis for the individual subjects in the study showed the relationship to be linear. From this relationship and the heights and ages of the subjects in the Tikuisis et al. study, it was determined that the Salorinne equations for male subjects correspond to an alveolar ventilation rate of 6.69 l/min STPD. In the absence of other data it is assumed that this same value applies to women. Thus, for each twenty-four hour period equations (26) and (27) are used to compute lung diffusion rates of CO for a base case alveolar ventilation rate of 6.69 1/min STPD. As will be seen, this value is adjusted to account for the actual ventilation rate experienced by the cohort during each individual exposure event.

Endogenous Rate of CO Production

The endogenous CO production rates taken from a number of sources show the rate to be distributed lognormally in the population (see Appendix for data and sources). The distribution is different for men and women. For a woman there is a further difference depending on whether she is in her premenstrual or postmenstrual phase. Table 2 presents these distributions classified by class, gender, and menstrual phase.

For each male cohort, pNEM/CO specifies a single value for endogenous CO production rate and uses it for all days of the year. For each female cohort between 18 and 64 years of age, pNEM/CO specifies one value of endogenous CO production rate to represent premenstrual days and one value to represent postmenstrual days. Females cohorts under 12 years and older than 50 are assumed to be premenstrual; consequently, pNEM/CO specifies a single value for endogenous CO production rate to be used for all days of the year. The specified values are randomly selected from the appropriate distributions presented in Table 2. A random number, z, is sampled from the standardized normal distribution, N(0,1) to make each selection. The appropriate endogenous CO production rate is then obtained from:

(Eq. 28) $$\dot{V}_{CO} = 0.01667 * (geom.mean) * (geom.S.D.)^{z}$$

The constant term converts ml/hr to ml/min.

A probabilistic algorithm within pNEM/CO assigns a menstrual phase to each day of the year for females cohorts aged 12 to 50 years. The algorithm randomly assigns a number between 1 and 28 to January 1. The number is increased by one for each successive day until number 28 is reached. The next day is numbered 1 and the 28-day numbering cycle is repeated until each day of the year has been assigned a number between 1 and 28. Days numbered 1 through 14 are identified as post-menstrual days; days numbered 15 through 28 are identified as pre-menstrual days.

INPUT DATA SUPPLIED WITH EACH EXPOSURE EVENT

Duration of Exposure Event

The duration of the exposure event in minutes is supplied by the main program to the COHb module.

Partial Pressure of Inspired Carbon Monoxide

The main program supplies the inspired CO concentration averaged over the duration of the exposure expressed as ppm. This quantity is converted to pressure via:

(Eq. 29) $$P_{I_{CO}} = (CO) * (P_b - 47) * 10^{-6}$$

Initial Percent COHb Level at Start of Exposure Event

The program retains the percent COHb computed at the end of the previous exposure event and uses this value as the initial percent COHb for the present event. The starting COHb at the beginning of an activity day is the final COHb level at the end of the preceding activity day. This latter procedure is used for the first activity day of the overall computation since the program starts the day before the overall period covered by the pNEM/CO computation.

Alveolar Ventilation Rate

The main program supplies the COHb module with ventilation rate derived from the algorithm discussed in Section 2.4.3 in the main body of this report.

Adjusted Pulmonary Diffusion Rate of CO

Given the alveolar ventilation rate for the exposure event the associated adjusted pulmonary diffusion rate can be calculated from:

(Eq. 30) $$D_{L_{CO}}(Adjusted) = D_{L_{CO}}(Base) + 0.000845\dot{V}_A - 5.65$$

(See discussion of base pulmonary diffusion rate.)

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Table 3. Literature Data Used to Derive Geometric Mean and Standard Deviation Lognormal Distribution of Endogenous Co Production Rate

ENDOGENOUS CO PRODUCTION RATE FOR MEN	
V_{co} (ml/hr)	REFERENCE
0.35	Coburn et al., 1963
0.35	"
0.4	"
0.39	"
0.43	"
0.35	"
0.51	"
0.42	"
0.57	"
0.45	"
0.4	Lynch and Moede, 1972
0.81	"
0.26	"
0.65	"
0.51	"
0.62	"
0.44	"
0.43	Berk et al., 1974
0.58	"
0.52	"
0.59	"
0.8	"
0.72	"
0.54	"

ENDOGENOUS CO PRODUCTION RATE FOR MEN	
V_{co} (ml/hr)	REFERENCE
0.45	Delivoria-Papadopoules et al., 1974
0.26	“
0.6	“
0.45	“
0.39	“
0.4	“
0.81	Brouillard et al., 1975
0.57	“
0.33	“
0.7	“
0.58	“
0.38	“
0.51	“
0.55	“
0.37	“
0.49	“
0.45	“
0.5	“
0.33	“
0.45	“
0.36	“
0.54	Werner and Lindahl, 1980
0.76	“
0.48	“
0.31	“
0.7	“

ENDOGENOUS CO PRODUCTION RATE FOR MEN	
V_{co} (ml/hr)	REFERENCE
0.36	"
0.65	"
0.38	Luomanmaki and Coburn, 1969
0.42	"
0.41	"
0.54	"
0.38	"
0.72	Lynch and Moede, 1972
0.37	"
0.23	"
0.33	"
0.42	"
0.44	"
0.29	"
0.48	"
0.57	Delivoria-Papadopoulos et al., 1974
0.54	"
0.72	"
0.99	"
0.48	"
0.53	"
0.43	"
0.64	Merke et al., 1975
0.86	"
0.35	"
0.52	"

ENDOGENOUS CO PRODUCTION RATE FOR MEN	
V_{co} (ml/hr)	REFERENCE
0.8	"
0.54	"
0.68	"
0.28	"
0.48	Lynch and Moede, 1972
0.23	"
0.25	"
0.2	"
0.22	"
0.15	"
0.21	"
0.23	Delivoria-Papadopoulos et al., 1974
0.51	"
0.34	"
0.41	"
0.26	"
0.16	"
0.3	"
0.4	Merke et al., 1975
0.47	"
0.23	"
0.24	"
0.55	"
0.32	"
0.43	"
0.35	"

Appendix F

Sensitive Population Estimates for Use in Carbon Monoxide Exposure Estimates

August 25, 1998

MEMORANDUM

SUBJECT: Sensitive Population Estimates for Use in Carbon Monoxide Exposure Analysis

FROM: Harvey M. Richmond
Risk and Exposure Assessment Group (MD-15)

TO: The files

This memo documents the procedure and resulting estimates for obtaining estimated prevalence of ischemic heart disease in the United States population by age and sex. The probabilistic NAAQS Exposure Model for CO (pNEM/CO) divides the population into distinct subpopulation groups based on age, sex, where individuals live and work, and whether individuals live in a gas stove home or not. While pNEM/CO is generally run for the entire adult population, EPA is most interested in exposure and carboxyhemoglobin estimates for the population which has been identified as the most sensitive population group, namely, individuals with diagnosed or undiagnosed ischemic heart disease (IHD). Prevalence estimates of diagnosed IHD are available based on the National Health Interview Survey broken down by age and sex (Adams and Marano, 1995). The estimated prevalence of diagnosed IHD for children (age 0-17) is 0.01 percent. According to this survey, approximately 8.0 million individuals are estimated to have diagnosed IHD in the civilian, non-institutionalized population. These estimates do not include individuals in the military or individuals in nursing homes or other institutions. In addition, as many as three to four million persons have been estimated to have silent ischemia or undiagnosed IHD (American Heart Association, 1990).

In order to provide estimates for use in pNEM/CO, I have used a best estimate of 3.5 million persons for undiagnosed IHD and have assumed that the prevalence for this group would be distributed in the same way as diagnosed IHD by age and sex. Tables 1 and 2 (see attachments) provide prevalence estimates for diagnosed, undiagnosed, and total IHD by age and sex.

Attachments

cc: J. Capel
D. McKee
J. Raub
A. Rosenbaum

Attachment 1

Table 1. Estimated Prevalence of Ischemic Heart Disease in the Male U.S. Population for 1994 (in percent)*

	Age <45	Age 45-64	Age > 64
Diagnosed IHD	0.38	8.19	19.2
Undiagnosed IHD	0.17	3.60	8.45
Total IHD	0.55	11.8	27.7

*For the civilian, non-institutionalized population.

Table 2. Estimated Prevalence of Ischemic Heart Disease in the Female U.S. Population for 1994 (in percent)*

	Age < 45	Age 45-64	Age > 64
Diagnosed IHD	0.13	3.25	12.3
Undiagnosed IHD	0.06	1.43	5.41
Total IHD	0.19	4.68	17.7

*For the civilian, non-institutionalized population.

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Appendix G

Algorithm for Air Exchange Rates Inside Motor Vehicles in pNEM/CO

M E M O R A N D U M

TO: Harvey Richmond

FROM: Jonathan Cohen, Ted Johnson, and Arlene Rosenbaum

DATE: November 17, 1999

SUBJECT: EPA 68-DO-0062 Work Assignment 3-03: Algorithm for Air Exchange Rates Inside Motor Vehicles in pNEM/CO

Background and Summary

Work Assignment 2-30 of EPA Contract No. 68-D6-0064 directed the ICF project team to update the pNEM/CO algorithm used to estimate air exchange rates in motor vehicles. Under Work Assignment 3-03 of the same contract, the team were requested to revise the speed distributions to reflect trip mean speeds rather than second by second speeds. This memorandum presents some alternative approaches for this part of the pNEM/CO model. We first briefly summarize how the mass balance model in pNEM/CO uses air exchange rates and summarize the current statistical model for simulating vehicular air exchange rates. We then discuss the sensitivity of the model to the air exchange rates, demonstrating that once the exchange rate exceeds 10 hr^{-1}, the pNEM/CO models are not very sensitive to the exact value of the air exchange rate. Data supplied by a California Air Resources Board (CARB) study (Rodes et al, 1998) show that the measured exchange rates are all above 20 hr^{-1} when the vehicle vents are open (and the windows are open or closed), but were measured to be as low as 2 hr^{-1} when the vehicle vents are closed (at very low speeds). Thus the application of the study data to pNEM/CO requires a reasonably accurate estimate of the frequency of driving with vents closed. Finally we present our proposed approach: Using the data from the CARB study, air exchange rates for a given speed and vent status (open or closed) are simulated from a log-normal distribution. The speed is simulated using trip mean speed distributions developed from the Spokane-Baltimore instrumented vehicle study (Cohen et al, 1994). To determine whether vents are open or closed, if there is no smoking present, we propose to use the same pNEM/CO algorithm that estimates the probability of having windows open or closed in a residence, as a function of daily average temperature and of whether or not an air conditioner is available. Obviously, behavior patterns for opening windows in residences are not the same as those for opening vents in vehicles, but there does not seem to be any available good data directly applicable for vehicles. To complete the simulation, the probability of having a functioning air conditioner is estimated using the results of an EPA Office of Mobile Sources study (Koupal, 1998).

An important indoor CO source is environmental tobacco smoke (ETS). The previous version of pNEM/CO includes additive increments for ETS exposures in several micro-environments, but no ETS impacts for the inside vehicle micro-environment. The model is currently being revised to add a mass balance model for ETS inside vehicles with a one minute averaging time. A constant emission rate based on an assumption of a single smoker smoking 2 cigarettes per hour will be assumed over the time period that the activity pattern indicates an in-vehicle environment with smoking present. Over this time period when there is smoking within the vehicle micro-environment, it will also be assumed that the vehicle vents are open, instead of applying the residential windows closed or open algorithm. See the memorandum by Rosenbaum, Johnson, and Cohen (1999) for some discussion on approaches for modeling ETS in various pNEM/CO micro-environments.

Note: After reviewing this memorandum, EPA directed that Version 2.1 of pNEM/CO treat vehicle window status using the same algorithm based on daily average temperature and the availability of air conditioning, regardless of whether or not smokers were present. This decision was made because of the lack of available data relating smoking in vehicles and window status. A sensitivity analysis was conducted which examined the impact on the results of assuming that vehicle windows were always open when the activity data indicated that a smoker was present. See Section 7 for a discussion of the results of this sensitivity analysis.

The Mass Balance Model (Assuming No ETS Contribution)

The pNEM/CO methodology includes a mass-balance model which is used to estimate CO concentrations when a cohort is assigned to an indoor or motor vehicle microenvironment. The mass-balance model is based on the generalized mass-balance model presented by Nagda, Rector, and Koontz (1987). As originally proposed, this model assumed that pollutant concentration decays indoors at a constant rate. For use in pNEM/CO, the Nagda model was revised to incorporate an alternative assumption that the indoor decay rate is proportional to the indoor concentration. The resulting model can be expressed by the differential equation

$$\frac{dC_{in}}{dt} = (1 - F_B)vC_{out} + \frac{S}{cV} - mvC_{in} - F_d C_{in} - \frac{qFC_{in}}{cV} \qquad (1)$$

in which

C_{in} = Indoor concentration (units: mass/volume)

F_B = Fraction of outdoor concentration intercepted by the enclosure (dimensionless fraction)

F_d = Pollutant decay coefficient (1/time)

ν = Air exchange rate (1/time)

C_{out} = Outdoor concentration (mass/volume)

S = Indoor generation rate (mass/time)

cV = Effective indoor volume where c is a dimensionless fraction (volume)

m = Mixing factor (dimensionless fraction)

q = Flow rate through air-cleaning device (volume/time)

F = Efficiency of the air-cleaning device (dimensionless fraction)

(This summary does not incorporate the adjustment for ETS impacts described above.)

As CO is a nonreactive pollutant, it is reasonable to assume 1) that the enclosure does not intercept any of the CO as it moves indoors, 2) that the CO does not decay once it enters the enclosure, and 3) that no CO is removed by air-filtration devices. Under these assumptions, the parameters F_B, F_d, and F in Equation 1 would be set equal to zero. If the additional assumptions are made that c and m are each equal to 1, the resulting differential equation is

$$\frac{dC_{in}}{dt} = vC_{out} + \frac{S}{V} - vC_{in} \tag{2}$$

It can be shown that this equation has the following exact solution:

$$C_{in}(t) = k_1 C_{in}(t - \Delta t) + k_2 C_{out}(t - \Delta t) + k_3 \tag{3}$$

where

$$k_1 = e^{-v\Delta t} \tag{4}$$

$$k_2 = 1 - e^{-v\Delta t} \tag{5}$$

$$k_3 + S(1 - e^{v\Delta t}) / vV \tag{6}$$

and Δt is a fixed time interval. Based on this relationship, the average indoor pollutant concentration of hour h [$\mathbf{C_{in}(h)}$] can be calculated by the expression

$$\mathbf{C_{in}(h)} = a_1 C_{in}(h - 1) + a_2 \mathbf{C_{out}}(h) + a_3 \quad (7)$$

where $C_{in}(h - 1)$ is the indoor concentration at the end of the preceding hour and $\mathbf{C_{out}}(h)$ is the average outdoor concentration during hour h. The other variables appearing in Equation 7 are defined by the following equations:

$$a_1 = z(h), \quad (8)$$

$$a_2 = 1 - z(h), \quad (9)$$

$$a_3 = \frac{S}{\nu V}[1 - z(h)] \quad (10)$$

$$z(h) = (1 - e^{-\nu}) / \nu \quad (11)$$

Equation 7 was used to construct a sequence of hourly average values for each combination of microenvironment (indoor and motor vehicle) and exposure district.

In constructing each sequence, the value of $\mathbf{C_{out}}$ for a particular hour was set equal to the value for outdoor concentration determined for that hour by the algorithm described in Subsection 2.4.1 of the pNEM/CO report. A value for air exchange rate (ν) was selected from a user-specified distribution each day at midnight and held constant for the entire day. This procedure was consistent with the procedure used to construct the exposure event sequence (EES) for each cohort. As discussed in Section 2 of the pNEM/CO report, each EES consisted of a series of person-days selected from an activity diary data base. Each person-day spanned a 24-hour period from midnight to midnight.

The term S/V represents the contributions of indoor sources to indoor levels. This term was included in the mass-balance equation when the microenvironment was indoors - residence and the cohort was characterized as using natural gas for cooking. The term was assumed to equal zero in the motor vehicle microenvironment.

Current Treatment of the Motor Vehicle Microenvironment in pNEM/CO

A point estimate of 36 air changes per hour was used for in-vehicle locations in the 1992 version of pNEM/CO. This value was obtained from Hayes (1991) based on his analysis of data presented by Peterson and Sabersky (1975).

In a study reported by Ott, Switzer, and Willis (1994), researchers measured an AER value of 13.1 air changes per hour in a car moving at 20 mph with windows closed. AER values of 67 to 120 were measured in the car at the same speed with windows open.

During the preparation of the most recent draft of the pNEM/CO report, Peggy Jenkins (1998) indicated that the California Air Resources Board would provide additional data on AER in vehicles in the near future. We expected that these data would provide a better basis for determining an AER distribution for vehicles. During the interim period, we modeled air exchange rates in vehicles by sampling from a lognormal distribution with geometric mean = 39.7 and geometric standard deviation = 1.76. This approach was based on the assumption that the AER distribution has a lognormal distribution and that the 2.5th and 97.5th percentiles of this distribution correspond to the lowest and highest reported AER values for vehicles (13 and 120 air changes per hour, respectively).

The remainder of this memorandum discusses potential improvements to this approach based on the data that were recently provided by CARB (Rodes et al, 1998).

Air Exchange Rate Data Provided by CARB

Table 1 lists the data provided by the CARB (Rodes et al, 1998). There are 11 AER values measured under test conditions which varied the ventilation setting, vehicle speed, and vehicle type. (The draft version of the CARB report shows that multiple measurements were made for some vehicle/vent combinations - our analysis used the average values given in their final report). Three of the 11 values were obtained from a 91 Caprice which was tested under all three ventilation conditions. Unfortunately, this vehicle was tested at only one speed (55 mph). The 97 Taurus was tested at two ventilation settings and one speed (55 mph). The 97 Explorer was tested at the same two ventilation settings and at all three speeds. Note that the none of Taurus and Explorer values represent conditions with windows open. There is only one value for windows open -- the 91 Caprice driven at 55 mph. For the statistical analysis, we grouped this special case of vent open and windows (partially) open with the other cases of vent open and windows closed so that we only considered two ventilation conditions (open or closed).

Sensitivity of pNEM/CO to Air Exchange Rate

To help determine the best approach for using the CARB data to revise the pNEM/CO model, we first considered whether or not the measured vehicular air exchange rates were high enough that detailed modeling of the exchange rate would not be needed. The following analysis shows that with vents open, the model predictions are not very sensitive to the exact value of the AER, since the AER is relatively high. However, with vents closed, the AER can be low enough to have an important impact (i.e. less than about 10 per hr), for some vehicles at low speeds. Thus the statistical modeling discussed in the final section of this memorandum is important for treating these cases of low AER.

Effect of Air Exchange Rate on Inside/Outside Ratio

Of the 11 AER values in Table 1, 9 values exceed 10 hr^{-1}. The two low values occurred with vents closed at low speeds. The analysis below suggests that once an AER exceeds about 10 hr^{-1} there is almost instantaneous mixing of inside and outside air. Under these conditions, the inside/outside ratio for a one-hour averaging time is essentially 1.0 and it doesn't really matter whether the AER value is 10 hr^{-1} or 100 hr^{-1}.

Equation 7 provides an estimate of the average indoor pollutant concentration of hour h [$\mathbf{C_{in}(h)}$] given values for the indoor concentration at the end of the preceding hour [$C_{in}(h - 1)$] and the average outdoor concentration during hour h [$\mathbf{C_{out}(h)}$]. In pNEM/CO, we assume that the source term S is equal to zero. Under these circumstances, the a_3 term in Equation 7 is equal to zero and the equation can be expressed as

$$\mathbf{C_{in}(h)} = a_1 C_{in}(h - 1) + a_2 \mathbf{C_{out}(h)} \qquad (12)$$

Consider the situation where the instantaneous concentration inside the vehicle at the end of the previous hour is zero [i.e., $a_1 C_{in}(h - 1) = 0$]. Equation 12 can now be expressed as

$$\mathbf{C_{in}(h)} = a_2 \mathbf{C_{out}(h)} \qquad (13)$$

Remember that $\mathbf{C_{in}(h)}$ is the <u>average</u> concentration inside the vehicle during hour h and that $\mathbf{C_{out}(h)}$ is the <u>average</u> concentration outside the vehicle during hour h. The ratio of these two quantities can be estimated by rearranging Equation 13 to obtain

$$\mathbf{C_{in}(h)/C_{out}(h)} = a_2 = 1 - z(h) = 1 - (1 - e^{-\nu})/\nu \qquad (14)$$

Note that the ratio is solely a function of the air exchange rate (ν).

Table 2 lists values of the inside/outside ratio calculated by Equation 14 for air exchange rates between 0.1 hr^{-1} and 100 hr^{-1}. The air exchange rates form a geometric series in which each air exchange rate is approximately 59 percent larger than the preceding value.

Note that the inside/outside ratio exceeds 0.9 when the air exchange rate for the hour exceeds 10. Consider a vehicle with an inside CO concentration equal to zero at time t = 0. The vehicle is driven for an hour under conditions in which the outside concentration is held constant at a non-zero value (say at 10 ppm). The inside concentration will rise from zero to some final value at t = 1 hour. According to Equation 9, the <u>average</u> inside concentration during the hour (the value that pNEM/CO uses in exposure estimates) will be about 90 percent of the outside concentration. If the outside value is 10 ppm, the average inside value will be 9 ppm. Note that we would over-estimate the <u>average</u> inside concentration by only 11 percent if we assumed the average inside concentration during the hour was equal to the average outside concentration.

We can calculate a similar error value for other air exchange rates. Table 2 lists these error values for air exchange rates between 0.1 hr^{-1} and 100 hr^{-1}. The following table lists the error values for air exchange rates between 10 hr^{-1} and 100 hr^{-1}.

Air exchange rate	Inside/outside ratio	Error (%) in assuming inside = outside
10.0	0.900	11.1
15.8	0.937	6.7
25.1	0.960	4.2
39.8	0.975	2.6
63.1	0.984	1.6
100	0.990	1.0

All of the AER values listed in Table 1 for vent open (windows closed or open) and speed = 55 mph exceed 39.8 hr^{-1}. Consequently, we could assume that inside = outside for these cases and make less than a 2.6 percent error.

The smallest AER value listed for vent open (windows closed or open) is 20.7 hr^{-1}. This value was measured in the 97 Explorer when speed = 0 and windows were closed. The error of assuming inside = outside associated with this AER is around 5 percent.

Note that the 97 Explorer has the smallest AER of the tested vehicles when the speed = 55 mph, the vent is open, and windows are closed. This suggests (1) that the 97 Explorer is the "tightest" of the three tested vehicles under these ventilation conditions and (2) that the other two vehicles are likely to have AER values greater than 20.7 at speed = 0. Consequently, we may be justified in assuming that AER > 20 hr^{-1} when vents are open and speed = 0, regardless of tested vehicle. When AER > 20 hr^{-1}, the error in assuming inside = outside is 5 percent or less.

This line of reasoning suggests that we should focus our analysis on the "vent closed" situation, as this is the only condition likely to produce inside concentrations which are significantly less than outside concentrations. The average AER value measured in the Caprice when the vent was closed and speed = 55 mph was 39 hr^{-1}. Although no AER values are reported for the Caprice for slower speeds when the vent was closed, the 1997 Explorer data shows that at slower speeds, AER values below 10 hr^{-1} occur with vents closed, and these cases are ones for which serious errors would be introduced by assuming perfect exchange between inside and outside air:

Measured AER from CARB study for 1997 Explorer with vent closed, low fan speed.

Speed	AER (hr^{-1})	C_{in}/C_{out}	Error %
0	1.8	0.54	85
35	5.6	0.82	21
55	13.5	0.93	8

The data for the Explorer shows that AER increases with increasing vehicle speed.

Proposed Algorithm

This section describes the steps of our proposed algorithm to update the current pNEM/CO algorithm for estimating AER inside motor vehicles. We first present the various steps of the algorithm that, in turn, simulates air conditioner availability, whether vents are open or closed (based on the presence or absence of smoking, ambient temperature, and air conditioner availability), vehicle speed, and finally AER (based on vent status and vehicle speed). We then describe the data analysis used to justify each step of the simulation.

1. <u>Temperature.</u> For each day, determine daily average temperature (DAT) from a supplementary temperature file.

2. <u>Air Conditioner Availability.</u> Select a random number (RN1) between zero and 1. If RN1 is 0.85 or below, then assume an air conditioner is available. Otherwise assume an air conditioner is unavailable (i.e., the vehicle does not have an air conditioner or the air conditioner is not functional).

3. <u>Vent Status.</u>
   If the activity pattern indicates that a smoker is present, then assume the vents are open (see note on page G-3).

   Otherwise, if the activity pattern indicates that a smoker is not present, apply the residential window status algorithm as described in the pNEM/CO project report. This algorithm determines window status based on AC system and the daily average temperature according to the probabilities listed in Table 3. For the current purpose, vehicles with functional air conditioners are equated to rooms in residences with room air conditioning systems, and vehicles with vents open are equated to residences with windows open:

   a) For each day, determine daily average temperature from step 1 and air conditioning (AC) system availability from step 2. Select RN2 between zero and 1.

   b) Assume step a specified 65 degrees and functional AC. RN2 will be evaluated against percentage values listed in Table 3 for functional AC - medium temperature range (i.e., 12.0, 44.2, and 43.8).

   c) If RN2 $\leq$ 0.120, vents are always closed. AER value is selected from the "vents closed" AER distribution.

   d) If 0.230 < RN2 $\leq$ 0.562, vents are always open. AER value is selected from the "vents open" AER distribution.

   e) If 0.562 < RN2, vents are open for 61.8 percent of the time (see last column). To deal with this case, assign a 0.618 probability for the vents being open. (An alternative approach, equivalent on average, would be to apply probabilities of 0.618 and 0.382 to AER estimates with vents open and vents closed, as in the residential windows algorithm). Select RN3 between zero and 1. If RN3 $\leq$ 0.618, assume the vents are open. Otherwise assume the vents are closed.

4. <u>Speed.</u> Select a random number (RN4) between zero and 1. Use this random number to select a vehicle speed using the distribution given in Table 4.

   a) If RN4 $\leq$ 0.0462, speed = 0 mph.

   b) If 0.0462 < RN4 $\leq$ 0.0462 + 0.0662 = 0.1124, speed = 5 mph.

   c) If 0.1124 < RN4 $\leq$ 0.1124 + 0.1276 = 0.2400, speed = 10 mph.

   d) Etc. Final case is 0.9988 < RN4, speed = 60 mph.

5. <u>Air Exchange Rate.</u> Simulate AER from a log-normal distribution. Vent status and speed were simulated in steps 3 and 4.

   a) Compute mean (of the logarithms) using the formulae

   If vent is closed, $\mu = 3.37311 - 2.46213 + 0.03696 \times \text{speed}$
   If vent is open, $\mu = 3.37311 + 0.01798 \times \text{speed}$

   b) Variance (of the logarithms) = $\sigma^2 = 0.27323$

   c) Simulate Z from a standard normal distribution

   d) AER = $\exp(\mu + \sigma Z)$

<u>Air Conditioner Availability.</u>

The analysis of air conditioner availability is based on an EPA Office of Mobile Sources report (Koupal, 1998). Figure 1 taken from Koupal (1998) shows the estimated percentage of LDVs (light duty vehicles, i.e., cars) and LDTs (light duty trucks) that have air conditioning systems by model year. For cars, the percentage increases from 88 to 98 % during 1992 to 2000 model years. For trucks, the percentage increases from 80 to 98 % during 1992 to 2000 model years. The appropriate percentage for the pNEM/CO model would, in principle, depend on the calendar year modeled, since the fleet distribution (percentage of on road fleet for each vehicle class and model year) changes continually. Based on Figure 1, a single value of 90 % base penetration for both cars and trucks is proposed, since this approximately represents the current on road fleet. However, even if a vehicle originally had an air conditioning system, that system may have malfunctioned and may not have been repaired. Figure 2, also taken from Koupal (1998) shows that between 0 and 7 % of systems are estimated to be malfunctioning, depending upon vehicle age. A reasonably representative malfunction rate taken from this figure is 5 %. Thus the percentage of the on-road fleet with functioning air conditioning systems can be estimated as 85 %. Step 1 assumes 85 % availability.

Vent Status.

The proposed algorithm is most sensitive to the estimated probabilities of having vents open or closed, since the CARB data shows that the AER is very sensitive to the vent status. Data directly giving estimates of the fraction of driving with vents open or closed does not seem to be currently available. The closest set of data to this objective seems to be a Phoenix study referenced in Koupal (1998) that gave the measured percentages of driving time that the compressor was in use for a vehicle driven in Phoenix and the ambient temperature during the summer. However, these data were not useful for the current purpose, since a) having vents open is not the same as having air conditioning on, and b) the ambient temperatures were unrepresentatively high (compared to the rest of the nation).

Our proposed approach for periods when smoking is present is to assume that the vents remain open. Since the pNEM/CO model is used to estimate CO exposures for non-smokers, it is not unreasonable to assume that the non-smoker would want to have the windows or vents open while smoking is present. However, this simplified approach does not allow the vent status to depend on the ambient temperature or the availability of an air conditioner in this situation of ETS exposure.

Our proposed approach for periods when smoking is not present uses the residential window open algorithm from pNEM/CO as a surrogate for vehicular vents being open. This assumes that a person would decide to open a car vent under the same temperature and air conditioning system availability conditions as a person in a residence deciding whether or not to open windows in a room where there was a room air conditioning system. An alternative approach might be to use the windows open rates for residences with central air conditioning systems, but we assume that the availability of a local air conditioning system in a room rather than the availability of central air conditioning is more parallel to the availability of air conditioning in a vehicle. Turning on the air conditioner in a vehicle is more comparable to turning on the room air conditioner in that room as opposed to overriding the default settings of a central air conditioning system (possibly with the controls in another room.) This approach is, of course, a large approximation.

One important consideration is that a vehicle driver or passenger can use the air conditioning system either with vents open (to condition incoming air) or with vents closed (to condition the indoor air), which is not the same as the situation for a residence. A possibly more realistic approach might be to assume that at high temperatures, if the probability model indicates the vehicle vents are closed, the model actually has the vents open for a few minutes (to quickly cool down the hot vehicle using the cooler outside air) and then has the vents closed. Implementation of that approach is not recommended since the air exchange rate algorithm will still have substantial uncertainty despite the extra model complexity.

Finally, note that Koupal (1998) argued that as well as the ambient temperature, the humidity is an important factor in the decision to use the air conditioner. A more sophisticated approach might model the decision to open or close vehicle vents based on the availability of an air conditioner, the ambient temperature, and the humidity. However, the humidity data for each simulated day are not readily available, nor are data that could be used to model vent status as a function of air conditioner availability, ambient temperature, and humidity.

Speed.

The speed distributions were originally proposed to be taken from Sierra Research's analysis (Carlson and Austin, 1997) of the 1992 instrumented vehicle study carried out in Spokane, Baltimore, and Atlanta, to assist in EPA's review of the Federal Test Procedure. In each city, a sample of vehicles were instrumented so that second-by-second speeds (and other information) could be recorded. The regular driver of that vehicle drove it for about one week with the instrumentation on. Since the Rodes et al (1998) study measured average air exchange rates for cruising at selected fixed speeds, instead of instantaneous speeds, the algorithm was later revised to use a distribution of trip mean speeds developed by ICF / Systems Applications International from the Spokane-Baltimore subset of the same instrumented vehicle study database (Cohen et al, 1994). The analysis by Cohen et al (1994) computed the distribution of the trip mean speed, where a trip (referred to as an "event" in the cited report) was defined as any continuous period of second by second records starting with a valid speed measurement and followed by at least 19 seconds of missing or invalid speed measurements. The requirement for a 19 second gap was designed so that short engine stalls or false starts would not be counted as a trip but would instead be included as part of a longer trip. The distributions used for pNEM/CO were based only on the vehicles installed with a 3-parameter data logger, rather than a 6-parameter data logger; the set of vehicles that could be fitted with the 3-parameter logger are more representative of the on-road fleet The trip mean speed distributions are shown in Table 4.

Air Exchange Rate.

For a given speed and vent status, the distribution of AER was estimated based on the CARB study data (Rodes et al, 1998). Using SAS, and the data in Table 1, a mixed model was fitted of the form:

$$\log(\text{AER}) = \text{vehicle} + \alpha \times \text{I(closed)} + \beta_O \times \text{speed} \times \text{I(open)} + \beta_C \times \text{speed} \times \text{I(closed)} + \text{Error}$$

I(closed) = 1 if vents are closed, = 0 if vents are open.

I(open) = 1 if vents are open, = 0 if vents are closed.

The parameters α, β_O, and β_C are fixed effects showing that the log(AER) varies linearly with speed, but has a different intercept and slope depending upon whether or not the vents were open. The fitted model had $\alpha = -2.46213$, $\beta_O = 0.01798$, and $\beta_C = 0.03696$. The estimated slope for the vent open case is one half the slope for the vent closed case. The value of α is the difference between the intercepts for vents open and vents closed.

The vehicle effect was assumed to be a normally distributed variable. Thus, instead of estimating separate fixed effects for the three vehicles, the statistical model assumes that these three vehicles were a random sample from the national fleet, each with an associated vehicle effect drawn from this normal distribution. The fitted model had a vehicle effect with mean 3.37311 and variance 0.22966. The estimated mean, 3.37311 is the mean value of the log(AER) for a stationary vehicle with vents open.

Finally, the error term was assumed to be a normally distributed variable with mean zero. The estimated error variance was 0.04357, giving a total variance of 0.22966 + 0.04357 = 0.27323 (including the vehicle to vehicle variability and the within vehicle variability).

Step 5 of the algorithm applies this statistical model to simulate air exchange rate from vehicle speed and vent status. The fitted model for the relationship between the air exchange rate and the vent status and speed is plotted in Figures 3 (raw scale) and 4 (log scale). The value on the y axis is the predicted value of the air exchange rate, i.e., the exponential power of the expected value of log(AER). For a given speed and vent status, the fitted log-normal mixed model assumes that the air exchange rate is drawn from a log-normal distribution centered at the predicted value (symmetrically distributed on the log scale).

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Table 1. Air Exchange Rate Data.

Test conditions		Air Exchange Rate (hr^{-1})		
Ventilation settings	Vehicle speed, mph[a]	91 Caprice	97 Taurus	97 Explorer
vent closed low fan speed	55	39	14	13.5
	35			5.6
	0			1.8
vent open low fan speed	55	98	76	55.5
	35			35.7
	0			20.7
vent open low fan speed front windows 1/3 open	55	160		

[a]The vehicle speed was constantly maintained throughout the AER measurement.

Reference: Rodes, C., L. Sheldon, D. Whitaker, A. Clayton, K. Fitzgerald, J. Flanagan, F. DiGenova, S. Hering, C. Frazier. 1998. **Measuring Concentrations of Selected Air Pollutants Inside California Vehicles**. Air Resources Board. Report No. 95-339. Final report.

Table 2. Ratios of Hourly Average Values of Inside Concentration to Outside Concentrations.

Air exchange rate, hr^{-1}	Ratio[a] = $\mathbf{C_{in}(h)/C_{out}(h)}$	Error in assuming $\mathbf{C_{in}(h)} = \mathbf{C_{out}(h)}$, percent
0.10	0.048	1967
0.16	0.075	1229
0.25	0.116	764
0.40	0.175	471
0.63	0.258	287
1.00	0.368	172
1.58	0.498	101
2.51	0.634	58
3.98	0.754	33
6.31	0.842	19
10.00	0.900	11.1
15.85	0.936	6.7
25.12	0.960	4.1
39.81	0.974	2.6
63.10	0.984	1.6
100.00	0.990	1.0

[a]$\mathbf{C_{in}(h)}$ is the average concentration inside the vehicle during hour h, and $\mathbf{C_{out}(h)}$ is the average concentration outside the vehicle during hour h. Ratios based on assumptions that instantaneous value of C_{in} at beginning of hour h equals zero, air exchange rate is constant during hour h, and C_{out} is constant during hour h.

Table 3. Estimated Percentage of Time With Indicated Vent Ratios by Air Conditioning System And Temperature Range

Air conditioning system	Temperature range[a]	Percentage of time with indicated vent ratio[b]			Mean of ratios not equal to 0 or 1
		Ratio = 0	Ratio = 1	0 < Ratio = <1	
Functional	Low	73.2	2.0	24.7	0.316
	Medium	12.0	44.2	43.8	0.618
	High	17.1	34.3	48.6	0.521
No air conditioning or not functional	Low	80.0	1.0	19.0	0.276
	Medium	4.7	59.1	36.2	0.716
	High	1.4	70.8	27.8	0.774

Based on Table 4-3 of pNEM/CO project report. Equates residences with vehicles.

[a] Low: 31° to 62°F.
Medium: 63° to 75°F.
High: 76°F and above.

[b] Ratio = (minutes vent open)/(minutes spent in vehicle).

Table 4. Vehicle trip mean speed distribution.

Speed (mph)	Frequency (%)
0	4.62
5	6.62
10	12.76
15	21.75
20	21.52
25	16.12
30	7.57
35	4.10
40	2.18
45	1.46
50	0.91
55	0.27
60	0.12

Reference: Cohen et al (1994). Table 2-17. For computational convenience, and to better reflect the likely experimental conditions of the Rodes et al (1998) study, the distribution in the cited Table 2-17 has been aggregated to 5 mph increments from the original 1 mph increments. The tabulated speeds 0, 5, 10, 15, . . . correspond to the measured speed ranges 0 to 2.5, 2.6 to 7.5, 7.6 to 12.5, 12.6 to 17.5, . . .

Figure 1. From Koupal (1998).

Figure 2 - Proposed Base Market Penetration Estimates

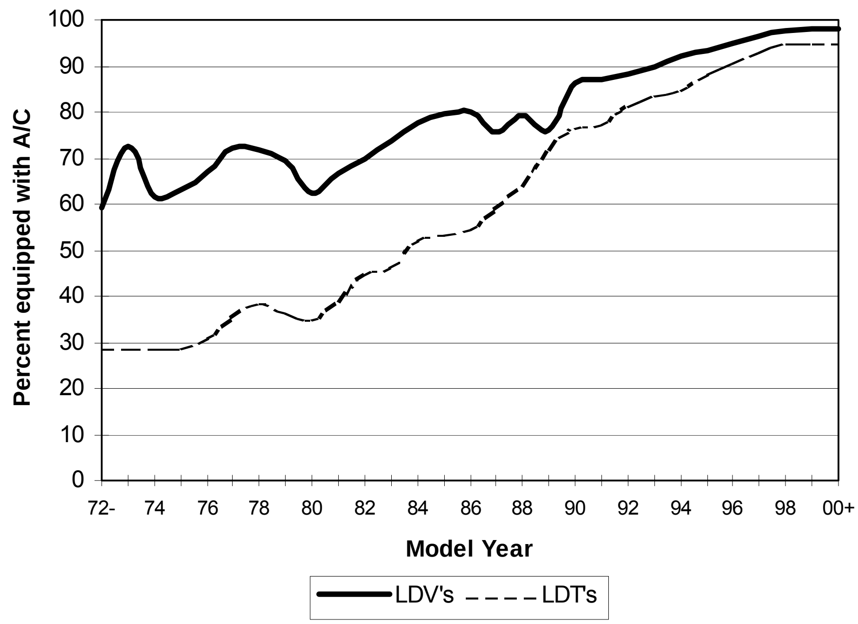


Figure 2. From Koupal(1998).

Figure 3 - Proposed Rate of Unrepaired Malfunctions

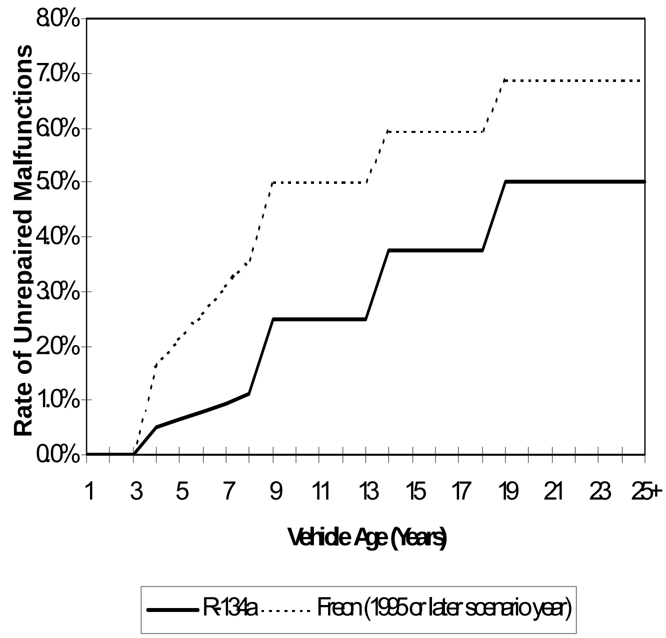
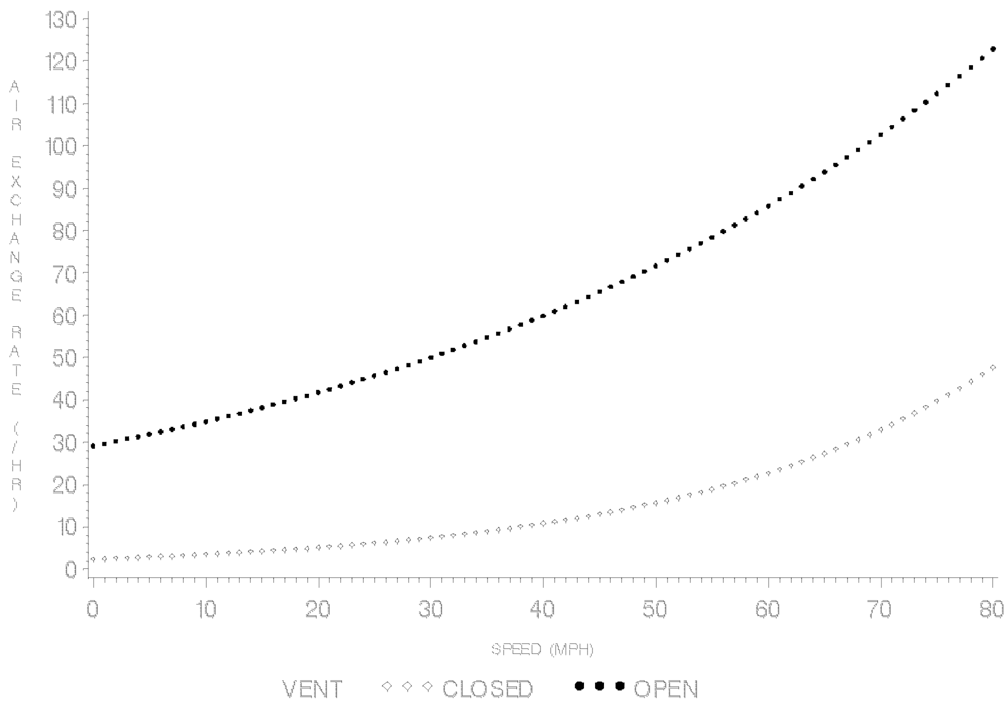


Fig 3. Air Exchange Rate Vs. Speed and Vent Status



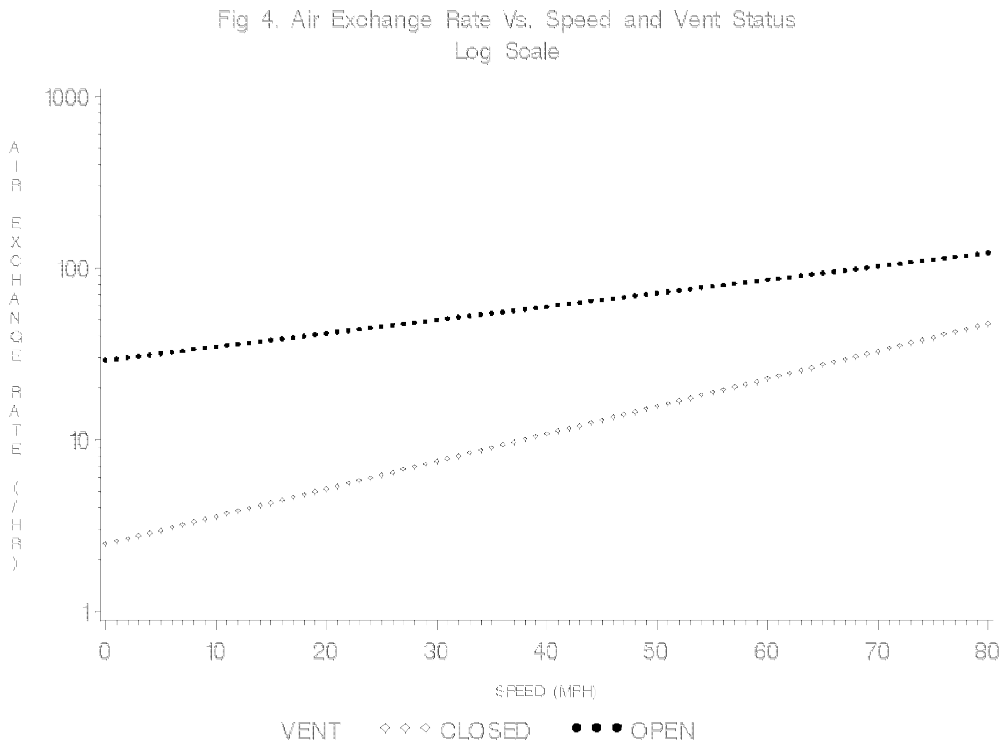


Fig 4. Air Exchange Rate Vs. Speed and Vent Status
Log Scale
AIR EXCHANGE RATE (/HR)
1000
100
10
1
0
10
20
30
40
50
60
70
80
SPEED (MPH)
VENT
CLOSED
OPEN

Appendix H

Analyses Supporting Proposed Modifications to the Mass Balance Algorithm and Gas Stove Algorithm in pNEM/CO

Memorandum

To: Arlene Rosenbaum
Systems Applications International

From: Ted Johnson
TRJ Environmental, Inc.

Date: September 23, 1998 (Rev. 1.2)

Project: EPA Work Assignment 1-19

Memo No. 1: Analyses Supporting Proposed Modifications to the Mass Balance Algorithm and Gas Stove Algorithm in pNEM/CO

Work Assignment 1-19 of EPA Contract No. 68-D6-0064 directs the ICF project team to propose and implement modifications to the Probabilistic NAAQS Exposure Model for Carbon Monoxide (pNEM/CO). In earlier work performed under EPA Contract No. 68-D3-0094, TRJ Environmental, Inc., (TRJ) assisted IT Corporation in developing a set of recommendations for modifying two components of pNEM/CO: the mass balance algorithm and the gas stove algorithm. The proposed modifications are summarized in two letters (dated June 9 and June 12, 1998) from Andy Law of IT Corporation to Harvey Richmond of the U.S. Environmental Protection Agency. This memorandum describes a series of analyses performed by TRJ in support of these modifications.

<u>Seasonal Variation for Fuel Use by Gas Stove Burners</u>

Based on recommendations made by analysts at IT Corporation under a prior work assignment, Harvey Richmond of EPA's Risk and Exposure Assessment Group (REAG) directed the IT project team to base all estimates of fuel use by gas stove burners on data obtained from a survey performed by Northern Illinois Gas Company (NIGAS). This survey included 752 gas appliances in 354 single-family residences. Harvey Richmond also requested that analysts incorporate the seasonal variation in gas stove burner use into the model. This section presents a method which meets these requirements.

A report by the Gas Research Institute (GRI) indicates that the arithmetic mean of burner gas use for the NIGAS survey was 21.8 therms = 2180 ft^3 per year (n = 57) with an arithmetic standard deviation of 8.9 therms = 890 ft^3 per year (unadjusted for age of occupants). The ratio of standard deviation to mean is 0.41. This value suggests that the underlying distribution is skewed, as the ratio for normal distributions fit to non-negative data is typically less than 0.33. If we assume that the distribution is lognormal, the corresponding values for geometric mean and standard deviation can be calculated by the expressions

$$GM = AM/[(ASD/AM)^2 + 1]^{0.5} \tag{1}$$

$$GSD = \exp\{\ln[(ASD/AM)^2 + 1]\}^{0.5} \tag{2}$$

in which GM = geometric mean, GSD = geometric standard deviation, AM = arithmetic mean, and ASD = arithmetic standard deviation. Making the appropriate substitutions, one obtains GM = 2018 ft^3 per year and GSD = 1.48 (dimensionless).

The GM must be converted to kilojoules for use in the pNEM/CO mass balance model. The 1992 pNEM/CO report notes that the Gas Research Institute estimates that the average heating value of natural gas in Denver is 1048 kilojoules per cubic feet. Applying this conversion factor, we obtain 2018 ft^3 per year x 1048 kilojoules/ft^3 = 2,114,864 kilojoules per year = 2.11 million kilojoules per year.

GEOMET provides the following equation for estimating daily gas use by burners (ft^3/day) when the date is converted to number of weeks since May 1:

$$y(x) = 6.37 - (1.21)[\sin(0.45 + 2\pi x/52)] \tag{3}$$

in which

x = number of weeks since May 1
y = mean gas stove consumption for week x, excluding pilot lights (ft^3/day).

The following normalized version of this equation produces a mean value of 1.0:

$$Y'(x) = 1.00 - (0.190)[\sin(0.45 + 2\pi x/52)]. \tag{4}$$

Equation 4 can be converted to the following equation which uses m = days since May 1 rather than x = weeks since May 1.

$$Y'(m) = 1.00 - (0.190)[\sin(0.45 + 2\pi m/365)]. \tag{5}$$

There are 17 weeks (120 days) from January 1 through April 30 and 35 weeks (245 days) from May 1 through December 31. The following versions of Equation 5 can be used with j = Julian date (i.e., j = 1 for January 1):

$$Y'(j) = 1.00 - (0.190)\{\sin[0.45 + (2\pi)(j - 120)/365]\} \text{ or} \tag{6}$$

$$Y'(j) = 1.00 - (0.190)\{\sin[-1.616 + (2\pi)(j)/365]\}. \tag{7}$$

As before, EFBURN is defined as the CO emission factor for stove burners for a particular hour. To use Equation 7 in calculating ERBURN, perform the following steps:

1. Go to the next day of the current sequence. The Julian date of this day is j.

2. Obtain value for AUB = annual fuel usage of burners from an appropriate distribution. As indicated above, we can assume that AUB follows a lognormal distribution with geometric mean = 2.11 million kilojoules per year and geometric standard deviation = 1.48.
3. $Y'(j) = 1.00 - (0.190)\{\sin[-1.616 + (2\pi)(j)/365]\}$.
4. ERBURN = (EFBURN)(AUB)(Y')/365.2 for all hours of day.

Fuel Use by Gas Stove Pilot Lights

Based on recommendations made by analysts at IT Corporation under a prior work assignment, Harvey Richmond directed the project team to base all estimates of fuel use by pilot lights on the NIGAS study discussed above. The NIGAS study measured total gas usage (burners plus pilot lights) for 33 stoves and reported an arithmetic mean of 57.1 therms and a standard deviation of 18.3 therms. As discussed above, the study measured gas usage by burners only for arithmetic mean of burner gas use for the NIGAS survey was 21.8 therms (n = 57) with an arithmetic standard deviation of 8.9 therms. The difference in means between the two samples, 57.1 - 21.8 = 35.3, provides an estimate of the mean fuel usage for pilot lights only. The corresponding difference in variances ($18.3^2 - 8.9^2 = 255.7$) provides an estimate of the variance of fuel usage by pilot lights. The square root of the estimated variance provides an estimate of the standard deviation (16.0). Consequently, we can estimate that the distribution of pilot light usage has an arithmetic mean of 35.3 therms = 3530 ft^3 and an arithmetic standard deviation of 16.0 therms = 1600 ft^3.

The ratio of standard deviation to mean is 16.0/35.3 = 0.45, suggesting that the underlying distribution is skewed. If we assume that the distribution is lognormal, the corresponding values for geometric mean and standard deviation can be calculated by Equations 1 and 2 above. Making the appropriate substitutions, we obtain GM = 3215 ft^3 per year and GSD = 1.84 (dimensionless). Applying the ft^3-to-kilojoule conversion factor cited above, we calculate the geometric mean to be 3215 ft^3 per year x 1048 kilojoules/ft^3 = 3,369,320 kilojoules per year = 3.37 million kilojoules per year. The GSD is unchanged.

Air Exchange Rates for Residences with Windows Closed

In the May 4 memorandum, Harvey Richmond directed the project team to use the data from Reference 8 of the Law letter to develop distributions for the region and seasons that are included in the analysis for Denver. Reference 8 is a journal article by D. M. Murray and D. E. Burmaster (Risk Analysis, Vol. 15, No. 4, 1995) which lists distributions of AER by season and climatic region based on data compiled by Brookhaven National Laboratory (BNL). Table 1 is an excerpt of the data from Murray and Burmaster which has been reformatted for easier analysis. The data applicable to Denver can be found under Region 2, which includes the State of Colorado. Parameters for the lognormal distribution are provided for each of four seasons and for all seasons combined. The four seasons and associated sample sizes are listed below.

Season 1 (n = 428): December, January, February
Season 2 (n = 43): March, April, May
Season 3 (n = 2): June, July, August
Season 4 (n = 23): September, October, November.

The indicated sample sizes are considered adequate for characterizing lognormal distributions appropriate for Seasons 1 and 2. The sample size for Season 4 (n = 23) is considered marginal, and the sample size for Season 3 (n = 2) is obviously inadequate. To provide better estimates for Seasons 3 and 4, we conducted a series of statistical analyses. We found that the following regression-based equation could be used to predict the geometric mean values with n > 20 in Table 1 with an R^2 value of 0.851 (adjusted R^2 = 0.778).

$$GM = 0.627 + (0.298)(S3) - (0.344)(R1) - (0.272)(R2) - (0.241)(R3)$$

where S3 equals 1 for Season 3, 0 otherwise.
R1 equals 1 for Region 1, 0 otherwise.
R2 equals 1 for Region 2, 0 otherwise.
R3 equals 1 for Region 3, 0 otherwise.

Applied to Season 3 in Region 2, this equation produces the estimate of GM = 0.627 + (0.298)(1) - (0.272)(1) = 0.653. This estimate is consistent with the GM values for Season 3 in Regions 1, 3, and 4 which tend to be larger than the GM values for the other three seasons.

The above equation is not applicable to Season 4, as it does not include the variable S4. Additional analyses found that the following applicable equation could be used to predict the geometric mean values with n > 20 in Table 1 with an R^2 value of 0.857 (adjusted R^2 = 0.715).

$$GM = 0.923 - (0.310)(S1) - (0.278)(S2) - (0.316)(S4) - (0.338)(R1) - (0.266)(R2) - (0.236)(R3)$$

where S1 equals 1 for Season 1, 0 otherwise.
S2 equals 1 for Season 2, 0 otherwise.
S4 equals 1 for Season 4, 0 otherwise.
R1 equals 1 for Region 1, 0 otherwise.
R2 equals 1 for Region 2, 0 otherwise.
R3 equals 1 for Region 3, 0 otherwise.

Applied to Season 4 in Region 2, this equation produces the estimate of GM = 0.923 - (0.316)(1) - (0.266)(1) = 0.341. As this estimate (0.341) is consistent with the GM value listed in Table 1 for Season 3 (0.309), we can make a case for using either value. I suggest that we use the listed value (0.309).

Similar analyses of the geometric standard deviation (GSD) values found that season and region were not good predictors of the GSD values in Table 1, which tended to fall within a relatively narrow range. Consequently, I suggest that we use the average GSD for Region 2 (2.010) as the GSD for Season 3 in Region 2 and the listed GSD (1.716) for Season 4.

In summary, I am proposing that the following seasonal distributions be used represent the AER values of Denver residences with windows closed.

Season	Months	Geometric mean	Geometric std. dev.
1	Dec, Jan, Feb	0.450	1.960
2	Mar, Apr, May	0.308	2.241
3	Jun, Jul, Aug	0.653	2.010
4	Sep, Oct, Nov	0.309	1.716

Note: Following the completion of the analysis described above, ICF became aware of potential errors in the BNL database analyzed by Murray and Burmaster. If the errors are significant, the analysis presented above may need to be revised when BNL issues a corrected database.

Air Exchange Rates for Residences with Windows Open

In the May 4 memorandum, Harvey Richmond directed the project team to use the draft “scripted house” report by Johnson, Weaver, and Mozier (1997) to develop a uniform distribution for the air exchange rates (AER) of residences with windows open. This report provides 24 hourly-average AERs measured in a residence under varying conditions. Table 2 is a listing of the nine hourly-average AER values measured when one or more windows were open. The values range from 0.78 to 2.92, appropriate lower and upper limits for a uniform distribution fit to the data.

I also evaluated the normal and lognormal distributions as models for the data. These data analyses indicated that the AER values could be reasonably characterized by a lognormal distribution with geometric mean = 1.336 hr^{-1} and geometric standard deviation = 1.550 (dimensionless). (The Wilk-Shapiro statistics for goodness-of-fit were 0.877 for the normal distribution and 0.960 for the lognormal distribution, where 1.000 indicates a perfect fit .) I recommend that we use the specified lognormal distribution in pNEM/CO with lower and upper bounds of 0.57 and 3.15. These bounds correspond to the 2.5th and 97.5th percentiles of the specified lognormal distribution and include the full range of observed values.

Residential Volumes

The May 4 memorandum directs analysts to use the 1995 Census Bureau Housing Survey (CBHS) to develop a distribution for volumes of residences in Denver. Consistent with the approach used in the 1992 pNEM/CO model, we will determine the distribution for living area (i.e., square footage) and assume a constant 8-foot ceiling height. Table 3 lists frequency data from the CBHS for Denver and Los Angeles (another possible study area for pNEM/CO analyses). Plots of these statistics indicate that the data are closely fit by lognormal distributions with the following values for geometric mean and geometric standard deviation.

		Geometric mean	Geometric std. dev.	Median
Square footage:	Denver	1926	1.62	2020
	Los Angeles	1604	1.64	1651

The values listed under median were provided in the CBHS listings and agree closely with the estimated geometric means. (The geometric mean of a "perfect" lognormal distribution is equal to its median).

Assuming an eight-foot ceiling and using 1 cubic meter = 35.315 cubic feet, the residential volumes can be modeled by lognormal distributions with the following parameters.

		Geometric mean	Geometric std. dev.
Volume, m^3:	Denver	436	1.62
	Los Angeles	363	1.64

The lognormal distribution used for Denver in the 1992 version of pNEM/CO had a geometric mean of 321 m^3 and a standard deviation of 1.62. The new geometric mean (436 m^3) represents an increase of 36 percent in the average residential volume for Denver residences. The geometric standard deviation is essentially unchanged.

Summary Table

Table 4 presents a summary of the distributions proposed in this memorandum. The lower and upper bounds for values to be selected from each distribution are initially set at the 2.5th and 97.5th percentiles of the distribution. These bounds may be changed after further analysis of the applicable data bases. Note also that the analysis of air exchange rates for residences with windows closed may need to revised when BNL issues a corrected database.

Table 1. Air Exchange Rates for Residences, Windows Closed (Murray and Burmaster, 1995)

Region	States	Season[a]	Sample size	Lognormal distribution fit to air exchange rate data	
				Geometric mean	Geometric standard deviation
All	All	All	2844	0.528	2.273
		1	1139	0.433	2.026
		2	1051	0.503	2.079
		3	529	1.008	2.479
		4	125	0.316	1.895
1	ID, MN, MT, NH, NY1, VT, WI	All	467	0.314	2.038
		1	161	0.271	2.223
		2	254	0.364	1.872
		3	5[b]	(0.643)	2.088
		4	47	0.216	1.749
2	CO, CT, IL, NJ, NY2, OH, PA, WA (includes Denver and New York)	All	496	0.430	2.010
		1	428	0.450	1.960
		2	43	0.308	2.241
		3	2[b]	(1.261)	na
		4	23[b]	(0.309)	(1.716)
3	CA3, MD, OR, WA	All	332	0.439	1.996
		1	96	0.384	1.802
		2	165	0.448	2.186
		3	34	0.555	1.844
		4	37	0.455	1.573
4	AZ, CA4, FL, TX (includes Los Angeles)	All	1549	0.687	2.243
		1	454	0.507	1.910
		2	589	0.619	1.950
		3	488	1.054	2.489
		4	18[b]	(0.416)	(2.034)

[a] Season 1: December, January, February; Season 2: March, April, May; Season 3: June, July, August; Season 4: September, October, November. [b] Sample size < 25.

Table 2. Data for Air Exchange Rates Measured During Scripted House Study When One or More Windows Were Open (Johnson, Weaver, and Mozier, 1997)

Start time	Office Door A	Office Window C	Office Door D	Bedroom Door E	Bedroom Window F	Great Room Window G	Great Room Window I	Heat	Draft conditions[a]	AER, hr^{-1}
6 am	Closed	OPEN	Open	Open	Closed	Closed	Closed	Off	no	1.61
9 am	Closed	OPEN	Open	Open	Closed	Closed	OPEN	Off	yes	2.92
10 am	Closed	OPEN	CLOSED	Open	Closed	Closed	OPEN	Off	no	0.80
11 am	Closed	OPEN	Open	Open	Closed	Closed	Closed	Off	no	2.13
6 pm	Closed	OPEN	CLOSED	Open	Closed	Closed	Closed	Off	no	0.96
7 pm	Closed	OPEN	Open	Open	Closed	Closed	Closed	Off	no	1.22
8 pm	Closed	OPEN	Open	Open	Closed	Closed	OPEN	Off	yes	1.35
9 pm	Closed	OPEN	CLOSED	Open	Closed	Closed	Closed	Off	no	0.78
4 am	Closed	OPEN	CLOSED	Open	Closed	Closed	Closed	ON	no	1.37
Varied during test?	No	Yes	Yes	No	No	No	Yes	Yes	Yes	See note b

[a] "Yes" indicates that air had unobstructed flow path from open Office Window C to open Great Window I.

[b] Open window AER statistics: geometric mean = 1.336 hr^{-1}, geometric standard deviation = 1.550.

Table 3. Statistics on Square Footage of Occupied Units.

Range of square footage for occupied units	Denver		Los Angeles	
	Number in thousands	Cumulative percent	Number in thousands	Cumulative percent
less than 500	1.0	0.2	20.7	1.7
500 to 749	9.3	2.5	37.0	4.7
750 to 999	34.1	10.6	104.9	13.2
1,000 to 1,499	75.6	28.6	354.8	42.0
1,500 to 1,999	86.0	49.2	326.1	68.5
2,000 to 2,499	86.7	69.8	199.6	84.7
2,500 to 2,999	49.8	81.7	66.8	90.1
3,000 to 3,999	53.4	94.5	77.1	96.3
4,000+	23.2	100.00	45.1	100.0
Total[a]	419.1	--	1232.1	--

[a] Omits 38,500 units which did not report square footage values.

Table 4. Summary of Distributions Proposed in this Memorandum.

Quantity	City	Distribution	Parameter[a]	Value
Annual fuel use by gas stove burners, kJ/yr (Use Equation 7 and four-step algorithm to determine seasonal patterns in gas use.)	Denver	Lognormal	GM	2.11 million
			GSD[b]	1.48
			Lower bound	0.98 million[c]
			Upper bound	4.55 million[d]
Annual fuel use by gas stove pilot light, kJ/yr	Denver	Lognormal	GM	3.37 million
			GSD[b]	1.84
			Lower bound	1.02 million[c]
			Upper bound	11.13 million[d]
Air exchange rate -- windows closed (Season 1), h^{-1}	Denver	Lognormal	GM	0.450
			GSD[b]	1.960
			Lower bound	0.120[c]
			Upper bound	1.683[d]
Air exchange rate -- windows closed (Season 2), h^{-1}	Denver	Lognormal	GM	0.308
			GSD[b]	2.241
			Lower bound	0.063[c]
			Upper bound	1.498[d]
Air exchange rate -- windows closed (Season 3), h^{-1}	Denver	Lognormal	GM	0.653
			GSD[b]	2.010
			Lower bound	0.166[c]
			Upper bound	2.566[d]
Air exchange rate -- windows closed (Season 4), h^{-1}	Denver	Lognormal	GM	0.309
			GSD[b]	1.716
			Lower bound	0.107[c]
			Upper bound	0.890[d]
Air exchange rate -- windows open, h^{-1}	Any	Lognormal	GM	1.34
			GSD[b]	1.55
			Lower bound	0.57[c]
			Upper bound	3.16[d]

Quantity	City	Distribution	Parameter[a]	Value
Residential volumes, m^3	Denver	Lognormal	GM	436
			GSD[b]	1.62
			Lower bound	169[c]
			Upper bound	1122[d]
Residential volumes, m^3	Los Angeles	Lognormal	GM	363
			GSD[b]	1.64
			Lower bound	138[c]
			Upper bound	957[d]

[a] GM = geometric mean, GSD = geometric standard deviation.
[b] GSD is a dimensionless quantity.
[c] Lower bound = 2.5^{th} percentile of proposed distribution.
[d] Upper bound = 97.5^{th} percentile of proposed distribution.

Appendix I

Distributions for Use with the Mass Balance and Gas Stove Algorithms in Applying pNEM/CO to Los Angeles

Memorandum

To: Arlene Rosenbaum
Systems Applications International

From: Ted Johnson
TRJ Environmental, Inc.

Date: April 21, 1999 (Rev. 1.6)

Project: EPA Work Assignment 2-30

Memo No. 2: Distributions for Use with the Mass Balance and Gas Stove Algorithms in Applying pNEM/CO to Los Angeles

Work Assignment 2-30 of EPA Contract No. 68-D6-0064 directs the ICF project team to provide input data necessary to apply Version 2.0 of the Probabilistic NAAQS Exposure Model for Carbon Monoxide (pNEM/CO) to Los Angeles. This memorandum provides some of the input data required by two components of pNEM/CO: the mass balance algorithm and the gas stove algorithm.

Seasonal Variation for Fuel Use by Gas Stove Burners

Based on recommendations made by analysts at IT Corporation under a prior work assignment, Harvey Richmond of EPA's Risk and Exposure Assessment Group (REAG) directed the project team to base all estimates of fuel use by gas stove burners on data obtained from a survey performed by Northern Illinois Gas Company (NIGAS). This survey included 752 gas appliances in 354 single-family residences. Harvey Richmond also requested that analysts incorporate the seasonal variation in gas stove burner use into the model. This section presents a method which meets these requirements. The application of this method to Denver was discussed previously in my memorandum of September 23, 1998.

A report by the Menkedick et al. (1993) for the Gas Research Institute (GRI) indicates that the arithmetic mean of burner gas use for the NIGAS survey was 21.8 therms = 2180 ft^3 per year (n = 57) with an arithmetic standard deviation of 8.9 therms = 890 ft^3 per year (unadjusted for age of occupants). The ratio of standard deviation to mean is 0.41. This value suggests that the underlying distribution is skewed, as the ratio for normal distributions fit to non-negative data is typically less than 0.33. If we assume that the distribution is lognormal, the corresponding values for geometric mean and standard deviation can be calculated by the expressions

$$GM = AM/[(ASD/AM)^2 + 1]^{0.5} \quad (1)$$

$$GSD = \exp\{\ln[(ASD/AM)^2 + 1]\}^{0.5} \quad (2)$$

in which GM = geometric mean, GSD = geometric standard deviation, AM = arithmetic mean, and ASD = arithmetic standard deviation.   Making the appropriate substitutions, one obtains GM = 2018 ft^3 per year and GSD = 1.48 (dimensionless).

The GM must be converted to kilojoules for use in the pNEM/CO mass balance model. The 1992 pNEM/CO report notes that the Gas Research Institute estimates that the average heating value of natural gas in Denver is 1048 kilojoules per cubic feet. IN a personal communication, the California Energy Commission told Pat Stiefer that the all western natural gas should have the same heating value. Assuming that the Denver conversion factor also applies to Los Angeles, we obtain 2018 ft^3 per year x 1048 kilojoules/ft^3 = 2,114,864 kilojoules per year = 2.11 million kilojoules per year.

As described below, we are proposing that the 2.11 million kilojoules value by multiplied by 0.82 to adjust for the differences between the population sampled by NIGAS and the Los Angeles study area population. The resulting estimate for the GM is 1.73 million kilojoules. The GSD is unchanged.

Wilkes and Koontz (1995) provides the following equation for estimating daily gas use by burners (ft^3/day) when the date is converted to number of weeks since May 1:

$$y(x) = 6.37 - (1.21)[\sin(0.45 + 2\pi x/52)] \qquad (3)$$

in which

x = number of weeks since May 1
y = mean gas stove consumption for week x, excluding pilot lights (ft^3/day).

The following normalized version of this equation produces a mean value of 1.0:

$$Y'(x) = 1.00 - (0.190)[\sin(0.45 + 2\pi x/52)]. \qquad (4)$$

Equation 4 can be converted to the following equation which uses m = days since May 1 rather than x = weeks since May 1.

$$Y'(m) = 1.00 - (0.190)[\sin(0.45 + 2\pi m/365)]. \qquad (5)$$

There are 17 weeks (120 days) from January 1 through April 30 and 35 weeks (245 days) from May 1 through December 31. The following versions of Equation 5 can be used with j = Julian date (i.e., j = 1 for January 1):

$$Y'(j) = 1.00 - (0.190)\{\sin[0.45 + (2\pi)(j - 120)/365]\} \text{ or} \qquad (6)$$

$$Y'(j) = 1.00 - (0.190)\{\sin[-1.616 + (2\pi)(j)/365]\}. \qquad (7)$$

As before, EFBURN is defined as the CO emission factor for stove burners for a particular hour. To use Equation 7 in calculating ERBURN, perform the following steps:

5. Go to the next day of the current sequence. The Julian date of this day is j.
6. Obtain value for AUB = annual fuel usage of burners from an appropriate distribution. As indicated above, we can assume that AUB follows a lognormal distribution with geometric mean = 1.73 million kilojoules per year and geometric standard deviation = 1.48.
7. $Y'(j) = 1.00 - (0.190)\{\sin[-1.616 + (2\pi)(j)/365]\}$.
8. ERBURN = (EFBURN)(AUB)(Y')/365.2 for all hours of day.

The distribution of EFBURN values previously used in the Denver analysis would be applied to Los Angeles.

Fuel Use by Gas Stove Pilot Lights

Based on recommendations made by analysts at IT Corporation under a prior work assignment, Harvey Richmond directed the project team to base all estimates of fuel use by pilot lights on the NIGAS study discussed above. The report by Menkedick et al. (1993) indicates that the NIGAS study measured total gas usage (burners plus pilot lights) for 33 stoves and reported an arithmetic mean of 57.1 therms and a standard deviation of 18.3 therms. As discussed above, the study measured gas usage by burners only for arithmetic mean of burner gas use for the NIGAS survey was 21.8 therms (n = 57) with an arithmetic standard deviation of 8.9 therms. The difference in means between the two samples, 57.1 - 21.8 = 35.3, provides an estimate of the mean fuel usage for pilot lights only. The corresponding difference in variances ($18.3^2 - 8.9^2 = 255.7$) provides an estimate of the variance of fuel usage by pilot lights. The square root of the estimated variance provides an estimate of the standard deviation (16.0). Consequently, we can estimate that the distribution of pilot light usage has an arithmetic mean of 35.3 therms = 3530 ft^3 and an arithmetic standard deviation of 16.0 therms = 1600 ft^3.

The ratio of standard deviation to mean is 16.0/35.3 = 0.45, suggesting that the underlying distribution is skewed. If we assume that the distribution is lognormal, the corresponding values for geometric mean and standard deviation can be calculated by Equations 1 and 2 above. Making the appropriate substitutions, we obtain GM = 3215 ft^3 per year and GSD = 1.84 (dimensionless). Applying the ft^3-to-kilojoule conversion factor cited above, we calculate the geometric mean to be 3215 ft^3 per year x 1048 kilojoules/ft^3 = 3,369,320 kilojoules per year = 3.37 million kilojoules per year.

If we apply the adjustment factor for Los Angeles (0.82) to 3.37 million kilojoules, we obtain an estimate of the GM for pilot lights of 2.76 million kilojoules per stove. The GSD remains equal to 1.84. Note that application of the adjustment factor to the NIGAS pilot light data assumes that pilot light use is proportionally lower in Los Angeles, an assumption which cannot be currently verified.

Development of Los Angeles Adjustment Factor (0.82)

Pat Stiefer has obtained gas stove data specific to Los Angeles which provides a basis for adjusting the NIGAS-derived values for application to Los Angeles. Table 1 lists data for six utility districts provided by the Demand Analysis Office of the California Energy Commission (CEC, 1998). Three of the districts span the Los Angeles study area (LADWP, BDG, and SCE). The average gas use per stove in these three districts ranges from 45.0 to 49.2 therms with 47 therms representing a reasonable overall estimate. Note that these values specify total gas use by the stove; the CEC did not provide separate estimates for burners and pilot lights.

As indicated above, the NIGAS study reported an average of total gas usage of 57.1 therms per stove based on 33 stoves. If we assume that Los Angeles residents use less gas per stove than the population sampled by NIGAS, we can calculate an appropriate adjustment ratio by the expression

$$\text{Adjustment ratio} = (47 \text{ therms})/(57.1 \text{ therms}) = 0.82. \qquad (8)$$

The adjusted GM for burner use would be 2.11 million kilojoules x 0.82 = 1.73 million kilojoules. The corresponding GSD of 1.48 would be unchanged, as this is a dimensionless quantity. Using the same adjustment approach, the GM for pilot light use would be estimated as 3.37 million kilojoules x 0.82 = 2.76 million kilojoules. Again, the GSD would remain unchanged at 1.84.

Prevalence of Gas Stoves

According to Jim Capel, we estimated that 19.6 percent of the Denver households used gas stoves for cooking and applied this single prevalence rate to all home districts. The demographic data listed in Table 2 provide a basis for estimating a corresponding prevalence rate for the Los Angeles study area. The data were compiled by Pat Stiefer from three reports (U.S. Department of Commerce, 1996a, 1996b, 1996c) listing statistics obtained from American Housing Survey (AHS). The area labeled Los Angeles in Table 2 includes the Los Angeles - Long Beach PMSA (i.e., Los Angeles County), a region which contains most of the census tracts included in the study area defined for Los Angeles pNEM/CO analysis. The remaining census tracts are located just outside Los Angeles County in Orange County or in Riverside County. Because of their similar demographics and close proximity to Los Angeles County, these bordering census tracts are likely to be better represented by the prevalence rate of Los Angeles County (79.8 percent) than by rates listed for Orange County (61.9 percent) or Riverside County (77.4 percent).

The 79.8 percent prevalence rate for Los Angeles County obtained from the AHS is consistent with the gas stove use rates listed in Table 1 for LADWP (78.6 percent) and BDG (78.4 percent). Taken together, the three estimates support an estimate of about 79 percent for the gas stove prevalence rate.

Air Exchange Rates for Residences with Windows Closed

In applying pNEM/CO to Los Angeles, we require distributions for air exchange rates in residences with windows closed. In our previous work applying pNEM/CO to Denver, we based the distributions on a journal article by D. M. Murray and D. E. Burmaster (1995). This article lists distributions of AER by season and climatic region based on data compiled by Brookhaven National Laboratory (BNL). Table 3 is an excerpt of the data from Murray and Burmaster which has been reformatted for easier analysis. The data applicable to Los Angeles can be found under Region 4, which includes the portion of California containing Los Angeles. Parameters for the lognormal distribution are provided for each of four seasons and for all seasons combined. The four seasons and associated sample sizes are listed below.

Season 1 (n = 454): December, January, February
Season 2 (n = 589): March, April, May
Season 3 (n = 488): June, July, August
Season 4 (n = 18): September, October, November.

The indicated sample sizes are considered adequate for characterizing lognormal distributions appropriate for Seasons 1, 2, and 3. The sample size for Season 4 (n = 18) is considered marginal. To provide better estimates for Season 4, we conducted a series of statistical analyses. We found that the following regression-based equation could be used to predict the geometric mean values with n > 20 in Table 3 with an R^2 value of 0.857 (adjusted R^2 = 0.715).

$$GM = 0.923 - (0.310)(S1) - (0.278)(S2) - (0.316)(S4) - (0.338)(R1) - (0.266)(R2) - (0.236)(R3)$$

where
S1 equals 1 for Season 1, 0 otherwise.
S2 equals 1 for Season 2, 0 otherwise.
S4 equals 1 for Season 4, 0 otherwise.
R1 equals 1 for Region 1, 0 otherwise.
R2 equals 1 for Region 2, 0 otherwise.
R3 equals 1 for Region 3, 0 otherwise.

Applied to Season 4 in Region 4, this equation produces the estimate of

$$GM = 0.923 - (0.316)(1) = 0.607.$$

This estimate is consistent with the GM value listed in Table 3 for Season 2 (0.619), the season with the most similar temperature conditions (i.e., Season 4 = Fall, Season 2 = Spring). Consequently, I suggest that we use this estimate (0.607) for Season 4 rather than the listed value (0.416).

Similar analyses of the geometric standard deviation (GSD) values found that season and region were not good predictors of the GSD values in Table 3, which tended to fall within a relatively narrow range. As the listed value for Season 4 in Region 4 (2.034) falls within the range of the other three seasons and appears to be a reasonable estimate, I suggest we use this value as the GSD for Season 4 in Los Angeles.

In summary, I am proposing that the following seasonal distributions be used to represent the AER values of Los Angeles residences with windows closed.

Season	Months	Geometric mean	Geometric std. dev.
1	Dec, Jan, Feb	0.507	1.910
2	Mar, Apr, May	0.619	1.950
3	Jun, Jul, Aug	1.054	2.489
4	Sep, Oct, Nov	0.607	2.034

Air Exchange Rates for Residences with Windows Open

In applying pNEM/CO to Los Angeles, we also require a distribution for air exchange rates in residences with windows open. In our previous work applying pNEM/CO to Denver, we based this distribution on data from the draft "scripted house" report by Johnson, Weaver, and Mozier (1997). As reported in the September 23 memorandum, analysis of the data suggested that we could represent AER values with windows open by a lognormal distribution with geometric mean = 1.336 hr^{-1} and geometric standard deviation = 1.550 (dimensionless) with lower and upper bounds of 0.57 and 3.15. I recommend we use this distribution in the pNEM/CO analysis of Los Angeles until we can acquire better data.

Residential Volumes

Table 4 is taken from my September 23 memorandum. It presents data obtained from the 1995 American Housing Survey (AHS) representing the distribution for volumes of residences in Denver and Los Angeles. As discussed in my September 23 memorandum, plots of these statistics indicate that the data are closely fit by lognormal distributions with the following values for geometric mean and geometric standard deviation.

		Geometric mean	Geometric std. dev.	Median
Square footage:	Denver	1926	1.62	2020
	Los Angeles	1604	1.64	1651

The values listed under "median" were provided in the AHS listings and agree closely with the estimated geometric means. (The geometric mean of a "perfect" lognormal distribution is equal to its median).

Assuming an eight-foot ceiling and using 1 cubic meter = 35.315 cubic feet, the residential volumes can be modeled by lognormal distributions with the following parameters.

		Geometric mean	Geometric std. dev.
Volume, m^3:	Denver	436	1.62
	Los Angeles	363	1.64

We previously used a lognormal distribution with GM = 436 and GSD = 1.62 to represent residential volume in applying pNEM/CO to Denver. Consistent with this approach, I recommend that we use a lognormal distribution with GM = 363 m^3 and GSD = 1.64 for residential volume in applying pNEM/CO to Los Angeles.

Altitude Above Sea Level

The COHb algorithm in pNEM/CO requires an estimate of altitude above sea level specific to the study area. The attached map shows the CO monitors which define home districts in Los Angeles and selected elevations. The elevation listings nearest to the 10 monitors range from 57 feet near West Los Angeles (No. 1) to 861 feet near Pasadena (No. 6). The most central listed elevation is 320 feet near Los Angeles (No. 3). I recommend that we use a value of 100 meters (328 feet) as an average for the area.

Summary Table

Table 5 presents a summary of the distributions and point estimates proposed in this memorandum for Los Angeles. The lower and upper bounds for values to be selected from each distribution are initially set at the 2.5th and 97.5th percentiles of the distribution. These bounds may be changed after further analysis of the applicable data bases.

Table 5 is limited to parameters which have values for Los Angeles that differ from the values used previously in applying pNEM/CO to Denver. The following parameters (organized by table where they are listed in the current draft of pNEM/CO report) are not discussed in this memorandum, as I am recommending that the values used previously for Denver be applied to both cities.

Table 2-5 (entire table)
    Non-zero passive smoking increments
Table 2-6 (entire table)
    Initial values for previous outdoor carbon monoxide concentration and upper bounds of indexing intervals

Table 2-8 (entire table)
    Percentage of persons with ischemic heart disease by demographic group
Table 4-1
    Burner emission factor
    Air exchange rate, residence - windows open
Table 4-2 (entire table)
    Air exchange rate, enclosed, nonresidential microenvironments
Table 4-3 (entire table)
    Window ratios
Table 4-5 (entire table)
    Probability of gas stove operation
    Assumed burner operation period

In addition, the physiological factors used previously to estimate ventilation rates in the Denver analysis (see Section 5, Appendix A, and Appendix C) should be applied to both cities. With the exception of altitude above sea level, the COHb parameters used previously (Appendix E of the project report) should also be applied to both cities.

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Table 1. Gas Stove Data Provided by Demand Analysis Office of the California Energy Commission.

Utility district	Approximate geographic area	Percent cooking w/gas	Number of gas stoves	Therms used by all stoves (millions)	Therms per stove[a]
Pacific Gas and Electric (PG&E)	northwest of Los Angeles	33.0	1,399,887	67.8	48.4
Sacramento Municipal Utility Division (SMUD)	Sacramento	30.5	130,319	6.2	47.6
Southern California Edison (SCE)	South coast outside downtown Los Angeles	68.6	2,772,522	131	47.3
Los Angeles Department of Water and Power (LADWP)	Los Angeles	78.6	982,891	48.4	49.2
San Diego Gas and Electric (SDG&E)	San Diego	46.5	486,537	20.5	42.1
Combined Municipal Districts of Burbank, Glendale, and Pasadena (BDG)	Burbank, Glendale, Pasadena	78.4	131,111	5.9	45.0

[a]Calculated by Ted Johnson.

Table 2. Fuel Use Statistics from the American Housing Survey (1996).

Statistics	Anaheim (1994)[a]	Los Angeles (1995)[b]	Riverside (1994)[c]
Total Housing Units (HU)	918,000	3,276,000	1,121,400
Total HU w/cooking fuel	915,500	3,165,200	1,101,900
Total HU w/natural gas cooking fuel	568,700	2,614,000	867,500
Prevalence of HU w/gas cooking fuel[d]	61.9 percent	79.8 percent	77.4 percent

[a]Anaheim = Orange County PMSA (includes all of Orange County).
[b]Los Angeles = Los Angeles - Long Beach PMSA (includes all of Los Angeles County.
[c]Riverside = Riverside-San Bernardino PMSA (Includes all of Riverside and San Bernardino Counties).
[d]Prevalence rate = 100 x (total HU w/natural gas cooking fuel)/(total housing units).

Table 3. Air Exchange Rates for Residences, Windows Closed (Murray and Burmaster, 1995)

Region	States	Season[a]	Sample size	Lognormal distribution fit to air exchange rate data	
				Geometric mean	Geometric standard deviation
All	All	All	2844	0.528	2.273
		1	1139	0.433	2.026
		2	1051	0.503	2.079
		3	529	1.008	2.479
		4	125	0.316	1.895
1	ID, MN, MT, NH, NY1, VT, WI	All	467	0.314	2.038
		1	161	0.271	2.223
		2	254	0.364	1.872
		3	5[b]	(0.643)	2.088
		4	47	0.216	1.749
2	CO, CT, IL, NJ, NY2, OH, PA, WA (includes Denver and New York)	All	496	0.430	2.010
		1	428	0.450	1.960
		2	43	0.308	2.241
		3	2[b]	(1.261)	na
		4	23[b]	(0.309)	(1.716)
3	CA3, MD, OR, WA	All	332	0.439	1.996
		1	96	0.384	1.802
		2	165	0.448	2.186
		3	34	0.555	1.844
		4	37	0.455	1.573
4	AZ, CA4, FL, TX (includes Los Angeles)	All	1549	0.687	2.243
		1	454	0.507	1.910
		2	589	0.619	1.950
		3	488	1.054	2.489
		4	18[b]	(0.416)	(2.034)

[a] Season 1: December, January, February; Season 2: March, April, May; Season 3: June, July, August; Season 4: September, October, November. [b] Sample size < 25.

Table 4. Statistics on Square Footage of Occupied Units.

Range of square footage for occupied units	Denver		Los Angeles	
	Number in thousands	Cumulative percent	Number in thousands	Cumulative percent
less than 500	1.0	0.2	20.7	1.7
500 to 749	9.3	2.5	37.0	4.7
750 to 999	34.1	10.6	104.9	13.2
1,000 to 1,499	75.6	28.6	354.8	42.0
1,500 to 1,999	86.0	49.2	326.1	68.5
2,000 to 2,499	86.7	69.8	199.6	84.7
2,500 to 2,999	49.8	81.7	66.8	90.1
3,000 to 3,999	53.4	94.5	77.1	96.3
4,000+	23.2	100.00	45.1	100.0
Total[a]	419.1	--	1232.1	--

[a] Omits 38,500 units which did not report square footage values.

Table 5. Summary of Parameter Estimates Proposed for Los Angeles in this Memorandum.

Quantity	Distribution	Parameter[a]	Value
Annual fuel use by gas stove burners, kJ/yr (Use Equation 7 and four-step algorithm to determine seasonal patterns in gas use.)	Lognormal	GM	1.73 million
		GSD[b]	1.48
		Lower bound	0.80 million[c]
		Upper bound	3.73 million[d]
Annual fuel use by gas stove pilot light, kJ/yr	Lognormal	GM	2.76 million
		GSD[b]	1.84
		Lower bound	0.84 million[c]
		Upper bound	9.12 million[d]
Gas stove prevalence rate	Point estimate	Point estimate	79 percent
Air exchange rate -- windows closed (Season 1), h^{-1}	Lognormal	GM	0.507
		GSD[b]	1.910
		Lower bound	0.143[c]
		Upper bound	1.802[d]
Air exchange rate -- windows closed (Season 2), h^{-1}	Lognormal	GM	0.619
		GSD[b]	1.950
		Lower bound	0.167[c]
		Upper bound	2.292[d]
Air exchange rate -- windows closed (Season 3), h^{-1}	Lognormal	GM	1.054
		GSD[b]	2.489
		Lower bound	0.176[c]
		Upper bound	6.296[d]
Air exchange rate -- windows closed (Season 4), h^{-1}	Lognormal	GM	0.607
		GSD[b]	2.034
		Lower bound	0.151[c]
		Upper bound	2.441[d]

Quantity	Distribution	Parameter[a]	Value
Air exchange rate -- windows open, h^{-1}	Lognormal	GM	1.34
		GSD[b]	1.55
		Lower bound	0.57[c]
		Upper bound	3.16[d]
Residential volumes, m^3	Lognormal	GM	363
		GSD[b]	1.64
		Lower bound	138[c]
		Upper bound	957[d]
Altitude above sea level, m	Point estimate	Point estimate	100

[a] GM = geometric mean, GSD = geometric standard deviation.
[b] GSD is a dimensionless quantity.
[c] Lower bound = 2.5[th] percentile of proposed distribution.
[d] Upper bound = 97.5[th] percentile of proposed distribution.

Appendix J

Differences in Human Activity Patterns Between Individuals With and Without Cardiovascular Disease

M E M O R A N D U M

TO: **Harvey Richmond**

FROM: Jonathan Cohen, Sergey Nikiforov, and Arlene Rosenbaum

DATE: January 15, 1999

SUBJECT: **EPA 68-DO-0062 Work Assignment 2-24: Task 2: Evaluation of Differences in Human Activity Patterns Between Individuals With or Without Cardiovascular Disease**

EVALUATION OF DIFFERENCES IN HUMAN ACTIVITY PATTERNS BETWEEN INDIVIDUALS WITH OR WITHOUT CARDIOVASCULAR DISEASE

SUMMARY

Activity pattern data from the National Human Activity Pattern Survey were used to compare activity patterns and exertion distributions between subjects with or without angina. The diary survey provided a 24-hour diary of activities. Exertion rates for each person in the survey were simulated 100 times. For each person, the body weight was simulated from a log-normal distribution specific to the age and gender. The resting metabolic rate was simulated using a regression against body weight, with coefficients depending on age and gender. Finally, the exertion rate was simulated for each activity and person by multiplying the simulated resting metabolic rate by a MET exertion ratio with a distribution specific to each type of activity. The current version of the probabilistic NAAQS Exposure Model for Carbon Monoxide (pNEM/CO), described in Johnson (1998), begins with the same set of physiological equations and statistical distributions for probabilistic simulation of exposure. The pNEM/CO model uses the much broader Consolidated Human Activity Data Base (CHAD) and simulates additional physiological variables, such as the ventilation rate. The description of the relevant probabilistic and physiological equations in this memorandum is largely based on Johnson (1998); see that memorandum for more detailed information.

Differences between angina and non-angina subjects were evaluated for several summary statistics: average and 95th percentile of the maximum daily 8-hour exertion, percentage of time spent outdoors or in a vehicle, average percentage of time at light, moderate or heavy exertion

levels. Age and gender have very significant effects on these summary statistics of activity and exertion. Since angina patients tend to be much older and tend to include more females than the general population, it is very important to adjust for age and gender effects when comparing angina and non-angina groups. Otherwise, one cannot distinguish between the angina effect and the effects of age and gender. Statistical analyses comparing angina to non-angina subjects were performed, adjusting for age and gender either by stratification (comparing subjects in a given age/gender subgroup), or by fitting a general linear model (with separate terms for age, gender, and angina effects and their interactions). These analyses showed that, overall, angina subjects tended to have less extreme exertion levels. More specifically, the maximum 8-hour exertion energies tended to be lower, as did the percentages of time above moderate or high exertion rate thresholds. The percentages of time spent outdoors or in a vehicle were generally not statistically significantly different between angina and non-angina subjects.

The large sample of NHAPS subjects produced, in many cases, statistically significant differences in the exertion rate summaries between angina and non-angina subjects. However, those differences were generally numerically small compared to the mean values. Therefore we conclude that the differences in activity and exertion between angina and non-angina subjects, although statistically significant, are not large enough to severely impact the validity of pNEM/CO modeling results that do not adjust for an angina/non-angina difference.

METHODOLOGY

For these analyses we used the National Human Activity Pattern Survey (NHAPS) database, a telephone survey of human activity patterns conducted for the USEPA between October 1992 and September 1994 by the Survey Research Center at the University of Maryland. See Klepeis et al. (1996, 1998) and Tsang and Klepeis (1996) for more details about the NHAPS study and various statistical analyses of those data. The NHAPS data (Triplett, 1996) are included in CHAD. (Other CHAD studies did not include questions about cardiovascular disease and so could not be used for these analyses comparing angina and non-angina respondents.) A nationally representative sample of 9,386 respondents completed a detailed diary listing all their activities and locations over a 24-hour period (either from the previous day or a previous weekend day). A few respondents did not state their age and/or gender and their data was not used in our analysis. Our analysis used 9,149 of the surveys. Respondents were also asked demographic questions, including age and gender, and health questions, including whether or not they have been told by a doctor that they have angina: 243 respondents (2.6 percent) had angina. Respondents were asked about employment status (e.g. full-time, part-time, or unemployed) but not about their occupation. Other follow-up questions (not used in our analyses) related to the respondent's exposure to either water or air pollution on the diary day. For each household, the respondent was randomly selected to be either the adult or child (under 18) with the next birthday; an adult provided proxy responses for a child.

The EPA report (Klepeis, Tsang and Behar, 1996), Section 3, shows that the sample is reasonably representative of the national population with respect to gender and age distributions. The NHAPS population slightly underrepresented males (46 % NHAPS compared to 49 % from the 1990 Census). The fraction of weekend (Saturday or Sunday) respondents was 33 %, close to the desired ratio of 2:7, but Thursdays, Fridays and Saturdays were underrepresented. The Fall season was significantly underrepresented. The database includes weights to adjust for varying selection probabilities, due to differences in the numbers of adults or children in a selected household, the numbers of non-business phones in a household, the numbers of non-business telephones in each census region, and to the survey stratification between weekend or weekdays and between children and adults. Based on discussions with the EPA WAM, it was decided that the weights would not be used in these analyses; the raw, unweighted data would be treated as an approximately simple random sample. Note that the statistical weights: 1) were not used in the pNEM/CO exposure modeling effort, 2) could not be used to accurately estimate standard errors of weighted means, and 3) were close to 1 for most respondents.

In pNEM/CO, each activity is assigned a probability distribution of the exertion rate (kilo-calories per minute). For this analysis, the 24-hour sequence of exertion rates was simulated 100 times for each person in the NHAPS sample; the sequence of activities is fixed but the simulated exertion rates vary. Following both CHAD and the exposure modeling methodology currently used in pNEM/CO, a constant simulated exertion rate is assumed throughout the time period of each listed activity in the 24-hour diary. If the individual repeats the same activity at a later time, with other activities intervening, the exertion rate is simulated again. SAS statistical software was used for the simulations and for the statistical analysis.

The assigned exertion rate distribution depends upon the type of activity, and the occupation, age, gender, and body weight of the respondent. The exertion rate (kilo-calories/minute = kcal/min), also referred to as average energy expenditure rate, EE, is defined as the product

$$EE = MET \times RMR.$$

MET is the metabolic equivalent of work, a dimensionless ratio (i.e., exertion compared to the resting metabolic rate) specific to each activity, and, in some cases, to an age group. RMR is the resting metabolic rate (kcal/min), approximately equal to the basal metabolic rate. We used the same set of MET statistical distributions supplied by Tom McCurdy that are currently used in pNEM/CO (and CHAD). For the work activity "at main job," the MET distribution depends on the occupation. Since occupation was not recorded in NHAPS, we followed the pNEM methodology and randomly selected the occupation based on census fractions of persons in each activity. The same occupation is assumed throughout a simulated person-day (in case the person repeats the work activity), but is randomly selected again for the next simulated person-day. Note that this procedure may bias the comparison between angina and non-angina subjects, since the distribution of occupation is expected to differ between angina subjects and the general population.

A single RMR value was simulated to represent each person-day. Thus the same person would have 100 simulated RMRs, one for each of the 100 days simulated. This reflects the assumption that each person represents the activity pattern for a group of persons with the same age and gender. As in pNEM/CO, RMR was simulated from a normal distribution where the mean is of the form a + b (Body Mass), and the standard deviation is the constant σ. The values of a, b, and σ are the values derived by Schofield (1985) for 12 age/gender combinations (this assumes basal metabolic rate is equivalent to resting metabolic rate). In turn, the body mass was simulated using the log-normal distributions estimated by Brainard and Burmaster (1992) and Burmaster and Crouch (1994). The parameters of the log-normal distributions depend on age and gender.

The statistical analysis used the following summary statistics of the activity and simulated exertion patterns for each person in the NHAPS study. The selection of these summary statistics was based on recommendations from the EPA WAM:

- Average maximum 8-hour energy expenditure. For each 8-hour period in a simulated person-day, starting every 10 minutes, integrate the simulated EE to give the energy expenditure in Mcal (millions of calories), i.e. sum the products of activity time and energy expenditure rate. For each simulated day, compute the maximum 8-hour energy expenditure, treating the simulated day in circular fashion so that the respondent is assumed to repeat exactly the same activity and exertion rate patterns on the day after the diary day. For example, the simulated activities for the period starting at 10 pm are assumed to follow the reported sequence of activities for the diary day from 10 pm to midnight and then the reported sequence from the beginning of the diary day until 6 am. To represent a typical value for the selected person, compute the average maximum 8-hour energy expenditure across the 100 simulations.

- 95th percentile maximum 8-hour energy expenditure. As in the last bullet, compute the maximum 8-hour energy expenditure for each simulated day. To represent an extreme value for the selected person, compute the fifth highest maximum 8-hour energy expenditure among the 100 simulations.

- Percentage time spent outdoors. This number is the same for all simulations, since the activity patterns are held constant.

- Percentage time spent in a vehicle. This number is the same for all simulations, since the activity patterns are held constant.

- Percentage time spent outdoors or in a vehicle. This number is the same for all simulations, since the activity patterns are held constant.

- Average percentage time with exertion rate above 2.39 kcal/min. For each simulated person-day, the percentage of that day with an EE (rate) above the threshold level of 2.39 kcal/min was computed; then, this percentage was averaged over the 100 simulations for that person. The statistic estimates the percentage time spent at or above the threshold exertion rate level over a long period, assuming the daily activity pattern was the same every day. The threshold of 2.39 kcal/min, which equals 0.010 MJ/min, represents “light” exertion (see below).

- Average percentage time with exertion rate above 5.97 kcal/min. The threshold of 5.97 kcal/min, which equals 0.025 MJ/min, represents “moderate” exertion (see below).

- Average percentage time with exertion rate above 9.55 kcal/min. The threshold of 9.55 kcal/min, which equals 0.040 MJ/min, represents “heavy” exertion (see below).

The exertion rate thresholds used for these analysis were originally defined as 0.010, 0.025, and 0.040 mega-joules per minute, but were converted into the more commonly used calorie units (1 joule equals 0.2388 calories). For purposes of exposure assessment, exertion categories (i.e., light, moderate, or heavy exertion) are more usefully defined by the ventilation rate VE (liters air per minute) rather than the energy expenditure rate EE (kilo-calories per minute). For the EPA's Ozone Criteria Document, the Environmental Criteria and Assessment Office categorized VE into ranges of 0-23, 24-43, 44-63, and 64+ liters of air per minute to define light, moderate, heavy, and very heavy exertion, respectively (based on a reference male adult with body weight 70 kg). To convert from EE to VE, EE is first multiplied by an energy conversion factor, ECF, to give the oxygen uptake rate VO2 (liters of oxygen per minute). ECF varies across the population, but is approximately 0.2 liters oxygen per kcal (Esmail, Bhambhani, and Brintnell, 1995). The "ventilatory equivalent rate" (VER) is the dimensionless ratio of VE (liters per minute) divided by VO2 (liters per minute) and has typical values from about 24 for light exertion to about 32 for peak exertion. Thus the selected energy expenditure rates are approximately equivalent to the following ventilation rates:

EE = 0.010 MJ/min = 2.39 kcal/min:
$$VE = EE \times ECF \times VER = 2.39 \times 0.2 \times 24 = 11.5 \text{ liters/min} = \text{light exertion}$$

EE = 0.025 MJ/min = 5.97 kcal/min:
$$VE = EE \times ECF \times VER = 5.97 \times 0.2 \times 28 = 33.4 \text{ liters/min} = \text{moderate exertion}$$

EE = 0.040 MJ/min = 9.55 kcal/min:
$$VE = EE \times ECF \times VER = 9.55 \times 0.2 \times 32 = 61.1 \text{ liters/min} = \text{heavy exertion}$$

The selected summary statistics were computed for each of the 243 angina subjects and 8,906 non-angina subjects in the NHAPS study. A statistical analysis compared the distributions of these summary statistics for persons with and without angina. For each summary statistic we compared the mean values between the angina and non-angina groups using standard t tests. The significance level (p-value) for the difference in means was computed using the Smith-Satterthwaite procedure, that tests for no difference in population means assuming that the two populations are normally distributed but may have different variances. P-values at or below 0.05 denote significant differences at the five percent level of significance. By the central limit theorem, the p-values for the t test comparisons should be reasonably accurate for the large samples used in the overall analyses, even if the normality assumption does not hold, but the p-values will be less accurate for the analyses of specific gender and age subgroups. We also compared variances using a standard F test, that assumes normality of the two populations.

Since the normality assumption may not be a sufficiently good approximation, we also applied two non-parametric tests that do not require specific parametric distributions. The non-parametric Wilcoxon test, also known as the Mann-Whitney-Wilcoxon test or the Rank Sum Test, was used to compare the central tendencies of the two distributions. This test assumes only that the populations have the same distributional shape, which may or may not be the normal distribution, but the distribution of values for angina population might be shifted by some constant value, and thus might have a different median than the non-angina population. The

Kolmogorov-Smirnov test was used to evaluate any possible differences between the two distributions, whether due to differences in means, medians, variances, or any other features of the distribution. This test uses the maximum absolute difference between the two cumulative distribution functions, assuming only that these distributions are continuous.

The mean, variance, median, and distribution function comparisons were made for all persons combined, separately for males and females, and then separately for four age groups within the male and female subgroups. Age groupings were chosen to include approximately 25 percent of angina subjects in each group. Separate comparisons for males and females are needed to distinguish whether any overall differences in exertion or activity are explained by the fact that angina subjects are more likely to be female than in the general population. Since activity patterns and exertion rates differ between males and females, any overall difference between the angina and non-angina groups might be explained by the greater propensity for females to get angina, rather than the direct effect of angina. Similarly, the subsetting by age group evaluates the effect of the different age distributions for angina subjects compared to the general population (angina subjects tend to be much older). This statistical analysis does not, and cannot, address questions as to whether the angina causes the change in exertion or activity patterns, or *vice versa*. We only examine whether or not the summary statistics of activity and exertion patterns are different for the two populations.

A general linear model approach was also used as an alternative method of adjusting for the effects of age and gender on the angina/non-angina comparison. We focused attention on a relatively simple statistical model with cubic terms in age (a simple linear function of age fitted poorly), gender, interactions between age and gender, and a single term for the effect of angina:

$$\begin{aligned}\text{Summary Statistic} = \; & I(\text{male})\{\alpha + \beta(\text{age}) + \chi(\text{age})^2 + \delta(\text{age})^3\} \\ & + I(\text{female})\{\varepsilon + \phi(\text{age}) + \gamma(\text{age})^2 + \delta(\text{age})^3\} \\ & + \varphi I(\text{angina}) + \text{error}\end{aligned}$$

where: I(male) = 1 for males, 0 for females; I(female) = 1 for females, 0 for males; I(angina) = 1 for persons having angina, 0 for persons not having angina. The errors are assumed to be normally distributed, statistically independent, and have mean zero and some constant variance.

This statistical model assumes that the expected value of the summary statistic is a cubic function of age, but is a different function for males and females. The selected model has the same coefficient for the cubic term for males and females, but different coefficients for the intercept, linear, and quadratic effects. The model also assumes that having angina changes the mean by a constant amount, which is the same factor for all age groups and both genders. A more sophisticated model might allow for interactions between angina and the age and gender variables, to allow for the possibility that the angina effect varies by gender and/or age. Note, however, that our statistical analysis clearly showed that age and gender were much more significant predictors of exertion patterns than the angina indicator, explaining most of the variability in the summary statistics.

Project resources were insufficient for a detailed exploration of alternative statistical models. We tried using logarithmic transformations to improve the model fit, but could not reasonably use such models in view of the large number of cases where the observed summary statistic was zero (the logarithm is then undefined). The model fit for the selected model (without taking logarithms) varied with the summary statistic. R squared goodness-of-fit statistics were extremely low, less than 0.05, for the percentages of time spent outdoors and/or in a vehicle. For the summary statistics based on the maximum 8-hour exertion and the percentages of time above exertion rate thresholds, the R squared statistics ranged from a poor fit, 0.25, to a fairly good fit, 0.48. The cases of poor fitting models may be because the selected statistical models poorly represent the relationship between age, gender, and angina and the activity/exertion summary statistic and/or because the activity/exertion pattern varies substantially between people of the same age, gender, and angina status.

RESULTS

Age, Gender, and Angina Disease Distributions

Table 1 shows the number of subjects with or without angina by gender and by age group. The four age groups were chosen to have approximately the same numbers of angina subjects. The strong association between angina and age is illustrated by the fact that 52/243 = 21 % of angina subjects are under 55 but 6877/8906 = 77 % of non-angina subjects are under 55. Angina subjects tend to be significantly older than the general population. The association between angina and gender is weaker. 103/243 = 42.3 % of angina subjects are male, but 4116/8906 = 46.2 % of non-angina subjects are male.

Overall Comparisons of Activity and Exertion Summary Statistics between Angina and Non-Angina Subjects

Table 2 compares the means between the angina and non-angina subjects, without stratification by age or gender. The average and 95th percentile of the maximum eight hour exertion has a statistically significantly lower mean for angina subjects. Furthermore, for each of the exertion levels 2.39, 5.97, and 9.55 kcal/min (0.010, 0.025, and 0.040 MJ/min), the mean percentage of time above each level was statistically significantly lower for the angina subjects. Non-angina subjects spend an average of 2.8 percent of their time doing activities requiring moderate or higher levels of exertion, defined by exertion rates above 5.97 kcal/min (0.025 MJ/min); angina subjects spend an average of 2.2 percent of their time doing such activities. All subjects spend over 75 percent of time in light or sedentary activities, with extertion rates below 2.39 kcal/min, including sleeping. All these exertion distribution comparisons show that angina subjects tend to do activities with less exertion than the general population. However, since the summary analyses in Table 2 do not take into account the marked differences between the age and gender distributions of angina and non-angina subjects, the lower exertion rates could be associated with the tendency for angina subjects to be older (and female) rather than the disease itself. The average percentages of time spent outdoors are nearly identical, and are not statistically significantly different between angina and non-angina subjects, but angina subjects spend statistically significantly less time in vehicles (4.5 % rather than 5.5 %, on average).

Table 2 compares the standard deviations using a F-test based on the variance ratio for angina vs.

non-angina subjects. In most cases the F tests show statistically significantly different variances (and, therefore, standard deviations).

Table 2 also uses the non-parametric Wilcoxon test to compare the central tendencies of the two distributions without the normality assumption required by the T test. Corresponding to the T test comparisons, the Wilcoxon test finds that the angina and non-angina distributions are significantly different in almost all cases; the angina subjects have a lower median value for each of the selected summary statistics. Exceptions are for the average maximum 8-hour exertion, just significant at the 7 % level, and the percentage of time spent outdoors, which has a non-significant p-value of 22 %.

Finally, Table 2 compares the distribution functions using the Kolmogorov-Smironov test. The distributions are statistically significantly different at the five and one percent levels in all cases except for the percentage of time spent outdoors, which shows no significant difference. For that variable, the T and Wilcoxon tests showed no statistically significant differences in central tendency although the F test showed a statistically significant difference in the population variances. If the population variances are different, so are the two distribution functions. The discrepancy between the F and Kolmogorov-Smirnov tests is partly explained by the fact that the F test is very sensitive to the assumption of normal distributions, whereas the Kolmogorov-Smirnov test only requires the distributions to be continuous. (Both tests assume that the mean and variances are constant for each population, which is inconsistent with the variation of the means and variances with age and gender shown in the stratified analyses in Tables 3 and 4.) The discrepancy is also partly explained by the fact that the Kolmogorov-Smirnov test is less powerful (less likely to detect a difference) than the other tests, because it makes the fewest assumptions and considers the widest class of alternative hypotheses.

Stratified Comparisons of Activity and Exertion Summary Statistics between Angina and Non-Angina Subjects

Tables 3 and 4 provide the same statistical comparisons as Table 2, stratified by gender and age group. The results show the mean values for the selected summary statistics are not consistently lower for each age and gender subgroup of angina subjects. For example, Table 2 showed that the angina subjects had a lower overall mean value of the average maximum 8-hour exertion than the non-angina subjects. Tables 3 and 4 show the mean is actually higher for angina subjects 0-54 of either gender and for males 75 or older. The mean average maximum 8-hour exertions are consistently higher for males of all age groups, with or without angina, compared to females. Similar patterns are found for the 95th percentile of the maximum 8-hour exertion.

The comparisons of the percentages of time spent outdoors or in a vehicle also vary across age and gender subgroups. The largest, and most surprising, angina vs. non-angina difference is for the mean percentage of time spent outdoors by 0-54 year old males: angina subjects have a mean of 17 % compared to the mean of 9 % for non-angina subjects. However the angina subjects in the 55-64 and 65-74 age groups of either gender spend less time outdoors, on average, than non-angina subjects.

The Table 3 and 4 comparisons of the mean percentages of time above the light, moderate or high exertion levels show a variety of patterns for different age groups, genders, and exertion levels.

Comparisons of Activity and Exertion Summary Statistics between Angina and Non-Angina Subjects Adjusted for Age and Gender Differences

Table 5 gives the results of the fitted general linear model. As explained above, the fitted model assumes that for each gender, the average value of the summary statistic is a cubic function of age. Furthermore, having angina changes the expected value by a fixed amount, which is assumed to be the same value for every age and gender. This angina effect is the coefficient reported in the table, together with its standard error and p-value. P-values less than or equal to 0.05 indicate summary statistics where the angina effect was statistically significant at the 5 percent significance level. The angina coefficient can be thought of as the effect of angina after adjusting for age and gender. The effects of age and gender are not reported, but in all cases were extremely statistically significant compared to the angina effect.

Table 5 also reports the R squared goodness-of-fit statistic, which is the squared correlation between the observed and predicted values. R squared values vary from 0 (the worst possible fit) to 1 (a perfect fit), and are often interpreted as the fraction of the variability in the dependent variable (summary statistic) that is explained by the regression model.

The first two rows of Table 5 show that the angina effect on the average and 95th percentile maximum 8-hour exertion is a statistically significant reduction (at the 6 and 1 % levels, respectively) for angina subjects compared to non-angina subjects. However, these reductions of 0.04 Mcal and 0.16 Mcal are small when compared to the overall mean values of 1.4 and 2.3 Mcal (non-angina subjects) reported in Table 2. The next three rows show that angina subjects tend to spend a little more time (0.7 percentage points) outdoors and a little less time (0.5 percentage points) in a vehicle compared to non-angina subjects; those differences are not statistically significant. The last four rows show that angina subjects tend to spend less time at moderate or high levels of exertion, after adjusting for age and gender, although the differences are at most 1 percentage point and are not statistically significant. For example, the unadjusted average percentage time above 2.39 kcal/min (0.010 MJ/min) was 23.5 % for non-angina subjects (Table 2), and the effect of angina is to reduce the expected percentage of time by 0.7. As shown in Tables 3 and 4, this is due to average reductions of up to 5 percentage points for ages 55 and older but increases of 6 (males) and 2 (females) percentage points for the 0-54 age group.

R squared goodness-of-fit statistics were extremely low, 0.05 or less, for the percentages of time spent outdoors and/or in a vehicle. Thus the regression models for those percentages give very poor predictions. There are two possible reasons for this. First, the combination of age, gender, and angina status may be strongly associated with the percentages of time spent outdoors or in a vehicle but the assumed form of the regression model may poorly represent the functional relationship. Second, the combination of age, gender, and angina status may be poorly associated with the percentages of time spent outdoors or in a vehicle so that those activity percentages vary mainly with the effects of factors other than age, gender, and angina status. In either case, those regression models are not recommended for use in predicting the activity percentages.

For the summary statistics based on the maximum 8-hour exertion and the percentages of time above exertion rate thresholds, the R squared statistics ranged from a poor fit, 0.25, to a reasonably good fit, 0.48. As above, the cases of poor fitting models may be because the selected statistical models poorly represent the relationship between age, gender, and angina and the activity/exertion summary statistic and/or because the activity/exertion pattern varies substantially between people of the same age, gender, and angina status. Alternative general linear models, or the more sophisticated generalized linear models, could be developed to improve the predictive ability of the statistical models.

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Table 1. Distribution of subjects according to their age, gender and disease status

Gender	Males			Females			All		
Age group	**Angina(%)**	**Non-angina(%)**	**All**	**Angina(%)**	**Non-angina(%)**	**All**	**Angina(%)**	**Non-angina(%)**	**All**
0-54	35 (1.0)	3307 (98.9)	3342	17 (0.5)	3570 (95.5)	3587	52 (0.8)	6877 (99.2)	6929
55-64	28 (6.5)	400 (93.5)	428	28 (5.4)	491 (94.6)	519	56 (5.9)	891 (94.1)	947
65-74	23 (7.9)	267 (92.1)	290	48 (9.6)	450 (91.4)	498	71 (9.0)	717 (91.0)	788
75+	17 (10.7)	142 (89.3)	159	47 (14.4)	279 (85.6)	326	64 (13.2)	421 (86.8)	485
Total	103 (2.4)	4116 (97.6)	4219	140 (2.8)	4790 (97.2)	4930	243 (2.6)	8906 (97.4)	9149

Table 2. Statistical Tests for the Association between Angina and Various Variables Representing Physical Exertion. All

Variable	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test	Kolmogorov-Smirnov Test
	Mean Angina	Mean Non-angina	P-value	St. Dev. Angina	St. Dev. Non-angina	P-value	P-value	P-value
Average maximum 8hr exertion (Mcal)	1.28	1.40	0.00	0.48	0.49	0.68	0.00	0.00
Ninety fifth percentile of maximum 8hr exertion (Mcal)	1.87	2.25	0.00	0.97	1.13	0.00	0.00	0.00
Percentage of time spent outdoors	6.73	6.74	0.99	12.87	11.63	0.02	0.22	0.23
Percentage of time spent in vehicle	4.55	5.55	0.01	6.19	7.13	0.00	0.00	0.00
Percentage of time spent outdoors or in vehicle	11.27	12.29	0.27	14.33	13.45	0.15	0.00	0.00
Average percentage of time with exertion above 2.39 kcal/min = 0.010MJ/min (light)	19.98	23.53	0.00	13.56	13.78	0.75	0.00	0.00
Average percentage of time with exertion above 5.97 kcal/min = 0.025 MJ/ min (moderate)	2.17	2.78	0.01	3.68	3.56	0.46	0.00	0.00
Average percentage of time with exertion above 9.55 kcal/min = 0.040 MJ/ min (heavy)	0.213	0.406	0.00	0.554	0.761	0.00	0.00	0.00

Table 3. Statistical Tests for the Association between Angina and Various Variables Representing Physical Exertion. Males

Variable	Age Group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test	Kolmogorov-Smirnov Test
		Mean Angina	Mean Non-angina	P-value	St. Dev. Angina	St. Dev. Non-angina	P-value	P-value	P-value
Average maximum 8hr exertion (Mcal)	0-54	1.85	1.59	0.00	0.49	0.55	0.34	0.02	0.02
	55-64	1.48	1.77	0.00	0.48	0.48	0.86	0.01	0.02
	65-74	1.39	1.49	0.36	0.47	0.48	0.96	0.41	0.82
	75+	1.27	1.20	0.52	0.44	0.42	0.65	0.51	0.95
Ninety fifth percentile of maximum 8hr exertion (Mcal)	0-54	2.94	2.68	0.17	1.06	1.30	0.13	0.22	0.06
	55-64	2.40	2.90	0.04	1.21	1.14	0.61	0.02	0.03
	65-74	1.91	2.17	0.14	0.78	0.94	0.31	0.26	0.63
	75+	1.73	1.67	0.71	0.69	0.76	0.68	0.55	0.88
Percentage of time spent outdoors	0-54	16.86	8.85	0.02	19.16	13.75	0.00	0.01	0.01
	55-64	9.28	10.02	0.79	14.26	13.86	0.78	0.65	1.00
	65-74	6.43	10.40	0.13	11.38	14.34	0.20	0.12	0.13
	75+	8.23	7.09	0.72	12.63	10.05	0.16	0.58	0.66
Percentage of time spent in vehicle	0-54	5.96	6.09	0.92	7.55	8.10	0.63	0.89	0.52
	55-64	3.99	6.87	0.00	3.78	9.63	0.00	0.18	0.19
	65-74	7.20	5.88	0.51	9.04	7.80	0.29	0.82	0.93
	75+	2.29	3.34	0.14	2.54	3.94	0.05	0.44	0.54

Table 3. Statistical Tests for the Association between Angina and Various Variables Representing Physical Exertion. Males

Variable	Age Group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test	Kolmogorov-Smirnov Test
		Mean Angina	Mean Non-angina	P-value	St. Dev. Angina	St. Dev. Non-angina	P-value	P-value	P-value
Percentage of time spent outdoors or in vehicle	0-54	22.83	14.94	0.02	19.28	15.52	0.05	0.02	0.02
	55-64	13.27	16.89	0.24	15.30	16.18	0.76	0.17	0.22
	65-74	13.63	16.29	0.45	15.87	15.91	1.00	0.19	0.29
	75+	10.51	10.43	0.98	12.86	10.39	0.19	0.69	0.41
Average percentage of time with exertion above 2.39 kcal/min = 0.010MJ/min (light)	0-54	34.76	27.78	0.00	13.33	15.18	0.34	0.02	0.05
	55-64	24.60	30.07	0.06	14.51	12.03	0.14	0.06	0.14
	65-74	21.92	23.32	0.63	13.23	12.48	0.64	0.67	0.84
	75+	18.24	15.87	0.41	11.13	10.37	0.63	0.39	0.74
Average percentage of time with exertion above 5.97 kcal/min = 0.025 MJ/ min (moderate)	0-54	6.63	4.46	0.05	6.37	4.31	0.00	0.02	0.01
	55-64	3.43	5.44	0.01	3.55	4.41	0.17	0.01	0.01
	65-74	2.27	3.27	0.08	2.47	3.46	0.06	0.20	0.40
	75+	2.02	1.62	0.53	2.42	2.41	0.92	0.43	0.59
Average percentage of time with exertion above 9.55 kcal/min = 0.040 MJ/ min (heavy)	0-54	0.662	0.735	0.59	0.792	0.986	0.11	0.55	0.15
	55-64	0.565	0.846	0.19	1.068	1.222	0.40	0.05	0.17
	65-74	0.155	0.388	0.01	0.361	0.716	0.00	0.06	0.04
	75+	0.132	0.157	0.79	0.331	0.512	0.05	0.55	0.96

Table 4. Statistical Tests for the Association between Angina and Various Variables Representing Physical Exertion. Females

Variable	Age Group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test	Kolmogorov-Smirnov Test
		Mean Angina	Mean Non-angina	P-value	St. Dev. Angina	St. Dev. Non-angina	P-value	P-value	P-value
Average maximum 8hr exertion (Mcal)	0-54	1.30	1.27	0.69	0.31	0.38	0.34	0.72	0.73
	55-64	1.21	1.27	0.33	0.32	0.33	1.00	0.56	0.22
	65-74	1.05	1.10	0.29	0.30	0.31	0.94	0.31	0.44
	75+	0.96	0.98	0.63	0.33	0.30	0.34	0.44	0.66
Ninety fifth percentile of maximum 8hr exertion (Mcal)	0-54	1.98	2.01	0.86	0.82	0.91	0.69	0.99	0.86
	55-64	1.79	1.92	0.41	0.80	0.77	0.68	0.33	0.28
	65-74	1.42	1.51	0.26	0.53	0.57	0.57	0.31	0.62
	75+	1.27	1.31	0.59	0.56	0.52	0.43	0.43	0.47
Percentage of time spent outdoors	0-54	3.64	5.11	0.42	7.29	9.58	0.20	0.43	0.91
	55-64	4.31	4.59	0.88	9.53	8.22	0.23	0.23	0.63
	65-74	2.84	4.14	0.14	5.51	7.34	0.02	0.49	0.53
	75+	3.79	2.27	0.40	12.04	4.60	0.00	0.76	1.00
Percentage of time spent in vehicle	0-54	4.54	5.35	0.55	5.48	5.98	0.72	0.40	0.35
	55-64	4.21	5.60	0.35	7.53	7.23	0.71	0.06	0.12
	65-74	5.26	4.15	0.23	5.94	6.18	0.77	0.15	0.19
	75+	2.82	2.94	0.86	4.37	4.34	0.91	0.72	0.96
Percentage of time	0-54	8.18	10.46	0.36	9.93	11.27	0.57	0.18	0.27

Table 4. Statistical Tests for the Association between Angina and Various Variables Representing Physical Exertion. Females

Variable	Age Group	T Test Comparison of Means			F Test Comparison of Standard Deviations			Wilcoxon Test	Kolmogorov-Smirnov Test
		Mean Angina	Mean Non-angina	P-value	St. Dev. Angina	St. Dev. Non-angina	P-value	P-value	P-value
spent outdoors or in vehicle	55-64	8.52	10.18	0.48	12.15	10.42	0.22	0.04	0.05
	65-74	8.10	8.29	0.88	8.21	9.38	0.26	0.99	0.86
	75+	6.61	5.21	0.45	12.36	6.25	0.00	0.77	0.97
Average percentage of time with exertion above 2.39 kcal/min = 0.010MJ/min (light)	0-54	23.50	21.40	0.49	12.28	12.15	0.86	0.41	0.69
	55-64	19.04	21.04	0.33	10.34	10.47	1.00	0.51	0.54
	65-74	13.97	15.46	0.26	8.45	9.53	0.31	0.43	0.76
	75+	11.31	11.84	0.73	9.75	8.61	0.24	0.51	0.89
Average percentage of time with exertion above 5.97 kcal/min = 0.025 MJ/ min (moderate)	0-54	1.44	1.59	0.71	1.66	1.97	0.44	0.73	0.74
	55-64	0.79	1.31	0.05	1.27	2.07	0.00	0.04	0.06
	65-74	0.65	0.68	0.87	1.35	1.56	0.22	0.51	0.88
	75+	0.75	0.43	0.23	1.73	1.31	0.01	0.84	0.67
Average percentage of time with exertion above 9.55 kcal/min = 0.040 MJ/ min (heavy)	0-54	0.101	0.184	0.06	0.170	0.324	0.00	0.63	0.80
	55-64	0.095	0.093	0.96	0.277	0.198	0.01	0.67	1.00
	65-74	0.028	0.030	0.89	0.076	0.110	0.00	0.85	0.99
	75+	0.025	0.016	0.44	0.075	0.077	0.90	0.28	0.83

Table 5. General Linear Models for the Association between Angina and Various Variables Representing Physical Exertion.

Variable	Angina Coefficient[1]	Standard Error	P-value	R squared
Average maximum 8hr exertion (Mcal)	-0.0445	0.0237	0.0608	0.4819
Ninety fifth percentile of maximum 8hr exertion (Mcal)	-0.1553	0.0581	0.0075	0.4114
Percentage of time spent outdoors	+0.6975	0.7648	0.3618	0.0388
Percentage of time spent in vehicle	-0.4805	0.4679	0.3045	0.0325
Percentage of time spent outdoors or in vehicle	+0.2170	0.8777	0.8047	0.0520
Average percentage of time with exertion above 2.39 kcal/min = 0.010 MJ/min (light)	-0.7359	0.6996	0.2929	0.4239
Average percentage of time with exertion above 5.97 kcal/min = 0.025 MJ/min (moderate)	-0.1730	0.1910	0.3650	0.3570
Average percentage of time with exertion above 9.55 kcal/min = 0.040 MJ/min (heavy)	-0.0933	0.0439	0.0334	0.2494

1. The angina coefficient is the expected difference (angina minus non-angina) between the summary statistic for angina and non-angina subjects of the same age and gender.

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Appendix K

Detection of Scenario Differences in Exposure Measures of pNEM/CO Simulations with Statistical Tests

TECHNICAL MEMORANDUM

To: Harvey Richmond, US EPA
From: Jonathan Cohen and Arlene Rosenbaum
Date: March 31, 2000
Re: Detection of scenario differences in exposure measures of pNEM/CO simulations with statistical tests

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BACKGROUND

The objective of this task was to compare exposure results for selected recent scenario simulations of pNEM/CO, using statistical methods to determine whether significant differences could be detected. To accomplish this objective results of pNEM/CO simulations for the following scenarios were examined:

4. Los Angeles, "As-Is", Indoor Sources Included
5. Los Angeles, "Attainment", Indoor Sources Included
6. Los Angeles, "Sensitivity", Indoor Sources Included
7. Los Angeles, "As-Is", Indoor Sources Omitted
8. Los Angeles, "Attainment", Indoor Sources Omitted

Scenario 1 was compared with scenarios 2 and 3; while scenario 4 was compared with scenario 5. The comparison of 1 with 2 and the comparison of 4 with 5 are assessments of the impact of changes in the fixed site outdoor concentrations on estimates of exposure concentrations. The comparison of 1 with 3 is an assessment of the impact of assumptions about window status in vehicles during smoking events on estimates of exposure concentrations.

For each scenario modeled with pNEM/CO, 10 simulations were conducted. For each set of 10 simulations, an identical set of initiation values (or "seeds") was specified for the random number generator used to make the Monte Carlo selections. Thus, the 10 simulations for each scenario are matched to the 10 simulations for every other scenario. That is, in spite of the random variation incorporated into the simulations, the first simulation of each scenario differs from the first simulation of every other scenario only by the change in the input data. For example, the only difference between the first simulation of the "as-is" scenario for Los Angeles (indoor sources included) and the first simulation of the "attainment" scenario for Los Angeles (indoor sources included) is the input data for the fixed site outdoor concentrations. This matching format allows us to more easily assess the variation due to changing any particular factor in the exposure assessment by keeping it separate from the variation due to the Monte Carlo process.

Because the only difference between the as-is and attainment simulations is a decrease in the fixed site outdoor concentrations, and because the fixed site outdoor concentrations influence the resulting exposure concentrations according to the modeling algorithms, for each attainment simulation every exposure measure will be less than or equal to the corresponding exposure measure for the as-is simulations. That is, we know that the exposure measures resulting from the attainment simulations will be lower by some amount than (or equal to) the corresponding measures resulting from the as-is simulations. This is an important point to keep in mind when interpreting some of the statistical tests discussed below.

RESULTS

Tables 1a - 1d present the results of statistical comparisons of the as-is and attainment simulations for Los Angeles with indoor source included (Scenarios 1 and 2). Tables 2a - 2d show the same information for the as-is and attainment simulations for Los Angeles with indoor sources omitted (Scenarios 4 and 5); and tables 3a - 3d for the as-is and sensitivity simulations for Los Angeles with indoor sources included (Scenarios 1 and 3).

In each table, the second column shows the Spearman correlation coefficient for the given exposure measure for the 10 pairs of matched simulations. The Spearman correlation coefficient, often referred to as Spearman's rho, is the usual product-moment correlation coefficient computed for the ranks of the 10 runs, i.e., the run with lowest value for each case is given rank 1 and the run with the highest value for each case is given rank 10. This non-parametric measure of correlation is less sensitive to the form of the underlying statistical distribution, but has a similar interpretation: values close to 1 indicate that the results for the as-is runs are almost in the same order as the runs for the attainment (or sensitivity) cases, and values close to zero are consistent with independence. Since we know that these simulations were matched to have the same initiation random seeds, a high positive correlation coefficient can be interpreted to mean that the run-to-run random variation is much larger than the effect of interest (between the as-is case and the other cases); a correlation coefficient close to one means that the impact of changing scenarios hardly changed the order of the results for the 10 runs. If the correlation coefficient were small or negative, this would mean that the run-to-run random variation is much smaller than the effect of interest.

In tables 1a - 1d, with a few exceptions, the correlation coefficients for the sets of matched simulations appear to be high for each exposure measure. This suggests that with indoor sources included the impact of changes in the fixed site outdoor concentrations is not great enough to substantially modify the relative magnitudes of the exposure measures from simulation to simulation. This contrasts with tables 2a - 2d, where there is poor and even negative correlation for several measures. This results from the greater influence of changes in outdoor concentrations on simulated exposure measures when indoor sources are not accounted for.

The third column in each table shows the mean difference for the 10 matched pairs. The fourth column shows the p-value for a one-sided paired t-test. A one-sided test is used because we know that the results for the attainment simulations cannot be higher than those for the as-is simulations. The paired t test compares the distribution of the arithmetic differences with zero, assuming that the 10 differences are independently drawn from a normal distribution with an unknown, but constant variance[1]. The p-value is the probability of getting the mean difference actually obtained, or greater, for a sample of 10 differences, if the distribution of differences had a true mean of zero. A low p-value indicates that the results obtained would be highly unlikely if the true average difference were zero.

In order to interpret the meaning of the p-values in this context, it is helpful to keep in mind that we know that the true mean difference, as would be measured by a hypothetically infinite number of runs, is positive (although not necessarily large enough to be important), since this follows from the definition of the as-is, attainment, and sensitivity simulations. The detection of this known difference by the t-test will depend on (a) the average size of the difference, (b) the standard deviation of the difference, and (c) the number of simulations. Therefore, the p-value is a measure of the ability of the Monte Carlo process to detect this difference based only on ten simulations. In other words, a p-value below 0.05 indicates that the average difference between the two scenarios is large enough to be detected at the five percent significance level with 10 simulations. A p-value above 0.05 indicates that the observed set of differences are not large enough (or not similar enough) for the average scenario difference to be demonstrably above zero based on a five percent statistical test with only 10 simulations.

For the as-is/attainment comparisons, both with and without indoor sources (tables 1a – 1d and 2a – 2d), the t-test generally shows statistically significant differences (> 95% confidence) in exposure measures at the lower CO and COHb levels, but often not at the higher levels. This is because the run-to-run variability of the person-days, person-hours, or persons above those high levels is relatively large (since these exposures are rare), and the mean difference is relatively small, and, therefore, less likely to be detected. In contrast, the paired t-test shows statistically significant differences at all exposure levels for the as-is/sensitivity comparisons, indicating that these differences are large enough at all levels to be detected with 10 simulations.

The fifth column shows the p-value for a Wilcoxon test. The Wilcoxon test is a non-parametric version of the t test designed to avoid the need for assumptions about the form of the distribution. Assuming only that the 10 differences are independently drawn from some common distribution, the Wilcoxon test addresses whether the median difference is zero , i.e. whether positive and negative differences are equally likely[2]. (The t test made the additional requirement that the distribution is normal). If the true distribution is normal, then the Wilcoxon test will be less likely to detect an effect. However, if the true distribution is not normal, then for many possible distributions, the Wilcoxon test will be more likely to detect an effect. Except at the very highest levels,

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[1] The arithmetic mean difference is divided by an estimate of its standard deviation and compared to a t distribution percentile.

[2] The Wilcoxon test statistic is based on ranking the non-zero unsigned differences from 1 to k (the number of non-zero differences) and then calculating the sum of the ranks that were assigned to the positive differences. A high rank sum is evidence that the true median is positive.

the Wilcoxon test p-values were consistently lower than the t test p-values, signifying a higher level of confidence. This is expected in view of the fact that in every case all the differences were positive or zero, indicating a high probability that the median difference is positive.

Finally, the sixth column shows the number of matched simulations that would have to be conducted to have a 95% probability of detecting a difference with 95% confidence, assuming that the true average difference and true standard deviation of the difference are both identical to our estimates derived from the 10 matched simulations that we actually conducted. This calculation was carried using the same assumptions as for a paired t test[3]. Under the given assumptions, the probability of detecting a difference with 95 % confidence was computed using the non-central t distribution, and the smallest size needed to make the detection probability 95% or greater is reported. Note that although a p-value of 0.05 or less may have been obtained for the particular 10 simulations that were conducted for this study, this does not imply there is a 95% probability of detecting a difference with 10 simulations. Rather, it is generally the case that if the p-value is close to 0.05, then the probability of detecting a difference in another set of 10 simulations is only about 50%, assuming the estimated and true means and standard deviations are equal.

The results in the sixth column can be used to evaluate whether the mean scenario difference is comparable to the run-to-run variation from 10 simulations. If the minimum sample size is much above 10, then 10 simulations are insufficient for the difference to be detected with 95% probability. However, any positive difference, however small, can be detected at any selected confidence level and with any selected probability of detection, as long as the number of simulations is large enough.

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[3] For each sample size, n, a difference will be detected with 95 % confidence if the mean difference divided by its estimated standard deviation exceeds the 95th percentile of a t distribution with n-1 degrees of freedom. This calculation estimates the probability of detecting any non-zero difference, rather than the much smaller probability that the difference is significantly greater than our estimate from the 10 matched runs.

Table 1a. Comparison of Los Angeles “As – is” and “Attainment” Cases, Indoor Sources Included:

Cumulative Person-days at 1-hour Daily Maximum Exposure Concentration

CO (ppm) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
60	1.00	6	0.041	0.031	30
50	0.99	196	0.110	0.001	64
45	0.81	476	0.087	0.002	52
40	0.72	427	0.049	0.001	33
35	0.90	1,032	0.001	0.001	7
30	0.96	3,983	0.000	0.001	4
25	0.82	14,141	0.000	0.001	3
20	0.66	43,369	0.000	0.001	3
15	0.81	198,472	0.000	0.001	2
10	0.75	1,087,175	0.000	0.001	2
0		0			

Table 1b. Comparison of Los Angeles “As – is” and “Attainment” Cases, Indoor Sources Included:

Cumulative Person-days at 8-hour Daily Maximum Exposure Concentration

CO (ppm) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
25	0.99	983	0.106	0.001	62
20	0.96	1,549	0.011	0.001	16
15	0.99	5,498	0.000	0.001	6
12	0.71	14,689	0.000	0.001	4
9	0.36	69,830	0.000	0.001	3
6	0.88	708,002	0.000	0.001	3
0		0			

Table 1c. Comparison of Los Angeles “As – is” and “Attainment” Cases, Indoor Sources Included:

Cumulative Number of Persons at 1-hour Daily Max COHb Levels

COHb (%) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
6.0	0.96	212	0.096	0.004	56
5.0	0.88	217	0.106	0.001	62
4.0	1.00	258	0.013	0.001	17
3.0	0.98	1,901	0.001	0.001	8
2.9	0.95	2,869	0.007	0.001	14
2.8	0.92	2,707	0.000	0.001	5
2.7	0.94	2,396	0.001	0.001	8
2.6	0.90	3,113	0.001	0.001	8
2.5	0.87	3,965	0.000	0.001	6
2.4	0.94	6,939	0.000	0.001	4
2.3	0.83	6,526	0.000	0.001	5
2.2	0.83	8,051	0.000	0.001	5
2.1	0.95	9,565	0.000	0.001	3
2.0	0.90	10,610	0.000	0.001	3
1.5	0.18	41,396	0.000	0.001	3
1.0	0.39	38,705	0.000	0.001	3
0.5		0			
0.0		0			

Table 1d. Comparison of Los Angeles "As – is" and "Attainment" Cases, Indoor Sources Included:

Cumulative Person-hours at 1-hour COHb Levels During CO Season

COHb (%) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
6.0	0.93	586	0.065	0.001	41
5.0	0.96	1,154	0.019	0.001	20
4.0	0.99	2,746	0.000	0.001	7
3.0	0.94	10,904	0.001	0.001	7
2.9	0.96	12,984	0.000	0.001	5
2.8	0.95	14,600	0.000	0.001	4
2.7	0.96	17,104	0.000	0.001	5
2.6	0.98	20,195	0.000	0.001	4
2.5	0.98	19,638	0.000	0.001	3
2.4	1.00	27,780	0.000	0.001	3
2.3	0.99	37,125	0.000	0.001	3
2.2	0.98	49,220	0.000	0.001	3
2.1	0.77	70,615	0.000	0.001	4
2.0	0.99	121,069	0.001	0.001	7
1.5	0.98	1,105,897	0.000	0.001	5
1.0	0.95	21,549,252	0.000	0.001	3
0.5	1.00	249,479,677	0.000	0.001	2
0.0		0			

Table 2a. Comparison of Los Angeles "As – is" and "Attainment" Cases, Indoor Sources Omitted:

Cumulative Person-days at 1-hour Daily Maximum Exposure Concentration

CO (ppm) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
60		0			
50		0			
45		6	0.167	0.25	106
40		251	0.158	0.031	98
35	0.34	279	0.133	0.001	79
30	0.30	1,714	0.002	0.001	9
25	-0.21	7,617	0.000	0.001	4
20	0.54	33,290	0.000	0.001	3
15	0.73	175,757	0.000	0.001	2
10	0.59	1,054,924	0.000	0.001	2
0		0			

Table 2b. Comparison of Los Angeles "As – is" and "Attainment" Cases, Indoor Sources Omitted:

Cumulative Person-days at 8-hour Daily Maximum Exposure Concentration

CO (ppm) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
25		0			
20		4	0.098	0.063	57
15	0.65	1,133	0.005	0.001	12
12	0.07	6,984	0.000	0.001	4
9	0.29	53,654	0.000	0.001	3
6	0.64	672,361	0.000	0.001	3
0		0			

Table 2c. Comparison of Los Angeles “As – is” and “Attainment” Cases, Indoor Sources Omitted:

Cumulative Number of Persons at 1-hour Daily Max COHb Levels

COHb (%) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
6.0		0			
5.0		0			
4.0		0.3	0.172	0.500	110
3.0	0.29	57	0.011	0.002	16
2.9	0.17	81	0.003	0.001	10
2.8	0.24	181	0.024	0.001	23
2.7	0.11	553	0.023	0.001	22
2.6	-0.10	686	0.010	0.001	16
2.5	-0.05	1,341	0.003	0.001	10
2.4	0.73	1,623	0.001	0.001	7
2.3	0.34	2,290	0.001	0.001	9
2.2	-0.02	3,777	0.000	0.001	5
2.1	-0.20	5,618	0.000	0.001	4
2.0	0.13	7,049	0.000	0.001	4
1.5	0.36	47,700	0.000	0.001	3
1.0	0.34	77,524	0.000	0.001	3
0.5		0			
0.0		0			

Table 2d. Comparison of Los Angeles “As – is” and “Attainment” Cases, Indoor Sources Omitted:

Cumulative Person-hours at 1-hour COHb Levels

COHb (%) ≥	Correlation coeff	Mean Δ: (as-is - att)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
6.0		0			
5.0		0			
4.0		0.3	0.172	0.500	110
3.0	-0.07	96	0.009	0.002	15
2.9	-0.30	132	0.002	0.001	9
2.8	-0.20	352	0.036	0.001	28
2.7	-0.08	811	0.018	0.001	20
2.6	-0.15	1,084	0.014	0.001	18
2.5	-0.23	2,419	0.013	0.001	17
2.4	0.63	3,204	0.004	0.001	12
2.3	0.90	5,937	0.001	0.001	8
2.2	0.92	11,682	0.000	0.001	6
2.1	0.69	28,997	0.003	0.001	11
2.0	0.83	68,286	0.016	0.001	19
1.5	0.83	1,802,078	0.049	0.001	34
1.0	0.80	23,100,237	0.000	0.001	5
0.5	0.51	268,317,881	0.000	0.001	3
0.0		0			

Table 3a. Comparison of Los Angeles "As – is" and "Sensitivity" Cases, Indoor Sources Included:

Cumulative Person-days at 1-hour Daily Maximum Exposure Concentration

CO (ppm) ≥	Correlation coeff	Mean Δ: (as-is - sens)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
60	0.54	131	0.002	0.001	9
50	0.62	481	0.000	0.001	4
45	0.74	861	0.000	0.001	4
40	0.73	1,654	0.000	0.001	3
35	0.98	3,261	0.000	0.001	3
30	0.83	7,852	0.000	0.001	3
25	0.93	17,342	0.000	0.001	3
20	0.59	39,540	0.000	0.001	3
15	0.90	91,908	0.000	0.001	2
10	0.95	203,499	0.000	0.001	2
0		0			

Table 3b. Comparison of Los Angeles “As – is” and “Sensitivity” Cases, Indoor Sources Included:

Cumulative Person-days at 8-hour Daily Maximum Exposure Concentration

CO (ppm) ≥	Correlation coeff	Mean Δ: (as-is -sens)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
25	0.99	3,250	0.000	0.001	4
20	0.99	5,355	0.000	0.001	3
15	0.99	10,787	0.000	0.001	3
12	0.89	18,152	0.000	0.001	3
9	0.99	36,534	0.000	0.001	2
6	1.00	84,541	0.000	0.001	2
0		0			

Table 3c. Comparison of Los Angeles "As – is" and "Sensitivity" Cases, Indoor Sources Included:

Cumulative Number of Persons at 1-hour Daily Max COHb Levels

COHb (%) ≥	Correlation coeff	Mean Δ: (as-is - sens)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
6.0	0.77	393	0.000	0.001	6
5.0	0.85	1,096	0.000	0.001	4
4.0	0.99	2,459	0.000	0.001	4
3.0	0.96	6,044	0.000	0.001	4
2.9	0.96	7,109	0.000	0.001	4
2.8	0.90	7,703	0.000	0.001	3
2.7	0.85	8,560	0.000	0.001	4
2.6	0.87	9,748	0.000	0.001	3
2.5	0.76	11,333	0.000	0.001	3
2.4	0.88	12,584	0.000	0.001	3
2.3	0.93	14,168	0.000	0.001	3
2.2	0.98	15,040	0.000	0.001	3
2.1	0.95	17,019	0.000	0.001	3
2.0	0.90	18,957	0.000	0.001	3
1.5	0.96	27,339	0.000	0.001	3
1.0	0.73	6,489	0.000	0.001	4
0.5		0			
0.0		0			

Table 3d. Comparison of Los Angeles "As – is" and "Sensitivity" Cases, Indoor Sources Included:

Cumulative Person-hours at 1-hour COHb Levels During CO Season

COHb (%) ≥	Correlation coeff	Mean Δ: (as-is - sens)	p-value: paired t-test	p-value: Wilcoxon test	sample size for 5% sig t-test (95 % probability)
6.0	0.73	2,349	0.000	0.001	6
5.0	0.93	6,049	0.000	0.001	5
4.0	0.95	15,882	0.000	0.001	4
3.0	0.99	38,869	0.000	0.001	3
2.9	0.96	43,939	0.000	0.001	3
2.8	0.99	49,051	0.000	0.001	3
2.7	0.96	55,720	0.000	0.001	3
2.6	0.95	63,130	0.000	0.001	3
2.5	0.96	71,410	0.000	0.001	3
2.4	0.87	80,246	0.000	0.001	3
2.3	0.93	91,687	0.000	0.001	3
2.2	0.95	105,191	0.000	0.001	3
2.1	0.94	120,752	0.000	0.001	3
2.0	0.99	138,678	0.000	0.001	3
1.5	1.00	350,873	0.000	0.001	2
1.0	1.00	1,114,447	0.000	0.001	2
0.5	1.00	2,008,799	0.000	0.001	2
0.0		0			