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Project Summary

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

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Under EPA Contract 68-02-3755, PEDCo Environmental conducted a study of personal exposure to carbon monoxide (CO) in Denver, Colorado. The target population for the study included all noninstitutionalized, nonsmoking residents of the urbanized portion of the metropolitan area who were between 18 and 70 years of age at the time of the study. A total of 454 study participants were obtained through the use of a screening questionnaire administered to several thousand households in the study area. Each participant was asked to carry a personal exposure monitor (PEM) and an activity diary for two consecutive 24-hour sampling periods and to provide a breath sample at the end of each sampling period. Each participant also completed a detailed background questionnaire. Analyses of approximately 900 person-days of PEM and activity diary data found that personal CO exposures were higher in microenvironments associated with motor vehicles such as parking garages and automobiles. Mean indoor residential exposure was increased 2.59 ppm by gas stove operation, 1.59 ppm by smokers, and 0.41 ppm by attached garages. The weighted means for daily maximum 1-hour and 8-hour exposures during the study period were 10.3 ppm and 4.9 ppm, respectively. Approximately 3 percent of the daily maximum 1-hour exposures exceeded 35 ppm; approximately 11 percent of the daily maximum 8-hour exposures exceeded 9 ppm. Only one of the 15 fixed-site monitors operating during the study reported daily maximum 1-hour values exceeding 35 ppm. Eleven fixed-site monitors reported daily maximum 8-hour values exceeding 9 ppm. Correlations between CO values recorded simultaneously by PEM's and by fixed-site monitors were generally higher for outdoor personal monitoring locations than for indoor locations; however, correlations were weak for most locations. Diurnal patterns for weekdays, Saturday, and Sundays were developed for hourly average exposures and composite fixed-site values.

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

Introduction

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

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

Data Collection Instruments and Procedures

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

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

The data collection instruments used in the Denver CO study included three questionnaires [screening, computer model input questionnaire (CMIQ), and study] providing background data on subjects and their families, a network of 15 fixed-site monitors, the PEM's and activity diaries carried by each subject, and breath sample bags. The screening questionnaire was administered on a household basis as a means of identifying persons eligible for study. It requested the name of each household member, relationship to head of household, sex, age, smoking status, occupation, and typical commute time. The completed screening questionnaires yielded a list of 2232 eligible individuals from which were selected a stratified sample of 1139 potential subjects. An attempt was made to administer the CMIQ to each potential subject. Part A of the CMIQ requested detailed data about the commuting habits of the respondent's household and determined if any member of the household was employed in one of nine occupational categories associated with high CO exposure. These data were collected for use in SHAPE, a population exposure model developed by Wayne Ott, and NEM, a population exposure model developed by the Strategies and Air Standards Division of EPA. Part B of the CMIQ verified the respondent's address and attempted to set up an appointment for the first visit by an interviewer. The study questionnaire was administered to each of 454 persons who actually participated in the study. It included detailed questions about the subject's home environment, work environment, commuting habits, occupation, leisure-time activities, and shopping habits. The study questionnaire also requested age, sex and education data.

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

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

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

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

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

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

Study Results

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

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

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

The accuracy of PEM measurements was determined daily based on a pre- and post-sampling check of zero and span. Using the change in slope as a measure of accuracy, 93 percent of the measurements were estimated to be within ±5 percent of the true concentration value. PEM's operated in pairs showed a mean percent difference in paired values of 5.0 percent with a standard deviation of 14.2 percent. PEM's attached to manifolds supplying sample ambient air to fixed-site monitors yielded paired values with a mean difference of 8.3 percent (fixed-site being higher) and a standard deviation of 22 percent.

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

A total of 859 breath samples were obtained and successfully analyzed for CO content. Thirty samples were lost because of leaks in the sample bag. One subject refused to provide a breath sample, and another was unable to provide a sample because of illness. Nine samples were not obtained for other reasons (e.g., subject could not fill breath bag).

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

The daily maximum 1-hour and 8-hour exposures calculated for the study sample were extrapolated to the Denver target population using weighting factors which accounted for the probability of selecting a particular subject into the sample and for nonresponse caused by refusals, instrument problems, and unacceptable activity diary data. The weighted means for daily maximum 1-hour and 8-hour exposures during the study period were 10.3 ppm and 4.9 ppm, respectively. Approximately 3 percent of the daily maximum 1-hour exposures exceeded 35 ppm; approximately 11 percent of the daily maximum 8-hour exposures exceeded 9 ppm.

Weighted linear regression analyses of the daily maximum 1-hour and 8-hour exposures predict that a member of the Denver target population who receives a daily maximum 8-hour exposure of 9 ppm would receive a daily maximum 1-hour exposure of 16.3 ppm. Similarly, a person receiving a daily maximum 1-hour exposure of 35 ppm would receive a daily maximum 8-hour exposure of 16.1 ppm.

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

Occupancy period was defined as the time a subject spends in a microenvironment during a single visit. Mean occupancy periods for in-transit microenvironments associated with motor vehicles and high CO levels were 30.8 minutes for trucks, 28.0 minutes for buses, 25.9 minutes for cars, and 23.0 minutes for motorcycles.

An analysis was conducted of residential indoor exposures to determine the contribution of three potential CO sources. Mean exposure was increased 2.59 ppm by gas stove operation, 1.59 ppm by smokers, and 0.41 ppm by attached garages.

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

Diurnal patterns for weekdays, Saturdays, and Sundays were developed for hourly average exposures and composite fixed-site values. In general, diurnal patterns for exposure were similar in shape to those for fixed-site data, although the exposure patterns contained midday peaks missing from the fixed-site patterns.

In general, this study suggests that 1) the methodology proposed by EPA for using personal monitors to estimate population exposure to CO in urban populations is sound, 2) CO exposures in microenvironments associated with motor vehicles are higher than exposures in microenvironments not associated with motor vehicles, and 3) CO exposures in the microenvironments defined for this study are not strongly correlated with CO concentrations simultaneously recorded at fixed-site monitors.

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The complete report, entitled "A Study of Personal Exposure to Carbon Monoxide in Denver, Colorado," (Order No. PB 84-146 125; Cost: $23.50, subject to change) will be available only from:
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