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# Project Summary

# Study of Carbon Monoxide Exposure of Residents of Washington, DC and Denver, Colorado

T. D. Hartwell, C. A. Clayton, R. M. Michie, R. W. Whitmore, H. S. Zelon, S. M. Jones, and D. A. Whitehurst

This report describes a study funded by the EPA and conducted by the Research Triangle Institute in 1982 and 1983 to evaluate methodology for collecting representative personal exposure monitoring (PEM) CO and corresponding activity data in an urbanized area. This involved telephone screening of households and sample selection of respondents in the metropolitan areas in and around Denver, Colorado and Washington, D.C. Data on CO breath levels were also collected in Washington, D.C. (PEDCo Environmental conducted the field work in Denver.) The target population in both cities consisted of the non-institutionalized, nonsmoking adults (ages 18 to 70) of these metropolitan areas. The data collected in the field were edited and appropriately weighted to produce CO exposure estimates for the target population.

Estimates of CO exposure for the winter of 1982-83 in Washington, D.C. were obtained using the data base constructed from the raw CO levels by activity data. This data was collected over a 24-hour period when the respondent carried a CO PEM and an activity diary. The data consisted of hourly CO values on 712 respondents, activity patterns and corresponding CO levels on 705 respondents, and CO breath measurements corresponding to the PEM CO data on 659 respondents. The size of the target population was estimated to be 1.22 million individuals.

The weighted average maximum hourly PEM CO level in Washington, D.C. was 6.74 ppm. The average maximum 8-hour CO level was 2.79 ppm. The percentage of the population with maximum hourly CO values over the 35 ppm CO standard was estimated to be 1.28 percent while the percentage with an 8-hour maximum over the 9 ppm standard was 3.9 percent.

Estimates were also made for subgroups of the population. Persons in high-exposure occupations (about 4.6% of the total population) generally exhibited higher CO exposure levels: it was estimated that about 24% of this high-exposure group had 1-hour CO exposures above the 35 ppm standard and that about 28% exceeded the 8-hour standard. It was also shown that CO levels were generally higher for commuters, especially for those with larger amounts of travel.

By combining PEM data with data from individuals' diaries, estimates of both CO levels and time durations for various activities and personal environments were made. For example, the activities "in parking garage or parking lot" and "travel, transit" had the highest average CO concentrations (6.93 ppm, and 4.51 ppm, respectively) while "sleeping" had an estimated CO concentration of only .85 ppm.

Variation from duplicate hourly PEM measurements under field condition were also analyzed. An analysis of variance of this data which considered person-to-person, hour-to-hour, and measurement variation indicated that about 5 to 6 percent of total variation

**among the hourly duplicate readings was due to deviation in measurements made by two PEMs at the same hour for the same person.**

***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

As the control of emission increases, the burden of proof on EPA to show that a particular level of emission control is justified also increases. It has become more and more important to show that a given level of control is justified for each air pollutant, with the relative risk of public health approximately comparable for each pollutant controlled.

A critical factor in determining the degree of risk to the population is the exposure of members of the population. In the past, monitoring of airborne pollutants has necessarily been based on the assumption that fixed-site monitoring is representative of concentrations surrounding the site, since monitoring techniques were generally not developed for determining personal exposures. Then to obtain estimates of population exposure, techniques such as computer simulation or overlaying isopleths of pollution concentrations measured at fixed sites on population density maps have been used. For some pollutants, these techniques may be reasonable approximations; however, recent work has shown that many pollutant concentrations are not homogeneous and that activity patterns play an important role in an individual's actual exposure. Therefore, data from ambient fixed sites often differ significantly from the concentrations with which people actually come into contact.

Accordingly, RTI and EPA formulated a study plan to develop and field test a population exposure methodology using CO while making sure that the methodology was broad enough to accommodate other pollutants of concern. The specific objectives of this study were the following:

- To develop a methodology for measuring the distribution of carbon monoxide (CO) exposures of a representative population of an urban area for assessment of the risk to the population.
- To test, evaluate, and validate this methodology by employing it in the execution of pilot field studies in Denver, Colorado, and in Washington, D.C.
- To obtain an activity-pattern data base related to CO exposures.

Carbon monoxide was selected for primary emphasis in the current study because:

- Accurate and portable field-tested instruments now are available for CO.
- Most of the CO to which the public is exposed can be attributed to motor vehicles.
- It appears that CO is a good "indicator" (i.e., surrogate) pollutant for estimating exposures to several other motor vehicle pollutants of interest.
- Because CO is a nonreactive air pollutant, it is simpler to treat analytically.
- The health effects of CO are reasonably well documented, and NAAQS based on these effects have been promulgated.
- Considerable data exist showing that CO varies spatially and that many locations in cities have concentrations that differ from those reported at fixed air monitoring stations.

The study was carried out in Washington, D.C. and Denver, Colorado during the winter of 1982-83 (the period of the year with maximum ambient CO concentrations). The population exposure profile was determined by direct measurement of CO with personal exposure monitors (PEMs) through the use of statistical inference from the statistically drawn sample. The study provided sufficient data to determine exposure as a function of concentrations within significant microenvironments (home, in-transit, work, and leisure) and individual activity patterns.

The report describes in detail the activities, results, and recommendations evolving from the study. It is extremely important to note that the study not only developed and tested methodology for measuring the distribution of CO in an urban area but also produced direct estimates of CO exposure that apply to two large metropolitan areas. In addition, a very important product of this work is a unique and valuable data base on individual exposures to CO and the corresponding activities that led to these exposures.

## Summary of Study Design and Procedures

The target population consisted of the *non-institutionalized, non-smoking adults* (ages 18 to 70) in the metropolitan areas in and around Denver, Colorado and Washington, D.C. A probability sample of the target population was selected in both cities. This sample was a stratified, three-stage, probability-based design. Area sample segments defined by Census geographic variables were selected at the first stage of sampling. Households were selected at the second stage, and a household member was administered a short screening interview covering all household members to identify individuals with characteristics believed to be positively correlated with CO exposure. Thus, household members with these characteristics could be oversampled in the third stage. Donnelley Market Corporation listings were used to help select households for the screening interview. The third stage sample was a stratified sample of screened eligible individuals (i.e., nonsmoking, aged 18 to 70). The individuals *in the third stage sample were administered* a Computer Model Input Questionnaire and were asked to carry a personal CO monitor and an Activity Diary for 24 or 48 hours (for Washington and Denver, respectively). A breath sample was also requested from these individuals and they were asked to fill out a Household (Study) Questionnaire. The third stage sample design also allocated individuals to specific days within the sampling period. A detailed discussion of the sample design is given in the report.

To carry out the sample design, RTI developed the data collection instruments and worked with EPA in obtaining OMB approval for the study. An initial telephone screening was carried out in both Denver and Washington, D.C. by using RTI's Computer Assisted Telephone Interviewing (CATI) system. This initial screening was supplemented by limited field screening in both sites. Specific information collected during this interview included: time spent in regular commuting and smoking status of each household member, as well as presence of gas appliances and attached garages in their residences. After the initial screening and the initial selection of potential participants, another telephone interview was conducted. The purpose of this call was to contact the selected individual to further explain the study and attempt to enroll him (her) into the study. If the individual agreed to be part of the study,

an appointment was established for a field interview. In addition, during this call, a Computer Model Input Questionnaire was administered which collected additional data on commuting patterns, demographics of household members, and household characteristics.

Finally, participating individuals were met at their home or other convenient location and given all study materials. These participants carried both a PEM (a model COED-1, which utilized a data acquisition package supplied by Magnus, Inc.) for the 24 hours of their participation and an Activity Diary in which to record a description of their activities. Participants were requested to push a button on their PEM every time they changed activities and to record descriptions of the new activities in their diaries. In addition, for a small sample of participants, a GE/HP PEM (which utilized a Hewlett-Packard HP-41CV programmable calculator) was used which allowed the participant to also enter an activity code into the monitor. Participants were also asked to complete a self-administered Household Questionnaire which provided information on themselves and on their home and work environments. The telephone screening and sample selection of individuals for both Denver and Washington were carried out by RTI as was the field work in Washington.

The results of the telephone screening and field activities for the study are described in detail in the report. Briefly, 8643 household screenings were attempted by RTI in Washington, D.C. and 4987 were attempted in Denver, Colorado. The successful screening rates were 75.8 percent in Washington and 70.4 percent in Denver. From these telephone and field screenings, 5418 eligible respondents were identified in Washington and 2232 in Denver. From this population of eligibles, 1987 individuals were selected for participation (i.e., to carry a PEM) in Washington and 1139 in Denver. Of these selected individuals, 58 percent actually scheduled appointments to carry a PEM in Washington. Finally, 35.8 percent of the individuals in Washington selected to participate contributed usable CO monitor data. This represented 712 sample respondents. Instrument failure was one of the major reasons for the low response rate. Specifically, CO data was not collected or was unusable for analysis purposes for 232 respondents (22% loss rate) due to monitor failure or malfunction. Usable CO breath data corresponding to the usable CO monitor data was collected on 659 sample respondents.

In order to successfully implement the study in Washington, D.C., a field office/laboratory was established in the offices of the Metropolitan DC Council of Governments. This office was used for several purposes including supervision of field staff, storage of supplies, maintenance of records, allocation of field assignments, and maintenance and repair of the PEMs. This office was visited twice nightly by all interviewers to receive PEMs and data collection forms for that evening and for return of completed study materials including the PEMs used the previous 24 hours. All calibrations of the PEMs during the study were carried out in this field laboratory. In addition to the field supervisor for the interviewers, the field laboratory was staffed with two full-time technicians working seven days per week throughout the study. A detailed description of the PEMs (COED-1s and GE/HPs) used in this study and the extensive daily technical support that they required is given in the report.

As mentioned above, breath samples were collected from respondents during the study. This required RTI to evaluate a method for collecting and measuring alveolar CO. The method essentially required each respondent to blow into a sample bag at the end of his 24-hour sampling period. This sealed bag was then returned to the field laboratory for CO analysis.

Throughout the field work, a quality control and assurance program was maintained for the sampling and analysis procedures employed. This included using field standards to calibrate all the CO monitors. The monitors were subject to calibration (two-point, zero/span) before they were put in the field and 24 hours later when they were returned from the field. The comparison of the two calibration curves was used to assign validity codes to the PEM data. Other quality control procedures employed were: a ten percent check of data transcribed from monitor memory to field data sheets; monitoring control charts on each monitor describing the course of differences between pre-sample and post-sample span, zero, battery voltage, and flow rate values; collecting duplicate colocated samples for the purpose of characterizing monitor precision; performing external and internal QA and QC audits; performing multipoint calibrations to assess monitor linearity during the study; and obtaining duplicate breath samples from respondents. The results of these extensive quality control and quality assurance procedures are given in the report.

After the field work was completed, the data were returned to RTI where detailed editing of the data was carried out by RTI editors. The data were then entered into computer files using RTI's mini-computer data base entry system. All data were keyed and then 100 percent key-verified. Extensive machine editing was carried out which resulted in identifying many computer records which required further manual editing. The process of editing the computer files took extensive staff time. In particular, checking the consistency of the PEM data with the diary data was a time consuming process.

Sampling weights were computed according to prescribed formulas. This involved extensive computations so that the weights could be used to draw inferences to the target populations. The sampling weights were then put on a computer file so that they could be merged with the corresponding field data.

Detailed statistical analyses were carried out using computer data files with PEM CO and activity diary data. Estimates computed during this analysis were weighted estimates for the population of inference—adult non-smokers in the Washington, D.C. metropolitan area. Standard errors of estimates were produced by using specially written software designed for analysis of data from complex sample surveys.

In particular, analyses were first produced for hourly CO exposure data. These analyses included computing statistics describing diurnal patterns, maximum hourly CO concentrations, maximum 8-hour CO concentrations, and mean hourly CO concentrations. Statistics included means, standard errors, and percentages of the population exceeding certain specified CO levels. Estimates of these statistics were computed for all days, week and weekend days, and low and high CO days (as indicated by fixed-site monitors). In addition, CO hourly level comparisons were also made for 3 occupational groups; 6 commuter groups (i.e., non-commuters; commuters who traveled up to 5 hours/week; etc.); and 4 categories describing the use of gas stoves.

Estimates were also produced for CO exposure levels for various activities (e.g., in transit) and locations (e.g., indoors—at residence). Statistics computed for each activity and location included mean CO level, the estimated standard error, and estimates of the proportion of the popula-

tion having CO levels above specified levels. The distribution of times spent in the various activities and locations were also computed.

Breath measurements taken at the end of each individuals' monitoring period were used to produce estimates of the distribution of CO breath levels in the Washington, D.C. area. Finally, using the duplicate CO monitor data, estimates were computed to assess variation in PEM measurements under field conditions.

## Summary of Study Results and Conclusions

Based on the experience gained during the Washington, D.C. and Denver PEM CO studies, the methodology developed, with some modifications (see the detailed report), may be used effectively in other areas of the country for collecting PEM data. Experience gained during this initial study will improve the execution of such similar studies. Modifications that are suggested include a different sampling design using the classified telephone directory listings, improvements in the CO monitors, and additional refinement of the method used to collect activity data. These modifications should make the methodology more cost effective, improve the response rate, and lead to more accurate activity information.

Important new information was learned for each of three sampling methodology studies of the project: (1) It was found that geographically classified telephone directory listings can be used in a cost-effective manner in association with standard area household sampling techniques for personal monitoring studies like the current CO study. The sampling design for the cost-effective use of these telephone directory listings differs substantially from the design used for the CO study, however (details are given in the report). (2) Sending lead letters to individuals who were selected for personal monitoring prior to calling to schedule an appointment was found to be an effective strategy. (3) The need for person-day sampling for studies that monitor personal exposure to airborne pollutants is apparent. The CO study gained valuable experience with this technique. Further study, possibly even another methodological study, is needed to refine this technique.

Based on experience derived during this project, two important conclusions were reached concerning the use of the COED-1 and GE/HP monitors for monitoring personal CO exposure:

- The COED monitors exhibited a less than desirable reliability during this study producing a final successful sample completion rate of only 78 percent. Since most of the lost samples can be attributed to unreliability of the monitor electronics, the battery packs, or the sample pump (169 of the 232 samples lost due to monitor malfunction), these monitors will probably become acceptable for future projects of this type providing that the recommendations discussed in the report are successfully incorporated into the monitor design. Excessive calibration drift accounted for the remaining 63 of the 232 samples lost due to monitor malfunction (approximately 6 percent of the samples attempted. The monitors exhibited high linearity (calibration $r^2 \cong 0.9997$), acceptable stability (86 percent within $\pm$ 10 percent of initial response levels after 24 hours), and reasonable precision (median standard deviation of duplicate measurements $\cong$ 0.25 ppm) during field monitoring.
- The GE/HP monitors will probably be acceptable for such monitoring following perfection of the design and incorporation of the recommendations suggested in the report. The full user-programmability of these monitors will add desirable flexibility, not achievable with the COED-1, to future monitoring projects. On-Board micro-processor monitoring of, and compensation for, parameters such as cell temperature and battery voltage may increase monitor stability and precision.

Concerning the monitoring of alveolar carbon monoxide by the method utilized during this project, the following conclusions were reached:

- The proposed method performed well, producing a mean difference between duplicate samples of 0.11 ppm $\pm$ 0.13 ppm at the 95 percent confidence level and an estimated accuracy of $\pm$ 0.3 ppm at 3.5 ppm and $\pm$ 1.0 ppm at 40 ppm. The proposed modification to the procedure concerning use of humidified zero and calibration matrices is, however, deemed necessary for procedural stability. The method is highly reliable (97.5 percent successful sample completion rate).

Using the data collected in the Washington, D.C. and Denver metropolitan areas with the Household Screening Questionnaire, weighted estimates were computed of population characteristics. These estimates were based on screening interviews in 4394 households in Washington and 2128 households in Denver. In particular, the population estimate for the number of households in the two areas was 953,714 for Washington and 345,163 for Denver. Population estimates of percentages of households with various characteristics were as follows:

| | Washington | Denver |
|---|---|---|
| Use Fireplace | 33% | 30% |
| Use Wood Stove | 4% | 6% |
| Use Gas Furnace | 56% | 71% |
| Use Gas Stove | 64% | 25% |
| Use Gas Hot Water | 57% | 78% |
| Have Attached Garage or Multi-Family Garage | 22% | 35% |

In addition to household characteristics, several estimates were also obtained for individuals' characteristics in the two areas. For example,

| | Washington | Denver |
|---|---|---|
| Male | 48% | 47% |
| Smokers (13 years or older) | 33% | 38% |
| Work (13 years or older) | 70% | 72% |
| Travel $\geq$ 3 times/week | 84% | 82% |

Regarding estimates of CO exposure for the winter of 1982-83 in Washington, D.C., a data base was constructed from the raw CO levels by activity data which consisted of hourly CO values on 712 respondents, activity patterns and corresponding CO levels on 705 respondents, and CO breath measurements corresponding to the PEM CO data on 659 respondents. These data were used to obtain estimates of CO exposure for the population of inference—the adult (18 to 70 years old), non-smokers in the urbanized portion of the Washington, D.C. SMSA. The size of this population was estimated to be 1.22 million individuals. The results presented below are weighted estimates which apply to this population.

The weighted average maximum hourly PEM CO level in Washington, D.C. was 6.74 ppm (this was computed as the weighted average of the maximum hourly CO value for each individual in the sample). The average maximum 8-hour CO level was 2.79 ppm. The percentage of the population with maximum hourly CO values over the 35 ppm CO standard was estimated to be 1.28 percent while the percentage with an 8-hour maximum over the 9 ppm standard was 3.9 percent.

Estimates were also made for subgroups of the population. Persons in high-exposure occupations (about 4.6% of the total population) generally exhibited higher CO exposure levels: it was estimated that about 24% of this high-exposure group had 1-hour CO exposures above the 35-ppm standard and that about 28% exceeded the 8-hour standard. It was also shown that CO levels were generally higher for commuters, especially for those with larger amounts of travel. For example, 8% of the commuters indicating 16 or more hours of travel per week were estimated to have maximum 8-hour CO concentrations over 9 ppm, whereas less than 1% of the non-commuters were estimated to have such levels.

Breath CO levels (taken at the end of the sampling periods, usually in the respondents' homes) for the adult non-smoking population in Washington averaged 5.12 ppm. Slightly higher levels were observed for persons with high occupational exposures and for persons with large amounts of travel.

By combining PEM data with data from individuals' diaries, estimates of both CO levels and time durations for various activities and personal environments were made. In general, these results were consistent with *a priori* expectations. For example, the activities "in parking garage or parking lot" and "travel, transit" had the highest average CO concentrations (6.93 ppm and 4.51 ppm, respectively) while "sleeping" had an estimated CO concentration of only .85 ppm. Among the environments considered, the three with the highest average CO concentrations were "indoor parking garage," "outdoor parking area," and "in transit-car." The average levels for these environments were 10.36, 4.67, and 5.05 ppm, respectively.

Variation from duplicate hourly PEM measurements under field conditions were also analyzed. An analysis of variance of this data which considered person-to-person, hour-to-hour, and measurement variation indicated that about 5 to 6 percent of total variation among the hourly duplicate readings was due to deviations in measurements made by two PEMs at the same hour for the same person.

*T. D. Hartwell, C. A. Clayton, R. M. Mitchie, R. W. Whitmore, H. S. Zelon, S. M. Jones, and D. A. Whitehurst are with Research Triangle Institute, Research Triangle Park, NC 27709.*
***Gerald G. Akland** is the EPA Project Officer (see below).*
*The complete report, entitled "Study of Carbon Monoxide Exposure of Residents of Washington, DC and Denver, Colorado," (Order No. PB 84-183 516; Cost: $20.50, subject to change) will be available only from:*
*National Technical Information Service*
*5285 Port Royal Road*
*Springfield, VA 22161*
*Telephone: 703-487-4650*
*The EPA Project Officer can be contacted at:*
*Environmental Monitoring Systems Laboratory*
*U.S. Environmental Protection Agency*
*Research Triangle Park, NC 27711*