TRJ Environmental

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Comments on Exposure Assessment Methodology
Described in Three Documents

Dear Mr. Cook:

In response to your request, I have reviewed the following documents:

A. EPA, 1999. Estimation of Motor Vehicle Toxic Emissions and Exposure in Selected Urban Areas. Prepared by Sierra Research, Inc., Radian International Corporation, and Energy and Environmental Analysis, Inc., for U.S. EPA, Office of Mobile Sources, Assessment and Modeling Division, Ann Arbor, Michigan, Report No. EPA-420-D-99-002, March 1999.

B. Sierra Research, Inc. 1998. On-Road Motor Vehicle National Toxics Exposure Estimates. Memorandum from Philip Heirigs to Rich Cook, U.S. EPA. October 15, 1998.

C. Sierra Research Work Plan. "Additional Analysis of the Impact of Control Programs on Motor Vehicle Emissions and Exposure in Urban Areas."

As my area of expertise is primarily exposure assessment, I have focused my review on the material in these documents concerned with exposure estimation.

General Comments. The general approach to city-specific exposure assessment described in these documents can be summarized by the following three-step methodology.

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1. Apply HAPEM-MS3 to each of nine defined urban areas to obtain estimates of quarterly average CO exposure for specific population groups (outdoor workers and children 0 to 17) and for the total population.

2. Adjust the estimates obtained in Step 1 by a factor representing the ratio of CO emissions from mobile sources to CO emissions from all sources.

3. Convert the adjusted CO exposure estimates obtained in Step 3 to corresponding estimates of exposure to one of six toxic pollutants (benzene, acetaldehyde, formaldehyde, 1,3-butadiene, MTBE, and diesel PM) using an appropriate toxic/CO ratio. The formula is

$$TOX_{exposure(\mu g/m3)} = [CO_{exposure(\mu g/m3)}/CO_{EF(g/mi)}]_{1990} \times TOX_{EF(g/mi)}. \quad (1)$$

The toxic/CO ratio accounts for the relationship between toxic and CO emissions from on-road vehicles, the increase in VMT from 1990 to the year under evaluation, and atmospheric transformation of the three reactive pollutants (1,3-butadiene, formaldehyde, and acetaldehyde).

I believe that I am best qualified to evaluate Step 1, in which HAPEM-MS3 is used to estimate CO exposures in specific urban areas. I designed the versions of HAPEM-MS which preceded HAPEM-MS3 and assisted in developing many of the databases used in applications of these models. Steps 2 and 3 are based on assumptions concerning emission inventories and CO/Toxic relationships which can be better evaluated by other reviewers.

The Sierra Research report (EPA 420-D-99-002a) references the report "Final Technical Report on the Analysis of Carbon Monoxide Exposure for Fourteen Cities Using HAPEM-MS3" by Glen and Shadwick (March 1998) as the source of information on HAPEM-MS3. This report provides a brief description of HAPEM-MS3 and comprehensive tabulations of the results of applying the model to 14 cities. However, more detailed descriptions of HAPEM-MS1, HAPEM-MS2, and HAPEM-MS3 can be found in the following six references:

HAPEM-MS1: Ted Johnson, Roy Paul, and Jim Capel. 1992. **Application of the Hazardous Air Pollutant Exposure Model (HAPEM) to Mobile Source Pollutants.** Project report prepared by IT Air Quality Services under Work Assignment 6, EPA Contract No. 68-DO-0062.

HAPEM-MS2: Ted Johnson, Mike McCoy, and Jim Capel. 1993. **Enhancements to the Hazardous Air Pollutant Exposure Model (HAPEM) as Applied to Mobile Source Pollutants.** Project report prepared by IT Air Quality Services under Work Assignments 19 and 28, EPA Contract No. 68-DO-0062.

HAPEM-MS2: Ted Johnson. September 30, 1993. "Evaluation of the Method Used to Extrapolate HAPEM-MS Exposure Estimates for Model Urban Areas to

Geographic Regions." Letter to Alan Huber prepared by IT Air Quality Services under Work Assignment II-8 of EPA Contract No. 68-DO-0062.

HAPEM-MS2: Graham Glen. 1994. **Details of the HAPEM-MS2 Exposure Model.** Project report prepared by ManTech Environmental Technology, Inc. for EPA Contract No. 68-DO-0106.

HAPEM-MS2: Ted Johnson, J. Warnasch, M. McCoy, J. Capel, and M. Riley. 1996. **Developmental Research for the Hazardous Air Pollutant Exposure Model (HAPEM) as Applied to Mobile Source Pollutants.** Project report prepared by IT Air Quality Services under EPA Contract No. 63-D-30094.

HAPEM-MS3: Ted Palma, Mike Riley, and J. Capel. 1996. **Development and Evaluation of Enhancements to the Hazardous Air pollutant Exposure Model (HAPEM-MS3).** Project report prepared by IT Air Quality Services under Work Assignment 2-8 of EPA Contract No. 63-D-30094.

In reviewing the three documents (A, B, and C), I found citations for only one of these six references (Ted Johnson, Mike McCoy, and Jim Capel. 1993. Enhancements to the Hazardous Air Pollutant Exposure Model (HAPEM) as Applied to Mobile Source Pollutants). It is not clear from the text in the three documents that researchers reviewed the material in the above reports. During our recent telephone conversation (8-4-99), I learned that your staff did review most of these documents. As discussed below, I think that it is important that the findings presented in Section 3 of the 1996 report by Ted Johnson, J. Warnasch, M. McCoy, J. Capel, and M. Riley (Developmental Research for the Hazardous Air Pollutant Exposure Model (HAPEM) as Applied to Mobile Source Pollutants) be considered in developing methods for calculating national exposure and risk estimates.

Cities Represented by HAPEM-MS3 Exposure Estimates

The report by Palma, Riley, and Capel (1996) describes HAPEM-MS3 and provides a sample application of the model to San Francisco. According to p. 13 of the report by Glen and Shadwick (1998), ManTech used HAPEM-MS3 to develop CO exposure estimates for the 14 cities listed below.

Baltimore*	Boston*	Chicago
Denver	Houston	Los Angeles*
Minneapolis/St. Paul	New York	Philadelphia
Phoenix	San Francisco*	Spokane
St. Louis	Washington, DC*	

Of these 14 cities, the five marked with asterisks were not included in the analysis performed by Sierra Research as reported in Document A. Considering the desirability of using as many modeled cities as possible in deriving a national estimate, it is unfortunate that Sierra Research did not use the exposure estimates for all 14 cities.

As discussed below, Ted Johnson et al. (1996) recommended the use of 20 cities in developing national exposure estimates.

I understand for our telephone conversation (8-5-99) that each of the five cities dropped from consideration were deficient with respect to either CO monitoring data or emissions data. In the case of monitoring data, analysts judged that too large a fraction of the city's population fell within District 19, defined as the area within 50 km of the city center that was not within 10 km of a CO monitor. This apparent problem is really just an artifact of the arbitrary radius (50 km) which has historically been used to define the exposed population of an urbanized area. It would be reasonable in cases in which District 19 is judged to be too large to reduce the radius from 50 km to a smaller value, given that the smaller value still produces a circle that includes a representative sample of the city's urban population.

Uncertainties Associated with HAPEM-MS3 Exposure Estimates

The most recent discussion of the uncertainties associated with HAPREM-MS3 exposure estimates can be found in the report by Glen and Shadwick (March 1998). The authors discuss in qualitative terms the potential effects of uncertainties in the data used to characterize air quality, the exposed population, temperature, activity patterns, and microenvironmental factors. They also discuss the results of an analysis conducted by Johnson et al. (1996) in which CO exposure estimates obtained from HAPEM-MS3 were compared with corresponding estimates obtained from pNEM/CO. They conclude that HAPEM-MS3 tends to under estimate the variance of exposure throughout the population. In particular, events producing high exposures are under represented. I agree with this conclusion, and suggest that future developmental work on HAPEM-MS focus on this deficiency.

One potential improvement is to increase the resolution of the model by increasing the number of defined cohorts. A larger number of cohorts should yield greater variability in simulated activity patterns and corresponding exposure estimates. In addition, some of the additional cohorts should represent special groups expected to have unusually high or low exposures relating to mobile sources.

Another possible improvement would be to replace model parameters currently represented by constants (point estimates) with distributions or probabilistic relationships. For example, the microenvironmental factors (currently represented by constants) could be replaced by distributions.

EPA may also wish to evaluate the merits of replacing HAPEM-MS3 with pHAP, a version of pNEM applicable to toxic pollutants. A draft report describing pHAP can be obtained from Mike Dusetzina, Risk and Exposure Assessment Group, OAQPS.

National Extrapolation as Implemented

Document B presents the method used to determine national exposure estimates. In developing this method, analysts first considered the approach used by Johnson,

Capel, and McCoy (1993). According to this approach, toxics exposure estimates obtained by applying HAPEM to each of 13 cities (11 urban, 2 rural) were mapped onto non-modeled cities and rural areas which were located in the same geographic region. In the case of Albuquerque, the benzene exposure was calculated by the equation

$$BZ_{exp\text{-}ALBQ} = BZ_{exp\text{-}PHX} \times (Co_{amb\text{-}ALBQ})/(CO_{amb\text{-}PHX})$$

in which

$BZ_{exp\text{-}ALBQ}$ = benzene exposure in Albuquerque (ALBQ), a non-modeled city

$Bz_{exp\text{-}PHX}$ = benzene exposure estimated for Phoenix by HAPEM

$CO_{amb\text{-}ALBQ}$ = average ambient CO concentration reported for Albuquerque

$CO_{amb\text{-}PHX}$ = average ambient CO concentration reported for Phoenix.

EPA expressed concern that approach would not yield reliable results unless the number of modeled cities was increased to 50. Consequently, the approach was not implemented due to the small number of modeled cities available, limited budget, and time constraints.

It should be noted that Section 3 of the report by Ted Johnson, J. Warnasch, M. McCoy, J. Capel, and M. Riley (1996) -- hereafter referred to as Johnson et al. (1996) -- provides a critique of the approach used by Johnson, Capel, and McCoy (1993). The major findings of Johnson et al. (1996) are summarized below.

1. There is a relatively strong relationship between mean ambient CO (model input) and estimated mean toxics exposure (output) for the various HAPEM models.

2. The lognormal distribution provides a good fit to the toxics exposure distributions obtained from HAPEM.

3. The variability in the toxics exposures estimated for a city can be expressed by the geometric standard deviation of the lognormal distribution fit tot the exposure estimates. There is a relatively strong relationship between this standard deviation and the standard deviation of the mean CO concentrations reported by fixed-site monitors in the city. The relationship can be represented by a straight line with a non-zero intercept.

4. The relationships identified in Conclusions 1 and 3 provide a means of estimating the toxics exposure distribution in a particular MSA (metropolitan statistical area) directly from its monitoring data. If a MSA has sufficient CO data for this purpose, there is no need to assign the MSA to a region or match it with a modeled city.

5. Analysts assumed that the mean CO concentration of a MSA without CO data (call it MSA X) is equal to a regional mean CO concentration. This approach is based on the assumption that the mean CO of MSA X is likely to be closer to that of nearby MSA's than distant MSA's. The regression analyses summarized in Table 3-5 of Ted Johnson, J. Warnasch, M. McCoy, J. Capel, and M. Riley (1996) suggest that MSA's in close proximity are no more likely to have similar CO values than widely separated MSA's.

6. Exposure estimates for non-modeled cities are highly dependent on the modeled cities to which they are matched.

7. The only database listing CO emission densities for most areas in the U.S. provides estimates by county rather than city or urbanized area. A comparison of these data with CO concentrations for modeled cities suggests that a county-specific emission density estimate cannot be used as a surrogate for average CO concentration.

Johnson et al. (1996) concluded that there was scant support for the continued matching of non-modeled cities with modeled cities as performed by Johnson, Capel, and McCoy (1993). Based on their findings, Johnson et al. (1996) proposed the following methodology for developing national exposure estimates.

1. Apply HAPEM to nine additional cities to produce a total of 20 modeled cities.

2. Using the results of these 20 HAPEM runs, develop empirical relationships between the distribution of ambient CO data (model input) and the distribution of exposure estimates (model output).

3. Apply these relationships to all other MSA's that have sufficient CO data. The result is a exposure distribution for each MSA expressed as the number of persons experiencing annual average exposures above specified concentrations. (The same approach could be used to develop exposure distributions by calendar quarter, if required).

4. Total the exposure distributions obtained in Step 3 and covert to percentage form.

5. Apply the exposure distribution determined in Step 4 to the urban population of the United States. This population will include MSA's with and without CO data. The result of step will be national estimates of the number of persons experiencing annual average exposures above specified levels. These exposure estimates can be easily converted into cancer incidence estimates.

Section 3.9 of Johnson et al. (1996) provides recommendations for the nine additional MSA's to be modeled (Birmingham, AL; Charlotte, NC; Cleveland, OH; El Paso, TX; Jacksonville, FL; Memphis, TN; Provo, UT; Reno, NV; and Seattle, WA) in Step 1. Section 3.10 discusses implementation of the subsequent steps.

A different approach was ultimately implemented by Sierra Research. As described by Philip Heirigs in Document B, Sierra Research combined the 1990 ambient CO estimates for the nine modeling cities to produce an population-weighted average of 1.35 ppm for modeled urban areas. They also determined the population-weighted average of CO monitoring data for all urban areas to be 1.22 ppm. These two values were then used to calculate a scaling ratio of 1.22 ppm/1.35 ppm = 0.90. The average 1990 CO exposure of the modeled cities was multiplied by this scaling factor to produce an estimate of average 1990 CO exposure for all urban areas. These 1990 CO exposure estimates were then multiplied by adjustment factors to obtain CO exposure estimates for future years. The adjustment factors were based on emission rates estimated from VMT and population statistics (see page 4 of Document B). The resulting CO exposures were converted to toxic exposure estimates using Equation 1 above. Further adjustments were made to account for pollutant reactivity when appropriate.

In Document B, Sierra Research states that time and resources did not permit a more thorough evaluation of the national emissions and exposure estimates. They provide a brief description (p. 6) of an alternative method (not implemented) for representing on-road vehicle toxics emissions according to temperature regime, fuel regime, and I/M regime.

I believe that the method for developing national estimates can be improved by using a method consisting of the following five steps: (1) run HAPEM on additional cities to increase the database of exposure estimates to 20+ cities, (2) apply statistical techniques to the HAPEM input/output data to develop a "repro model" that can be used to predict model output (exposure estimates) as a function of the fixed-site data used as input, (3) apply the repro model to non-modeled cities with adequate fixed-site monitoring data to develop exposure estimates, (4) combine and population-weight the exposure estimates for all cities to obtain a "national" exposure "profile" expressed as concentration versus percentile, and (5) apply the national exposure profile to national urban population to obtain national exposure estimates. This is basically the approach proposed by Johnson et al. (1996) discussed above. Adjustments for special emission conditions could be made within the estimation process as appropriate.

(The term "repro model" was coined by Tom McCurdy to denote a simplified equation or algorithm that reproduces the operation of a complex model without requiring the analyst to actually run the model. Typically, the repro model uses statistical relationships to predict a selected output parameter of the complex model based on the values of a few key input parameters.)

Work Plan

Document C is the Work Plan, "Additional Analysis of the Impact of Control Programs on Motor Vehicle Emissions and Exposure in Urban Areas," prepared by Sierra Research. The Work Plan describes 12 tasks. Nine are concerned with the development of emission estimates for various scenarios. Three tasks (9, 10, and 11) are focused on developing and evaluating exposure estimates.

In Task 9, analysts will prepare exposure estimates and corresponding cancer risk estimates (adjusted according to the new emission estimates) for Atlanta and the nine cities used in previous assessments. Comment on Task 9: Task 10 produces exposure estimates for 10 cities. Johnson et al. (1996) recommended the use of 20 cities and recommended the addition of the following additional areas: Birmingham, AL; Charlotte, NC; Cleveland, OH; El Paso, TX; Jacksonville, FL; Memphis, TN; Provo, UT; Reno, NV; and Seattle, WA.

In Task 10, analysts will develop nationwide estimates for CO emissions and exposure for 1990. These estimates will then be adjusted for other years and scenarios by using the nationwide emission estimates prepared under another task. As part of Task 10, Sierra Research will conduct a review of the methodology used in the Regulatory Impact Analysis (RIA) for the ozone NAAQS revision, in which the impacts of changes to the ozone standard were investigated only for a small number of cities without extrapolating to nationwide impacts. They will assess the applicability of this approach and make recommendations on the best approach to generating and presenting results. Comment on Task 10: In addition to evaluating the ozone RIA approach (which does not provide national estimates), I would recommend that OMS investigate the approach described in Section 3 of Johnson et al. (1996) and summarized above. This approach provides national exposure estimates using a methodology which makes use of an in-depth analysis of the relationship between monitoring data and HAPEM-derived exposure estimates.

Under Task 11, Sierra research will compare 1996 calendar year exposure estimates with available monitoring data. Comment on Task 11: As the nature of this comparison and the goals of the task are not stated, it is difficult to evaluate this task.

A General Comment About Pollutant Ratios

An important assumption of the HAPEM approach described in the three documents under review is that CO can be used as a surrogate for other pollutants emitted by motor vehicles. A model utilizing emission factors is used to estimate the ratio of Pollutant X to CO at the emission point. This ratio is applied to ambient CO concentrations measured at fixed-site monitors to estimate corresponding concentrations of Pollutant X in the ambient air. Microenvironmental factors are applied to the ambient concentrations to estimate concentrations in specific microenvironments.

If Pollutant X undergoes atmospheric transformation after being emitted by a motor vehicle, the X-to-CO ratio may change as an air parcel moves from emission point to

exposure point. Modeling this change is difficult, as it requires estimates of reaction rates and atmospheric residence times which are affected by a number of poorly characterized factors. An alternative approach would be to (1) statistically analyze data collected by co-located monitors measuring Pollutant X and CO and (2) use the resulting distribution of observed X-to-CO ratios to represent the range of typical ratios at the point of exposure. This approach could use data from both fixed-site monitors and personal exposure monitors.

For example, I am currently participating in a field study funded by EPA in which formaldehyde and CO are being simultaneously measured at a number of fixed-site monitors in Sacramento, including some sites upwind and downwind of the city. In the same study, technicians are carrying personal monitors that measure formaldehyde and CO simultaneously. Each technician follows a prepared script that guides him through various microenvironments that appear in HAPEM (including outdoors). Data obtained from studies of this kind provide a means for determining representative X-to-CO ratios at or near the point of exposure, rather than at the point of emission. The data can be statistically analyzed to determine the effects that local emission rates, time of day, season, temperature, and other factors have on the X-to-CO ratio.

In addition, I would recommend that EPA review the following recent articles which describe pertinent research relating to tailpipe vs. nontailpipe emissions, chemical mass balance models, source apportionment, and atmospheric residence times.

Pierson, W. R., D. E. Schorran, E. M. Fujita, and J. C. Sagebiel. 1999. "Assessment of Nontailpipe Hydrocarbon Emissions from Motor Vehicles." **Journal of the Air and Waste Management Association**. Vol. 49, p. 498 (May 1999).

Graboski, M. S., D. L. Mowery, and J. McClellan. 1998. "Microenvironmental Exposure Analysis: Evaluation of the Toxicity of Conventional and Oxygenated Fuels." **Alternative Fuels 1998**. SP-1391. (Reprint available from SAE International as Paper No. 982535 in the SAE Technical Paper Series).

Fujita, E. M., and J. G. Watson. 1998. "Validation and Applications Protocol for Source Apportionment of Volatile Organic Compounds and Fine Particles." **Measurement of Toxic and Related Air Pollutants**. Proceedings of a Specialty Conference Cosponsored by the Air and Waste Management Association and the U. S. Environmental Protection Agency. Cary, North Caroline, September 1 - 3, 1998.

I hope these comments are helpful. Please call me if you have any questions.

Sincerely,

TRJ Environmental, Inc.

Ted Johnson