ESTIMATING OZONE EXPOSURES FOR THE GENERAL POPULATION IN EIGHT URBAN AREAS USING A PROBABILISTIC VERSION OF NEM

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ESTIMATING OZONE EXPOSURES IN THE CHICAGO URBAN AREA USING A SECOND-GENERATION PROBABILISTIC VERSION OF NEM

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File: CHICAGO.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) currently is reviewing the ozone (O_3) primary national ambient air quality standard (NAAQS) to determine if the existing standard protects public health with an adequate margin of safety. In order to evaluate whether alternative O_3 NAAQSs provide an adequate margin of safety, the EPA Office of Air Quality Planning and Standards (OAQPS) assesses such factors as the nature and severity of health effects associated with O_3 exposure, the degree of total human exposure (i.e., indoor and outdoor) to O_3, and the risks (probabilities) of ozone-related health effects occurring in the exposed population when alternative O_3 NAAQS are just attained. This paper discusses an EPA analysis of O_3 exposure estimates for parts of the New York metropolitan area which employed the pNEM/O3 model developed by International Technology-Air Quality Services (IT-AQS). A report by Johnson, et al. (1) describes this model in detail and presents initial results of applying it to nine U.S. urban areas, including Chicago. Exposure estimates for parts of the Los Angeles area are discussed in an EPA memorandum (2) that was reviewed by the Clean Air Science Advisory Committee (CASAC) at a public meeting. Exposure estimates for the Philadelphia area are described in an AWMA paper (3). Exposure estimates for Houston are described in an AWMA specialty conference paper (4). New York results are contained in an EPA paper (5). Additional analyses of O_3 exposure estimates for the remaining urban areas that were modeled will be forthcoming.

OVERVIEW

Pursuant to section 108 of the Clean Air Act, the Environmental Criteria Assessment Office (ECAO) within the Office of Research and Development (ORD) is preparing a criteria document (6) for O_3. This document will be a comprehensive summary and critical assessment of the latest scientific research relevant to assessing the effects of a criteria pollutant. The document will be reviewed by CASAC, part of the EPA's independent Science Advisory Board, and by the general public. Upon completion of the criteria document, OAQPS will prepare a Staff Paper that summarizes and integrates scientific information presented in the criteria document considered to be most relevant to decisions on alternative NAAQS and various analyses (e.g., air quality, exposure, and risk).

An important aspect of health risk assessment is an analysis of population exposure (7). Such an analysis provides the population basis for "headcount risk" estimates developed as part of EPA's NAAQS risk assessment work. Estimates of population exposure also provide important information regarding the number of people that may experience varying levels of O_3 as they go through their daily activities.

Since 1980, OAQPS has used the NAAQS Exposure Model (NEM) to analyze human exposure associated with the "criteria air pollutants" covered by Title I of the Clean Air Act, as amended. Recent versions of this model use Monte Carlo analyses to define numeric values for certain variables inherent in the model. These version of NEM are called pNEM,

an acronym for "probabilistic" NEM. To differentiate among the various pollutant-specific versions of pNEM, the one described here is denoted as pNEM/O3.

Analysis of population exposure under alternative O_3 NAAQS requires that significant factors contributing to total human exposure be taken into account. These factors include the temporal and spatial distribution of people and O_3 concentrations throughout an urban area, the variation of ozone levels within each microenvironment, and the effects of exercise (increased ventilation) on ozone uptake in exposed individuals.

To date, the most recent version of pNEM/O3--the "second generation" version--has been applied to nine major urban areas. These areas vary in size from Denver with 1.4 million people to New York with over 10.6 million people. pNEM/O3 partitions all land within a selected urban area into large "exposure districts." The number of exposure districts defined for each urban area varies from 6 to 16 in the set of nine areas recently modeled; the number of districts reflects the number of monitors having valid air quality data in a study area. Most of the nine urban areas have 10 or more districts within their boundaries.

People living within each exposure district, as estimated by the U.S. Bureau of Census in 1990, are assigned to a single discrete point, the population centroid. O_3 air quality within each exposure district is estimated for each hour of the O_3 season using data from a nearby monitoring site. Because O_3 in the ambient air generally is modified considerably when entering a building or vehicle, outdoor O_3 estimates are adjusted using a mass-balance model to account for 3 indoor microenvironments. These microenvironments are: indoors-at-home, indoors-other, and within a motor vehicle. The mass-balance model used in pNEM/O3 is a simplified version of the generalized Nagda, Rector, and Koontz (NRK) model (8). For our use, this model was revised to incorporate the assumption that indoor decay rate is proportional to indoor O_3 concentration. It was further revised to incorporate assumptions concerning ozone decay rates suggested by Weschler, et al (9). The resulting revised mass-balance model is fully described in Ref. 1.

Because both the intake dose received and susceptibility to effects of pollution may vary with age, occupation, and intensity of exercise, the total population of each study area is divided into 9 age-occupation (A-O) groups. Each A-O group is further subdivided into cohorts depending upon (1) the type of air conditioning system present in the home, if any, and (2) home-to-work commuting patterns.

While many types of exposure metrics are provided by pNEM/O3 only those for the non-outdoor working population in Chicago are discussed in this paper. Exposure estimates for children are included in the results discussed here. Estimates for outdoor workers--a major population sub-group of concern from an O_3 exposure perspective--will be completed in the Fall of 1994.

It should be noted that all versions of pNEM systematically underestimate the highest part of the exposure distribution. (See Ref. 1 for an evaluation of pNEM/O3 results against real-time personal exposure monitoring data.) Thus, results presented here have a downward bias.

AIR QUALITY SCENARIOS INVESTIGATED

Six air quality scenarios were modeled for the Chicago urban area (and the other 8 urban areas); the scenarios are all on a daily maximum basis. They are:

1. 1991 air quality--the "as is" scenario
2. Attain 1h 1Ex 0.12 ppm--the current standard
3. Attain 8h 1Ex 0.08 ppm
4. Attain 8h 1Ex 0.10 ppm
5. Attain 8h 5Ex 0.06 ppm
6. Attain 8h 5Ex 0.08 ppm

Ex stands for "expected exceedances," as defined by EPA in 40 Code of Federal Regulations 50.9, and h is the usual symbol for hour(s). Thus, a full description of the first alternative NAAQS scenarios is: attain the 1 hour daily maximum-one expected exceedance NAAQS of 0.12 ppm. The other standards follow the same format. The 5Ex NAAQS would allow 5 daily exceedances per year, on average, if they were implemented.

The iterative adjustment procedure used by IT-AQS to simulate just-attaining the 5 alternative NAAQS listed above involves a complex procedure of fitting Weibull equations to the 1991 O_3 data, modifying parameters of the equations so that the "worst" monitor just achieves the desired standard, and then re-specifying the entire O_3 pattern for all districts in Chicago. The procedure is described in detail by Johnson, et al. (1).

CHICAGO RESULTS

Results are based upon 10 runs (realizations) of the pNEM/O3 model for each air quality scenario. Based on a previous analysis of sets of 10-run results versus a 108-run result (10), the author believes that results from only 10 runs of the model will adequately predict the mean and variance observed in 100 or more runs of pNEM/O3. Ten runs of the model will not, however, adequately represent the entire range of possible outcomes. Additional runs can only increase this range. This is an obvious shortcoming of the analyses presented here, but limited resources preclude undertaking more runs.

This paper includes tabular data on (1) the number and percent of people and children exposed, and (2) the number and percent of person-occurrences for children and the adult, non-outdoor worker population in Chicago. (A person-occurrence is the metric that focuses on an event: when the exposure-of-concern is reached regardless of who reaches it. One hundred person-occurrence could be 10 people experiencing the exposure 10 times, 100 people experiencing it once, one person experiencing it 100 times, or any combination thereof.) Even though data are discussed here regarding the absolute and relative number (percentage) of people exposed, it must be noted that "people" should not be used as an exposure metric. The cohort-specific activity-days data base used for pNEM/O3 modeling (and for all other exposure models that use human activity information) provides no more than three days of data for a single individual. Thus, rigorous inferences from these data can be made only to "person-days" of exposure or "person-occurrences" of exposure, where an occurrence can be 1h, 8h, or 24h time period in pNEM/O3. Only when activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to people exposed over the year (or to children, or to outdoor workers as the case may be). This point usually is ignored in the general exposure assessment literature.

All exposure estimates presented in this paper pertain to "daily maximum dose," (MAXD) where dose is defined as the product of ozone concentration and ventilation rate over a defined time period. Note that maximum daily dose does not necessarily occur during the time period of maximum ozone concentration in a given urban area.

Ventilation rate is a very important factor in estimating total dose for any air pollutant (11). The ventilation rate metric used in pNEM/O3 is "equivalent ventilation rate" (EVR), or ventilation rate (in liters per minute) divided by body surface area (BSA, in units of m^2). EVR has units of $l\ min^{-1}\ m^{-2}$. It is a surrogate indicator for the number of O_3 molecules that enter the oral-nasal cavities per unit time period.

The Chicago urban area population analyzed here includes 6.2 million NOW (non-outdoor worker) people and 1,156,500 children. There are 1,321 million possible daily maximum NOW person-occurrences (NOW people x 214 days in the O_3 season). The equivalent figure for children is 247,491,000.

Exposure results appear in Tables 1 and 2. Table 1 includes 1h daily maximum dose exposure estimates, while Table 2 provides similar results for 8h exposure estimates.

The results indicate that:

1. Currently (1991), fewer than 0.5% of the NOW population experience a daily maximum dose (MAXD) O_3 exposure @ >0.12 ppm @ an EVR of 30 $l\ min^{-1}\ m^{-2}$ or higher, which is thought by many researchers to be a dose rate of concern (12). All of these exposures occur only on one day during the O_3 season.

2. Currently (1991), about 2% of the children in Chicago exceed the 0.12 ppm/30 EVR max dose exposure level. This is about 80% of the NOW exposed population. All of the children exposed at that level are predicted to experience only 1 day/season.

3. Such MAXD exposures are reduced whenever one of the alternative standards are attained. For the relatively few people expected to have a MAXD exposure >0.12 ppm @ $\geq$30 EVR when an alternative NAAQS is attained, all of them are predicted to experience only one such daily 1h exposure per season.

While not shown in Table 1, the results of O_3 exposures >0.12 ppm at any exercise level are considerably higher than the numbers presented in that Table. For instance, currently (1991) about one million adults and 312,500 children are predicted to experience one or more daily exposure >0.12 ppm when exercise level is ignored. This is about 16% of the adult population and 27% of the children in the Chicago urban area. Thus, exercise level, and its associated ventilation rate, at maximum dose greatly affects pNEM/O3 MAXD exposure estimates.

The same general findings apply to the 8h results (Table 2), although relatively more people may be affected. The level of concern here is a MAXD exposure of >0.08 ppm for 8h @ an EVR $\geq$15 l min^{-1} m^{-2}. (Obviously, the EVR of concern drops as the averaging period increases, just as the O_3 concentration of concern drops. People cannot hold an EVR of 30 l min^{-1} m^{-2} for an extended period of time(11).)

The 8h results indicate that:

1. Currently (1991), about 1% of the NOW population are estimated to experience a daily maximum dose O_3 exposure level of concern. About 3% of these people may experience such a MAXD exposure on more than one day during the O_3 season; no one is estimated to experience this exposure on more than two days.
2. Currently (1991), over 4% of children in the Chicago area may experience the 8h MAXD of concern. In fact, about 83% of the total population experiencing this 8h MAXD are children. About 97% of the children may experience this MAXD on only one day, while 3% may experience it on 2 days.
3. Attaining any of the alternative NAAQS reduces the 8h MAXD exposure of concern, although almost 4% of children may experience that exposure if the 8h 1Ex 0.10 ppm NAAQS is attained (5% of them on 2 days). Attaining the current NAAQS (1h 1Ex 0.12 ppm) may also result in almost 4% of children experiencing the 8h MAXD of concern one or two times during the O_3 season in Chicago. In addition, attaining the 8h 5Ex NAAQS of 0.08 ppm is estimated to leave a small percentage (0.1%) of children at or above the 8h MAXD of concern--all on one day, however.

Consistent with the 1h results, it is estimated that approximately 32% in the NOW population of Chicago currently (1991) experiences one or more 8h exposures at maximum daily dose when ventilation level is ignored. (This result is not shown in Table 2.) This contrasts with the 1% of the NOW population who may experience the same 8h O_3 concentration at exercise. Again, exercise levels--expressed as EVR--greatly affect pNEM/O3 exposure results. This same pattern holds true for children in Chicago, but the percentage is higher: 50% of all children may experience an 8h 0.08 ppm exposure if breathing rate is ignored, as compared to 4% at exercise.

Note that all of the estimates have variability, reflecting the Monte Carlo sampling process that produces a different estimate for each run. The range in the estimates are between a factor of 2-to-3 in most cases, which seems reasonable.

Statistical tests of the exposure distributions were undertaken using a two-sample Kolmogorov-Smirnov (K-S) non-parametric test. The null hypothesis was that the cumulative frequency exposure distributions for the various air quality scenarios are the same for each exposure metric being tested. The test statistic was the maximum difference between the two distributions (Dn); it was evaluated using a large-sample F statistic. The significance level is 0.05, using the chi-square approximation. The test indicates that the exposure indicators shown in Tables 1 and 2 vary significantly across the six air quality scenarios with the following exceptions.

For the AsIs and 8h 1Ex 0.10 ppm pair:

> NOW people exposed, NOW person-occurrences, and number of people exposed on one day/ozone season at 1h 0.12 ppm @ exercise and at 8h 0.08 ppm @ exercise and at any exercise level.
>
> Children exposed, children occurrences, and number of children exposed on one day/season at 1h 0.12 ppm @ exercise and at 8h 0.08 ppm @ exercise and at any exercise level.

For the AsIs and current NAAQS (1h 1Ex 0.12 ppm) pair:

> NOW people and children, NOW person- and children-occurrences, and number of people and children exposed on one day/O_3 season to 8h 0.08 ppm @ exercise and at any exercise level.

For the current standard (1h 1Ex 0.12 ppm) and 8h 1Ex 0.08 ppm pair:

> NOW people exposed, NOW person-occurrences, and number of people exposed on one day/O_3 season at 1h 0.12 ppm or 8h 0.08 ppm @ exercise and at any exercise level.
>
> Children exposed, children-occurrences, and number of children exposed on one day/O_3 season at 1h 0.12 ppm for any exercise level and at 8h 0.08 ppm @ exercise and at any exercise level.

Note that these are not strong statistical tests and that some of the K-S test requirements were not met. Random sampling was not used. The sample "observations" simply are results of a simulation model; the population of interest, then, can only be the set of possible outcomes produced by the model. A large-sample test statistic was applied to small samples (10 runs). These caveats aside, 43 "cannot rejects" out of 118 tests is three times as many as are expected based on a "pure-chance" probability of rejecting a true hypothesis (5%). This 36% cannot-reject rate is more than quadruple similar rates seen in most of the urban areas that were analyzed (2-5). The conclusions that have to be reached in the Chicago urban area are: (1) attaining a 1h 1Ex NAAQS of 0.12 ppm--the current standard--may not greatly affect exposure @ exercise for non-outdoor workers or children, (2) attaining an 8h 1Ex NAAQS of 0.10 ppm may also not greatly affect exposure @ exercise for the same two groups, and (3) the current standard cannot be distinguished from an 8h 1Ex 0.08 ppm standard on the basis of exposures reduced.

SUMMARY

The analyses of 5 alternative standards ozone NAAQS in the Chicago area (1h 1Ex 0.12 ppm; 8h 1Ex 0.10 pm; 8h 5Ex 0.08 ppm; 8h 1Ex 0.08 ppm; and 8h 5Ex 0.06 ppm) indicate that attainment of the current standard or the 8h 1Ex 0.10 ppm alternative may not significantly reduce exposures at exercise in the Chicago urban area. This finding applies to both the 1h and 8h estimates, but are more important for the 8h results since more people and children are currently estimated to experience 8h MAXD levels of concern than the 1h MAXD levels.

The reader should remember the early caveat about the downward bias inherent in pNEM results. While every effort has been made to present "best estimates," it is inherently difficult to predict the upper end of the population exposure distribution using human activity data bases that consist of only 1-3 days of information and that also under-represent adults and children who exercise regularly. Year-long activity data from all segments of the population are needed to adequately estimate the true population exposure distribution.

REFERENCES

1. T. Johnson, J. Capel, and M. McCoy. **Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data.** Durham, NC: IT-AQS, 1993 (Draft).

2. T. McCurdy. "Los Angeles Ozone Exposure Estimates," **EPA Memorandum;** November 4, 1993.

3. T. McCurdy, et al. "Estimating Ozone Exposures in Philadelphia Using a Second-Generation Probabilistic Version of NEM." **Paper A210 presented at the 87th Annual Meeting of AWMA**; Cincinnati, June 1994.

4. T. McCurdy, et al. "Estimating ozone Exposures in Houston Using a Second-Generation Probabilistic Version of NEM." **Paper presented at the Tropospheric Ozone Specialty Conference,** Air and Waste Management Association; Orlando, 1994.

5. T. McCurdy. "Estimating Ozone Exposures in the New York Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, February 1994.

6. Environmental Criteria and Assessment Office. **Air Quality Criteria for Ozone and Photochemical Oxidants.** Research Triangle Park, NC: 1994 (Draft).

7. H.M. Richmond and T. McCurdy. "Use of Exposure Analysis and Risk Assessment in the Ozone NAAQS Review." **Paper 88-121.3 presented at the 81st Annual Meeting of APCA**; Dallas, June 19-24, 1988.

8. N.L. Nagda, H.E. Rector, and M.D. Koontz. **Guidelines for Monitoring Air Quality.** Washington, DC: Hemisphere Pub. Co., 1987.

9. C.J. Weschler, H.C. Shields, and D.V. Nike. "Indoor Ozone: Recent Findings," in: R. Burglund (ed.), **Tropospheric Ozone in the Environment II.** Pittsburgh: Air & Waste Management Association, 1992.

10. T. McCurdy. "Testing pNEM/O3 Runs to Determine if a Set of 10 Runs is 'Representative'," **EPA Memorandum;** April 19, 1994.

11. W.C. Adams. **Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities.** Davis CA: University of California, 1993.

12. M. Absil, P. Narducci, R. Whitfield, and H.M. Richmond. "Chronic Lung Injury Risk Estimates for Urban Areas Having Ozone Patterns Similar to Those in the

Northeast." Paper presented at the **AWMA Specialty Conference on Tropospheric Ozone and the Environment II**; Atlanta, November 4-7, 1991.

Table 1. ESTIMATES OF 1h "MAXIMUM DOSAGE" EXPOSURES IN CHICAGO TO O_3 CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	27,000	3,500	0	10,300	0	0
Percent of Total Population	0.4	0.1	0	0.2	0	0
Range in this percentage for all runs	*-2.0	0.0-0.2	-	0.0-1.7	-	-
Mean Est. of Person-Occurrences	27,000	3,500	0	10,300	0	0
Percent of Total Per-Occurrences	@	@	0	@	0	0
Range in this percentage for all runs	@-@	@-@	-	@-@	-	-
Mean Est. of Occurrences/Person Exposed	1.00	1.00	-	1.00	-	-
Number of Days/Season Exposed (% Exposed)	100	100	-	100	-	-
1 Day	0	0	-	0	-	-
2 Days	0	0	-	0	-	-
3 Days	0	0	-	0	-	-
>3 Days						
CHILDREN	21,700	2,900	0	10,200	0	0
Mean Estimate of the Number of Children	1.9	0.3	0	0.9	0	0
Percent of Children Population	0.0-10.5	0.0-1.1	-	0.0-8.8	-	-
Range in this percentage for all runs						
Percent of Total Exposed Population	80.4	82.9	-	99.0	-	-
Mean Estimate of Children-Occurrences	21,700	2,900	0	10,200	0	0
Percent of total Child-Occurrences	@	@	0	@	0	0
Range in this percentage for all runs	@-@	@-@	-	@-@	-	-
Mean Estimate of Occurrences/Child Exposed	1.00	1.00	-	1.00	-	-
Number of Days Exposed/Season (% Exposed)						
1 Day	100	100	-	100	-	-
2 Days	0	0	-	0	-	-
3 Days	0	0	-	0	-	-
>3 Days	0	0	-	0	-	-

Notes:[a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h "MAXIMUM DOSAGE" EXPOSURES IN CHICAGO TO O_3 CONCENTRATIONS EXCEEDING 0.08 PPM AND EVR[a] EQUALED OR EXCEEDED 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL NON-OUTDOOR WORKER EXPOSED POPULATION						
Mean Estimate of the Number of People	60,400	45,100	3,200	49,500	0	0
Percent of Total Population	1.0	0.7	0.1	0.8	0	0
Range in this percentage for all runs	*-2.0	0.2-1.5	0.0-0.3	0.5-1.2	-	-
Mean Est. of person-Occurrences	62,200	47,200	3,200	50,800	0	0
Percent of total Per.-Occurrences	@	@	@	0.8	0	0
Range in this percentage for all runs	@-@	@-@	@-@	0.4-1.2	-	-
Mean Est. of Occurrences/Person Exposed	1.02	1.05	1.00	1.03	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	97	95	100	97	-	-
2 Days	3	5	0	3	-	-
3 Days	0	0	0	0	-	-
4 Days	0	0	0	0	-	-
>4 Days	0	0	0	0	-	-
CHILDREN						
Mean Estimate of the Number of Children	50,400	41,800	2,100	42,000	0	0
Percent of Children Population	4.4	3.6	0.1	3.6	0	0
Range in this percentage for all runs	0.0-9.0	1.0-7.0	0.0-0.8	2.1-5.6	-	-
Percent of Total Exposed Population	83.4	92.7	65.6	84.8	-	-
Mean Estimate of Children-Occurrences	52,200	43,900	2,100	43,300	0	0
Percent of Total Child-Occurrences	*	*	@	*	0	0
Range in this percentage for all runs	0.0-*	@-*	0.0-@	*-*	-	-
Mean Estimate of Occurrences/Child Exposed	1.04	1.05	1.00	1.03	-	-
Number of Days/Season (% Exposed)						
1 Day	97	95	100	97	-	-
2 Days	3	5	0	3	-	-
3 Days	0	0	0	0	-	-
4 Days	0	0	0	0	-	-
>4 Days	0	0	0	0	-	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

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To date, the most recent version of pNEM/O3--the "second generation" version--has been applied to nine major urban areas. These areas vary in size from Denver with 1.4 million people to New York with over 10.6 million people. pNEM/O3 partitions all land within a selected urban area into large "exposure districts." The number of exposure districts defined for each urban area varies from 6 to 16 in the set of nine areas recently modeled; the number of districts reflects the number of monitors having valid air quality data in a study area. Most of the nine urban areas have 10 or more districts within their boundaries.

People living within each exposure district, as estimated by the U.S. Bureau of Census in 1990, are assigned to a single discrete point, the population centroid. O_3 air quality within each exposure district is estimated for each hour of the O_3 season using data from a nearby monitoring site. Because O_3 in the ambient air generally is modified considerably when entering a building or vehicle, outdoor O_3 estimates are adjusted using a mass-balance model to account for 3 indoor microenvironments. These microenvironments are: indoors-at-home, indoors-other, and within a motor vehicle. The mass-balance model used in pNEM/O3 is a simplified version of the generalized Nagda, Rector, and Koontz (NRK) model (9). For our use, this model was revised to incorporate the assumption that indoor decay rate is proportional to indoor O_3 concentration. It was further revised to incorporate assumptions concerning ozone decay rates suggested by Weschler, et al (10). The resulting revised mass-balance model is fully described in Ref. 1.

Because both the intake dose received and susceptibility to effects of pollution may vary with age, occupation, and intensity of exercise, the total population of each study area is divided into 9 age-occupation (A-O) groups. Each A-O group is further subdivided into cohorts depending upon (1) the type of air conditioning system present in the home, if any, and (2) home-to-work commuting patterns.

While many types of exposure metrics are provided by pNEM/O3 only those for the non-outdoor working population in Denver are discussed in this paper. Exposure estimates for children are included in the results discussed here. Estimates for outdoor workers--a major population sub-group of concern from an O_3 exposure perspective--will be completed in the Fall of 1994.

It should be noted that all versions of pNEM systematically underestimate the highest part of the exposure distribution. (See Ref. 1 for an evaluation of pNEM/O3 results against real-time personal exposure monitoring data.) Thus, results presented here have a downward bias.

AIR QUALITY SCENARIOS INVESTIGATED

Six air quality scenarios were modeled for the Denver urban area (and the other 8 urban areas); the scenarios are all on a daily maximum basis. They are:

1. 1990 air quality--the "as is" scenario
2. Attain 1h 1Ex 0.12 ppm--the current standard
3. Attain 8h 1Ex 0.08 ppm
4. Attain 8h 1Ex 0.10 ppm
5. Attain 8h 5Ex 0.06 ppm
6. Attain 8h 5Ex 0.08 ppm

Ex stands for "expected exceedances," as defined by EPA in 40 Code of Federal Regulations 50.9, and h is the usual symbol for hour(s). Thus, a full description of the first alternative NAAQS scenarios is: attain the 1 hour daily maximum-one expected exceedance NAAQS of 0.12 ppm. The other standards follow the same format. The 5Ex NAAQS would allow 5 daily exceedances per year, on average, if they were implemented.

The iterative adjustment procedure used by IT-AQS to simulate just-attaining the 5 alternative NAAQS listed above involves a complex procedure of fitting Weibull equations to the 1990 O_3 data, modifying parameters of the equations so that the "worst" monitor just achieves the desired standard, and then re-specifying the entire O_3 pattern for all districts in Denver. The procedure is described in detail by Johnson, et al. (1).

Denver had relatively good O_3 air quality in 1990 in that it had few days with a 1h daily maximum concentration >0.11 ppm. The area's "design value"--the second-highest 1h daily value measured at any site in the urban area--was 0.115, which is lower than the current standard. Denver's 1990 monitored 8h values were also correspondingly low. Thus, just-attaining some of the alternatives listed above can result in higher 1h and 8h O_3 peak concentrations being included than were monitored in 1990. Exposure estimates for these alternatives similarly can be higher than those predicted for 1990. These results follow directly from the logic used to evaluate alternative NAAQS (8), and are quite feasible in reality.

DENVER RESULTS

Results are based upon 10 runs (realizations) of the pNEM/O3 model for each air quality scenario. Based on a previous analysis of sets of 10-run results versus a 108-run result (11), the author believes that results from only 10 runs of the model will adequately predict the mean and variance observed in 100 or more runs of pNEM/O3. Ten runs of the model will not, however, adequately represent the entire range of possible outcomes. Additional runs can only increase this range. This is an obvious shortcoming of the analyses presented here, but limited resources preclude undertaking more runs.

This paper includes tabular data on (1) the number and percent of people and children exposed, and (2) the number and percent of person-occurrences for children and the adult, non-outdoor worker population in Denver. (A person-occurrence is the metric that focuses on an event: when the exposure-of-concern is reached regardless of who reaches it. One hundred person-occurrence could be 10 people experiencing the exposure 10 times, 100 people experiencing it once, one person experiencing it 100 times, or any combination thereof.) Even though data are discussed here regarding the absolute and relative number (percentage) of people exposed, it must be noted that "people" should not be used as an exposure metric. The cohort-specific activity-days data base used for pNEM/O3 modeling (and for all other exposure models that use human activity information) provides no more than three days of data for a single individual. Thus, rigorous inferences from these data can be made only to "person-days" of exposure or "person-occurrences" of exposure, where an occurrence can be 1h, 8h, or 24h time period in pNEM/O3. Only when activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to people exposed over the year (or to children, or to outdoor workers as the case may be). This point usually is ignored in the general exposure assessment literature.

All exposure estimates presented in this paper pertain to "daily maximum dose," (MAXD) where dose is defined as the product of ozone concentration and ventilation rate over a defined time period. Note that maximum daily dose does not necessarily occur during the time period of maximum ozone concentration in a given urban area.

Ventilation rate is a very important factor in estimating total dose for any air pollutant (12). The ventilation rate metric used in pNEM/O3 is "equivalent ventilation rate" (EVR), or ventilation rate (in liters per minute) divided by body surface area (BSA, in units of m^2). EVR has units of $l\ min^{-1}\ m^{-2}$. It is a surrogate indicator for the number of O_3 molecules that enter the oral-nasal cavities per unit time period.

The Denver urban area population analyzed here includes 1.5 million NOW (non-outdoor worker) people and 260,000 children. There are 317.7 million possible daily maximum NOW person-occurrences (NOW people x 214 days in the O_3 season). The equivalent figure for children is 55.6 million.

Exposure results appear in Tables 1 and 2. Table 1 includes 1h daily maximum dose exposure estimates, while Table 2 provides similar results for 8h exposure estimates.

The 1h results indicate that:

1. Currently (1990), it is estimated that no one in Denver would experience a daily maximum dose (MAXD) O_3 exposure @ >0.12 ppm @ an EVR of 30 l min^{-1} m^{-2} or higher, which is thought by many researchers to be a dose rate of concern (12).

2. One hour MAXD exposures of concern are estimated to increase if two of the alternative NAAQS standards that were analyzed were just attained. The two NAAQS are the current O_3 standard (1h 1Ex 0.12 ppm) and an 8h 1Ex 0.10 ppm. Just-attaining the latter NAAQS shows more exposures, but the percent of the NOW population exposed is quite low: <0.1%. The percentage of children so exposed to the 1h MAXD of >0.12 ppm @ ≥30 EVR is higher however; it is estimated to be 1.1%. The reason for the difference in relative magnitude is that over 93% of people exposed at the MAXD of concern are children. (At the current 1h NAAQS, only 12.3% of MAXD exposures are attributed to children so their relative impacts are small: <0.5%.)

3. None of the 1h MAXD exposures of concern occur on more than one day/O_3 season for the two alternative NAAQS that are estimated to have them.

While not shown in Table 1, the results of O_3 exposures >0.12 ppm at any exercise level are considerably higher than the numbers presented in that Table. For instance, currently (1990) about 61,000 adults and 19,000 children are predicted to experience one or more daily exposure >0.12 ppm when exercise level is ignored. This is about 5% of the adult population and 7% of the children in the Denver urban area. (As compared to no adult or children exposure @ 30 EVR exercise.) The corresponding estimates for non-exercising exposure when the current standard is just attained is 85,000 (7%) for adults and 28,000 for children (11%). Similar estimates for attainment of the 8h 1Ex 0.10 ppm NAAQS alternative are 118,000 (10%) for adults and 72,000 for children (28%). Both of the just-attaining analyses for these two alternatives indicate that exposures >0.12 ppm @ any exercise level would occur on more than 1 day/season, unlike the situation that occurs when exercise @ 30 EVR is considered. Thus, exercise level, and its associated ventilation rate, at maximum dose greatly affects pNEM/O3 MAXD exposure estimates.

The 8h results (Table 2), indicate that relatively more people may be exposed. The level of concern here is a MAXD exposure of >0.08 ppm for 8h @ an EVR ≥15 l min^{-1} m^{-2}. (Obviously, the EVR of concern drops as the averaging period increases, just as the O_3 concentration of concern drops. People cannot hold an EVR of 30 l min^{-1} m^{-2} for an extended period of time(12).)

The 8h results indicate that:

1. Currently (1990), <1% of the NOW population are estimated to experience a daily maximum dose O_3 exposure level of concern. All of these exposures are estimated to occur on 1 day during the O_3 season, and all of them involve children.

2. Attaining any of the alternative NAAQS--except the 8h 5Ex 0.06 ppm--still results in some people being exposed to the 8h MAXD of concern. The absolute and relative numbers of people involved are quite small for the 8h 1Ex 0.08 ppm and 8h 5Ex 0.08 ppm alternatives, however. In both cases, about 0.1% of NOW people are involved, and 0.2-0.3% of the children. It should be noted that only one run of the 10 undertaken for each of these two standards had non-zero exposures; thus, their estimates should be viewed with caution.

3. The absolute and relative number of NOW people and children estimated to be exposed to the 8h MAXD of concern is rather large for the 8h 1Ex 0.10 ppm and 1h 1Ex 0.12 ppm NAAQS alternatives. For the 1h alternative--the current standard--over 1% of the NOW population and almost 7% of children may receive an 8h MAXD of concern, over 10% of them receiving two days of this exposure during the O_3 season. The absolute estimates and relative proportion of people and children are even higher for the 8h 1Ex 0.10 ppm alternative. It is estimated that 3.2% of NOW people and 13.4% of children will experience the 8h MAXD of concern for this standard when it is just attained. About 8-9% of these exposures may occur on 2 days during the O_3 season.

Putting the 8h MAXD estimates into perspective, the results indicate that currently (1990) over 117,000 NOW people might experience an 8h exposure >0.08 ppm @ any exercise level. (In other words, when exercise is ignored; this estimate is not shown in Table 2.) This contrasts to the 100 NOW people estimated to experience the same O_3 air quality concentration @ 15 EVR or higher. The corresponding estimates for children are 38,600 @ any exercise level versus 100 @ 15+ EVR. Obviously, exercise levels--expressed as EVR--greatly affect 8h pNEM/O3 exposure estimates.

For the record, the 8h any-exercise estimates for the non-zero alternative NAAQS are:

	8h 1Ex 0.10	8h 5Ex 0.08	1h 1Ex 0.12	8h 1Ex 0.08
NOW People	623,300	31,200	489,800	44,500
(%)	42.0	2.1	33.0	3.0
Children	142,200	10,400	132,900	10,600
(%)	54.7	4.0	51.1	4.1

Contrast these estimates with those appearing in Table 2 for insight into the impact of exercise level on exposure estimates. The any-exercise estimates are 1-2 orders of magnitude higher than the ≥15 EVR estimates.

Note that all of the estimates have variability, reflecting the Monte Carlo sampling process that produces a different estimate for each run. The range in the estimates are between a factor of 2-to-3 in most cases, which seems reasonable.

Statistical tests of the exposure distributions were undertaken using a two-sample Kolmogorov-Smirnov (K-S) non-parametric test. The null hypothesis was that the cumulative frequency exposure distributions for the various air quality scenarios are the same for each exposure metric being tested. The test statistic was the maximum difference between the two distributions (Dn); it was evaluated using a large-sample F statistic. The significance level is 0.05, using the chi-square approximation. The test indicates that the exposure indicators shown in Tables 1 and 2 vary significantly across the six air quality scenarios with the following exceptions.

For the AsIs and 8h 1Ex 0.08 ppm pair:

Children exposed and children-occurrences at 8h 0.08 ppm for any exercise level.

For the AsIs and 1h 1Ex 0.12 ppm (the current NAAQS) pair:

NOW people and children, NOW person occurrences, and children occurrences at 1h 0.12 ppm for any exercise level.

For the current standard and 8h 1Ex 0.10 ppm pair:

NOW people, person-occurrences, and number of people exposed on one day/season at 1h 0.12 ppm during $\geq$30 EVR exercise.

Children at 8h 0.08 ppm at any exercise level.

NOW persons and number of people exposed at 8h 0.08 ppm during $\geq$15 EVR exercise. (Note the person-occurrences metric at this MAXD was not statistically different for this pair of NAAQS scenarios.)

For the 8h 1Ex 0.08 ppm and 8h 5Ex 0.08 ppm pair:

NOW people and person-occurrences, and children and children-occurrences at 8h 0.08 ppm at any exercise level.

Compared with the K-S analyses undertaken for the previous urban areas (2-6), the above results are unusual. Most of the non-rejects involve the "any exercise" metrics, which are not the main exposure/exercise conditions of concern. The only exercising metric that could not be rejected as coming from the same distribution was the current standard/8h 1Ex 0.10 ppm pair, and not all exercising metrics could be so treated. In other words, the reject/cannot reject pattern was not consistent across all of the exercising exposure metrics. (Nor was it consistent for the any-exercise metrics.)

Note that these are not strong statistical tests and that some of the K-S test requirements were not met. Random sampling was not used. The sample "observations" simply are results of a simulation model; the population of interest, then, can only be the set of possible outcomes produced by the model. A large-sample test statistic was applied to small samples (10 runs). These caveats aside, 14 "cannot rejects" out of 126 tests is twice as many as are expected based on a "pure-chance" probability of rejecting a true hypothesis (5%). This 11.1% cannot-reject rate is about the same at the rates seen in most of the urban areas that were analyzed (2-6). Unlike most of these areas, there is not a clear-cut picture produced by the K-S testing exercise in Denver. There is not a consistent pattern--especially at exercise--associated with the alternative NAAQS investigated.

SUMMARY

The analyses of 5 alternative standards ozone NAAQS in the Denver area (1h 1Ex 0.12 ppm; 8h 1Ex 0.10 pm; 8h 5Ex 0.08 ppm; 8h 1Ex 0.08 ppm; and 8h 5Ex 0.06 ppm) indicate that attainment of the current standard or the 8h 1Ex 0.10 ppm alternative may not minimize exposures at exercise in the Denver urban area. This finding applies to both the 1h and 8h estimates, but are more important for the 8h results since more people and children are estimated to experience 8h MAXD levels of concern than the 1h MAXD levels under these alternative NAAQS.

The reader should remember the early caveat about the downward bias inherent in pNEM results. While every effort has been made to present "best estimates," it is inherently difficult to predict the upper end of the population exposure distribution using human activity data bases that consist of only 1-3 days of information and that also under-represent adults and children who exercise regularly. Year-long activity data from all segments of the population are needed to adequately estimate the true population exposure distribution.

REFERENCES

1. T. Johnson, J. Capel, and M. McCoy. **Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data.** Durham, NC: IT-AQS, 1993 (Draft).

2. T. McCurdy. "Los Angeles Ozone Exposure Estimates," **EPA Memorandum;** November 4, 1993.

3. T. McCurdy, et al. "Estimating Ozone Exposures in Philadelphia Using a Second-Generation Probabilistic Version of NEM." **Paper A210 presented at the 87th Annual Meeting of AWMA**; Cincinnati, June 1994.

4. T. McCurdy, et al. "Estimating ozone Exposures in Houston Using a Second-Generation Probabilistic Version of NEM." **Paper presented at the Tropospheric Ozone Specialty Conference,** Air and Waste Management Association; Orlando, 1994.

5. T. McCurdy. "Estimating Ozone Exposures in the New York Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, February 1994.

6. T. McCurdy. "Estimating Ozone Exposures in the Chicago Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

7. Environmental Criteria and Assessment Office. **Air Quality Criteria for Ozone and Photochemical Oxidants.** Research Triangle Park, NC: 1994 (Draft).

8. H.M. Richmond and T. McCurdy. "Use of Exposure Analysis and Risk Assessment in the Ozone NAAQS Review." **Paper 88-121.3 presented at the 81st Annual Meeting of APCA**; Dallas, June 19-24, 1988.

9. N.L. Nagda, H.E. Rector, and M.D. Koontz. **Guidelines for Monitoring Air Quality.** Washington, DC: Hemisphere Pub. Co., 1987.

10. C.J. Weschler, H.C. Shields, and D.V. Nike. "Indoor Ozone: Recent Findings," in: R. Burglund (ed.), **Tropospheric Ozone in the Environment II.** Pittsburgh: Air & Waste Management Association, 1992.

11. T. McCurdy. "Testing pNEM/O3 Runs to Determine if a Set of 10 Runs is 'Representative'," **EPA Memorandum;** April 19, 1994.

12. W.C. Adams. **Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities.** Davis CA: University of California, 1993.

13. M. Absil, P. Narducci, R. Whitfield, and H.M. Richmond. "Chronic Lung Injury Risk Estimates for Urban Areas Having Ozone Patterns Similar to Those in the Northeast." Paper presented at the **AWMA Specialty Conference on Tropospheric Ozone and the Environment II**; Atlanta, November 4-7, 1991.

Table 1. ESTIMATES OF 1h "MAXIMUM DOSAGE" EXPOSURES IN DENVER TO O_3 CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	0	2,900	0	700	0	0
Percent of Total Population	0	0.1	0	*	0	0
Range in this percentage for all runs	-	0.0-0.9	-	0.0-0.4	-	-
Mean Est. of Person-Occurrences	0	2,900	0	700	0	0
Percent of Total Per-Occurrences	0	@	0	@	0	0
Range in this percentage for all runs	-	0.0-@	-	0.0-@	-	-
Mean Est. of Occurrences/Person Exposed	-	1.00	-	1.00	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	-	100	-	100	-	-
2 Days	-	0	-	0	-	-
3 Days	-	0	-	0	-	-
>3 Days	-	0	-	0	-	-
CHILDREN						
Mean Estimate of the Number of Children	0	2,700	0	100	0	0
Percent of Children Population	0	1.1	0	*	0	0
Range in this percentage for all runs	-	0.0-4.9	-	0.0-0.3	-	-
Percent of Total Exposed Population	-	93.4	-	12.3	-	-
Mean Estimate of Children-Occurrences	0	2,700	0	100	0	0
Percent of total Child-Occurrences	0	@	0	@	0	0
Range in this percentage for all runs	-	0.0-@	-	0.0-@	-	-
Mean Estimate of Occurrences/Child Exposed	-	1.00	-	1.00	-	-
Number of Days Exposed/Season (% Exposed)						
1 Day	-	100	-	100	-	-
2 Days	-	0	-	0	-	-
3 Days	-	0	-	0	-	-
>3 Days	-	0	-	0	-	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h "MAXIMUM DOSAGE" EXPOSURES IN DENVER TO O_3 CONCENTRATIONS EXCEEDING 0.08 PPM AND EVR[a] EQUALED OR EXCEEDED 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL NON-OUTDOOR WORKER EXPOSED POPULATION						
Mean Estimate of the Number of People	100	47,200	800	20,800	1,600	0
Percent of Total Population	@	3.2	0.1	1.4	0.1	0
Range in this percentage for all runs	@-0.1	0.9-4.8	0.0-0.6	0.0-3.6	0.0-1.1	-
Mean Est. of person-Occurrences	100	50,100	800	23,200	1,600	0
Percent of total Per.-Occurrences	@	*	@	@	@	0
Range in this percentage for all runs	@-@	@-*	0.0-@	0.0-*	0.0-*	-
Mean Est. of Occurrences/Person Exposed	1.00	1.06	1.00	1.12	1.00	-
Number of Days/Season Exposed (% Exposed)						
1 Day	100	92	100	89	100	-
2 Days	0	8	0	11	0	-
3 Days	0	0	0	0	0	-
4 Days	0	0	0	0	0	-
>4 Days	0	0	0	0	0	-
CHILDREN						
Mean Estimate of the Number of Children	100	34,800	800	17,100	500	0
Percent of Children Population	0.1	13.4	0.3	6.6	0.2	0
Range in this percentage for all runs	0.0-0.5	3.2-20.2	0.0-3.2	0.0-13.1	0.0-1.8	-
Percent of Total Exposed Population	100.0	73.7	100.0	82.2	31.3	-
Mean Estimate of Children-Occurrences	100	37,700	800	19,500	500	0
Percent of Total Child-Occurrences	@	0.1	@	*	@	0
Range in this percentage for all runs	0.0-@	*-0.1	0.0-*	0.0-0.1	0.0-*	-
Mean Estimate of Occurrences/Child Exposed	1.00	1.08	1.00	1.14	1.00	-
Number of Days/Season (% Exposed)						
1 Day	100	91	100	86	100	-
2 Days	0	9	0	14	0	-
3 Days	0	0	0	0	0	-
4 Days	0	0	0	0	0	-
>4 Days	0	0	0	0	0	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

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ESTIMATING OZONE EXPOSURES IN HOUSTON USING A SECOND-GENERATION PROBABILISTIC VERSION OF NEM

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INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is currently reviewing the ozone (O_3) primary national ambient air quality standard (NAAQS) to determine if the existing standard protects public health with an adequate margin of safety. In order to evaluate whether alternative O_3 NAAQSs provide an adequate margin of safety, the EPA Office of Air Quality Planning and Standards (OAQPS) assesses such factors as the nature and severity of health effects associated with O_3 exposure, the degree of total human exposure (i.e., indoor and outdoor) to O_3, and the risks (probabilities) of ozone-related health effects occurring in the exposed population when alternative O_3 NAAQS are just attained. This paper discusses an EPA analysis of O_3 exposure estimates for parts of the Houston metropolitan area which employed the pNEM/O_3 model developed by International Technology - Air Quality Services (IT-AQS). A report by Johnson, et al. (1) describes this model in detail and presents initial results of applying it to nine U.S. urban areas, including Houston. Exposure estimates for parts of the Los Angeles area are discussed in an EPA memorandum (2) that was recently reviewed by the Clean Air Science Advisory Committee (CASAC) at a public meeting. Exposure estimates for the Philadelphia area are described in an AWMA paper (3). Additional analyses of O_3 exposure estimates for the remaining six urban areas that were modeled will be forthcoming.

OVERVIEW

Pursuant to section 108 of the Clean Air Act, the Environmental Criteria Assessment Office (ECAO) within the Office of Research and Development (ORD) is preparing a criteria document (4) for O_3. This document will be a comprehensive summary and critical assessment of the latest scientific research relevant to assessing the effects of a criteria pollutant. The document will be reviewed by CASAC, part of the EPA's independent Science Advisory Board, and by the general public. Upon completion of the criteria document, OAQPS will prepare a Staff Paper that summarizes and integrates scientific information presented in the criteria document considered to be most relevant to decisions on alternative NAAQS and various analyses (e.g., air quality, exposure, and risk).

An important aspect of health risk assessment is an analysis of population exposure. Such an analysis provides the population basis for "headcount risk" estimates developed as part of EPA's NAAQS risk assessment work. Estimates of population exposure also provide important information regarding the number of people that may experience varying levels of O_3 as they go through their daily activities.

Since 1980, OAQPS has used the NAAQS Exposure Model (NEM) to analyze human exposure associated with the "criteria air pollutants" covered by Title I of the Clean Air Act, as amended. Recent versions of this model use Monte Carlo analyses to define numeric values for certain variables inherent in the model. These version of NEM are called pNEM,

an acronym for "probabilistic" NEM. To differentiate among the various pollutant-specific versions of pNEM, the one described here is denoted as pNEM/O3.

Analysis of population exposure under alternative O_3 NAAQS requires that significant factors contributing to total human exposure be taken into account. These factors include the temporal and spatial distribution of people and O_3 concentrations throughout an urban area, the variation of ozone levels within each microenvironment, and the effects of exercise (increased ventilation) on ozone uptake in exposed individuals.

To date, the most recent version of pNEM/O3--the "second generation" version--has been applied to nine major urban areas. These areas vary in size from Denver with 1.4 million people to New York with over 10.6 million people. pNEM/O3 partitions all land within a selected urban area into large "exposure districts." The number of exposure districts defined for each urban area varies from 6 to 16 in the set of nine areas recently modeled; the number of districts reflects the number of monitors having valid air quality data in a study area. most of the nine urban areas have 10 or more districts within their boundaries.

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Because both the intake dose received and susceptibility to effects of pollution may vary with age, occupation, and intensity of exercise, the total population of each study area is divided into 9 age-occupation (A-O) groups. Each A-O group is further subdivided into cohorts depending upon (1) the type of air conditioning system present in the home, if any, and (2) home-to-work commuting patterns.

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It should be noted that all versions of pNEM systematically underestimate the highest part of the exposure distribution. (See Ref. 1 for an evaluation of pNEM/O3 results against real-time personal exposure monitoring data.) Thus, results presented here have a downward bias.

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5. Attain 8h 5Ex 0.06 ppm
6. Attain 8h 5Ex 0.08 ppm

Where Ex stands for "expected exceedances," as defined by EPA in 40 Code of Federal Regulations 50.9, and h is the usual symbol for hour(s). Thus, a full description of the first alternative NAAQS scenarios is: attain the 1 hour daily maximum-one expected exceedance NAAQS of 0.12 ppm. The other standards follow the same format. The 5Ex NAAQS would allow 5 daily exceedances per year, on average, if they were implemented.

The iterative adjustment procedure used by IT-AQS to simulate just-attaining the 5 alternative NAAQS listed above involves a complex procedure of fitting Weibull equations to the 1990 O_3 data, modifying parameters of the equations so that the "worst" monitor just achieves the desired standard, and then re-specifying the entire O_3 pattern for all districts in Houston. The procedure is described in detail by Johnson, et al. (1).

HOUSTON RESULTS

Results are based upon 10 runs (realizations) of the pNEM/O3 model for each air quality scenario. Based on a previous analysis of sets of 10-run results versus a 108-run result (8), the author believes that results from only 10 runs of the model will adequately predict the mean and variance observed in 100 or more runs of pNEM/O3. Ten runs of the model will not, however, adequately represent the entire range of possible outcomes. Additional runs can only increase this range. This is an obvious shortcoming of the analyses presented here, but limited resources preclude undertaking more runs.

This paper includes tabular data on (1) the number and percent of people and children exposed, and (2) the number and percent of person-occurrences for children and the adult, non-outdoor worker population in Houston. (A person-occurrence is the metric that focuses on an event: when the exposure-of-concern is reached regardless of who reaches it. One hundred person-occurrence could be 10 people experiencing the exposure 10 times, 100 people experiencing it once, one person experiencing it 100 times, or any combination thereof.) Even though data are discussed here regarding the absolute and relative number (percentage) of people exposed, it must be noted that "people" should not be used as an exposure metric. The cohort-specific activity-days data base used for pNEM/O3 modeling (and for all other exposure models that uses human activity information) provides no more than three days of data for a single individual. Thus, rigorous inferences from these data can be made only to "person-days" of exposure or "person-occurrences" of exposure, where an occurrence can be 1h, 8h, or 24h time period in pNEM/O3. Only when activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to people (or children, or outdoor workers as the case may be). This point is usually ignored in the general exposure assessment literature.

All exposure estimates presented in this paper pertain to "daily maximum dose," (MAXD) where dose is defined as the product of ozone concentration and ventilation rate over a defined time period. Note that maximum daily dose does not necessarily occur during the time period of maximum ozone concentration in a given urban area.

Ventilation rate is a very important factor in estimating total dose for any air pollutant (9). The ventilation rate metric used in pNEM/O3 is "equivalent ventilation rate" (EVR), or ventilation rate (in liters per minute) divided by body surface area (BSA, in units of m^2). EVR has units of $l\ min^{-1}\ m^{-2}$. It is a surrogate indicator for the number of O_3 molecules that enter the oral-nasal cavities per unit time period.

The Houston population analyzed here includes 2,370,510 NOW (non-outdoor worker) people and 489,900 children. There are 865,236,900 possible daily maximum NOW person-occurrences (NOW people x 365 days in the O_3 season). The equivalent figure for children is 178,813,140.

Exposure results appear in Tables 1 and 2. Table 1 includes 1h daily maximum dose exposure estimates, while Table 2 provides similar results for 8h exposure estimates.

The results indicate that:

1. Currently (1990), fewer than 3% of the NOW population experience a daily maximum dose (MAXD) O_3 exposure @ >0.12 ppm @ an EVR of 30 $l\ min^{-1}\ m^{-2}$, which is thought by many researchers to be a dose rate of concern (9). Almost all--96%--of these exposures occur only on one day during the O_3 season.

2. Currently (1990), about 7% of the children in Houston exceed the 0.12 ppm/30 EVR max dose exposure level. This is about 53% of the NOW exposed population. 93% of the children exposed at that level are predicted to experience only 1 day/season, but 6% may experience two such exposures.

3. Such MAXD exposures are greatly reduced whenever one of the alternative standards are attained. For the relatively few children or adults having a MAXD exposure >0.12 ppm @ ≥30 EVR when an alternative NAAQS is attained, all of them are predicted to experience only one such daily 1h exposure per season.

While not shown in Table 1, the results of O_3 exposures >0.12 ppm at any exercise level are considerably higher than the numbers presented in that Table. For instance, currently (1990) about 1.7 million adults and 482,000 children are predicted to experience one or more daily exposure >0.12 ppm when exercise level is ignored. This is about 89% of the adult population and 99% of the children in Houston. Thus, exercise level, and its associated ventilation rate, at maximum dose greatly affects pNEM/O3 MAXD exposure estimates.

The same general findings apply to the 8h results (Table 2), although relatively more people may be affected. The level of concern here is a MAXD exposure of >0.08 ppm for 8h @ an EVR ≥15 l min^{-1} m^{-2}. (Obviously, the EVR of concern drops as the averaging period increases, just as the O_3 concentration of concern drops. People cannot hold an EVR of 30 l min^{-1} m^{-2} for an extended period of time(9).)

The 8h results indicate that:

1. Currently (1990), over 5% of the NOW population are estimated to experience a daily maximum dose O_3 exposure level of concern. About 11% of these people may experience such a MAXD exposure on more than one day during the O_3 season. Two percent of the applicable population may experience the exposure of concern on 3 days.

2. Currently (1990), over 19% of children in Houston may experience the 8h MAXD of concern. In fact, about 79% of the total population experiencing this 8h MAXD are children. Almost 86% of the children may experience this MAXD on only one day; 12% may experience it on 2 days, and 2% may see it on 3 days.

3. Attaining any of the alternative NAAQS reduces the MAXD exposure of concern, although about 1% of the children population might experience that exposure even if the current NAAQS (1h 1Ex 0.12 ppm) standard is attained. All of these exposures are estimated to occur only on one day, however. The 8h 1Ex standard of 0.10 ppm allows almost 5% of the children to experience the 8h MAXD exposure of concern--all on only one day of the season, however.

Consistent with the 1h results, it is estimated that almost everyone (85%) in the NOW population of Houston currently (1990) experiences one or more 8h exposures at maximum daily dose when ventilation level is ignored. (This result is not shown in Table 2.) This contrasts with the 5.0% of the NOW population who may experience the same 8h O_3 concentration at exercise. Again, exercise levels--expressed as EVR--greatly affect pNEM/O3 exposure results. This same pattern holds true for children in Houston, but the percentage is higher: 93% of all children may experience an 8h 0.08 ppm exposure if breathing rate is ignored, as compared to 19% at exercise.

Note that all of the estimates have variability, reflecting the Monte Carlo sampling process that produces a different estimate for each run. The range in the estimates are between a factor of 2-to-3 in most cases, which seems reasonable.

Statistical tests of the exposure distributions were undertaken using a two-sample Kolmogorov-Smirnov (K-S) non-parametric test. The null hypothesis was that the cumulative frequency exposure distributions for the various air quality scenarios are the same for each exposure metric being tested. The test statistic was the maximum difference between the two distributions (Dn); it was evaluated using a large-sample F statistic. The significance level is 0.05, using the chi-square approximation. The test indicates that all of the exposure indicators shown in Tables 1 and 2 vary significantly across the six air quality scenarios with the following exceptions, all for the 8h 5Ex 0.08 ppm/1h 1Ex 0.12 ppm pair of standards.

NOW adults and children with a 1hDM exposure >0.12 ppm at <u>any</u> exercise level.

NOW- and children-occurrences at a MAXD exposure >0.12 ppm at exercise levels of concern. (Surprisingly, the corresponding people or children indicators were not found to have statistically significant distributions.)

NOW-people, children, NOW-occurrences, and children-occurrences for the 8h MAXD indicator (>0.08 ppm @ $\geq$15 EVR).

Note that these are not strong statistical tests and that some of the K-S test requirements were not met. Random sampling was not used. The sample "observations" simply are results of a simulation model; the population of interest, then, can only be the set of possible outcomes produced by the model. A large-sample test statistic was applied to small samples (10 or 11 runs). In addition, 8 "cannot rejects" out of 152 tests is about 5% of the total tests made--about the same value as the "pure-chance" probability. It is of interest, however, to note that all 8 exposure metrics that were not rejected using the K-S test involved the same paired air quality scenarios, which supports the finding that those scenarios do not differ significantly with respect to estimated O_3 exposures.

SUMMARY

The analyses of 5 alternative standards ozone NAAQS in Houston (1h 1Ex 0.12 ppm; 8h 1Ex 0.10 pm; 8h 5Ex 0.08 ppm; 8h 1Ex 0.08 ppm; and 8h 5Ex 0.06 ppm) indicate that attainment of each standard probably will reduce the percentage of the exposed population--

both adults and children--experiencing 1h ozone exposures thought to increase health risks. The analyses also found that for all air quality scenarios that were examined, just attaining an alternative O_3 standard reduces multiple-day 1h exposures for the air quality/exercise levels of interest.

The picture is not quite so rosy, however, for 8h MAXD exposures of concern, especially for children. Attaining a 8h 1Ex 0.10 ppm is predicted to reduce 8h MAXD exposures of concern to 1% of the NOW population, but 96% of this population is composed of children. This results in almost 5% of all children being exposed--albeit only on one day--to the 8h MAXD of >0.08 ppm @ $\geq$15 EVR for this standard. In addition, attaining the current 1h standard results in 0.6% of children being exposed to the 8h MAXD of concern. These 8h results are quite different than those for Los Angeles (2) and Philadelphia (3).

The reader should remember the early caveat about the downward bias inherent in the pNEM results. While every effort has been made to present "best estimates," it is inherently difficult to predict the upper end of the population exposure distribution using human activity data bases that consist of only 1-3 days of information and that also under-represent adults and children who exercise regularly. Year-long activity data from all segments of the population are needed to adequately estimate the true population exposure distribution.

REFERENCES

1. T. Johnson, J. Capel, and M. McCoy. **Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data.** Durham, NC: IT-AQS, 1993 (Draft).

2. T. McCurdy. "Los Angeles Ozone Exposure Estimates," **EPA Memorandum;** November 4, 1993.

3. T. McCurdy, et al. "Estimating Ozone Exposures in Philadelphia Using a Second-Generation Probabilistic Version of NEM." **Paper A210 presented at the 87th Annual Meeting of AWMA**; Cincinnati, June 1994.

4. Environmental Criteria and Assessment Office. **Air Quality Criteria for Ozone and Photochemical Oxidants.** Research Triangle Park, NC: 1994 (Draft).

5. H.M. Richmond and T. McCurdy. "Use of Exposure Analysis and Risk Assessment in the Ozone NAAQS Review." **Paper 88-121.3 presented at the 81st Annual Meeting of APCA**; Dallas, June 19-24, 1988.

6. N.L. Nagda, H.E. Rector, and M.D. Koontz. **Guidelines for Monitoring Air Quality.** Washington, DC: Hemisphere Pub. Co., 1987.

7. C.J. Weschler, H.C. Shields, and D.V. Nike. "Indoor Ozone: Recent Findings," in: R. Burglund (ed.), **Tropospheric Ozone in the Environment II.** Pittsburgh: Air & Waste Management Association, 1992.

8. T. McCurdy. "Testing pNEM/O3 Runs to Determine if a Set of 10 Runs is 'Representative'," **EPA Memorandum;** April 19, 1994.

9. W.C. Adams. **Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities.** Davis CA: University of California, 1993.

10. M. Absil, P. Narducci, R. Whitfield, and H.M. Richmond. "Chronic Lung Injury Risk Estimates for Urban Areas Having Ozone Patterns Similar to Those in the Northeast." Paper presented at the **AWMA Specialty Conference on Tropospheric Ozone and the Environment II**; Atlanta, November 4-7, 1991.

Table 1. ESTIMATES OF 1h "MAXIMUM DOSAGE" EXPOSURES IN HOUSTON TO O_3 CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	66,100	3,700	1,600	0	0	0
Percent of Total Population	2.8	0.2	0.1	0	0	0
Range in this percentage for all runs	1.6-4.3	0.1-0.7	0.0-0.7	-	-	-
Mean Est. of Person-Occurrences	68,100	3,700	1,600	0	0	0
Percent of Total Per-Occurrences	0.01	@	@	0	0	0
Range in this percentage for all runs	@-.01	@-@	0.0-@	-	-	-
Mean Est. of Occurrences/Person Exposed	1.03	1.00	1.00	-	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	96	100	100	-	-	-
2 Days	3	0	0	-	-	-
3 Days	1	0	0	-	-	-
>3 Days	0	0	0	-	-	-
CHILDREN						
Mean Estimate of the Number of Children	35,000	1,600	0	0	0	0
Percent of Children Population	7.1	0.3	0	0	0	0
Range in this percentage for all runs	2.1-15.0	0.0-2.6	-	-	-	-
Percent of Total Exposed Population	53.0	43.2	-	-	-	-
Mean Estimate of Children-Occurrences	36,900	1,600	0	0	0	0
Percent of total Child-Occurrences	*	@	0	0	0	0
Range in this percentage for all runs	*-*	0.0-*	-	-	-	-
Mean Estimate of Occurrences/Child Exposed	1.05	1.00	-	-	-	-
Number of Days Exposed/Season (% Exposed)						
1 Day	93	100	-	-	-	-
2 Days	6	0	-	-	-	-
3 Days	1	0	-	-	-	-
>3 Days	0	0	-	-	-	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate ÷ body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h "MAXIMUM DOSAGE" EXPOSURES IN HOUSTON TO O_3 CONCENTRATIONS EXCEEDING 0.08 PPM AND EVR[a] EQUALED OR EXCEEDED 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 5Ex 0.08 ppm	Attain 8h 1Ex 0.10 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL NON-OUTDOOR WORKER EXPOSED POPULATION						
Mean Estimate of the Number of People	119,500	1,000	23,800	800	2,800	0
Percent of Total Population	5.0	*	1.0	*	0.1	0
Range in this percentage for all runs	2.1-7.5	0.0-0.4	*-3.1	0.0-0.3	0.0-0.6	-
Mean Est. of person-Occurrences	134,300	1,000	23,800	800	2,800	0
Percent of total Per.-Occurrences	0.02	@	0.01	@	@	0
Range in this percentage for all runs	0.01-0.03	0.0-@	@-0.01	0.0-@	0.0-@	-
Mean Est. of Occurrences/Person Exposed	1.15	1.00	1.00	1.00	1.00	-
Number of Days/Season Exposed (% Exposed)						
1 Day	89	100	100	100	100	-
2 Days	9	0	0	0	0	-
3 Days	2	0	0	0	0	-
>3 Days	0	0	0	0	0	
CHILDREN						
Mean Estimate of the Number of Children	94,100	1,000	22,800	800	2,800	0
Percent of Children Population	19.2	0.2	4.7	0.2	0.6	0
Range in this percentage for all runs	8.4-28.8	0.0-1.8	0.0-14.7	0.0-1.6	0.0-2.7	-
Percent of Total Exposed Population	78.7	100.0	95.8	100.0	100.0	-
Mean Estimate of Children-Occurrences	108,800	1,000	22,800	800	2,800	0
Percent of Total Child-Occurrences	0.06	@	0.01	@	@	0
Range in this percentage for all runs	*-0.12	0.0-@	0.0-0.04	0.0-@	0.0-@	-
Mean Estimate of Occurrences/Child Exposed	1.16	1.00	1.00	1.00	1.00	-
Number of Days/Season (% Exposed)						
1 Day	86	100	100	100	100	-
2 Days	12	0	0	0	0	-
3 Days	2	0	0	0	0	-
>3 Days	0	0	0	0	0	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

November 4, 1993
(Revised March 9, 1994)

MEMORANDUM

SUBJECT: Los Angeles Ozone Exposure Estimates

FROM: Tom McCurdy
Ambient Standards Branch (MD-12)

TO: Interested Parties

SUMMARY

This memo summarizes analyses that I have done on ozone (O_3) exposure estimates for Los Angeles produced by International Technology - Air Quality Services (IT-AQS). The estimates are a result of applying our pNEM/O_3 exposure model to six air quality scenarios representing 1991 "as is" conditions and five hypothetical situations when alternative 1h and 8h O_3 standards are just attained. Unless otherwise noted, the exposure estimates provided in this summary represent the mean value of ten runs of the model.

The analyses were undertaken for the total population--excluding outdoor workers--and for children. Outdoor worker exposures will be evaluated in the next few months when a better human activity data base can be constructed for outdoor workers than we currently have.

Analyses of "as is" air quality conditions for the year 1991 indicate that:

1) 80% of the total non-outdoor working population at "any" breathing rate experiences one or more exposures >0.12 ppm on a 1h daily maximum basis.

2) While at a high exercise level (equivalent ventilation rate (EVR) of 30 or higher), only 9% of the total non-outdoor working population experiences one or more exposure >0.12 ppm (1h maximum daily basis). For children only, the percentage who experiences one or more exposures >0.12 ppm (1h maximum daily basis) at this exercise level is 27%.

3) 11% of the total non-outdoor working population experiences one or more exposures >0.08 ppm 8h daily maximum average when at a breathing rate of 15 EVR or higher; 37% percent of the children experiences such an exposure at the same breathing rate.

4) 21% percent of the total non-outdoor working population experiences one or more exposure >0.06 ppm 8h daily maximum average when at a breathing rate of 15 EVR or higher; 69% of the children experiences such an exposure at the same breathing rate.

The analyses of 5 alternative standards (1h 1 Ex 0.12 ppm; 8h 1 Ex 0.10 ppm; 8h 5 Ex 0.08 ppm; 8h 1 Ex 0.08 ppm; and 8h 5 Ex 0.06 ppm) indicate that when any alternative standard that was examined is just attained, the percentage of the exposed population is sharply reduced. For all cases, except the 8h 1 Ex 0.10 alternative, the percentage of both the total non-outdoor work population and children alone exposed at exercise one or more times to the level of concern is well below 1%. The 8h exposures to 0.08 ppm or higher for the 8h 1 Ex 0.10 alternative are 1% for the total non-outdoor working population and 3% for children. These analyses also found that for all air quality scenarios that were examined, just attaining an alternative O_3 standard reduces multiple-day exposures for the air quality/ exercise levels of interest.

DETAILS

IT-AQS has completed its modeling of O_3 exposures estimates for six air quality scenarios. Those scenarios are:

1. 1991 air quality--the "as is" scenario
2. Attain 1h 1Ex 0.12 ppm--the current standard
3. Attain 8h 1Ex 0.08 ppm
4. Attain 8h 1Ex 0.10 ppm
5. Attain 8h 5Ex 0.06 ppm
6. Attain 8h 5Ex 0.08 ppm

The model used for exposure assessment is the most recent version of pNEM/O_3--"probabilistic" NAAQS Exposure Model applied to O_3. The model is described in a draft IT-AQS report entitled:

> Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data (September 1993).

The report was written by Ted Johnson, project manager for IT-AQS, and two of his staff members: Jim Capel and Mike McCoy.

Modeling results exist for all nine urban areas that we plan to evaluate. We wanted to model a year that allowed us to reasonably match up 1990 census data with air quality information. We used 1990 or 1991 as the year of analysis in an area, using the year with the greatest number of O_3 monitors reporting valid data. The following situations were modeled:

Urban Area	Year	Population
Chicago	1991	6,175,000
Denver	1990	1,485,000
Houston	1990	2,371,000
Los Angeles	1991	10,371,000
Miami	1991	1,942,000
New York	1991	10,658,000
Philadelphia	1991	3,786,000
St. Louis	1990	1,707,000
Washington, DC	1991	3,085,000

All of these areas violated the existing O_3 standard in the year analyzed except Miami. The areas are located in every EPA region, except 10--the northwest, which has only one non-attainment area (Portland).

While modeling results exist for the above areas, they have not yet been analyzed or summarized. Only the Los Angeles results have been thoroughly evaluated, and these results are described in this memo.

Estimates for two population groups will be described: (1) all people except outdoor workers--who constitute about 10% of the adult working population, and (2) children--everyone younger than 19 years of age. Outdoor worker exposure estimates will be evaluated after IT-AQS can construct a larger file of human activity patterns that better reflect the amount of time that true outdoor workers (i.e., those individuals who work outdoors at least 6 hours per day, on average) spend outside in their daily occupation. In developing this new data base, we will probably focus on people working in the following industrial classification categories:

1. agriculture, forestry and fisheries (101-031)
2. mining (040-050)
3. construction (060)

These workers currently are under-represented in our NEM human activity data base.

Our results are based upon 10 runs (realizations) of $pNEM/O_3$ for each air quality scenario. Based on my previous analyses of sets of 10-run results versus a 108-run result (see the attached April 19, 1993 memo), I feel that the estimates presented here adequately represent the mean and overall distribution expected if more runs of pNEM/O_3 were undertaken. What 10-runs do not adequately represent, however, is the entire range of possible outcomes. More runs could only increase this range.

This memo includes tabular and graphical data on (1) the number and percent of people exposed, and (2) the number and percent of person-occurrences for the two population groups mentioned above. Even though data are discussed here regarding the absolute and relative (percentage) number of people exposed, it must be remembered that we really should not be using "people" as an exposure metric. The cohort-specific activity-days data base used for pNEM/O_3 modeling (and for <u>all</u> other exposure models that uses human activity information) is based upon one, two, or three days of data from a single individual. Thus, inferences from these data rigorously can only be made to "person-days" of exposure, or "person-occurrences" of exposure, where an occurrence can be 1h, 8h, or a day in pNEM/O_3. This metric also applies to children-occurrences or children-days of exposure.

Only if activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to <u>people</u> (or kids, or outdoor workers as the case may be). This point is never discussed in the general exposure assessment literature but should be.

Data for three exposure indicators are included.

1. daily maximum dose 1h exposures >.12 ppm at an equivalent breathing rate (EVR) of 30 liters or higher per minute per square meter of body surface area (l min^{-1} m^{-2}). This is about 55-60 l min^{-1} for adults. These results are shown in Table 1 and Figure 1.

2. daily maximum dose 8h exposures >0.08 ppm at 15 EVR. This is about 20-30 l min^{-1} for adults and 12-25 l min^{-1} for children. These results are depicted in Table 2 and Figure 2.

3. daily maximum dose 8h exposures >0.06 ppm at 15 EVR. See Table 3 and Figure 3 for results.

Other indicators were evaluated and many others can be evaluated. One of the purposes of this memo is to obtain definitive feedback on what indicators should be presented in the O_3 staff paper. Therefore, please review the information presented to see if all exposure indicators of interest and importance are covered.

As an example of an available but unreported indicator, daily max dose 8h exposures to 0.10 ppm or higher were analyzed. However, exposures at this high an 8h average were seen only under the "as is" air quality scenario. Hence, I do not provide a table/figure for this indicator. For the record, however, pNEM/O_3 indicates that currently 630,700 people on average are exposed to 8h 0.10 ppm or higher for an average of 1.4 times per year. This is about 6.1% of the LA population that was analyzed. The range in population estimate is 527,100-814,700, or 5.1-7.9%. The range in occurrences per exposed person is 1.3-1.7 times per year.

To put the numbers and percentages that follow into perspective, the baseline "denominators" used in the Los Angeles analyses are:

Total population :	10,371,115
Children population :	1,954,886
Total daily maximum person-occurrences:	3,785,456,975
Total daily children-occurrences:	713,533,390
Total hourly person-occurrences:	90,850,867,400

Exposures to the air quality levels of interest are much higher, of course, at "any" breathing rate than at the relatively high breathing rates of interest. The following statistics are for exposures to 1h and 8h concentrations of interest at any breathing rate for the "as is" air quality scenario:

	1h 0.12 ppm	8h 0.10 ppm	8h 0.08 ppm	8h 0.06 ppm
Mean Number of People Exposed	8,305,200	4,556,100	7,196,600	9,872,400
Mean % of Tot. Population	80.1	43.9	69.4	95.2
Range in this Percentage	76.7-82.7	40.8-51.2	67.3-71.2	94.1-97.2

Note the relatively high mean percentage estimates and the quite narrow range in these estimates. The 1h 0.12 ppm estimate of 80.1% of the total population is about 15% lower than comparable estimates from previous REHEX and SAI/NEM O_3 modeling analyses. Their runs, however, are for the late 1980 time period when O_3 air quality was worse than it currently is (i.e. than 1991, our "as is" year).

In fact, two districts in the Los Angeles area did not exceed a 0.12 ppm 1h O_3 concentration level in 1991. These districts are Long Beach and Hawthorne. They comprise about 15% of the modeled urban area population base and include major employment centers that boost daytime inhabitants to over that relative level. Thus, the 80% estimate is plausible given the amount of time spent indoors by most people, especially in air conditioned spaces where O_3 levels are a fraction (1/4 to 1/2) of that seen outside at the same time.

Other modeling differences can account for the disparity in people estimated to experience a 0.12 ppm O_3 level. For instance, the two non-EPA studies noted above used modeled O_3 air quality data, whereas ours used transformed ambient monitoring data. In addition, our pNEM/O_3 analyses explicitly incorporates sequential time spent indoors as a function of time-of-day, whereas REHEX does not and SAI/NEM used the old 1982 NEM activity patterns that are out of date.

A more in-depth review of the outputs follows.

<u>Table 1/Figure 1</u>

pNEM/O_3 estimates that 9.1% of the total population currently experiences O_3 exposures >0.12 ppm 1-h at high exercise ($\geq$ 30 EVR). Over half (56%) of these people are children, and over 25% of children (27.1%) experience one or more of these exposures per O_3 season (i.e., per year in LA). About 31% of the exposed children experience more than 1 day of exposure at a 1h 30 EVR or higher.

Attaining any of the alternative ambient standards listed in Table 1 dramatically reduces 1h O_3 exposures at high exercise. Attaining the last two standards (the 8h 1Ex 0.08 and 8h 5EX 0.06 scenarios) reduces 1h high-exercise exposures to zero. Note that no child or person would be exposed to more than one day of 0.12 1h @30 EVR exposure if any alternative O_3 NAAQS analyzed here is attained.

Some of the data shown in Table 1 is depicted in Figure 1. The figure is good for depicting the range in estimates for any scenario. Note that the middle-three scenarios have 3-5 orders of magnitude of range in their estimates of 1h 0.12 ppm @30 EVR exposures. This is a much larger range than seen in previous NEM exposure analyses, and probably reflects the higher--and in my opinion, better--ventilation rate data recently developed by IT for the high exercise level.

<u>Table 2/Figure 2</u>

More people, both absolutely and relatively, are exposed to 0.08 ppm 8h @ 15 EVR than to 0.12 ppm 1h @ 30 EVR for all the air quality scenarios except the last one. The differences are larger for children than for the entire population. For instance, Table 2 indicates that almost 37% of children currently see 0.08 8h @15 EVR one or more times/year (range: 31-44%). About 51% of these exposed children see more than one exposure/year.

The estimates of exposure to 0.08 ppm 8h @15 EVR drop rather rapidly with attainment of the alternative NAAQS. See Figure 2. Note again the rather large range in estimates for the middle three scenarios.

Table 3/Figure 3

The air quality indicator of interest here is 0.06 ppm 8h @ 15 EVR. Because this is a relatively low 8h average for Los Angeles, a large number and percentage of people experience this exposure for all of the scenarios evaluated. Contrary to the previous indicators, except for the last NAAQS air quality scenario, the indicator range estimated for each scenario is quite narrow.

Most of the people exposed to 0.06 ppm 8h @ 15 EVR or above are children. The proportion of children only varies between 61-74% for the first 5 scenarios. (This jumps to 86% for the last, quite low 8h 5Ex 0.06 ppm scenario.)

Table 3 does not include an estimate of the percent of exposed children or the total population that sees more than one day/season over the indicator of interest. It just was too much work to evaluate that data for this preliminary analysis; the data are available to obtain that estimate, however. A superficial examination of this exposure indicator, however, indicates that all (100%) of children exposed to 0.06 ppm for 8h at 15+ EVR saw more than one day per year under the first two air quality scenarios. While this percentage drops off for the next 3 scenarios, some children and adults obviously saw more than 1 day per year (because mean occurrences/personal exposed is >1.0). No one saw more than 1 day for the 8h 5EX 0.06 ppm scenario, the alternative that allows up to five exceedances per year.

FINAL COMMENTS

The results presented here represent only a fraction of the data available from pNEM/O_3 modeling exercise. Comments and recommendations are hereby solicited regarding the type of exposure indicators evaluated, the format of presentation, and emphasis. All comments and questions regarding this memo and the pNEM/O_3 modeling effort should be directed to Tom McCurdy at the address given above or by calling (919)541-5658.

Table 1. ESTIMATES OF 1h OZONE EXPOSURES IN LOS ANGELES TO OZONE CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	947,400	23,100	3,000	900	0	0
Percent of Total Population	9.1	0.2	*	*	0	0
Range in This Percentage	7.2-11.4	0.0-0.7	0.0-0.2	0.0-*0.1	-	-
Mean Est. of Person-Occurrences	1,097,500	23,100	3,000	900	0	0
Percent of Total Per.-Occurrences	0.03	@	@	@	0	0
Mean Est. of Occurrences/Person Exposed	1.2	1.0	1.0	1.0	0	0
Percent of People > 1 day/Year Exposure	22.0	0	0	0	0	0
Number of Days Exposed/Season (% Exposed)						
1 Day	78	100	100	100	-	-
2 Days	16	0	0	0	-	-
3 Days	4	0	0	0	-	-
4 Days	1	0	0	0	-	-
5 Days	1	0	0	0	-	-
>5 Days	0	0	0	0	-	-
EXPOSED CHILDREN						
Percent of total Exp. Pop. Who are Children	56.0	85.0	53.0	100.0	-	-
Mean Estimate of the Number of Children	530,400	19,700	1,600	900	0	0
Percent of Children	27.1	1.0	0.1	*	0	0
Range in this Percentage	18.8-31.8	0.0-3.4	0.0-0.8	0.0-0.5	-	-
Mean est. of Children-Occurrences	949,200	19,700	1,600	900	0	0
Percent of total Child.-Occurrences	0.1	@	@	@	0	0
Mean Est. of Occurrences/Child Exposed	1.8	1.0	1.0	1.0	0	0
Percent of Children > 1 Day/Year Exposure	42.0	0	0	0	0	0
Number of Days Exposed/Season (% Exposed)						
1 Day	69	100	100	100	-	-
2 Days	21	0	0	0	-	-
3 Days	7	0	0	0	-	-
4 Days	2	0	0	0	-	-
5 Days	1	0	0	0	-	-
>5 Days	0	0	0	0	-	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate ÷ body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h OZONE EXPOSURES IN LOS ANGELES TO OZONE CONCENTRATIONS EXCEEDING AND EVR[a] EQUALED OR EXCEEDED 0.08 PPM 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	1,122,800	106,300	7,700	5,000	1,700	0
Percent of Total Population	10.8	1.0	0.1	*	*	0
Range in This Percentage	9.3-13.5	0.6-1.7	0.0-0.2	0.0-0.1	0.0-0.1	-
Mean Est. of Person-Occurrences	1,990,300	116,200	7,700	5,000	1,700	0
Percent of Total Per.-Occurrences	0.05	@	@	@	@	0
Mean Est. of Occurrences/Person Exposed	1.8	1.1	1.0	1.0	1.0	0
Percent of People > 1 day/Year Exposure	45.0	7.7	0	0	0	0
Number of Days Exposed/Season (% Exposed)						
1 Day	55	93	100	100	100	-
2 Days	25	5	0	0	0	-
3 Days	12	2	0	0	0	-
4 Days	5	0	0	0	0	-
5 Days	2	0	0	0	0	-
>5 Days	1	0	0	0	0	-
EXPOSED CHILDREN						
Percent of total Exp. Pop. Who are Children	63.9	61.3	49.4	0	41.2	-
Mean Estimate of the Number of Children	718,000	65,200	3,800	0	700	0
Percent of Children	36.7	3.3	0.2	0	*	0
Range in this Percentage	30.8-43.5	0.5-7.6	0.0-0.7	-	0.0-0.4	-
Mean est. of Children-Occurrences	1,389,300	72,500	3,800	0	700	0
Percent of total Child.-Occurrences	0.2	*	*	0	*	0
Mean Est. of Occurrences/Child Exposed	1.9	1.1	1.0	0	1.0	0
Percent of Children > 1 Day/Year Exposure	51.3	7.9	0	0	0	0
Number of Days Exposed/Season (% Exposed)						
1 Day	49	92	100	-	100	-
2 Days	26	5	0	-	0	-
3 Days	14	3	0	-	0	-
4 Days	6	0	0	-	0	-
5 Days	3	0	0	-	0	-
>5 Days	2	0	0	-	0	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate ÷ body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.

@Less than 0.005% but >0.

ESTIMATING OZONE EXPOSURES IN THE MIAMI URBAN AREA USING A SECOND-GENERATION PROBABILISTIC VERSION OF NEM

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File: MIAMI.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) currently is reviewing the ozone (O_3) primary national ambient air quality standard (NAAQS) to determine if the existing standard protects public health with an adequate margin of safety. In order to evaluate whether alternative O_3 NAAQSs provide an adequate margin of safety, the EPA Office of Air Quality Planning and Standards (OAQPS) assesses such factors as the nature and severity of health effects associated with O_3 exposure, the degree of total human exposure (i.e., indoor and outdoor) to O_3, and the risks (probabilities) of ozone-related health effects occurring in the exposed population when alternative O_3 NAAQS are just attained. This paper discusses an EPA analysis of O_3 exposure estimates for parts of the Miami metropolitan area which employed the pNEM/O3 model developed by International Technology-Air Quality Services (IT-AQS). A report by Johnson, et al. (1) describes this model in detail and presents initial results of applying it to nine U.S. urban areas, including Miami. Exposure estimates for parts of the Los Angeles area are discussed in an EPA memorandum (2) that was reviewed by the Clean Air Science Advisory Committee (CASAC) at a public meeting. Exposure estimates for the Philadelphia area are described in an AWMA paper (3). Exposure estimates for Houston are described in an AWMA specialty conference paper (4). New York, Chicago, and Denver results are contained in EPA papers (5-7). Additional analyses of O_3 exposure estimates for the remaining urban areas that were modeled will be forthcoming.

OVERVIEW

Pursuant to section 108 of the Clean Air Act, the Environmental Criteria Assessment Office (ECAO) within the Office of Research and Development (ORD) is preparing a criteria document (8) for O_3. This document will be a comprehensive summary and critical assessment of the latest scientific research relevant to assessing the effects of a criteria pollutant. The document will be reviewed by CASAC, part of the EPA's independent Science Advisory Board, and by the general public. Upon completion of the criteria document, OAQPS will prepare a Staff Paper that summarizes and integrates scientific information presented in the criteria document considered to be most relevant to decisions on alternative NAAQS and various analyses (e.g., air quality, exposure, and risk).

An important aspect of health risk assessment is an analysis of population exposure (9). Such an analysis provides the population basis for "headcount risk" estimates developed as part of EPA's NAAQS risk assessment work. Estimates of population exposure also provide important information regarding the number of people that may experience varying levels of O_3 as they go through their daily activities.

Since 1980, OAQPS has used the NAAQS Exposure Model (NEM) to analyze human exposure associated with the "criteria air pollutants" covered by Title I of the Clean Air Act, as amended. Recent versions of this model use Monte Carlo analyses to define numeric values for certain variables inherent in the model. These version of NEM are called pNEM,

an acronym for "probabilistic" NEM. To differentiate among the various pollutant-specific versions of pNEM, the one described here is denoted as pNEM/O3.

Analysis of population exposure under alternative O_3 NAAQS requires that significant factors contributing to total human exposure be taken into account. These factors include the temporal and spatial distribution of people and O_3 concentrations throughout an urban area, the variation of ozone levels within each microenvironment, and the effects of exercise (increased ventilation) on ozone uptake in exposed individuals.

To date, the most recent version of pNEM/O3--the "second generation" version--has been applied to nine major urban areas. These areas vary in size from Denver with 1.4 million people to New York with over 10.6 million people. pNEM/O3 partitions all land within a selected urban area into large "exposure districts." The number of exposure districts defined for each urban area varies from 6 to 16 in the set of nine areas recently modeled; the number of districts reflects the number of monitors having valid air quality data in a study area. Most of the nine urban areas have 10 or more districts within their boundaries.

People living within each exposure district, as estimated by the U.S. Bureau of Census in 1990, are assigned to a single discrete point, the population centroid. O_3 air quality within each exposure district is estimated for each hour of the O_3 season using data from a nearby monitoring site. Because O_3 in the ambient air generally is modified considerably when entering a building or vehicle, outdoor O_3 estimates are adjusted using a mass-balance model to account for 3 indoor microenvironments. These microenvironments are: indoors-at-home, indoors-other, and within a motor vehicle. The mass-balance model used in pNEM/O3 is a simplified version of the generalized Nagda, Rector, and Koontz (NRK) model (10). For our use, this model was revised to incorporate the assumption that indoor decay rate is proportional to indoor O_3 concentration. It was further revised to incorporate assumptions concerning ozone decay rates suggested by Weschler, et al (11). The resulting revised mass-balance model is fully described in Ref. 1.

Because both the intake dose received and susceptibility to effects of pollution may vary with age, occupation, and intensity of exercise, the total population of each study area is divided into 9 age-occupation (A-O) groups. Each A-O group is further subdivided into cohorts depending upon (1) the type of air conditioning system present in the home, if any, and (2) home-to-work commuting patterns.

While many types of exposure metrics are provided by pNEM/O3 only those for the non-outdoor working population in Miami are discussed in this paper. Exposure estimates for children are included in the results discussed here. Estimates for outdoor workers--a major population sub-group of concern from an O_3 exposure perspective--will be completed in the Fall of 1994.

It should be noted that all versions of pNEM systematically underestimate the highest part of the exposure distribution. (See Ref. 1 for an evaluation of pNEM/O3 results against real-time personal exposure monitoring data.) Thus, results presented here have a downward bias.

AIR QUALITY SCENARIOS INVESTIGATED

Six air quality scenarios were modeled for the Miami urban area (and the other 8 urban areas); the scenarios are all on a daily maximum basis. They are:

1. 1991 air quality--the "as is" scenario
2. Attain 1h 1Ex 0.12 ppm--the current standard
3. Attain 8h 1Ex 0.08 ppm
4. Attain 8h 1Ex 0.10 ppm
5. Attain 8h 5Ex 0.06 ppm
6. Attain 8h 5Ex 0.08 ppm

Ex stands for "expected exceedances," as defined by EPA in 40 Code of Federal Regulations 50.9, and h is the usual symbol for hour(s). Thus, a full description of the first alternative NAAQS scenarios is: attain the 1 hour daily maximum-one expected exceedance NAAQS of 0.12 ppm. The other standards follow the same format. The 5Ex NAAQS would allow 5 daily exceedances per year, on average, if they were implemented.

The iterative adjustment procedure used by IT-AQS to simulate just-attaining the 5 alternative NAAQS listed above involves a complex procedure of fitting Weibull equations to the 1991 O_3 data, modifying parameters of the equations so that the "worst" monitor just achieves the desired standard, and then re-specifying the entire O_3 pattern for all districts in Miami. The procedure is described in detail by Johnson, et al. (1).

Miami had relatively good O_3 air quality in 1991 in that it had few days with a 1h daily maximum concentration >0.11 ppm. The area's "design value"--the second-highest 1h daily value measured at any site in the urban area--was 0.123, which is very close to the current standard. Miami's 1991 monitored 8h values were also correspondingly low. Thus, just-attaining some of the alternatives listed above can result in higher 1h and 8h O_3 peak concentrations being included than were monitored in 1991. Exposure estimates for these alternatives similarly can be higher than those predicted for 1991. These results follow directly from the logic used to evaluate alternative NAAQS (9), and are quite feasible in reality.

MIAMI RESULTS

Results are based upon 10 runs (realizations) of the pNEM/O3 model for each air quality scenario. Based on a previous analysis of sets of 10-run results versus a 108-run result (12), the author believes that results from only 10 runs of the model will adequately predict the mean and variance observed in 100 or more runs of pNEM/O3. Ten runs of the model will not, however, adequately represent the entire range of possible outcomes. Additional runs can only increase this range. This is an obvious shortcoming of the analyses presented here, but limited resources preclude undertaking more runs.

This paper includes tabular data on (1) the number and percent of people and children exposed, and (2) the number and percent of person-occurrences for children and the adult, non-outdoor worker population in Miami. (A person-occurrence is the metric that focuses on an event: when the exposure-of-concern is reached regardless of who reaches it. One hundred person-occurrence could be 10 people experiencing the exposure 10 times, 100 people experiencing it once, one person experiencing it 100 times, or any combination thereof.) Even though data are discussed here regarding the absolute and relative number (percentage) of people exposed, it must be noted that "people" should not be used as an exposure metric. The cohort-specific activity-days data base used for pNEM/O3 modeling (and for all other exposure models that use human activity information) provides no more than three days of data for a single individual. Thus, rigorous inferences from these data can be made only to "person-days" of exposure or "person-occurrences" of exposure, where an occurrence can be 1h, 8h, or 24h time period in pNEM/O3. Only when activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to people exposed over the year (or to children, or to outdoor workers as the case may be). This point usually is ignored in the general exposure assessment literature.

All exposure estimates presented in this paper pertain to "daily maximum dose," (MAXD) where dose is defined as the product of ozone concentration and ventilation rate over a defined time period. Note that maximum daily dose does not necessarily occur during the time period of maximum ozone concentration in a given urban area.

Ventilation rate is a very important factor in estimating total dose for any air pollutant (13). The ventilation rate metric used in pNEM/O3 is "equivalent ventilation rate" (EVR), or ventilation rate (in liters per minute) divided by body surface area (BSA, in units of m^2). EVR has units of $l\ min^{-1}\ m^{-2}$. It is a surrogate indicator for the number of O_3 molecules that enter the oral-nasal cavities per unit time period.

The Miami urban area population analyzed here includes 1.9 million NOW (non-outdoor worker) people and 327,000 children. There are 709 million possible daily maximum NOW person-occurrences (NOW people x 365 days in the O_3 season). The equivalent figure for children is 119.5 million.

Exposure results appear in Tables 1 and 2. Table 1 includes 1h daily maximum dose exposure estimates, while Table 2 provides similar results for 8h exposure estimates.

The 1h results indicate that:

1. Currently (1991), it is estimated that very few ($\leq$0.1%) of NOW people and children would experience a daily maximum dose (MAXD) O_3 exposure @ >0.12 ppm @ an EVR of 30 l min^{-1} m^{-2} or higher, which is thought by many researchers to be a dose rate of concern (13). About 42% of the NOW people so exposed are children, and all MAXD exposures occur only on one day/O_3 season.

2. Attainment of the two 8h 0.08 ppm NAAQS, both 1 Ex and 5 Ex, are expected to decrease NOW people exposures to the 1h MAXD of concern, and eliminate children exposures to that dose rate. Just-attaining the current standard might result in a small increase in the number and proportion of NOW people exposed to the MAXD of concern. However, no children are expected to be so exposed for this NAAQS. None of the 1h MAXD exposures of concern occur on more than one day/O_3 season for these two alternative NAAQS.

While not shown in Table 1, the estimates of O_3 exposures >0.12 ppm at any exercise level are considerably higher than the numbers presented in that Table. For instance, currently (1991) about 20,000 adults and 8,000 children are predicted to experience one or more daily exposure >0.12 ppm when exercise level is ignored. This is about 1% of the adult population and 2% of the children in the Miami urban area. (As compared to <0.1% adult and 0.1% children exposure, on average, @ 30 EVR exercise.) The corresponding estimates for non-exercising exposure when the current standard is just attained is 62,000 (4%) for adults and 12,000 for children (4%). Similar estimates for attainment of the 8h 1Ex 0.10 ppm NAAQS alternative are 137,000 (8%) for adults and 32,000 for children (10%), and are 21,000 (1%) for NOW adults and 4,000 (1%) for children when the 8h 5Ex standard of 0.08 ppm is just attained. Thus, exercise level, and its associated ventilation rate, at maximum dose greatly affects pNEM/O3 MAXD exposure estimates.

The 8h results (Table 2), indicate that relatively more people may be exposed. The level of concern here is a MAXD exposure of >0.08 ppm for 8h @ an EVR $\geq$15 l min^{-1} m^{-2}. (Obviously, the EVR of concern drops as the averaging period increases, just as the O_3 concentration of concern drops. People cannot hold an EVR of 30 l min^{-1} m^{-2} for an extended period of time(13).)

The 8h results indicate that:

1. Currently (1991), no one in the NOW population--including children--is estimated to experience an 8h MAXD of concern.

2. Attaining the next 3 NAAQS listed in Table 2 indicates that NOW-people may be exposed to the 8h MAXD of concern. A goodly proportion of these people are children, with the range in the estimate of the children's proportion of this exposed population being 39.5-88.9%. The absolute and relative numbers of NOW-people being so affected are relatively small ($\leq$0.4%) for the current standard (1h 1Ex 0.12

ppm) and the 8h 5 Ex 0.08 ppm alternative standard. The proportion of children so affected is estimated to be 1% for these two NAAQS.

3. Attaining the 8h 1 Ex 0.10 ppm NAAQS is estimated to result in a significant number of children being exposed at the 8h 0.08 ppm MAXD of concern: about 13,400 children (4.1% of children in the modeled part of Miami). It should be noted that a very small percentage (0.1%) of the NOW-people exposed at this MAXD may experience two days of exposure during the O_3 season, which is the entire year in Miami.

Putting the 8h MAXD estimates into perspective, the results indicate that currently (1991) only 3,500 NOW people might experience an 8h exposure >0.08 ppm @ any exercise level. (In other words, when exercise is ignored; this estimate is not shown in Table 2.) This compares to no one estimated to experience the same O_3 air quality concentration @ 15 EVR or higher. The corresponding estimates for children are no exposures at any exercise or at 15+ EVR. Exercise level in Miami's As Is results hardly make a difference in the number of people exposed to the 0.12 ppm concentration level. This contrasts to all of the other urban areas previously modeled (2-7), which had far fewer exposures at exercise than when exercise level is ignored.

For the record, the 8h any-exercise estimates for the non-zero alternative NAAQS are:

	8h 1Ex 0.10	8h 5Ex 0.08	1h 1Ex 0.12
NOW People	428,100	90,900	242,800
(%)	22.0	4.7	12.5
Children	92,800	24,100	73,300
(%)	28.3	7.4	22.4

Contrast these estimates with those appearing in Table 2 for insight into the impact of exercise level on exposure estimates. The any-exercise estimates are 1-1.5 orders of magnitude higher than the ≥15 EVR estimates.

Note that all of the estimates have variability, reflecting the Monte Carlo sampling process that produces a different estimate for each run. The range in the estimates are between a factor of 2-to-3 in most cases, which seems reasonable.

Statistical tests of the exposure distributions were undertaken using a two-sample Kolmogorov-Smirnov (K-S) non-parametric test. The null hypothesis was that the cumulative frequency exposure distributions for the various air quality scenarios are the same for each exposure metric being tested. The test statistic was the maximum difference between the two distributions (Dn); it was evaluated using a large-sample F statistic. The significance level is 0.05, using the chi-square approximation. The test indicates that the exposure indicators shown in Tables 1 and 2 vary significantly across the six air quality scenarios with the following exceptions.

For the AsIs and 8h 5Ex 0.08 ppm pair:

> NOW people and occurrences and children and children-occurrences at 1h >0.12 ppm exposures at any exercise level.

For the As Is and the current standard (1h 1Ex 0.12 ppm) pair:

> Children and children-occurrences at >0.12 ppm at any exercise level.

For the current standard and 8h 5Ex 0.08 ppm pair:

> NOW person-occurrences, children exposed, and children-occurrences at 1h >0.12 ppm at any exercise level.
>
> NOW people, NOW person-occurrences, and the number of people exposed on one day/season at 1h >0.12 ppm at ≥30 EVR.

For the current standard and 8h 1Ex 0.10 ppm pair:

> Children exposed, children-occurrences, and the number of children exposed on one day/season at 8h >0.08 ppm at ≥15 EVR and at any exercise level.
>
> Children exposed and children-occurrences at 1h >0.12 ppm at any exercise level.

Compared with the K-S analyses undertaken for most of the previous urban areas (2-7), the above results are unusual. Most of the non-rejects involve the "any exercise" metrics, which are not the main exposure/exercise conditions of concern. The only exercising metrics that could not be rejected as coming from the same distribution involved the current standard and two alternative NAAQS. The current standard/8h 5EX 0.08 pair could not be rejected for the 1h >0.12 ppm at 30+ EVR exposure metric. The current standard/8h 1Ex 0.10 ppm pair could not be rejected for the 8h >0.08 ppm at ≥15 EVR. However, there is no real consistent pattern among the exposure metrics and air quality standard pairs that were tested.

Note that these are not strong statistical tests and that some of the K-S test requirements were not met. Random sampling was not used. The sample "observations" simply are results of a simulation model; the population of interest, then, can only be the set of possible outcomes produced by the model. A large-sample test statistic was applied to small samples (10 runs). These caveats aside, 19 "cannot rejects" out of 92 tests is four times as many as are expected based on a "pure-chance" probability of rejecting a true hypothesis (5%). This 21% cannot-reject rate is about quadruple the rates seen in most of the urban areas that were analyzed (2-7). Unlike most of these areas, there is not a clear-cut picture produced by the K-S testing exercise in Miami. There is not a consistent pattern--especially at exercise--associated with the alternative NAAQS investigated.

SUMMARY

The analyses of 5 alternative standards ozone NAAQS in the Miami area (1h 1Ex 0.12 ppm; 8h 1Ex 0.10 pm; 8h 5Ex 0.08 ppm; 8h 1Ex 0.08 ppm; and 8h 5Ex 0.06 ppm) indicate that attainment of the current standard or the 8h 1Ex 0.10 ppm and 8h 5Ex 0.08 ppm alternatives may not minimize exposures at exercise in the Miami urban area. These findings apply to both the 1h and 8h estimates, but are more important for the 8h results since more people and children are estimated to experience 8h MAXD levels of concern than the 1h MAXD levels under these alternative NAAQS.

The reader should remember the early caveat about the downward bias inherent in pNEM results. While every effort has been made to present "best estimates," it is inherently difficult to predict the upper end of the population exposure distribution using human activity data bases that consist of only 1-3 days of information and that also under-represent adults and children who exercise regularly. Year-long activity data from all segments of the population are needed to adequately estimate the true population exposure distribution.

REFERENCES

1. T. Johnson, J. Capel, and M. McCoy. **Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data.** Durham, NC: IT-AQS, 1993 (Draft).

2. T. McCurdy. "Los Angeles Ozone Exposure Estimates," **EPA Memorandum;** November 4, 1993.

3. T. McCurdy, et al. "Estimating Ozone Exposures in Philadelphia Using a Second-Generation Probabilistic Version of NEM." **Paper A210 presented at the 87th Annual Meeting of AWMA**; Cincinnati, June 1994.

4. T. McCurdy, et al. "Estimating ozone Exposures in Houston Using a Second-Generation Probabilistic Version of NEM." **Paper presented at the Tropospheric Ozone Specialty Conference,** Air and Waste Management Association; Orlando, 1994.

5. T. McCurdy. "Estimating Ozone Exposures in the New York Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, February 1994.

6. T. McCurdy. "Estimating Ozone Exposures in the Chicago Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

7. T. McCurdy. "Estimating Ozone Exposures in the Denver Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

8. Environmental Criteria and Assessment Office. **Air Quality Criteria for Ozone and Photochemical Oxidants.** Research Triangle Park, NC: 1994 (Draft).

9. H.M. Richmond and T. McCurdy. "Use of Exposure Analysis and Risk Assessment in the Ozone NAAQS Review." **Paper 88-121.3 presented at the 81st Annual Meeting of APCA**; Dallas, June 19-24, 1988.

10. N.L. Nagda, H.E. Rector, and M.D. Koontz. **Guidelines for Monitoring Air Quality.** Washington, DC: Hemisphere Pub. Co., 1987.

11. C.J. Weschler, H.C. Shields, and D.V. Nike. "Indoor Ozone: Recent Findings," in: R. Burglund (ed.), **Tropospheric Ozone in the Environment II.** Pittsburgh: Air & Waste Management Association, 1992.

12. T. McCurdy. "Testing pNEM/O3 Runs to Determine if a Set of 10 Runs is 'Representative'," **EPA Memorandum;** April 19, 1994.

13. W.C. Adams. **Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities.** Davis CA: University of California, 1993.

14. M. Absil, P. Narducci, R. Whitfield, and H.M. Richmond. "Chronic Lung Injury Risk Estimates for Urban Areas Having Ozone Patterns Similar to Those in the Northeast." Paper presented at the **AWMA Specialty Conference on Tropospheric Ozone and the Environment II**; Atlanta, November 4-7, 1991.

Table 1. ESTIMATES OF 1h "MAXIMUM DOSAGE" EXPOSURES IN MIAMI TO O_3 CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	500	300	300	900	0	0
Percent of Total Population	*	*	*	*	0	0
Range in this percentage for all runs	0.0-0.1	0.0-0.1	0.0-0.1	0.0-0.3	-	-
Mean Est. of Person-Occurrences	500	300	300	900	0	0
Percent of Total Per-Occurrences	@	@	@	@	0	0
Range in this percentage for all runs	0.0-@	0.0-@	0.0-@	0.0-@	-	-
Mean Est. of Occurrences/Person Exposed	1.00	1.00	1.00	1.00	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	100	100	100	100	-	-
2 Days	0	0	0	0	-	-
3 Days	0	0	0	0	-	-
>3 Days	0	0	0	0	-	-
CHILDREN						
Mean Estimate of the Number of Children	200	0	0	0	0	0
Percent of Children Population	0.1	0	0	0	0	0
Range in this percentage for all runs	0.0-0.6	-	-	-	-	-
Percent of Total Exposed Population	41.8	0	0	0	-	-
Mean Estimate of Children-Occurrences	200	0	0	0	0	0
Percent of total Child-Occurrences	@	0	0	0	0	0
Range in this percentage for all runs	0.0-@	-	-	-	-	-
Mean Estimate of Occurrences/Child Exposed	1.00	-	-	-	-	-
Number of Days Exposed/Season (% Exposed)						
1 Day	100	-	-	-	-	-
2 Days	0	-	-	-	-	-
3 Days	0	-	-	-	-	-
>3 Days	0	-	-	-	-	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h "MAXIMUM DOSAGE" EXPOSURES IN MIAMI TO O_3 CONCENTRATIONS EXCEEDING 0.08 PPM AND EVR[a] EQUALED OR EXCEEDED 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL NON-OUTDOOR WORKER EXPOSED POPULATION						
Mean Estimate of the Number of People	0	23,900	3,600	8,600	0	0
Percent of Total Population	0	1.2	0.2	0.4	0	0
Range in this percentage for all runs	-	0.5-2.2	0.0-1.5	*-1.1	-	-
Mean Est. of person-Occurrences	0	23,900	3,600	8,600	0	0
Percent of total Per.-Occurrences	0	@	@	@	0	0
Range in this percentage for all runs	-	@-@	0.0-@	@-@	-	-
Mean Est. of Occurrences/Person Exposed	-	1.00	1.00	1.00	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	-	100	100	100	-	-
2 Days	-	0	0	0	-	-
3 Days	-	0	0	0	-	-
4 Days	-	0	0	0	-	-
>4 Days	-	0	0	0	-	-
CHILDREN						
Mean Estimate of the Number of Children	0	13,400	3,200	3,400	0	0
Percent of Children Population	0	4.1	1.0	1.0	0	0
Range in this percentage for all runs	-	0.0-11.9	0.0-9.0	0.0-6.5	-	-
Percent of Total Exposed Population	-	56.1	88.9	39.5	-	-
Mean Estimate of Children-Occurrences	0	13,400	3,200	3,400	0	0
Percent of Total Child-Occurrences	0	*	@	@	0	0
Range in this percentage for all runs	-	0.0-*	0.0-@	0.0-@	-	-
Mean Estimate of Occurrences/Child Exposed	-	1.00	1.00	1.00	-	-
Number of Days/Season (% Exposed)						
1 Day	-	100	100	100	-	-
2 Days	-	0	0	0	-	-
3 Days	-	0	0	0	-	-
4 Days	-	0	0	0	-	-
>4 Days	-	0	0	0	-	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

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ESTIMATING OZONE EXPOSURES IN PHILADELPHIA USING A SECOND-GENERATION PROBABILISTIC VERSION OF NEM

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February 1994

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INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is currently reviewing the ozone (O_3) primary national ambient air quality standard (NAAQS) to determine if the existing standard protects public health with an adequate margin of safety. To evaluate whether alternative O_3 NAAQSs provide an adequate margin of safety, the EPA Office of Air Quality Planning and Standards (OAQPS) assesses such factors as the nature and severity of health effects associated with O_3 exposure, the degree of total human exposure (i.e., indoor and outdoor) to O_3, and the risks (probabilities) of ozone-related health effects occurring in the exposed population when alternative O_3 NAAQS are just attained. This paper discusses an EPA analysis of O_3 exposure estimates for parts of the Philadelphia metropolitan area which employed the pNEM/O3 model developed by International Technology - Air Quality Services (IT-AQS). A report by Johnson, et al. (1) describes this model in detail and presents initial results of applying it to nine U.S. urban areas, including Philadelphia. Exposure estimates for parts of the Los Angeles area are discussed in an EPA memorandum (2) that was recently reviewed by the Clean Air Science Advisory committee (CASAC) at a public meeting. Additional analyses of O_3 exposure estimates for the remaining seven urban areas (see below) that were modeled will be forthcoming.

OVERVIEW

Pursuant to section 108 of the Clean Air Act, the Environmental Criteria Assessment Office (ECAO) within the Office of Research and Development (ORD) is preparing a criteria document (4) for O_3. This document will be a comprehensive summary and critical assessment of the latest scientific research relevant to assessing the effects of a criteria pollutant. The document will be reviewed by CASAC, part of the EPA's independent Science Advisory Board, and by the general public. Upon completion of the criteria document, OAQPS will prepare a Staff Paper that summarizes and integrates scientific information presented in the criteria document considered to be the most relevant to decisions on alternative NAAQS and various analyses (e.g., air quality, exposure, and risk). Figure 1 illustrates the relationships among scientific research, criteria document development, the OAQPS Staff Paper, and exposure and risk assessment.

An important aspect of health risk assessment is an analysis of population exposure. Such an analysis provides the population basis for "headcount risk" estimates developed as part of EPA's NAAQS risk assessment work. Estimates of population exposure also provide important information regarding the number of people that may experience varying levels of O_3 as they go through their normal daily life.

Since 1980, OAQPS has used the NAAQS Exposure Model (NEM) to analyze human exposure associated with the "criteria air pollutants" covered by Title I of the Clean Air Act, as amended. Recent versions of this model use Monte Carlo analyses to define numeric

values for certain variables inherent in the model. These versions of NEM are called pNEM, an acronym for probabilistic" NEM. to differentiate among the various pollutant-specific versions of pNEM, the one described here is denoted as pNEM/O3.

Analysis of population exposure under alternative O_3 NAAQS requires that significant factors contributing to total human exposure be taken into account. These factors include the temporal and spatial distribution of people and O_3 concentrations throughout an urban area, the variation of ozone levels within each microenvironment, and the effects of exercise (increased ventilation) on ozone uptake in exposed individuals.

To date, the most recent version of pNEM/O3--the "second generation" version--has been applied to nine major urban areas. These areas vary in size from Denver with 1.4 million people to New York with over 10.6 million people. pNEM/O3 partitions all land within a selected urban area into large "exposure districts." The number of exposure districts defined for each urban area varies from 6 to 16 in the set of nine areas recently modeled; the number of districts reflects the number of monitors having valid air quality data in a study area. Most of the nine urban areas have 10 or more districts within their boundaries.

People living within each exposure district, as estimated by the U.S. Bureau of Census in 1990, are assigned to a single discrete point, the population centroid. O_3 air quality within each exposure district is estimated for each hour of the O_3 season using data from a nearby monitoring site. Because O_3 in the ambient air generally is modified considerably when entering a building or vehicle, outdoor O_3 estimates are adjusted using a mass-balance model to account for 3 indoor microenvironments. These microenvironments are: indoors-at-home, indoors-other, and within a motor vehicle. The mass-balance model used in pNEM/O3 is a simplified version of the generalized Nagda, Rector, and Koontz (NRK) model (5). For our use, this model was revised to incorporate the assumption that indoor decay rate is proportional to indoor O_3 concentration. It was further revised to incorporate assumptions concerning ozone decay rates suggested by Weschler, et al (6). The resulting revised mass-balance model is fully described in Ref. 1.

Because both the intake dose received and susceptibility to effects of pollution may vary with age, occupation, and intensity of exercise, the total population of each study area is divided into 9 age-occupation (A-O) groups. Each A-O group is further subdivided into cohorts depending upon (1) the type of air conditioning system present in the home, if any, and (2) home-to-work commuting patterns.

While many types of exposure metrics are provided by pNEM/O3, only those for the non-outdoor working population in Philadelphia are discussed in this paper. Exposure estimates for children in Philadelphia are not included in the results discussed here. Estimates for outdoor workers--a major population sub-group of concern from an O_3 exposure perspective--will be completed in the Fall of 1994.

AIR QUALITY SCENARIOS INVESTIGATED

Six air quality scenarios were modeled for Philadelphia (and the other 8 urban areas); the alternative NAAQS scenarios all are on a daily maximum basis:

1. 1991 air quality--the "as is" scenario
2. Attain 1h 1Ex 0.12 ppm--the current standard
3. Attain 8h 1Ex 0.08 ppm
4. Attain 8h 1Ex 0.10 ppm
5. Attain 8h 5Ex 0.06 ppm
6. Attain 8h 5Ex 0.08 ppm

Ex stands for "expected exceedances," as defined by EPA in 40 Code of Federal Regulations 50.9, and h is the usual symbol for hour(s). Thus, a full description of the first alternative NAAQS scenarios is: attain the 1 hour daily maximum-one expected exceedance NAAQS of 0.12 ppm. The other standards follow the same format. The 5Ex NAAQS would allow 5 daily exceedances per year, on average, if they were implemented.

The iterative adjustment procedure used by IT-AQS to simulate just-attaining the 5 alternative NAAQS listed above involves a complex procedure of fitting Weibull distributions to the 1991 O_3 data, modifying parameters of the equations so that the "worst" monitor just achieves the desired standard, and then re-specifying the entire O_3 pattern for all districts in Philadelphia. The procedure is described in detail by Johnson, et al. (1).

PHILADELPHIA RESULTS

Results are based upon 10 runs (realizations) of the pNEM/O3 model for each air quality scenario. Based on a previous analysis of sets of 10-run results versus a 108-run result (7), the authors think that results from only 10 runs of the model will adequately predict the mean and variance observed in 100 or more runs of pNEM/O_3. Ten runs of the model will not, however, adequately represent the entire range of possible outcomes. Additional runs can only increase this range. This is an obvious shortcoming of the analyses presented here, but limited resources preclude undertaking more runs.

This paper includes tabular data on (1) the number and percent of people exposed, and (2) the number and percent of person-occurrences for the adult, non-outdoor worker population in Philadelphia. (A person-occurrence is the metric that focuses on an event: when the exposure-of-concern is reached regardless of who reaches it. One hundred person-occurrences could be 10 people experiencing the exposure 10 times, 100 people experiencing it once, one person experiencing it 100 times, or any combination thereof.) Even though data are discussed here regarding the absolute and relative number (percentage) of people exposed, it must be noted that "people" should not be used as an exposure metric. The cohort-specific time/activity data base used for pNEM/O3 modeling (and for all other exposure models that uses human activity information) provides no more than three days of data from a single individual. Thus, rigorous inferences from these data rigorously can be made only to "person-days" of exposure or "person-occurrences" of exposure, where each occurrence relates to a 1h, 8h, or 24h time period in pNEM/O3. Only when activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to people (or children, or outdoor workers as the case may be). This point is usually ignored in the general exposure assessment literature.

All exposure estimates presented in this paper pertain to "daily maximum dose," (MAXD) where dose is defined as the product of ozone concentration and ventilation rate over a defined time period. Note that maximum daily dose does not necessarily occur during the time period of maximum ozone concentration in a given urban area.

Ventilation rate is a very important factor in estimating total dose for any air pollutant (8). The ventilation rate metric used in pNEM/O3 is "equivalent ventilation rate" (EVR), or ventilation rate (in liters per minute) divided by body surface area (BSA, in units of m^2). EVR has units of $l\ min^{-1}\ m^{-2}$. It is a surrogate indicator for the number of O_3 molecules that enter the oral-nasal cavities per unit time period.

The Philadelphia population analyzed here includes 3,785,810 NOW (non-outdoor worker) people and 810,163,340 possible daily maximum NOW person-occurrences (NOW people x 214 days in the O_3 season).

Exposure results appear in Tables 1 and 2. Table 1 includes 1h daily maximum dose exposure estimates, while Table 2 provides similar results for 8h exposure estimates.

The results indicate that:

1. Currently (1991), fewer than 2% of the NOW population experience a daily maximum dose (MAXD) O_3 exposure @ >0.12 ppm @ an EVR of 30 $l\ min^{-1}\ m^{-2}$ or higher. This exposure/breathing rate combination is thought by many researchers to be a dose rate of concern (9). Almost all--96%--of these MAXD exposures occur only on one day during the O_3 season.

2. Such MAXD exposures are greatly reduced whenever one of the alternative standards are attained. For the relatively few people having a MAXD exposure >0.12 ppm @ $\geq$30 EVR when an alternative NAAQS is attained, all of them experience only one such 1h exposure per season.

While not shown in Table 1, the results of O_3 exposures >0.12 ppm at any exercise level are considerably higher than the exposure numbers presented in the Table. For instance, currently (1991) about 2.7 million people are predicted to experience one or more daily exposures >0.12 ppm when exercise level is ignored. This is about 70% of the total NOW population in Philadelphia. Thus, exercise level, and its associated ventilation rate, at maximum dose greatly affects pNEM/O3 MAXD exposure estimates.

The same findings apply to the 8h results (Table 2), although relatively more people are affected. The level of concern here is MAXD exposure @ >0.08 ppm for 8h @ an EVR $\geq$15 l min^{-1} m^{-2}. (Obviously, the EVR of concern decreases as the averaging period increases, just as the O_3 concentration of concern decreases.) People cannot maintain an EVR of 30 l min^{-1} m^{-2} for an extended period of time (8).

The 8h results indicate that:

1. Currently, over 6% of the NOW population experience a daily maximum dose O_3 exposure level of concern. About 15% of these people may experience such a MAXD exposure on more than one day during the O_3 season. One percent of the applicable population may experience the exposure of concern on 3 days.

2. Attaining any of the alternative NAAQS reduces the MAXD exposure to the level of concern, although about 1% of the NOW population would experience that exposure even if the current NAAQS (1h 1Ex 0.12 ppm) or the 8h 1Ex 0.10 ppm standards was attained; however, almost all of these exposures occur on only one day.

Consistent with the 1h results, almost everyone (90%) in Philadelphia currently (1991) experiences one or more 8h exposures >0.08 ppm at maximum daily dose when ventilation level is ignored. (This result is not shown in Table 2.) This contrasts to the 6.4% of the NOW population who experience the same 8h O_3 concentration at exercise. Again, exercise levels--expressed as EVR--greatly affect pNEM/O3 exposure results.

Note that all of the estimates exhibit variability, reflecting the Monte Carlo sampling process that produces a different estimates for any run. The range in the estimates are between a factor of 2-to-3 in most cases, which seems reasonable.

Statistical tests of the exposure distributions were undertaken using a two-sample Kolmogorov-Smirnov (K-S) non-parametric test. The null hypothesis was that the cumulative frequency distributions for the various air quality scenarios are the same for each exposure metric being tested. The test statistic was the maximum difference between the two distributions (Dn); it was evaluated using a large-sample F statistic. The significance level was 0.05, using the chi-square approximation. The tests indicate that all of the exposure indicators shown in Tables 1 and 2 vary significantly across the six air quality scenarios with the following exceptions:

Persons with an 8h MAXD exposure $\geq$0.08 ppm @ $\geq$15 EVR for the 1h 1Ex 0.12 ppm and 8h 1Ex 0.10 ppm NAAQS.

Person-occurrences for the same exposure condition and air quality scenarios as above.

The number of people with 1 day of exposure >0.08 ppm @ $\geq$15 EVR for the same two air quality scenarios.

Note that these are not strong statistical tests and that some of the K-S test requirements were not met. Random sampling was not used. The sample "observations" simply are results of a simulation model; the population of interest, then, can only be the set of possible outcomes produced by the model. A large-sample test statistic was applied to small samples (10 or 11 runs). In addition, three "cannot rejects" out of 74 tests is about 4% of the total tests made--about the same value as the "pure-chance" probability. It is of interest, however, to note that all three exposure metrics that were not rejected using the K-S test involved the same paired air quality scenarios, which supports the finding that those scenarios do not differ significantly with respect to estimated O_3 exposures.

SUMMARY

The analyses of 5 alternative standards ozone NAAQS (1h 1Ex 0.12 ppm; 8h 1Ex 0.10 pm; 8h 5Ex 0.08 ppm; 8h 1Ex 0.08 ppm; and 8h 5Ex 0.06 ppm) indicate that attainment of each standard probably will sharply reduce the percentage of the exposed population experiencing ozone exposures thought to increase health risks. With the exception of the 1h 1Ex 0.12 and 8h 1Ex 0.10 alternatives, the percentage of non-outdoor worker population exposed at relatively high exercise levels one or more times to the level of concern is well below 1%. The 8h exposures to 0.08 ppm or higher for the NOW population are 1.1% for the 8h 1 Ex 0.05 standard and 0.9% for the 0.12 standard. A K-S test cannot distinguish between these two standards for most exposure indicators. (This finding is not applicable to the Los Angeles results (2).) The analyses also found that for all air quality scenarios that were examined, just attaining an alternative O_3 standard reduces multiple-day exposures for the air quality/exercise levels of interest.

REFERENCES

1. T. Johnson, J. Capel, and M. McCoy. **Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data.** Durham, NC: IT-AQS, 1993 (Draft).

2. T. McCurdy. "Los Angeles Ozone Exposure Estimates," **EPA Memorandum;** November 4, 1993.

3. H.M. Richmond and T. McCurdy. "Use of Exposure Analysis and Risk Assessment in the Ozone NAAQS Review." **Paper 88-121.3 presented at the 81st Annual Meeting of APCA**; Dallas, June 19-24, 1988.

4. Environmental Criteria and Assessment Office. **Air Quality Criteria for Ozone and Photochemical Oxidants.** Research Triangle Park, NC: 1994 (Draft).

5. N.L. Nagda, H.E. Rector, and M.D. Koontz. **Guidelines for Monitoring Air Quality.** Washington, DC: Hemisphere Pub. Co., 1987.

6. C.J. Weschler, H.C. Shields, and D.V. Nike. "Indoor Ozone: Recent Findings," in: R. Burglund (ed.), **Tropospheric Ozone in the Environment II.** Pittsburgh: Air & Waste Management Association, 1992.

7. T. McCurdy. "Testing pNEM/O3 Runs to Determine if a Set of 10 Runs is 'Representative'," **EPA Memorandum;** April 19, 1994.

8. W.C. Adams. **Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities.** Davis CA: University of California, 1993.

9. M. Absil, P. Narducci, R. Whitfield, and H.M. Richmond. "Chronic Lung Injury Risk Estimates for Urban Areas Having Ozone Patterns Similar to Those in the Northeast." Paper presented at the **AWMA Specialty Conference on Tropospheric Ozone and the Environment II**; Atlanta, November 4-7, 1991.

Table 1. ESTIMATES OF 1h "MAXIMUM DOSAGE" EXPOSURES IN PHILADELPHIA TO O_3 CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	70,000	4,100	0	300	0	0
Percent of Total Population	1.8	0.1	0	*	0	0
Range in this percentage for all runs	0.6-4.1	0.0-0.7	-	0.0-*	-	-
Mean Est. of Person-Occurrences	72,800	4,100	0	300	0	0
Percent of Total Per.-Occurrences	.01	@	0	@	0	0
Range in this percentage for all runs	@-.02	0.0-@	-	0.0-@	-	-
Mean Est. of Occurrences/Person Exposed	1.02	1.00	-	1.00	-	-
Number of Days Exposed/Season (% Exposed)						
1 Day	96	100	-	100	-	-
2 Days	4	0	-	0	-	-
>2 Days	0	0	-	0	-	-

Notes:

[a]Equivalent ventilation rate. It is equal to ventilation rate ÷ body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h "MAXIMUM DOSAGE" EXPOSURES IN PHILADELPHIA TO O_3 CONCENTRATIONS EXCEEDING 0.08 PPM AND EVR[a] EQUALED OR EXCEEDED 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL NON-OUTDOOR WORKER EXPOSED POPULATION						
Mean Estimate of the Number of People	243,700	41,700	1,100	35,000	500	0
Percent of Total Population	6.4	1.1	*	0.9	*	0
Range in this percentage for all runs	4.7-9.6	0.2-2.2	0.0-0.1	*-2.4	0.0-0.1	-
Mean Est. of Person-Occurrences	289,100	42,500	1,100	35,000	500	0
Percent of Total Per.-Occurrences	0.04	0.01	@	@	@	0
Range in this percentage for all runs	0.03-0.05	@-0.01	0.0-@	@-@	0.0-@	-
Mean Est. of Occurrences/Person Exposed	1.19	1.01	1.00	1.00	1.00	-
Number of Days Exposed/Season (% Exposed)						
1 Day	85	99	100	100	100	-
2 Days	14	1	0	0	0	-
3 Days	1	0	0	0	0	-
>3 Days	0	0	0	0	0	

Notes:

[a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in l min^{-1} m^{-2}

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ESTIMATING OZONE EXPOSURES IN THE ST. LOUIS URBAN AREA USING A SECOND-GENERATION PROBABILISTIC VERSION OF NEM

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March 1994

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INTRODUCTION

The U.S. Environmental Protection Agency (EPA) currently is reviewing the ozone (O_3) primary national ambient air quality standard (NAAQS) to determine if the existing standard protects public health with an adequate margin of safety. In order to evaluate whether alternative O_3 NAAQSs provide an adequate margin of safety, the EPA Office of Air Quality Planning and Standards (OAQPS) assesses such factors as the nature and severity of health effects associated with O_3 exposure, the degree of total human exposure (i.e., indoor and outdoor) to O_3, and the risks (probabilities) of ozone-related health effects occurring in the exposed population when alternative O_3 NAAQS are just attained. This paper discusses an EPA analysis of O_3 exposure estimates for parts of the St. Louis metropolitan area which employed the pNEM/O3 model developed by International Technology-Air Quality Services (IT-AQS). A report by Johnson, et al. (1) describes this model in detail and presents initial results of applying it to nine U.S. urban areas, including St. Louis. Exposure estimates for parts of the Los Angeles area are discussed in an EPA memorandum (2) that was reviewed by the Clean Air Science Advisory Committee (CASAC) at a public meeting. Exposure estimates for the Philadelphia area are described in an AWMA paper (3). Exposure estimates for Houston are described in an AWMA specialty conference paper (4). New York, Chicago, Denver, and Washington, DC results are contained in EPA papers (5-9).

OVERVIEW

Pursuant to section 108 of the Clean Air Act, the Environmental Criteria Assessment Office (ECAO) within the Office of Research and Development (ORD) is preparing a criteria document (10) for O_3. This document will be a comprehensive summary and critical assessment of the latest scientific research relevant to assessing the effects of a criteria pollutant. The document will be reviewed by CASAC, part of the EPA's independent Science Advisory Board, and by the general public. Upon completion of the criteria document, OAQPS will prepare a Staff Paper that summarizes and integrates scientific information presented in the criteria document considered to be most relevant to decisions on alternative NAAQS and various analyses (e.g., air quality, exposure, and risk).

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an acronym for "probabilistic" NEM. To differentiate among the various pollutant-specific versions of pNEM, the one described here is denoted as pNEM/O3.

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To date, the most recent version of pNEM/O3--the "second generation" version--has been applied to nine major urban areas. These areas vary in size from Denver with 1.4 million people to New York with over 10.6 million people. pNEM/O3 partitions all land within a selected urban area into large "exposure districts." The number of exposure districts defined for each urban area varies from 6 to 16 in the set of nine areas recently modeled; the number of districts reflects the number of monitors having valid air quality data in a study area. Most of the nine urban areas have 10 or more districts within their boundaries.

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Because both the intake dose received and susceptibility to effects of pollution may vary with age, occupation, and intensity of exercise, the total population of each study area is divided into nine age-occupation (A-O) groups. Each A-O group is further subdivided into cohorts depending upon (1) the type of air conditioning system present in the home, if any, and (2) home-to-work commuting patterns.

While many types of exposure metrics are provided by pNEM/O3, only those for the non-outdoor working population in St. Louis are discussed in this paper. Exposure estimates for children are included in the results discussed here. Estimates for outdoor workers--a major population sub-group of concern from an O_3 exposure perspective--will be completed in the Fall of 1994.

It should be noted that all versions of pNEM systematically underestimate the highest part of the exposure distribution. (See Ref. 1 for an evaluation of pNEM/O3 results against real-time personal exposure monitoring data.) Thus, results presented here have a downward bias.

AIR QUALITY SCENARIOS INVESTIGATED

Six air quality scenarios were modeled for the St. Louis urban area (and the other eight urban areas); the scenarios are all on a daily maximum basis. They are:

1. 1990 air quality--the "as is" scenario
2. Attain 1h 1Ex 0.12 ppm--the current standard
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4. Attain 8h 1Ex 0.10 ppm
5. Attain 8h 5Ex 0.06 ppm
6. Attain 8h 5Ex 0.08 ppm

Ex stands for "expected exceedances," as defined by EPA in 40 Code of Federal Regulations 50.9, and h is the usual symbol for hour(s). Thus, a full description of the first alternative NAAQS scenarios is: attain the 1 hour daily maximum-one expected exceedance NAAQS of 0.12 ppm. The other standards follow the same format. The 5Ex NAAQS would allow 5 daily exceedances per year, on average, if they were implemented.

The iterative adjustment procedure used by IT-AQS to simulate just-attaining the 5 alternative NAAQS listed above involves a complex procedure of fitting Weibull equations to the 1990 O_3 data, modifying parameters of the equations so that the "worst" monitor just achieves the desired standard, and then re-specifying the entire O_3 pattern for all districts in St. Louis. The procedure is described in detail by Johnson, et al. (1).

St. Louis had relatively good O_3 air quality in 1990 in that its "design value"--the second-highest 1h daily value measured at any site in the urban area--was 0.130 ppm. This value is only slightly above the current O_3 standard concentration of 0.12 ppm.

ST. LOUIS RESULTS

Results are based upon 10 runs (realizations) of the pNEM/O3 model for each air quality scenario. Based on a previous analysis of sets of 10-run results versus a 108-run result (14), the author believes that results from only 10 runs of the model will adequately predict the mean and variance observed in 100 or more runs of pNEM/O3. Ten runs of the model will not, however, adequately represent the entire range of possible outcomes. Additional runs can only increase this range. This is an obvious shortcoming of the analyses presented here, but limited resources preclude undertaking more runs.

This paper includes tabular data on (1) the number and percent of people and children exposed, and (2) the number and percent of person-occurrences for children and the adult, non-outdoor worker population in St. Louis. (A person-occurrence is the metric that focuses on an event: when the exposure-of-concern is reached regardless of who reaches it. One hundred person-occurrence could be 10 people experiencing the exposure 10 times, 100 people experiencing it once, one person experiencing it 100 times, or any combination thereof.) Even though data are discussed here regarding the absolute and relative number (percentage) of people exposed, it must be noted that "people" should not be used as an exposure metric. The cohort-specific activity-days data base used for pNEM/O3 modeling (and for all other exposure models that use human activity information) provides no more than three days of data for a single individual. Thus, rigorous inferences from these data can be made only to "person-days" of exposure or "person-occurrences" of exposure, where an occurrence can be 1h, 8h, or 24h time period in pNEM/O3. Only when activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to people exposed over the year (or to children, or to outdoor workers as the case may be). This point usually is ignored in the general exposure assessment literature.

All exposure estimates presented in this paper pertain to "daily maximum dose," (MAXD) where dose is defined as the product of ozone concentration and ventilation rate over a defined time period. Note that maximum daily dose does not necessarily occur during the time period of maximum ozone concentration in a given urban area.

Ventilation rate is a very important factor in estimating total dose for any air pollutant (15). The ventilation rate metric used in pNEM/O3 is "equivalent ventilation rate" (EVR), or ventilation rate (in liters per minute) divided by body surface area (BSA, in units of m^2). EVR has units of $l\ min^{-1}\ m^{-2}$. It is a surrogate indicator for the number of O_3 molecules that enter the oral-nasal cavities per unit time period.

The St. Louis urban area population analyzed here includes 1.71 million NOW (non-outdoor worker) people and 313,000 children. There are 365 million possible daily maximum NOW person-occurrences (NOW people x 214 days in the O_3 season). The equivalent figure for children is 67 million.

Exposure results appear in Tables 1 and 2. Table 1 includes 1h daily maximum dose exposure estimates, while Table 2 provides similar results for 8h exposure estimates.

The 1h results indicate that:

1. Currently (1990), it is estimated that <1% of NOW people and children would experience a daily maximum dose (MAXD) O_3 exposure @ >0.12 ppm @ an EVR of 30 $l\ min^{-1}\ m^{-2}$ or higher, which is thought by many researchers to be a dose rate of concern (15). About 57% of the NOW people so exposed are children, and all MAXD exposures occur only on one day/O_3 season.

2. Attainment of the alternative NAAQS investigated is expected to substantially decrease or eliminate NOW people and children exposures to the 1h MAXD of concern. None of the 1h MAXD exposures of concern occur on more than one day/O_3 season for the alternative NAAQS.

While not shown in Table 1, the estimates of O_3 exposures >0.12 ppm at any exercise level are considerably higher than the numbers presented in that Table. For instance, currently (1990) about 129,400 adults and 51,700 children are predicted to experience one or more daily exposure >0.12 ppm when exercise level is ignored. This is about 9.3% of the adult population and 16.5% of the children in the St. Louis urban area. (As compared to <1% adult and children exposure, on average, @ 30 EVR exercise.) Thus, exercise level, and its associated ventilation rate, at maximum dose greatly affects pNEM/O3 MAXD exposure estimates.

The 8h results (Table 2), indicate that many more people may be exposed but that the overall proportion of the total population exposed to the MAXD is small. The level of concern here is a MAXD exposure of >0.08 ppm for 8h @ an EVR $\geq$15 l min^{-1} m^{-2}. (Obviously, the EVR of concern drops as the averaging period increases, just as the O_3 concentration of concern drops. People cannot hold an EVR of 30 l min^{-1} m^{-2} for an extended period of time (16).)

The 8h results indicate that:

1. Currently (1990), <1% of the NOW population and about 4% of the children are estimated to experience the 8h MAXD of concern. These exposures occur on only one day/season.
2. Attaining the alternative NAAQS that were investigated do not guarantee that there will be no 8h MAXD exposures of concern--except for the last two alternatives shown in Table 2. Attaining the 8h 1Ex 0.10 ppm O_3 standard in St. Louis could result in almost 2% of children exposed to the concern dose rate. Attaining the current standard (1h 1Ex 0.12 ppm) could result in almost 2% of children being so exposed at exercise. Both of these estimates are relatively high when compared to results from some of the other urban areas than were modeled (2-9).

Putting the 8h MAXD estimates into perspective, the results indicate that currently (1990) 332,700 NOW people might experience an 8h exposure >0.08 ppm @ any exercise level. (In other words, when exercise is ignored; this estimate is not shown in Table 2.) This compares to 13,200 people estimated to experience the same O_3 air quality concentration @ 15 EVR or higher. The corresponding estimates for children are 51,700 exposures at any exercise level versus 11,700 at 15+ EVR. Thus, exercise level certainly makes a large difference when 8h exposures to specific O_3 concentration levels are being estimated.

For the record, the 8h any-exercise estimates for the non-zero alternative NAAQS are:

	8h 1Ex 0.10	8h 5Ex 0.08	1h 1Ex 0.12	8h 1Ex 0.08
NOW People	262,900	78,200	280,900	3,300
(%)	15.4	4.6	16.5	0.2
Children	64,100	25,900	73,300	200
(%)	20.5	8.3	23.4	0.1

Contrast these estimates with those appearing in Table 2 for insight into the impact of exercise level on exposure estimates. The any-exercise estimates are 1-1.5 orders of magnitude higher than the $\geq$15 EVR estimates.

Note that all of the estimates have variability, reflecting the Monte Carlo sampling process that produces a different estimate for each run. The range in the estimates are between a factor of 2-to-3 in most cases, which seems reasonable.

Statistical tests of the exposure distributions were undertaken using a two-sample Kolmogorov-Smirnov (K-S) non-parametric test. The null hypothesis was that the cumulative frequency exposure distributions for the various air quality scenarios are the same for each exposure metric being tested. The test statistic was the maximum difference between the two distributions (Dn); it was evaluated using a large-sample F statistic. The significance level is 0.05, using the chi-square approximation. The test indicates that the exposure indicators shown in Tables 1 and 2 vary significantly across the six air quality scenarios with the following exceptions.

For the AsIs and current standard (1h 1Ex 0.12 ppm) pair:

> All exposure indicators that were tested <u>except</u> for the NOW population and NOW-occurrences exposed to 1h >0.12 ppm at any exercise level.

For the AsIs and 8h 1Ex 0.10 ppm pair:

> All exposure indicators that were tested <u>except</u> for the 1h >0.12 ppm exposures for the NOW population and for children at any exercise level, and the 8h >0.08 ppm exposures for children at any exercise level.

For the current standard (1h 1Ex 0.12 ppm) and 8h 1Ex 0.10 ppm pair:

> All exposure indicators that were tested <u>except</u> for the NOW population and NOW-occurences to 0.12 ppm at any exercise level and at exercise $\geq$30 EVR, and for

children and children-occurrences exposed to a MAXD of 0.12 ppm at exercise ≥30 EVR.

For the 8h 1Ex 0.08 ppm and 8h 5Ex 0.08 ppm pair:

Children and children-occurrences exposed to the 1h MAXD of 0.12 ppm at any exercise level.

The results of the K-S testing procedure undertaken in St. Louis are similar to those for Miami (8) and Washington, DC (9). Many exposure indicator pairs could not be distinguished with respect to attaining some of the alternative NAAQS in both areas. These standards do not make much impact on human exposure for the indicators listed above. However, there is no real consistent pattern among the exposure metrics and air quality standard pairs that were tested.

Note that these are not strong statistical tests and that some of the K-S test requirements were not met. Random sampling was not used. The sample "observations" simply are results of a simulation model; the population of interest, then, can only be the set of possible outcomes produced by the model. A large-sample test statistic was applied to small samples (10 runs). These caveats aside, 32 "cannot rejects" out of 103 tests is six times as many as are expected based on a "pure-chance" probability of rejecting a true hypothesis (5%). This 31% cannot-reject rate is about quadruple the rates seen in many of the urban areas that were analyzed (2-9). Unlike these areas, there is not a clear-cut picture produced by the K-S testing exercise in St. Louis. There is not a consistent pattern among the exposure metrics associated with the alternative NAAQS investigated.

SUMMARY

The analyses of 5 alternative standards ozone NAAQS in the St. Louis area (1h 1Ex 0.12 ppm; 8h 1Ex 0.10 pm; 8h 5Ex 0.08 ppm; 8h 1Ex 0.08 ppm; and 8h 5Ex 0.06 ppm) indicate that attainment of any of the alternatives will reduce--but not completely eliminate--exposures to the 8h MAXD of concern. In particular, attaining the current standard (1h 1Ex 0.12 ppm) and the 8 1 Ex 0.10 ppm alternative NAAQS does not protect a small, but important, percentage of children from experiencing the 8h MAXD of 0.08 ppm at ≥15 EVR.

The reader should remember the early caveat about the downward bias inherent in pNEM results. While every effort has been made to present "best estimates," it is inherently difficult to predict the upper end of the population exposure distribution using human activity data bases that consist of only 1-3 days of information and that also under-represent adults and children who exercise regularly. Year-long activity data from all segments of the population are needed to adequately estimate the true population exposure distribution.

REFERENCES

1. T. Johnson, J. Capel, and M. McCoy. **Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data.** Durham, NC: IT-AQS, 1993 (Draft).

2. T. McCurdy. "Los Angeles Ozone Exposure Estimates," **EPA Memorandum;** November 4, 1993.

3. T. McCurdy, et al. "Estimating Ozone Exposures in Philadelphia Using a Second-Generation Probabilistic Version of NEM." **Paper A210 presented at the 87th Annual Meeting of AWMA**; Cincinnati, June 1994.

4. T. McCurdy, et al. "Estimating ozone Exposures in Houston Using a Second-Generation Probabilistic Version of NEM." **Paper presented at the Tropospheric Ozone Specialty Conference,** Air and Waste Management Association; Orlando, 1994.

5. T. McCurdy. "Estimating Ozone Exposures in the New York Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, February 1994.

6. T. McCurdy. "Estimating Ozone Exposures in the Chicago Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

7. T. McCurdy. "Estimating Ozone Exposures in the Denver Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

8. T. McCurdy. "Estimating Ozone Exposures in the Miami Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

9. T. McCurdy. "Estimating Ozone Exposures in the Washington, DC Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

10. Environmental Criteria and Assessment Office. **Air Quality Criteria for Ozone and Photochemical Oxidants.** Research Triangle Park, NC: 1994 (Draft).

11. H.M. Richmond and T. McCurdy. "Use of Exposure Analysis and Risk Assessment in the Ozone NAAQS Review." **Paper 88-121.3 presented at the 81st Annual Meeting of APCA**; Dallas, June 19-24, 1988.

12. N.L. Nagda, H.E. Rector, and M.D. Koontz. **Guidelines for Monitoring Air Quality.** Washington, DC: Hemisphere Pub. Co., 1987.

13. C.J. Weschler, H.C. Shields, and D.V. Nike. "Indoor Ozone: Recent Findings," in: R. Burglund (ed.), **Tropospheric Ozone in the Environment II.** Pittsburgh: Air & Waste Management Association, 1992.

14. T. McCurdy. "Testing pNEM/O3 Runs to Determine if a Set of 10 Runs is 'Representative'," **EPA Memorandum;** April 19, 1994.

15. W.C. Adams. **Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities.** Davis CA: University of California, 1993.

16. M. Absil, P. Narducci, R. Whitfield, and H.M. Richmond. "Chronic Lung Injury Risk Estimates for Urban Areas Having Ozone Patterns Similar to Those in the Northeast." Paper presented at the **AWMA Specialty Conference on Tropospheric Ozone and the Environment II**; Atlanta, November 4-7, 1991.

Table 1. ESTIMATES OF 1h "MAXIMUM DOSAGE" EXPOSURES IN ST. LOUIS TO O_3 CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	5,100	200	0	0	0	0
Percent of Total Population	0.3	*	0	0	0	0
Range in this percentage for all runs	0.0-1.3	0.0-0.1	-	-	-	-
Mean Est. of Person-Occurrences	5,100	200	0	0	0	0
Percent of Total Per-Occurrences	@	@	0	0	0	0
Range in this percentage for all runs	0.0-*	0.0-@	-	-	-	-
Mean Est. of Occurrences/Person Exposed	1.00	1.00	-	-	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	100	100	-	-	-	-
2 Days	0	0	-	-	-	-
3 Days	0	0	-	-	-	-
>3 Days	0	0	-	-	-	-
CHILDREN						
Mean Estimate of the Number of Children	2,900	0	0	0	0	0
Percent of Children Population	0.9	0	0	0	0	0
Range in this percentage for all runs	0.0-4.6	-	-	-	-	-
Percent of Total Exposed Population	56.9	0	0	0	-	-
Mean Estimate of Children-Occurrences	2,900	0	0	0	0	0
Percent of total Child-Occurrences	@	0	0	0	0	0
Range in this percentage for all runs	0.0-@	-	-	-	-	-
Mean Estimate of Occurrences/Child Exposed	1.00	-	-	-	-	-
Number of Days Exposed/Season (% Exposed)						
1 Day	100	-	-	-	-	-
2 Days	0	-	-	-	-	-
3 Days	0	-	-	-	-	-
>3 Days	0	-	-	-	-	-

Notes: [a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h "MAXIMUM DOSAGE" EXPOSURES IN ST. LOUIS TO O_3 CONCENTRATIONS EXCEEDING 0.08 PPM AND EVR[a] EQUALED OR EXCEEDED 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL NON-OUTDOOR WORKER EXPOSED POPULATION						
Mean Estimate of the Number of People	13,200	6,700	2,400	5,300	0	0
Percent of Total Population	0.8	0.4	0.1	0.3	0	0
Range in this percentage for all runs	0.2-1.7	0.0-1.1	0.0-1.1	0.1-0.6	-	-
Mean Est. of person-Occurrences	13,200	6,700	2,400	5,300	0	0
Percent of total Per.-Occurrences	@	@	@	@	0	0
Range in this percentage for all runs	@-*	@-@	0.0-@	@-@	-	-
Mean Est. of Occurrences/Person Exposed	1.00	1.00	1.00	1.00	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	100	100	100	100	-	-
2 Days	0	0	0	0	-	-
3 Days	0	0	0	0	-	-
4 Days	0	0	0	0	-	-
>4 Days	0	0	0	0	-	-
CHILDREN						
Mean Estimate of the Number of Children	11,700	5,100	2,400	5,100	0	0
Percent of Children Population	3.7	1.6	0.8	1.6	0	0
Range in this percentage for all runs	0.0-9.2	0.0-5.7	0.0-5.9	0.6-3.1	-	-
Percent of Total Exposed Population	88.6	76.1	100.0	96.2	-	-
Mean Estimate of Children-Occurrences	11,700	5,100	2,400	5,100	0	0
Percent of Total Child-Occurrences	*	@	@	*	-	0
Range in this percentage for all runs	0.0-*	0.0-*	0.0-*	@-*	-	-
Mean Estimate of Occurrences/Child Exposed	1.00	1.00	1.00	1.00	-	-
Number of Days/Season (% Exposed)						
1 Day	100	100	100	100	-	-
2 Days	0	0	0	0	-	-
3 Days	0	0	0	0	-	-
4 Days	0	0	0	0	-	-
>4 Days	0	0	0	0	-	-

Notes: [a]Equivalent ventilation rate. It is equal to venti lation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

ESTIMATING OZONE EXPOSURES IN THE WASHINGTON, DC URBAN AREA USING A SECOND-GENERATION PROBABILISTIC VERSION OF NEM

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File: WASH.DC

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) currently is reviewing the ozone (O_3) primary national ambient air quality standard (NAAQS) to determine if the existing standard protects public health with an adequate margin of safety. In order to evaluate whether alternative O_3 NAAQSs provide an adequate margin of safety, the EPA Office of Air Quality Planning and Standards (OAQPS) assesses such factors as the nature and severity of health effects associated with O_3 exposure, the degree of total human exposure (i.e., indoor and outdoor) to O_3, and the risks (probabilities) of ozone-related health effects occurring in the exposed population when alternative O_3 NAAQS are just attained. This paper discusses an EPA analysis of O_3 exposure estimates for parts of the Washington, DC metropolitan area which employed the pNEM/O3 model developed by International Technology-Air Quality Services (IT-AQS). A report by Johnson, et al. (1) describes this model in detail and presents initial results of applying it to nine U.S. urban areas, including Washington, DC. Exposure estimates for parts of the Los Angeles area are discussed in an EPA memorandum (2) that was reviewed by the Clean Air Science Advisory Committee (CASAC) at a public meeting. Exposure estimates for the Philadelphia area are described in an AWMA paper (3). Exposure estimates for Houston are described in an AWMA specialty conference paper (4). New York, Chicago, Denver, and Miami results are contained in EPA papers (5-8). Additional analyses of O_3 exposure estimates for St. Louis, the last urban area modeled, will be forthcoming.

OVERVIEW

Pursuant to section 108 of the Clean Air Act, the Environmental Criteria Assessment Office (ECAO) within the Office of Research and Development (ORD) is preparing a criteria document (9) for O_3. This document will be a comprehensive summary and critical assessment of the latest scientific research relevant to assessing the effects of a criteria pollutant. The document will be reviewed by CASAC, part of the EPA's independent Science Advisory Board, and by the general public. Upon completion of the criteria document, OAQPS will prepare a Staff Paper that summarizes and integrates scientific information presented in the criteria document considered to be most relevant to decisions on alternative NAAQS and various analyses (e.g., air quality, exposure, and risk).

An important aspect of health risk assessment is an analysis of population exposure (10). Such an analysis provides the population basis for "headcount risk" estimates developed as part of EPA's NAAQS risk assessment work. Estimates of population exposure also provide important information regarding the number of people that may experience varying levels of O_3 as they go through their daily activities.

Since 1980, OAQPS has used the NAAQS Exposure Model (NEM) to analyze human exposure associated with the "criteria air pollutants" covered by Title I of the Clean Air Act, as amended. Recent versions of this model use Monte Carlo analyses to define numeric

values for certain variables inherent in the model. These version of NEM are called pNEM, an acronym for "probabilistic" NEM. To differentiate among the various pollutant-specific versions of pNEM, the one described here is denoted as pNEM/O3.

Analysis of population exposure under alternative O_3 NAAQS requires that significant factors contributing to total human exposure be taken into account. These factors include the temporal and spatial distribution of people and O_3 concentrations throughout an urban area, the variation of ozone levels within each microenvironment, and the effects of exercise (increased ventilation) on ozone uptake in exposed individuals.

To date, the most recent version of pNEM/O3--the "second generation" version--has been applied to nine major urban areas. These areas vary in size from Denver with 1.4 million people to New York with over 10.6 million people. pNEM/O3 partitions all land within a selected urban area into large "exposure districts." The number of exposure districts defined for each urban area varies from 6 to 16 in the set of nine areas recently modeled; the number of districts reflects the number of monitors having valid air quality data in a study area. Most of the nine urban areas have 10 or more districts within their boundaries.

People living within each exposure district, as estimated by the U.S. Bureau of Census in 1990, are assigned to a single discrete point, the population centroid. O_3 air quality within each exposure district is estimated for each hour of the O_3 season using data from a nearby monitoring site. Because O_3 in the ambient air generally is modified considerably when entering a building or vehicle, outdoor O_3 estimates are adjusted using a mass-balance model to account for 3 indoor microenvironments. These microenvironments are: indoors-at-home, indoors-other, and within a motor vehicle. The mass-balance model used in pNEM/O3 is a simplified version of the generalized Nagda, Rector, and Koontz (NRK) model (11). For our use, this model was revised to incorporate the assumption that indoor decay rate is proportional to indoor O_3 concentration. It was further revised to incorporate assumptions concerning ozone decay rates suggested by Weschler, et al (12). The resulting revised mass-balance model is fully described in Ref. 1.

Because both the intake dose received and susceptibility to effects of pollution may vary with age, occupation, and intensity of exercise, the total population of each study area is divided into nine age-occupation (A-O) groups. Each A-O group is further subdivided into cohorts depending upon (1) the type of air conditioning system present in the home, if any, and (2) home-to-work commuting patterns.

While many types of exposure metrics are provided by pNEM/O3, only those for the non-outdoor working population in Washington, DC are discussed in this paper. Exposure estimates for children are included in the results discussed here. Estimates for outdoor workers--a major population sub-group of concern from an O_3 exposure perspective--will be completed in the Fall of 1994.

It should be noted that all versions of pNEM systematically underestimate the highest part of the exposure distribution. (See Ref. 1 for an evaluation of pNEM/O3 results against real-time personal exposure monitoring data.) Thus, results presented here have a downward bias.

AIR QUALITY SCENARIOS INVESTIGATED

Six air quality scenarios were modeled for the Washington, DC urban area (and the other eight urban areas); the scenarios are all on a daily maximum basis. They are:

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Ex stands for "expected exceedances," as defined by EPA in 40 Code of Federal Regulations 50.9, and h is the usual symbol for hour(s). Thus, a full description of the first alternative NAAQS scenarios is: attain the 1 hour daily maximum-one expected exceedance NAAQS of 0.12 ppm. The other standards follow the same format. The 5Ex NAAQS would allow 5 daily exceedances per year, on average, if they were implemented.

The iterative adjustment procedure used by IT-AQS to simulate just-attaining the 5 alternative NAAQS listed above involves a complex procedure of fitting Weibull equations to the 1991 O_3 data, modifying parameters of the equations so that the "worst" monitor just achieves the desired standard, and then re-specifying the entire O_3 pattern for all districts in Washington, DC. The procedure is described in detail by Johnson, et al. (1).

Washington, DC had moderate O_3 air quality in 1991 in that its "design value"--the second-highest 1h daily value measured at any site in the urban area--was 0.174 ppm. This value is considerably above the current O_3 standard concentration of 0.12 ppm. The area also had a number of relatively high 8h daily maximum concentrations in 1991.

WASHINGTON, DC RESULTS

Results are based upon 10 runs (realizations) of the pNEM/O3 model for each air quality scenario. Based on a previous analysis of sets of 10-run results versus a 108-run result (13), the author believes that results from only 10 runs of the model will adequately predict the mean and variance observed in 100 or more runs of pNEM/O3. Ten runs of the model will not, however, adequately represent the entire range of possible outcomes. Additional runs can only increase this range. This is an obvious shortcoming of the analyses presented here, but limited resources preclude undertaking more runs.

This paper includes tabular data on (1) the number and percent of people and children exposed, and (2) the number and percent of person-occurrences for children and the adult, non-outdoor worker population in Washington, DC. (A person-occurrence is the metric that focuses on an event: when the exposure-of-concern is reached regardless of who reaches it. One hundred person-occurrence could be 10 people experiencing the exposure 10 times, 100 people experiencing it once, one person experiencing it 100 times, or any combination thereof.) Even though data are discussed here regarding the absolute and relative number (percentage) of people exposed, it must be noted that "people" should not be used as an exposure metric. The cohort-specific activity-days data base used for pNEM/O3 modeling (and for all other exposure models that use human activity information) provides no more than three days of data for a single individual. Thus, rigorous inferences from these data can be made only to "person-days" of exposure or "person-occurrences" of exposure, where an occurrence can be 1h, 8h, or 24h time period in pNEM/O3. Only when activity data are available sequentially for an entire year for individuals in a cohort can inferences be made to people exposed over the year (or to children, or to outdoor workers as the case may be). This point usually is ignored in the general exposure assessment literature.

All exposure estimates presented in this paper pertain to "daily maximum dose," (MAXD) where dose is defined as the product of ozone concentration and ventilation rate over a defined time period. Note that maximum daily dose does not necessarily occur during the time period of maximum ozone concentration in a given urban area.

Ventilation rate is a very important factor in estimating total dose for any air pollutant (14). The ventilation rate metric used in pNEM/O3 is "equivalent ventilation rate" (EVR), or ventilation rate (in liters per minute) divided by body surface area (BSA, in units of m^2). EVR has units of $l\ min^{-1}\ m^{-2}$. It is a surrogate indicator for the number of O_3 molecules that enter the oral-nasal cavities per unit time period.

The Washington, DC urban area population analyzed here includes 3.1 million NOW (non-outdoor worker) people and 488,000 children. There are 660 million possible daily maximum NOW person-occurrences (NOW people x 214 days in the O_3 season). The equivalent figure for children is 104 million.

Exposure results appear in Tables 1 and 2. Table 1 includes 1h daily maximum dose exposure estimates, while Table 2 provides similar results for 8h exposure estimates.

The 1h results indicate that:

1. Currently (1991), it is estimated that 1.5% of NOW people and children would experience a daily maximum dose (MAXD) O_3 exposure @ >0.12 ppm @ an EVR of 30 $l\ min^{-1}\ m^{-2}$ or higher, which is thought by many researchers to be a dose rate of concern (14). About 16% of the NOW people so exposed are children, and most MAXD exposures occur only on one day/O_3 season.

2. Attainment of the alternative NAAQS investigated are expected to substantially decrease NOW people exposures to the 1h MAXD of concern, and eliminate children exposures to that dose rate. None of the 1h MAXD exposures of concern occur on more than one day/O_3 season for the alternative NAAQS.

While not shown in Table 1, the estimates of O_3 exposures >0.12 ppm at <u>any</u> exercise level are considerably higher than the numbers presented in that Table. For instance, currently (1991) about 1.8 million adults and 359 thousand children are predicted to experience one or more daily exposure >0.12 ppm when exercise level is ignored. This is about 58% of the adult population and 74% of the children in the Washington, DC urban area. (As compared to 1.5% adult and children exposure, on average, @ 30 EVR exercise.) Thus, exercise level, and its associated ventilation rate, at maximum dose greatly affects pNEM/O3 MAXD exposure estimates.

The 8h results (Table 2), indicate that many more people may be exposed. The level of concern here is a MAXD exposure of >0.08 ppm for 8h @ an EVR $\geq$15 l min^{-1} m^{-2}. (Obviously, the EVR of concern drops as the averaging period increases, just as the O_3 concentration of concern drops. People cannot hold an EVR of 30 l min^{-1} m^{-2} for an extended period of time (15).)

The 8h results indicate that:

1. Currently (1991), about 3% of the NOW population and 15% of the children are estimated to experience the 8h MAXD of concern. These exposures mostly occur on only one day/season, but some adults and children could see up to 3 days of MAXD exposures >0.08 ppm @ 15+ EVR.

2. Attaining the alternative NAAQS that were investigated do not guarantee no 8h MAXD exposures of concern--except for the very stringent 8h 5Ex 0.06 ppm NAAQS. Attaining the 8h 1Ex 0.10 ppm O_3 standard in Washington, DC could result in over 2% of children exposed to the concern dose. Many of these exposures could occur on more days--about 15%. Attaining the current standard (1h 1Ex 0.12 ppm) could result in over 1% of children being so exposed at exercise. Both of these estimates are relatively high when compared to results from the other urban areas than were modeled (2-8).

Putting the 8h MAXD estimates into perspective, the results indicate that currently (1991) 2.4 million NOW people might experience an 8h exposure >0.08 ppm @ any exercise level. (In other words, when exercise is ignored; this estimate is not shown in Table 2.) This compares to 91 thousand people estimated to experience the same O_3 air quality concentration @ 15 EVR or higher. The corresponding estimates for children are 443,000 exposures at any exercise level versus 73,900 at 15+ EVR. Thus, exercise level certainly makes a large difference when 8h exposures to specific O_3 concentration levels are being estimated.

For the record, the 8h any-exercise estimates for the non-zero alternative NAAQS are:

	8h 1Ex 0.10	8h 5Ex 0.08	1h 1Ex 0.12	8h 1Ex 0.08
NOW People	623,200	197,600	459,900	44,700
(%)	20.2	6.4	14.9	1.4
Children	152,000	57,100	109,600	9,000
(%)	31.2	11.7	22.5	1.8

Contrast these estimates with those appearing in Table 2 for insight into the impact of exercise level on exposure estimates. The any-exercise estimates are 1-1.5 orders of magnitude higher than the $\geq$15 EVR estimates.

Note that all of the estimates have variability, reflecting the Monte Carlo sampling process that produces a different estimate for each run. The range in the estimates are between a factor of 2-to-3 in most cases, which seems reasonable.

Statistical tests of the exposure distributions were undertaken using a two-sample Kolmogorov-Smirnov (K-S) non-parametric test. The null hypothesis was that the cumulative frequency exposure distributions for the various air quality scenarios are the same for each exposure metric being tested. The test statistic was the maximum difference between the two distributions (Dn); it was evaluated using a large-sample F statistic. The significance level is 0.05, using the chi-square approximation. The test indicates that the exposure indicators shown in Tables 1 and 2 vary significantly across the six air quality scenarios with the following exceptions.

For the AsIs and 8h 1Ex 0.10 ppm pair:

> Number of NOW people and children expected to be exposed to 8h 0.08 ppm levels at 15+ EVR exercise levels.

For the current standard and 8h 1Ex 0.10 ppm pair:

> All exposure indicators that were investigated except for NOW people and NOW-occurrences at 8h 0.08 ppm at any exercise level.

For the current standard and 8h 5Ex 0.08 ppm pair:

> NOW people, NOW-occurrences, and the number of people exposed on 1 day/O_3 season at 1h >0.12 ppm at $\geq$30 EVR.
>
> Children and children-occurrences exposed to 1h >0.12 ppm at any exercise level.

For the 8h 1Ex 0.08 ppm and 8h 5Ex 0.08 ppm pair:

> NOW people, NOW-occurrences, and the number of people exposed on 1 day/O_3 season at 1h >0.12 ppm at ≥30 EVR.

The results of the K-S testing procedure undertaken in Washington, DC are similar to those for Miami (8). Many exposure indicator pairs could not be distinguished with respect to attaining some of the alternative NAAQS in both areas. These standards do not make much impact for the indicators listed above. However, there is no real consistent pattern among the exposure metrics and air quality standard pairs that were tested.

Note that these are not strong statistical tests and that some of the K-S test requirements were not met. Random sampling was not used. The sample "observations" simply are results of a simulation model; the population of interest, then, can only be the set of possible outcomes produced by the model. A large-sample test statistic was applied to small samples (10 runs). These caveats aside, 24 "cannot rejects" out of 145 tests is three times as many as are expected based on a "pure-chance" probability of rejecting a true hypothesis (5%). This 17% cannot-reject rate is about double the rates seen in most of the urban areas that were analyzed (2-8). Unlike most of these areas, there is not a clear-cut picture produced by the K-S testing exercise in Washington, DC. There is not a consistent pattern--especially at exercise--associated with the alternative NAAQS investigated.

SUMMARY

The analyses of 5 alternative standards ozone NAAQS in the Washington, DC area (1h 1Ex 0.12 ppm; 8h 1Ex 0.10 pm; 8h 5Ex 0.08 ppm; 8h 1Ex 0.08 ppm; and 8h 5Ex 0.06 ppm) indicate that attainment of any of the alternatives will sharply reduce--but not completely eliminate--exposures to 1h and 8h MADs of concern. In particular, attaining the current standard (1h 1Ex 0.12 ppm) and the 8 1 Ex 0.10 ppm alternative NAAQS does not protect a small, but important, percentage of children from experiencing the 8h MAXD of 0.08 ppm at ≥15 EVR. The current standard is more protective than the 8h 1Ex 0.10 ppm alternative.

The reader should remember the early caveat about the downward bias inherent in pNEM results. While every effort has been made to present "best estimates," it is inherently difficult to predict the upper end of the population exposure distribution using human activity data bases that consist of only 1-3 days of information and that also under-represent adults and children who exercise regularly. Year-long activity data from all segments of the population are needed to adequately estimate the true population exposure distribution.

REFERENCES

1. T. Johnson, J. Capel, and M. McCoy. **Estimation of Ozone Exposures Experienced by Urban Residents Using a Probabilistic Version of NEM and 1990 Population Data.** Durham, NC: IT-AQS, 1993 (Draft).

2. T. McCurdy. "Los Angeles Ozone Exposure Estimates," **EPA Memorandum;** November 4, 1993.

3. T. McCurdy, et al. "Estimating Ozone Exposures in Philadelphia Using a Second-Generation Probabilistic Version of NEM." **Paper A210 presented at the 87th Annual Meeting of AWMA**; Cincinnati, June 1994.

4. T. McCurdy, et al. "Estimating ozone Exposures in Houston Using a Second-Generation Probabilistic Version of NEM." **Paper presented at the Tropospheric Ozone Specialty Conference,** Air and Waste Management Association; Orlando, 1994.

5. T. McCurdy. "Estimating Ozone Exposures in the New York Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, February 1994.

6. T. McCurdy. "Estimating Ozone Exposures in the Chicago Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

7. T. McCurdy. "Estimating Ozone Exposures in the Denver Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

8. T. McCurdy. "Estimating Ozone Exposures in the Miami Urban Area Using a Second-Generation Probabilistic Version of NEM." **EPA Paper**, March 1994.

9. Environmental Criteria and Assessment Office. **Air Quality Criteria for Ozone and Photochemical Oxidants.** Research Triangle Park, NC: 1994 (Draft).

10. H.M. Richmond and T. McCurdy. "Use of Exposure Analysis and Risk Assessment in the Ozone NAAQS Review." **Paper 88-121.3 presented at the 81st Annual Meeting of APCA**; Dallas, June 19-24, 1988.

11. N.L. Nagda, H.E. Rector, and M.D. Koontz. **Guidelines for Monitoring Air Quality.** Washington, DC: Hemisphere Pub. Co., 1987.

12. C.J. Weschler, H.C. Shields, and D.V. Nike. "Indoor Ozone: Recent Findings," in: R. Burglund (ed.), **Tropospheric Ozone in the Environment II.** Pittsburgh: Air & Waste Management Association, 1992.

13. T. McCurdy. "Testing pNEM/O3 Runs to Determine if a Set of 10 Runs is 'Representative'," **EPA Memorandum;** April 19, 1994.

14. W.C. Adams. **Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities.** Davis CA: University of California, 1993.

15. M. Absil, P. Narducci, R. Whitfield, and H.M. Richmond. "Chronic Lung Injury Risk Estimates for Urban Areas Having Ozone Patterns Similar to Those in the Northeast." Paper presented at the **AWMA Specialty Conference on Tropospheric Ozone and the Environment II**; Atlanta, November 4-7, 1991.

Table 1. ESTIMATES OF 1h "MAXIMUM DOSAGE" EXPOSURES IN WASHINGTON, DC TO O_3 CONCENTRATIONS EXCEEDING 0.12 PPM AND EVR[a] EQUALED OR EXCEEDED 30 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL EXPOSED POPULATION						
Mean Estimate of the Number of People	45,800	1,900	400	800	0	0
Percent of Total Population	1.5	0.1	*	*	0	0
Range in this percentage for all runs	0.7-2.0	0.0-0.1	0.0-0.1	0.0-0.1	-	-
Mean Est. of Person-Occurrences	46,000	1,900	400	800	0	0
Percent of Total Per-Occurrences	*	@	@	@	0	0
Range in this percentage for all runs	@-*	0.0-@	0.0-@	0.0-@	-	-
Mean Est. of Occurrences/Person Exposed	1.0	1.00	1.00	1.00	-	-
Number of Days/Season Exposed (% Exposed)						
1 Day	99	100	100	100	-	-
2 Days	1	0	0	0	-	-
3 Days	0	0	0	0	-	-
>3 Days	0	0	0	0	-	-
CHILDREN						
Mean Estimate of the Number of Children	7,300	0	0	0	0	0
Percent of Children Population	1.5	0	0	0	0	0
Range in this percentage for all runs	0.0-4.8	-	-	-	-	-
Percent of Total Exposed Population	15.9	0	0	0	-	-
Mean Estimate of Children-Occurrences	7,300	0	0	0	0	0
Percent of total Child-Occurrences	*	0	0	0	0	0
Range in this percentage for all runs	0.0-*	-	-	-	-	-
Mean Estimate of Occurrences/Child Exposed	1.00	-	-	-	-	-
Number of Days Exposed/Season (% Exposed)						
1 Day	100	-	-	-	-	-
2 Days	0	-	-	-	-	-
3 Days	0	-	-	-	-	-
>3 Days	0	-	-	-	-	-

Notes:[a]Equivalent ventilation rate. It is equal to ventilation rate/body surface area; units are in $l\ min^{-1}\ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.

Table 2. ESTIMATES OF 8h "MAXIMUM DOSAGE" EXPOSURES IN WASHINGTON, DC TO O_3 CONCENTRATIONS EXCEEDING 0.08 PPM AND EVR[a] EQULAED OR EXCEEDED 15 ONE OR MORE TIMES PER OZONE SEASON UNDER SIX AIR QUALITY SCENARIOS

Statistic	As Is Situation (1991)	Attain 8h 1Ex 0.10 ppm	Attain 8h 5Ex 0.08 ppm	Attain 1h 1 Ex 0.12 ppm	Attain 8h 1 Ex 0.08 ppm	Attain 8h 5 Ex 0.06 ppm
TOTAL NON-OUTDOOR WORKER EXPOSED POPULATION						
Mean Estimate of the Number of People	90,600	12,300	1,300	9,100	400	0
Percent of Total Population	2.9	0.4	*	0.3	*	0
Range in this percentage for all runs	1.6-5.0	0.1-0.0	0.0-0.2	0.0-1.0	0.0-0.1	-
Mean Est. of person-Occurrences	96,500	13,900	1,300	9,100	400	0
Percent of total Per.-Occurrences	*	@	@	@	@	0
Range in this percentage for all runs	@-*	@-@	0.0-@	0.0-@	0.0-@	-
Mean Est. of Occurrences/Person Exposed	1.06	1.13	1.00	1.00	1.00	-
Number of Days/Season Exposed (% Exposed)						
1 Day	94	87	100	100	100	-
2 Days	5	13	0	0	0	-
3 Days	1	0	0	0	0	-
4 Days	0	0	0	0	0	-
>4 Days	0	0	0	0	0	-
CHILDREN						
Mean Estimate of the Number of Children	73,900	11,000	1,300	5,800	400	0
Percent of Children Population	15.2	2.3	0.3	1.2	0.1	0
Range in this percentage for all runs	7.2-27.0	0.3-5.3	0.0-1.5	0.0-5.5	0.0-0.8	-
Percent of Total Exposed Population	81.6	89.4	100.0	63.7	100.0	-
Mean Estimate of Children-Occurrences	79,800	12,600	1,300	5,800	400	0
Percent of Total Child-Occurrences	0.1	*	@	*	@	0
Range in this percentage for all runs	*-0.1	@-*	0.0-@	0.0-*	0.0-@	-
Mean Estimate of Occurrences/Child Exposed	1.08	1.15	1.00	1.00	1.00	-
Number of Days/Season (% Exposed)						
1 Day	93	85	100	100	100	-
2 Days	6	15	0	0	0	-
3 Days	1	0	0	0	0	-
4 Days	0	0	0	0	0	-
>4 Days	0	0	0	0	0	-

Notes: [a]Equivalent ventilation rate. It is equal to venti lation rate/body surface area; units are in $l \ min^{-1} \ m^{-2}$

*Less than 0.05% but > 0.005%

@Less than 0.005% but >0.