EVALUATION OF THE DISPERSION ALGORITHMS USED IN EPA'S HUMAN EXPOSURE MODEL

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ETO STUDY GROUP
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Prepared by
Bruce A. Egan
David W. Heinold
Robert T. Schlaak

ENVIRONMENTAL RESEARCH & TECHNOLOGY, INC.
696 Virginia Road, Concord, Massachusetts 01742

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1. INTRODUCTION

The Ethylene Oxide (ETO) Study Group of the Chemical Manufacturers Association (CMA) has retained ERT, Inc. to evaluate dispersion algorithms of U.S. EPA's Human Exposure Model (HEM) as it has been applied in the EPA assessment of ambient ETO concentrations. Specific objectives of ERT's efforts are to identify the strengths, weaknesses, and areas for improvement of the model based upon comparisons with other widely used and state-of-the-art modeling techniques. The areas which may lead to the modeling uncertainty or inaccuracy are prioritized. Based on these results, ERT provides recommendations for further study.

Two types of potential uncertainty are associated with the EPA's application of HEM to ETO, input data error and modeling error. While this study will focus on the performance of the model in comparison to other techniques, the way in which the model was used is ultimately of equal importance to any ETO impact assessment.

The HEM approach used by EPA to assess the potential long-term health impacts of ETO from manufacturing facilities is based on the standard univariate Gaussian algorithms found in the U.S. EPA Climatological Dispersion Model (CDM). This model computes long-term (e.g., annual) concentrations for both point and area sources. Emissions from each source are assumed to be distributed uniformly in the crosswind direction within each of sixteen 22.5° wind direction sectors. The frequencies of transport in each sector is determined by a climatological wind frequency (wind rose). The vertical pollutant distribution is governed by the Gaussian distribution with reflection from both the surface and an elevated inversion. The long-term concentration of any particular location is determined by adding up the product of the computed concentration and frequency for each meteorological category (wind speed, wind direction, stability).

Predicted long-term ETO concentrations are assumed to be indicative of lifetime exposure in the vicinity of each ETO manufacturing facility. Lifetime carcinogenic risk is then computed by calculating the overall population-weighted dose and multiplying by an upper limit estimate of carcinogenic potency.

2. DISPERSION ALGORITHMS

The physical characterization of ETO dispersion by HEM has been critically analyzed in terms of the following components: building wake effects, plume rise, urban/rural dispersion coefficients, terrain treatment, wind frequency distribution and atmospheric fate. The major findings are discussed briefly below.

2.1 Building Wake Effects

Building downwash is an important consideration for ETO because most emissions come from short stacks and vents that are subject to the additional turbulent mixing caused by the presence of buildings. HEM computes the effects of building wakes on plumes by incorporating a method described below into CDM, which does not explicitly treat downwash effects. The method accepted by EPA in regulatory applications is the algorithm found in the Industrial Source Complex (ISC) model. ERT has recently modified the ISC algorithm to more realistically treat downwash effects.

The effects of downwash in univariate Gaussian dispersion models are represented by an enhancement of the vertical dispersion parameters. HEM calculates this enhancement by effectively setting $\sigma_z' = \text{constant} \cdot A^{1/2}$ where "A" is the cross-sectional area of the building. Although Briggs states that the constant should be a function of the building shape a single value is used in HEM such that dispersion can be highly geometry dependent close to the source.

In the ISC algorithm vertical dispersion enhancement increases with downwind distance out to a distance of 10 building heights (h_b) and is constant thereafter according to the equation:

$$\sigma_z' = 0.7\ h_b + 0.067\ (x-3h_b)$$

where x is a downwind distance from 3 h_b to 10 h_b. (For buildings that are taller than they are wide h_b is replaced by the building width).

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TABLE 2-1

COMPARISON OF GROUND LEVEL ANNUAL AVERAGE IMPACT FROM A ROOFTOP RELEASE

		ISC/ERT	HEM Cubic*	HEM Squat*
x = 100 m				
Stability	A	0.8	0.9	0.8
	B	5.5	5.5	6.2
	C	5.9	4.3	6.6
	D	19.1	5.2	16.2
	E	23.5	4.0	21.7
	F	30.3	0.3	7.4
Total		85.0	20.2	58.8
x = 300 m				
Stability	A	0.3	0.2	0.2
	B	2.0	1.8	1.6
	C	2.2	2.2	2.1
	D	7.1	6.1	7.1
	E	8.7	5.4	8.6
	F	4.3	0.7	3.2
Total		24.6	16.4	22.7

*cubic building - h_b = 30m, W_b = 30m
squat building - h_b = 30m, W_b = 120m

vents that may be appropriate for many ETO sources. For these situations, plume rise is generally negligible and, therefore, ignored in modeling assessments.

2.3 Urban/Rural Dispersion

HEM uses the standard Turner (1969) pollutant dispersion rates for the vertical and a 22.5° section average for the horizontal. This type of treatment of horizontal mixing is appropriate for such long-term climatological models and is standard practice. The unique feature of the model is that it uses a seven stability classification scheme that differs for rural and urban areas. In rural areas neutral stability at night is modeled as slightly stable. In urban areas neutral stability is assumed for all point sources whenever the wind rose specifies stable conditions. For area sources all stabilities are shifted downward to the more unstable category for urban conditions.

The theory behind this adjustment for urban areas is that the atmosphere over urban areas is usually unstable due to roughness and the heat island effect even when the adjacent rural areas are stable. Similar methods are commonly employed by other dispersion models to adjust the rural Turner dispersion rates. Another method that may be more appropriate for urban areas is to use an alternate set of dispersion coefficients such as used in EPA's RAM-Urban model.

The major differences between these treatments of urban dispersion are manifested when assessing releases from tall stacks (e.g. $\geq$ 50 m). For th relatively low emission heights common to ETO sources, the treatment of urban dispersion is a much less critical factor and, therefore, does not contribute appreciably to modeling uncertainty.

2.4 Terrain Treatment

The HEM model assumes that all receptors are at a common elevation with respect to an emission source. For emission points affected by building downwash or otherwise close to the ground terrain affects are not likely to be important, especially on a long-term average basis. This is more complex than this equation implies, not enough is presently known about the details of these mechanisms to warrant the use of a more sophisticated approach.

3. HEM APPLICATION FOR ETO

The ETO exposure assessment performed by EPA for production facilities made use of a mixture of site-specific and generic data that was input into HEM. Site-specific data included (1) annual emissions from point and area sources, (2) spatial distribution of population density and (3) meteorological frequency data. Generic data was used for source characteristics and location, and decay rate. Given that the purpose of the EPA assessment is to derive an overall U.S. population-based risk to ETO site-to-site inequities are not likely to be important. However, the risk associated with an individual facility may be misrepresented by the EPA assessment.

ERT has proposed an extension of the present study to quantitatively evaluate the inaccuracies of the EPA impact assessment for ETO. Given that the ETO study committee of CMA has decided at this time not to go forward with this effort only a qualitative discussion is possible.

Emission rates are the single most important data used in the impact assessment because exposure is directly proportional. In addition, the characterization of various emission sources at each plant (e.g., ground level vs., elevated, point vs. area, building dimensions) will have a bearing on projected ambient impacts. In the EPA assessment estimated emissions are distributed by source type using generic values of stack height, etc. All emissions are assumed to be centered at a single location with the nearest off-site receptors forming a circle at a fixed distance. This could lead to a significant overestimation of maximum individual risk. For these reasons better information on emission rates is very important.

The wind frequency data were generated from available wind roses tabulated from nearby airport records by the National Climatic Center. The length of the data used to predict a lifetime dose ranges from 5 to 20 years. This is probably adequate to assess inter-annual variability of meteorological or coastal effects, the available wind rose data used by EPA may not be representative at some plant sites. Since the population is not uniformly distributed, this could lead to

4. CONCLUSIONS AND RECOMMENDATIONS

ERT's study of the dispersion methodology used in HEM has resulted in the following conclusions:

1. HEM, if used appropriately, is a useful tool to estimate lifetime population-weighted exposure. Because of the artificial source configuration and its relationship to nearest receptors used in the EPA assessment, the maximum individual exposure may be overestimated.

2. The major differences between HEM and other long-term modeling approaches is the treatment of downwash. The algorithm is likely to be no more conservative than other approaches used in regulatory practice but results depend on the specific building geometry.

3. The accuracy of the EPA study for each site could be improved by further data on the following:

   - emissions (rate, location, source type)
   - atmospheric fate of ETO
   - location of nearest fence line and residences to assess maximum individual risk.
   - local meteorological frequency
   - local topography.