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Atmospheric Diffusion for Control Room Habitability Assessments

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Pacific Northwest Laboratory
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ABSTRACT

This report presents the results of an evaluation of the procedure used by the NRC staff to assess nuclear reactor control room habitability. The evaluation is based on experimental data collected in seven sets of field experiments at nuclear power plant sites. The procedure is generally conservative, but the models in the procedure show little skill in predicting the effects of different atmospheric conditions on maximum effluent concentrations in building wakes. Two alternative building-wake models have been developed using the experimental data. The first model differs significantly from current models in the manner in which wind speed enters the model. The second model is an extension of the first model that has more desirable asymptotic behavior and includes consideration of the mitigating effect of plume rise on concentrations in building wakes. A set of nonmathematical guidelines is offered for use in evaluating potential control room air intake locations.

CONTENTS

FIGURES

TABLES

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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) staff assesses the habitability of nuclear reactor control rooms using the Murphy-Campe Procedure, which includes a set of three models for estimating diffusion in building wakes. The Pacific Northwest Laboratory (PNL) was requested to identify and review experimental data pertinent to diffusion in building wakes, to compare the experimental data with Murphy-Campe model diffusion estimates, and to recommend changes to the standard NRC approach or recommend a new approach, as appropriate.

A review of the literature identified 29 experimental data sets for potential use in evaluation of the Murphy-Campe models and procedure. Following screening, data from seven field experiments were included in the data base used for model and procedure evaluation.

The Murphy-Campe procedure is generally conservative, but the models in the procedure show little skill in predicting the effects of different atmospheric conditions on maximum effluent concentrations in building wakes. They perform best for ground-level releases, accounting for about 30% of the variation in the observed centerline concentrations in the data set. They account for significantly smaller fractions of the variability of the concentrations for elevated releases (13%) and almost none of the variability in concentrations at receptors on or near the buildings (<5%).

Two alternative building-wake models have been developed using the experimental data. The first model, which is based on ground-level release data, differs significantly from previous wake models in the manner in which wind speed enters the model. The second model is an extension of the first model that has more desirable asymptotic behavior and includes consideration of the mitigating effect of plume rise on concentrations in building wakes. For ground-level releases, the new models account for about 60% of the variation in observed concentrations in the data set. They have about the same tendency to underpredict concentrations as the Murphy-Campe models, but they have less tendency for large overpredictions. The new models are also slightly better than the Murphy-Campe models in accounting for the variation in concentrations in wakes that result from elevated releases (20%), but they are still poor predictors of concentrations on or adjacent to building surfaces. The failure of the models with respect to this last data set may be the result of the limited number of samples collected on or adjacent to buildings during each experiment.

A set of non-mathematical guidelines is offered for use in evaluating potential control room air intake locations. By following the guidelines, it should be possible to distinguish between good and bad locations, but it may not be possible to determine which of several similar locations is best or worst.

INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) assesses the habitability of nuclear reactor control rooms for a variety of potential accident scenarios. In these assessments, the staff of the Office of Nuclear Regulation estimates atmospheric dispersion in the wakes of buildings using a procedure that includes a set of three models that have become known as the Murphy-Campe models (Murphy and Campe 1974). The procedure, which has limited experimental basis, has been thought to be overly conservative (i.e., predict excessively high concentrations in wakes) for a number of source-receptor configurations. As a result, the NRC contracted with the Pacific Northwest Laboratory (PNL) to identify and review experimental data pertinent to diffusion in building wakes, to compare the experimental results with Murphy-Campe model diffusion estimates, and to recommend changes to the standard NRC approach or recommend a new approach, as appropriate.

The results of the PNL study are presented in this report. The Murphy-Campe models are generally conservative, but they show little skill in predicting the effects of different atmospheric conditions on maximum effluent concentrations in building wakes. An alternative building-wake model has been developed using available experimental data. For ground-level releases, the new model accounts for more than 60% of the variation in maximum concentrations in building wakes; the Murphy-Campe models account for slightly more than 30% of the variation.

Completion of the evaluation of building-wake diffusion data and revision of the building-wake diffusion model provide a basis for the review of applications for operating licenses and the re-review of some licensing actions for operating reactors. These reviews are needed for completion of the TMI action plan requirement III.D.3.4. The results of the study also provide a basis for revision of the treatment of building-wake diffusion in several NRC computer codes including PAVAN (Bander 1982), XOQDOQ (Sagendorf, Goll and Sandusky), IRDAM (Poeton, et al. 1983), MESOI (Ramsdell, Athey and Glantz 1983), and MESORAD (Scherpelz, et al. 1986). Finally, the new model provides insights that may be used in the identification of optimal locations for control room air intakes.

The next three chapters deal with the evaluation of the Murphy-Campe models and procedure. The first of these chapters starts with a brief description of the usual method of estimating atmospheric diffusion in building wakes and ends with a description of the Murphy-Campe procedures and models that are used by the NRC staff. The following chapter discusses experimental data available for use in evaluation of the Murphy-Campe models and procedure, and the last of these chapters discuss the results of the evaluation.

Following the evaluation of the Murphy-Campe models and procedure, the report presents the development of models to be used in estimating maximum concentrations of material released at ground level in building wakes. The development begins with a graphical analysis of the variation of maximum concentrations with distance and wind speed and ends with a multiple linear regression analysis of the data. The result of the regression analysis is a model in which concentrations are a function of projected building area, distance, wind speed, and atmospheric stability. In the next chapter, the regression model is modified to have desirable asymptotic properties, extended for use with elevated releases, and adjusted for regulatory applications.

The final two chapters of the report summarize the finding of the study. The first of these chapters presents a final comparison of the new models with the Murphy-Campe and PAVAN models and makes recommendations regarding the use of the new models. The second chapter presents a set of general guidelines for use in evaluating control room air intake locations without models. These guidelines will differentiate good locations from bad ones, but they may not single out the best location from similar locations.

There are six appendices at the end of the report. Appendix A lists the data from the EBR-II diffusion experiments; these data have not been published previously. Appendices B, C, and D contain the data sets used in the study. Appendix E presents supplementary information from the regression analysis and an examination of the sensitivity of the model to variations in parameter values. Finally, Appendix F contains a FORTRAN implementation of the new model.

CURRENT BUILDING-WAKE DIFFUSION MODELS

Atmospheric diffusion is a process in which turbulent air motions spread material that has been released to the atmosphere. This chapter provides a brief description of models that are used to describe the spread of the material. The models discussed are simple models that are frequently used in regulatory applications. In the first part of chapter the discussion is general; the Murphy-Campe models and procedure are discussed specifically in the second part of the chapter.

A SIMPLE BUILDING-WAKE DIFFUSION MODEL

In many situations in the absence of buildings, atmospheric diffusion is adequately described by a straight-line Gaussian model. One common form of the Gaussian diffusion model is

$$\chi/Q = (\pi\ U\ \sigma_y\ \sigma_z)^{-1}\ F(y)\ G(z) \qquad (1)$$

where χ/Q = normalized concentration in the plume (s/m^3)

σ_y, σ_z = lateral and vertical diffusion coefficients evaluated for given atmospheric stability and distance between the source and receptor (m)

U = the mean wind speed at 10 m (m/s)

F(y) = an exponential term that describes the off-axis reduction in concentration in the horizontal

G(z) = an exponential term that describes the off-axis reduction in concentration in the vertical.

This model assumes that the receptor is at ground level and that the ground acts as a reflecting surface. Its derivation is described in many texts (cf. Gifford 1968, or Barr and Clements 1984).

Numerous diffusion experiments have been performed to evaluate the diffusion coefficients in the Gaussian model. In general these diffusion experiments have been conducted at relatively flat locations where the surface roughness is minimal. Consequently, the diffusion coefficient parameterizations that have been developed from the experimental data reflect the atmospheric turbulence of these locations. As air flows past a building, the building increases the turbulence which results in more rapid diffusion downwind of the building than would otherwise be expected. Building-wake diffusion models attempt to account for this additional turbulence.

Straight-line Gaussian models have been modified in several ways to account for the increased turbulence in building wakes. These modifications typically involve either adding a term to the model that includes the projected area of the building or redefining the diffusion coefficients so that they have minimum values that are related to building dimensions. For example, the normalized concentration on the plume axis in the wake of a building may be estimated by

$$\chi/Q = [(\pi \sigma_y \sigma_z + cA) U]^{-1} \tag{2}$$

where c is a building wake constant which typically has a value of 0.5, and A is the minimum projected area of the building (m^2).

This modification, which has been attributed to Fuquay (Gifford 1960), is presented in Regulatory Guide 1.145 (NRC 1982) and is incorporated in the PAVAN (Bander 1982) and XOQDOQ (Sagendorf, Goll and Sandusky 1982) computer codes. An algebraically equivalent form of this modification is

$$\chi/Q = (\pi \Sigma_y \Sigma_z U)^{-1} \tag{3}$$

where Σ_y is $(\sigma_y^2 + cA/\pi)^{1/2}$, and Σ_z is $(\sigma_z^2 + cA/\pi)^{1/2}$.

Definitions of Σ_y and Σ_z that are based on building width and height rather than area have also been suggested (e.g., Huber and Snyder 1976 and 1982).

These modifications have the desirable asymptotic property that at large distances from the source the concentrations estimated by the wake model are essentially the same as concentrations estimated by the unmodified model. However, the concentration estimates near the source are relatively independent of distance from the source. This property of the modified models is not particularly realistic and may be inappropriate for models used in evaluating control room habitability.

MURPHY-CAMPE MODELS AND PROCEDURE

The procedure used by the NRC staff in evaluating control room habitability is based on the procedure described by Murphy and Campe (1974) that uses three atmospheric dispersion models. The specific model to be used in an evaluation is selected from the three models on the basis of source-receptor geometry.

When both the source and the receptor are essentially points and the difference in elevation between the point and receptor is less than 30% of the height of containment, atmospheric dispersion is estimated using

$$\chi/Q = (3\pi U \sigma_y \sigma_z)^{-1}. \tag{4}$$

Equation (4) is the straight-line Gaussian model that assumes that the plume is at ground level and that the diffusing material is reflected by the ground. The three in the denominator is a building wake factor taken from Regulatory Guides 1.3 and 1.4 (NRC 1974 a and b) to account for the additional turbulence in building wakes. It should be noted that application of this model to an elevated release and an elevated receptor is contrary to the ground-level assumption made in deriving the equation.

In the following three situations--point source and point receptor with a difference in elevation greater than 30% of the containment building height, diffuse source and point receptor, and point source and volume receptor--the normalized concentration is computed using

$$\chi/Q = \{U\ [\pi\sigma_y\ \sigma_z + A/(K + 2)]\ \}^{-1} \quad (5)$$

where $K = 3/(s/d)^{1.4}$

s = the distance from the surface of the containment building to the receptor (m)

d = the diameter of the containment building (m)

A = the minimum projected area of the containment building (m^2)

Equation (5) is the wake model given in Equation (3) with the expression 1/(K+2), replacing the building wake constant. For receptors very near the containment building, K becomes large and reduces the effect of the building wake on diffusion. As the distance between the containment building and the receptor increases, K decreases so that the value of the expression approaches 0.5, which is the value generally given to the wake constant. Equation (5) has the same asymptotic behavior as Equation (2) at large distances from the source, but it also asymptotically approaches the straight-line Gaussian model near the source.

The third Murphy-Campe model is used for point or diffuse sources when there are alternate receptors. In this instance, the receptors are assumed to be located in positions to minimize the probability that both receptors are contaminated at the same time. Several meteorological scenarios can lead to simultaneous contamination of two receptors including wind reversals and meandering. A third, and more likely, scenario involves near calm winds during which the released material spreads out in all directions. In this situation, normalized concentrations are estimated using

$$\chi/Q = (2\ \pi\ U\ L\ x)^{-1} \quad (6)$$

where L is the containment height divided by $2^{1/2}$ (m), and x is the distance from the release point to the closest receptor (m).

The containment height is divided by $2^{1/2}$ for consistency with NRC policy to limit the wake factor to one-half the projected area of the containment building. Equation (6) essentially describes model in which material is uniformly dispersed in air flowing through a pipe with rectangular cross section. The cross-sectional dimensions of the pipe are L and $2\pi x$.

This model has a problem because the scenarios in which it is to be used explicitly assume that the wind speed is near zero (at least no mean direction is defined and therefore the mean wind speed is zero). However, as the mean wind speed is allowed to approach zero, χ/Q in Equation (6) becomes undefined.

This problem is avoided numerically by assuming a minimum wind speed, which is typically in the range of 0.5 to 1 m/s.

Design Criterion 19 of Appendix A of 10 CFR 50 requires that control rooms for nuclear power plants be designed so that control room personnel will not receive in excess of 5 rem whole body radiation or its equivalent to any part of the body during the duration of an accident. Meteorological conditions that result in concentrations that are exceeded no more than 5% of the time are used. According to Murphy and Campe (1974), typical meteorological conditions are a stable atmosphere (F stability) and a low wind speed (0.5 to 1.5 m/s). The actual conditions used are determined using a building wake dispersion model and a joint frequency distribution for wind direction, wind speed, and atmospheric stability.

Experimental data that have been used to evaluate the Murphy-Campe models and procedure are described in the next chapter. The following chapter presents the results of the evaluation.

BUILDING-WAKE DIFFUSION DATA

Building-wake diffusion data were selected for use in the evaluation of the Murphy-Campe models and procedure in a three-phase procedure. The initial phase was a literature search to identify potential data sets. The potential data sets were evaluated in the second phase, and selected data sets were acquired in the third phase. The reference section lists potential sources of data identified in the first phase of the selection process. It also lists references on building wake diffusion that summarize experimental results, for example Hosker (1982) and Hosker and Pendergrass (1986). The results of the screening phase presented in the first portion of this chapter. The second portion of the chapter describes the data set selected for use in the evaluation.

INITIAL SCREENING

On the basis of the literature search, 29 data sets were selected for further evaluation. Those data sets are listed in Table 1 along with associated references. The data sets are grouped by type of experiment. The five sets in the first group contain data that were obtained in similar experiments conducted in the field and in wind tunnels. Half of the remaining 24 data sets contain the results of field experiments, and the remaining sets contain data resulting from wind tunnel experiments. On further evaluation of the available data, the number of data sets under consideration was reduced to 14. The range of measurements in each of these data sets is indicated in Table 2.

The field studies listed in Table 2 provide data that are directly applicable to the evaluation of the Murphy-Campe models and procedure. However, each field study includes a specific building configuration and limited range of meteorological conditions. Nevertheless, the seven field experiments listed in Table 2 involved 152 separate tracer release periods in which useful data were collected. Further, two or three tracers were released in many of these periods, so that the total number of releases is 242. Consequently, the field experimental data, taken as a group, were deemed adequate to evaluate the Murphy-Campe models and procedure. The following section describes the field data base in more detail.

The wind tunnel studies provide more building configurations and wider variation of wind directions for each configuration than the field studies. However, the interpretation of data obtained in wind tunnel experiments must be based on model scaling assumptions. Further, the data obtained in wind tunnels are limited by the inability of wind tunnels to fully simulate the meandering of the wind or simulate a full range of atmospheric stabilities. Ogawa, Oikawa, and Uehara (1983a and 1983b) conducted experiments on diffusion in the vicinity of cubes in the field and in a wind tunnel. Normalized concentration patterns in the downwind wake region were similar in the two sets of experiments. However, the normalized concentrations on the surface of the cube in the wind tunnel experiments were higher than corresponding concentrations in the field experiments. This result raises questions regarding quantitative use of the results of wind tunnel experiments to estimate flow and diffusion around buildings. Data from the experiments listed in Table 2 do not permit direct point-by-point comparisons of concentrations on or near building surfaces.

TABLE 1. Experimental Data Sets Selected for Initial Evaluation

Field and Wind Tunnel Studies

Univ. of Michigan Laboratory (Martin 1965)
EBR-II (Dickson, Start and Markee 1969; Halitsky 1977)
Rancho Seco Nuclear Power Station (Start et al. 1978; Sagendorf et al. 1980; Allwine et al. 1980; Kothari, Meroney and Boumeester 1981)
EOCR Reactor Building (Start, et al. 1980; Sagendorf, et al. 1980; Hatcher and Meroney 1977; Hatcher et al. 1978)
Cube (Ogawa, Oikawa, and Uehara 1983a and 1983b)

Field Studies

MTR-ETR (Islitzer 1965)
Central Heating Plant (Munn and Cole 1965, Lawson 1965)
CANDU Nuclear Power Generating Station (Munn and Cole 1967)
Hanford (Hinds 1969)
Hinkley Point "A" Nuclear Power Station (Rodliffe and Fraser 1971)
Three Mile Island Nuclear Station (GPUSC 1972)
Peach Bottom Atomic Power Station (Philadelphia Electric Company 1974)
Cal. Tech. Spalding Laboratory (Drivas and Shair 1974)
Millstone Nuclear Power Station (Johnson et al. 1975, Thuillier 1982)
Casaccia Nuclear Research Center (Cagnetti 1975)
Duane Arnold Energy Center (Thuillier and Mancuso 1980, Thuillier 1982)
Single-story, flat-roofed building (Jones and Griffiths 1984)

Wind Tunnel Studies

NIH Clinical Center (Halitsky 1962)
Berkeley and Bradwell Nuclear Power Stations (Davies and Moore 1964)
Shoreham Nuclear Power Station (Meroney, Cermak and Chaudry 1968a, 1968b)
Avon Lake Power Plant (Meroney et al. 1974)
Floating Nuclear Power Plant (Meroney et al. 1974)
Cube (Robins and Castro 1977a, 1977b)
Cubes and Rectangular Blocks (Vincent 1977, 1978)
Rectangular Prism (Wilson and Netterville 1978)
Square building (Koga and Way 1979)
Rectangular building (EPA-FMF) (Huber and Snyder 1982)
Cubical Building (Li, Meroney and Peterka 1982)
Grand Gulf Nuclear Station (Cermak, Meroney and Neff 1983)

TABLE 2. Experimental Data Sets Selected for Further Evaluation

Experiment	Receptor Locations On Building	Near wake	Far wake
Field Experiments			
MTR-ETR			XX
EBR-II[a]		XX	XX
TMI			XX
Millstone			XX
Rancho Seco	XX	XX	XX
EOCR	XX	XX	XX
Duane Arnold	XX		XX
Wind Tunnel Experiments			
EBR-II			XX
EOCR		XX	XX
Rancho Seco		XX	XX
NIH	XX	XX	
Shoreham			XX
Grand Gulf	XX		
Floating NPS	XX		

(a) The data for these experiments, which were not found in the open literature, are listed in Appendix B. They were provided by Mr. E. H. Markee.

Field and wind tunnel diffusion studies have been conducted for the EBR-II, Rancho Seco, and EOCR building complexes. Data from these studies were to be used to calibrate the wind tunnel data. However, on further investigation, it was determined that data for the EBR-II and EOCR building complexes could not be used to calibrate the wind tunnel data. Only the Rancho Seco field and wind tunnel data are directly comparable. The square of the correlation coefficient between 48 normalized centerline concentrations observed in the wind tunnel by Allwine et al. (1980) and the corresponding value observed in the field by Start et al. (1978) is 0.19. This correlation, which is statistically significant, is too low to permit a useful calibration based on the Rancho Seco data. As a result, no wind tunnel data were selected for inclusion in the final data base. Although wind tunnel data have been excluded from the data base to be used in the evaluation of the Murphy-Campe model or procedure, the results of wind tunnel experiments provide insights that are useful in establishing guidelines for the placement of control room air intakes relative to short stacks, vents and other possible release locations.

FINAL DATA BASE

The data chosen for use in evaluation of the Murphy-Campe models and procedure were all obtained in experiments conducted in the wake of actual reactor buildings. The physical characteristics of the reactor buildings are listed in Table 3. Building dimensions were taken from the original data reports. These values are generally representative of the buildings for the current purpose. However, they are likely to differ somewhat from the actual dimensions when the buildings are viewed from a specific direction. Table 3 also lists the total number of release periods in each set, the release heights used, and the number of releases at each height. Releases in the Millstone experiments and some of the releases in the Duane Arnold experiments were made through operating stacks and vents with significant upward momentum. The effective diameters of the stacks and vents through which these releases were made are listed in Table 3; the vertical velocity for each release is listed with the experimental data in Appendix C.

The reactors at Three Mile Island (TMI), Millstone, Rancho Seco, and Duane Arnold are commercial power reactors. The projected areas for these reactors are typical of the projected building areas for recent generation power reactors. As a result, the variation in areas among these facilities is relatively small. The buildings used in the MTR-ETR, EBR-II, and EOCR experiments are experimental reactors at the Idaho National Engineering Laboratory. They are smaller than commercial reactors. When the seven data sets are combined, the projected buildings areas range from 665 to 2050 m^2. Thus, the data are sufficient for at least a partial evaluation of building size on wake diffusion.

The data from the experiments fall into two basic groups--data obtained downwind of the buildings, and data obtained on or immediately adjacent to the buildings. The data obtained downwind of the buildings have been divided by release height (ground and elevated releases). Approximate plume centerline concentrations downwind of the buildings have been determined in each of experiment. These concentrations and the data associated with them are listed in Appendices B and C. Further division of the elevated release data by vertical velocity of the release (zero and greater than zero) was used in the development of a new model.

Appendix D contains data for all samplers with concentrations above background that were located on or adjacent to buildings. The number of samplers located on and adjacent to the buildings in these experiments was not sufficient to ensure that the maximum concentrations on building surfaces were observed. Consequently, many of these data may not be maximum concentrations. However, the data are still of value in evaluating the Murphy-Campe models and procedure.

Table 4 shows the range of conditions covered in each set of experiments. The individual sets generally cover only a limited range of conditions. However, in the aggregate, the sets cover a wide range of conditions. Plume

TABLE 3. Physical Characteristics Represented in the Selected Building-Wake Experimental Data Sets

Expt. Site	Bldg. Area (m2)	Bldg. Height (m)	Bldg. Width (m)	Release Height (m)	Stack Diam. (m)	Release Periods	No. of Releases
MTR-ETR	1700	24	60	1.		13	13
EBR-II	665	29	27	1.		15	15
TMI	2000	44	46	1.		5	5
Millstone	1950	45	50	27.6 48.3	1.4 2.1	36	26 36
Rancho Seco	2050	43	48	4. 18.5 43.		22	27 12 5
EOCR	1090	25	52	1. 23. 30.		22	22 22 20
DAEC	1850	43	51	1. 23.5[(a)] 45.7	 1.8[(b)]	39	11 16 12

(a) vent capped, flow = 1.9 m^3/s, vertical velocity = 0.0
(b) effective diameter

centerline data are available for locations between 8 and 1200 m downwind of ground-level releases and for locations between 23 and 1200 m downwind of elevated releases. Data on or adjacent to buildings are available for receptors at distances between 6 and 91 m from the release point. In addition, data are available for experiments conducted with wind speeds between 0.3 and 11.6 m/s and for all atmospheric stability classes based on temperature difference as defined in Regulatory Guide 1.23 (NRC 197_).

In Table 4, and throughout this report, numerical values are used to represent atmospheric stability classes instead of alphabetic characters. Atmospheric stability increases as the numerals representing the classes increase. For example, Class 1 is extremely unstable and corresponds to the usual Pasquill-Gifford stability class A; Class 4 is neutral corresponds to D, and Class 7 is extremely stable and corresponds to G.

Joint distributions of the available data by wind speed and atmospheric stability for the ground and elevated releases and for the near and on building receptors are shown in Table 5. The last column for each data set contains the distribution of wind speeds for the set. These distributions are not

TABLE 4. Range of Experimental Conditions in Selected Data Sets

Expt. Site	Rel. Pt.(a)	Distance (m) Min.	Distance (m) Max.	10 m Wind Speed (m/s) Min.	10 m Wind Speed (m/s) Max.	Atmospheric Stability Class Min.	Atmospheric Stability Class Max.
MTR-ETR	G	100	850	2.1	5.9	1	7
EBR-II	G	30	600	4.4	11.6	1	7
TMI	G	149	244	0.6	1.8	5	7
Millstone	E	350	800	2.9	11.2	1	7
Rancho Seco	G	62	800	0.5	5.3	1	7
	E	63	800	0.8	5.3	1	7
	B	6	88	0.5	5.3	1	7
EOCR	G	8	1200	0.5	8.0	1	7
	E	23	1200	0.5	8.0	1	7
	B	6	41	1.2	4.9	1	7
DAEC	G	300	1000	2.0	4.6	1	5
	E	300	1000	0.3	3.8	1	6
	B	25	91	0.3	4.6	1	6

(a) G = Ground-level releases
E = Elevated releases
B = On/near building receptors

drastically different from climatological wind speed distributions. The distributions of data among the atmospheric stability classes are contained in the last row for each set. There are not many data for stability classes 2 and 3. However, these classes are defined by very narrow temperature gradient ranges. If the data are grouped by the broader stability categories of unstable, near neutral, and stable, the data distributions are reasonably close to climatological stability distributions.

Thus, the available data provide a good base for evaluation of the representation of distance, wind speed, and atmospheric stability in the Murphy-Campe models. In addition, Table 5 shows that there are sufficient data for low wind speed and stable atmospheric conditions to evaluate the procedure used by the NRC staff in evaluating control room habitability.

TABLE 5. Distribution of Experimental Data Points by 10-m Wind Speed and Atmospheric Stability Class

10-m Wind Speed	Atmospheric Stability Class 1	2	3	4	5	6	7	All
Ground-level Releases								
< 2.0	2	0	0	12	29	23	21	87
2.0 - 3.9	49	0	4	23	15	5	50	146
4.0 - 7.9	13	0	0	12	41	9	6	81
> 7.9	18	0	0	0	9	0	0	27
All	82	0	4	47	94	15	77	341
Elevated Releases								
< 2.0	14	2	4	30	25	15	25	115
2.0 - 3.9	16	5	4	48	35	7	54	169
4.0 - 7.9	6	0	2	26	19	14	0	67
> 7.9	6	4	8	52	0	0	0	70
All	42	11	18	156	79	36	79	421
Building Surface Receptors								
< 2.0	18	1	2	13	33	12	16	95
2.0 - 3.9	18	1	2	28	14	6	59	128
4.0 - 7.9	6	0	0	7	14	15	0	42
> 7.9	0	0	0	0	0	0	0	0
All	42	2	4	48	61	33	75	265

MURPHY-CAMPE MODEL AND PROCEDURE EVALUATION

The last chapter described the data base chosen for use in evaluating the Murphy-Campe models and procedure. The first part of this chapter is an evaluation of the Murphy-Campe models. In it Murphy-Campe model predictions of normalized concentrations (χ/Q) at the plume centerline are compared with the maximum values observed in building-wake diffusion experiments. Normalized concentrations predicted by the PAVAN model are also compared with the observations. The second part of the chapter evaluates the Murphy-Campe procedure. This is done by examining model performance for a subset of the data taken in experiments conducted during low wind speed, stable atmospheric conditions. These conditions have been assumed to be the conditions under which concentrations would be highest in building wakes.

MODEL EVALUATION

Plume centerline concentrations have been estimated by the three Murphy-Campe models and PAVAN for comparison with the concentrations observed in the 7 building wake diffusion experiments. This section presents the comparison of those estimates with the observed values and examines some of the systematic errors in the model estimates.

Normalized, centerline concentrations estimated by Murphy-Campe Model 1 are plotted against observed concentrations for the ground-level releases in Figure 1, and Model 2 concentration estimates are plotted against observed concentrations for the elevated releases in Figure 2. The figures provide graphical evidence that neither model is a particularly skilled predictor of maximum concentrations in building wakes in the specific application for which it is intended. If the models were good predictors of the observed concentrations, the data points shown in the figures would fall along or near the solid diagonal lines.

The data points falling outside of the area enclosed by the dashed diagonal lines indicate pairs of model estimates and observed concentrations that differ by more than a order of magnitude. Those points that fall below the lower dashed diagonal lines show that occasionally the underpredictions of the maximum concentrations are significant. The Murphy-Campe Model 1 underpredicted the centerline concentrations for ground-level releases by an order of magnitude in 34 instances (approximately 10% of the time). It had a maximum underprediction of about two orders of magnitude. In terms of underprediction, Murphy-Campe Model 2 performed better, it underpredicted the concentration by more than an order of magnitude only once.

Both models tend to overpredict centerline concentrations more frequently and by greater amounts than they underpredict. Model 1 overpredicted 78 of the concentrations by more than an order of magnitude. Of these 78 overpredictions, 14 were by more than two orders of magnitude, and two were by more three orders of magnitude. Model 2 overpredicted the centerline concentration by an order of magnitude or more 160 times, 46 overpredictions exceeded two orders of magnitude, and 9 exceeded three orders of magnitude.

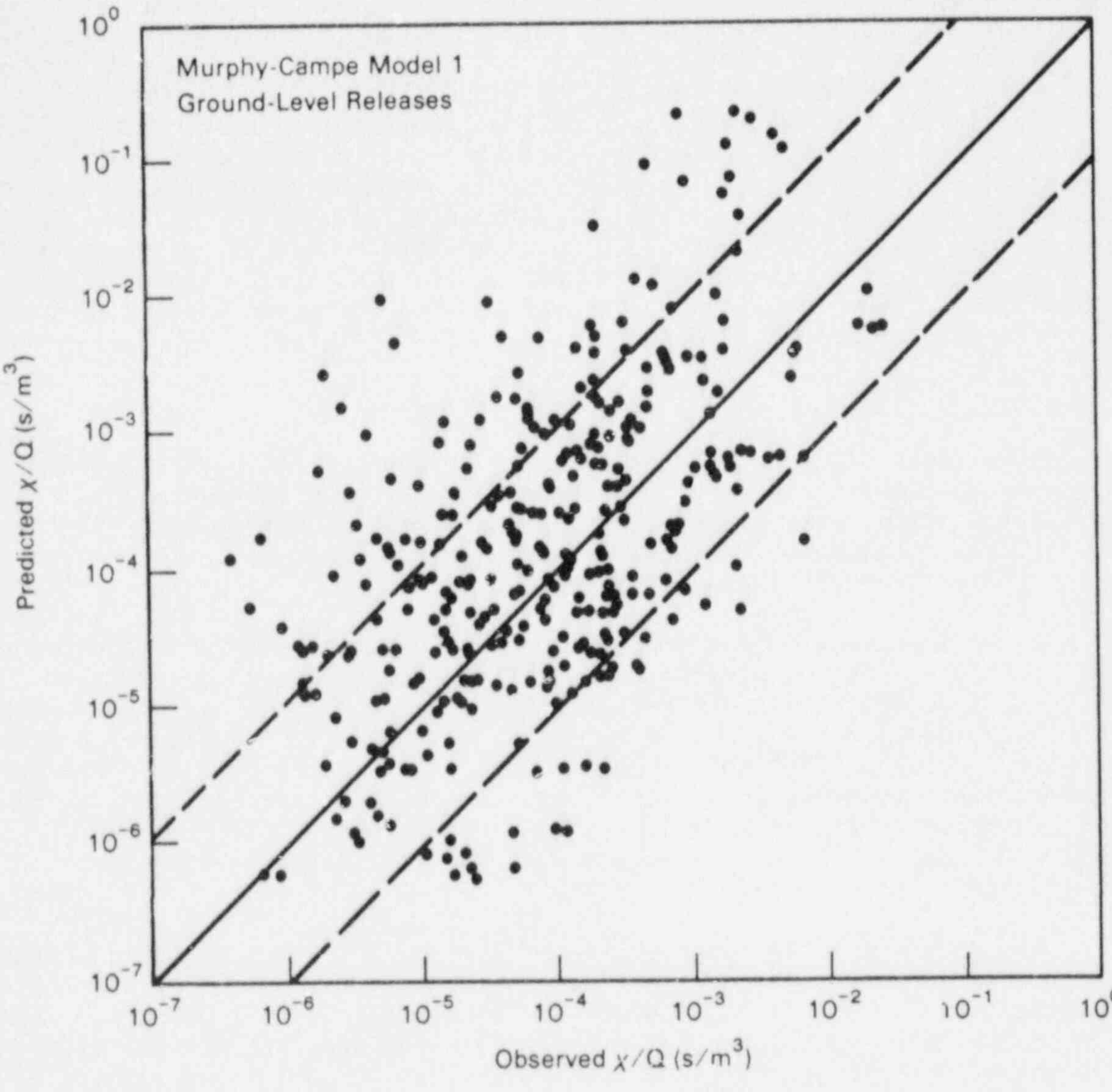

FIGURE 1. Comparison of Normalized Concentrations Predicted by Murphy-Campe Model 1 for Ground-Level Releases with Observed Concentrations

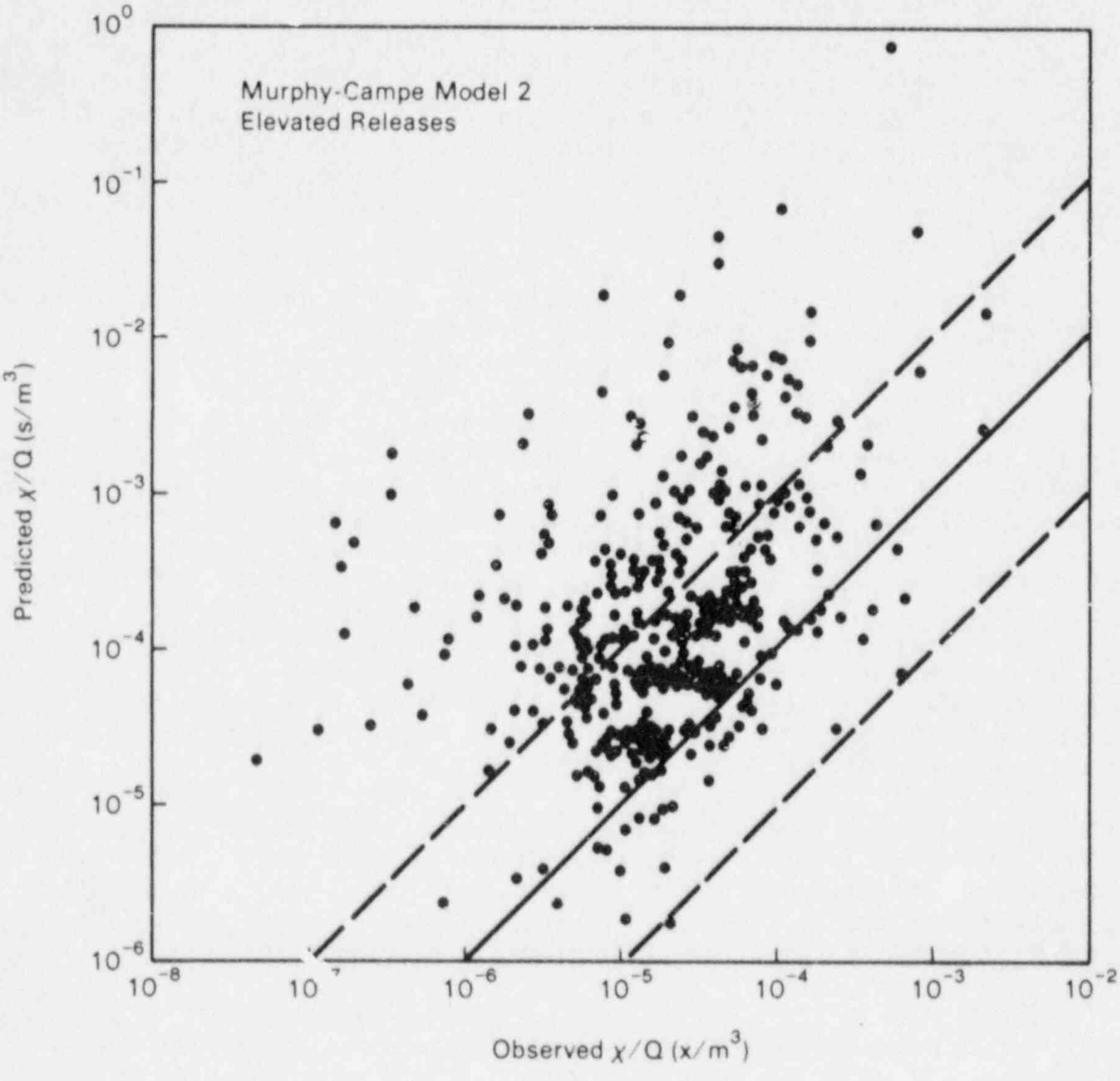

FIGURE 2. Comparison of Normalized Concentrations Predicted by Murphy-Campe Model 2 for Elevated Releases with Observed Concentrations

Murphy-Campe Model 3 did not perform as well as either Model 1 or Model 2. It tended toward large underpredictions of the maximum concentrations. When Model 3 predictions were compared with the observed centerline concentrations for the ground-level releases, the predictions underestimated the concentrations by more than an order of magnitude in more than 40% of the cases. When compared with observed centerline concentrations for the elevated releases, Model 3 underpredicted more than 30% of the time. The model overpredicted observed concentrations by more than an order of magnitude in 20 cases. Five of these cases were for ground-level releases, and the remaining 15 were for elevated releases.

PAVAN is used both ground-level and elevated releases. Its performance was similar to the performance of Murphy-Campe Model 1 for ground-level releases and to the performance of Murphy-Campe Model 2 for elevated releases.

The ratio of observed to predicted concentrations is one measure of a model's performance for a specific case. When the ratio is larger than one, the model has underpredicted the concentration, and when it is smaller than one concentration has been overpredicted. A distribution of these ratios determined from the results of several cases provides a general indication of model performance. Figure 3 presents cumulative frequency distributions for the ratios of observed concentrations for ground-level and elevated releases to model predictions. It shows that using Murphy-Campe Models 1 and 2 as specified tends to underestimate concentrations about 25% of the time. PAVAN underestimates concentrations slightly less frequently. When underestimates greater than an order of magnitude are considered, PAVAN performs better than the combination of the Murphy-Campe models.

Figure 3 also shows the distribution of the observed to predicted concentration ratios for Murphy-Campe Model 3. Model 3 is clearly not as good as the other models. It underpredicted almost 80% of the maximum concentrations observed downwind of the buildings, and more than 35% of these underpredictions were by more than an order of magnitude.

The square of the correlation coefficient between predicted and observed values (r^2) provides another, more quantitative, measure of the performance of models. It gives the fraction of the variation in the observed values that is accounted for by the model. Table 6 gives these fractions for each of the models for all data sets. The models perform best for ground-level releases. Murphy-Campe Models 1 and 2 and PAVAN account for about 30% of the variation in the observed centerline concentrations for these releases, while Murphy-Campe Model 3 accounts for less than 20% of the variation. The models account for significantly smaller fractions of the variability of the concentrations for elevated releases, and almost none of the variability in concentrations at receptors on or near the buildings. However, as a result of the relatively large number of data observations in each data set, all values in Table 6 are significantly different from zero at a 95% confidence level except for Murphy-Campe Model 3 predictions of the concentrations at receptors on or adjacent to buildings.

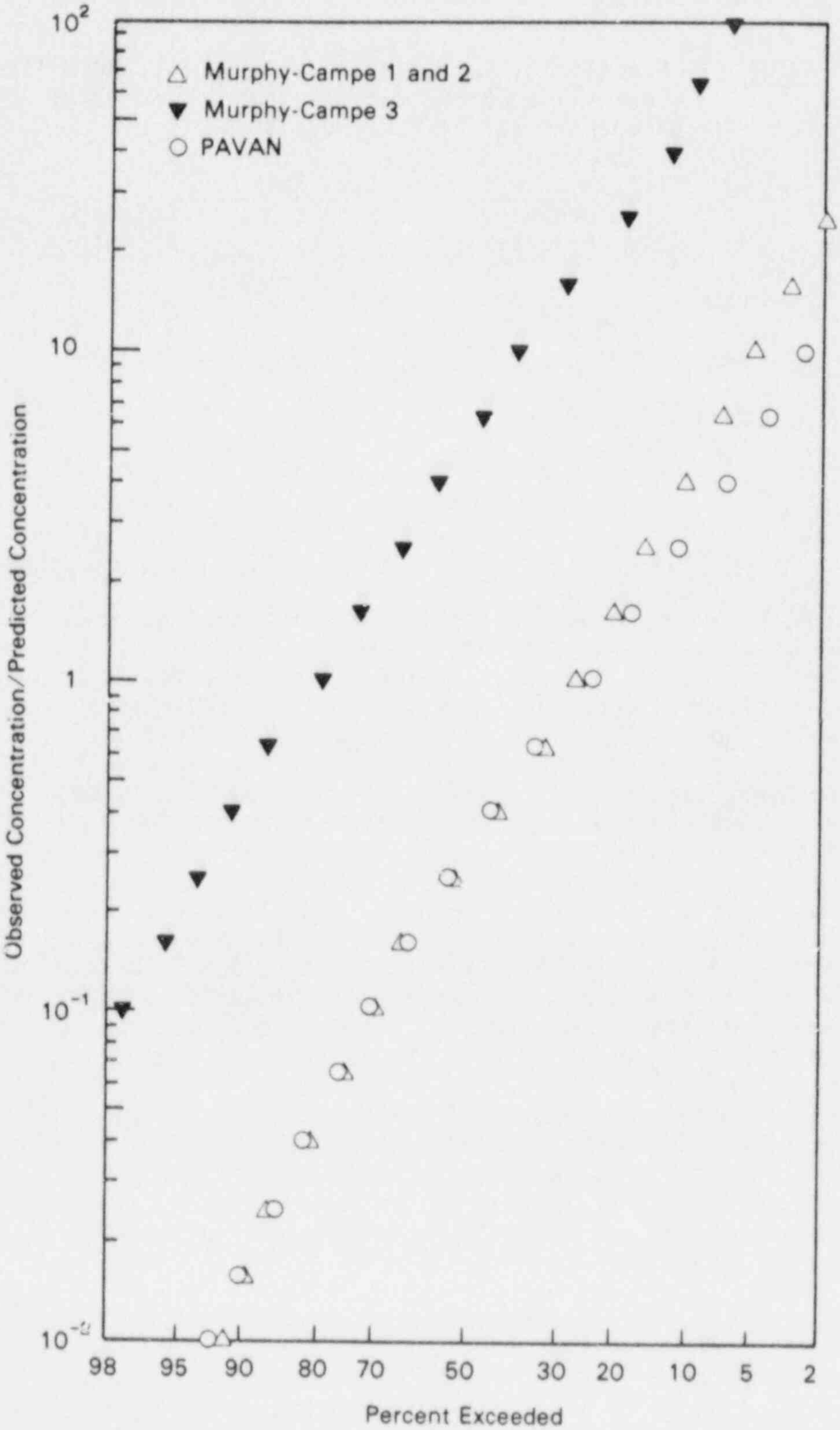

FIGURE 3. Cumulative Frequency Distributions for the Ratio of Observed to Predicted Concentrations for the Murphy-Campe and PAVAN Models

TABLE 6. Fraction of Variation in the Observed Normalized Centerline Concentrations in Building Wakes Accounted for by Wake Models

Model	Data Set Ground Releases	 Elevated Releases	 Building Receptors
Murphy-Campe 1	0.310	0.139	0.049
Murphy-Campe 2	0.272	0.133	0.019
Murphy-Campe 3	0.180	0.085	0.006
PAVAN	0.293	0.134	0.075

PROCEDURE EVALUATION

The Murphy-Campe procedure calls for using meteorological conditions that result in concentrations that are exceeded no more than 5% of the time in evaluation of control room habitability. Given the models in the procedure, those meteorological conditions are typically a stable atmosphere and low wind speed. The models have been shown to have limited predictive ability under the wide range of meteorological conditions represented in the available data. However, that limited ability does not necessarily mean that the procedure results in concentration underestimates in low wind speed, stable atmospheric conditions.

A subset of the data has been used to evaluate the Murphy-Campe procedure. This subset consists of observations made during experiments during stable atmospheric conditions (stability classes 5, 6, and 7) with wind speeds of 2 m/s or less at the 10-m level outside of the building wake. Stability classes were determined using temperature differences and the class definitions contained in Regulatory Guide 1.23 (NRC 1972).

Table 7 contains a summary of the results of comparison of model predictions with normalized concentrations observed at the center of the wake for the data in the subset. Murphy-Campe Models 1 and 2 tend to overpredict the concentrations under these conditions. Model 3 overpredicts concentrations on, and adjacent to, buildings but underpredicts the concentrations downwind of the buildings.

Three of the five concentrations that were underpredicted by Murphy-Campe Model 1 were at distances greater than 400 m from the release point. These underpredictions are not significant in the context of control room habitability because it is unlikely tnat a control room air intake would be located more than 400 m from the reactor building. The other two occurred at distances of 72 and 300 m. In these cases, the underpredictions were by less

TABLE 7. Comparison of Model Predictions of Normalized Centerline Concentrations With Observed Values for Experiments With Low Wind Speeds and Stable Atmospheric Conditions

Model	Data Set(a)	No. of Observations	No. of Under Predictions
Murphy-Campe 1	G	75	5
	E	65	9
	B	62	0
Murphy-Campe 2	G	75	4
	E	65	7
	B	62	0
Murphy-Campe 3	G	75	53
	E	65	28
	B	62	0

(a) G = Ground-level releases
E = Elevated releases
B = Receptors on/near buildings

than a factor of two. Examination of cases in which Murphy-Campe Model 2 underpredicted concentrations for elevated releases showed that all of the underpredictions occurred at a distance of 400 m or more.

The underpredictions of Murphy-Campe Model 1 for elevated releases and of Murphy-Campe Model 2 for ground-level releases were also examined. All of the underpredictions of Model 1 and three of the underpredictions of Model 2 were at distances of 400 m and greater. The remaining underprediction of Model 2 was at a distance of 72 m. In this case, as with the other two underpredictions near the source for ground-level releases, the concentration was underpredicted by less than a factor of two.

Thus, the building-wake models included in the Murphy-Campe procedure do not display much skill in predicting maximum concentrations, but the general procedure is conservative for point receptors not in the immediate vicinity of the source.

The procedure for multiple intakes also appears to be conservative as long as the closest intake is on or immediately adjacent to the building from which a release will occur. However, this last conclusion is more tentative than first because the experiments used in the evaluation did not have sufficient samplers to ensure that maximum concentrations on the building surfaces were observed. If the Murphy-Campe procedure is applied to a multiple intake situation in which the closest intake is not on the building from which the release occurs, the procedure may not be conservative. This conclusion follows from the large fraction of the downwind concentrations that were underestimated by Model 3. A conservative result can be obtained in this case by using Model 1 or 2 as appropriate.

Although the Murphy-Campe procedure is generally conservative, the failure of the Murphy-Campe models as predictive tools is sufficient to warrant examination of alternative models and procedures. The following chapters present the development of a new building wake diffusion model.

DIFFUSION IN BUILDING WAKES

Historically, analysis of building-wake diffusion data collected in field experiments has been directed toward modification of the Gaussian plume diffusion model. These analyses start with an implicit assumption that a modified Gaussian model can adequately describe diffusion in building wakes. Cursory analysis of the performance of the standard building-wake diffusion models calls that assumption into question. For example, Figure 4 shows the ratio of the observed centerline concentrations for ground-level releases to concentrations predicted by Murphy-Campe Model 2 as a function of the 10 m wind speed. The ratios tend to increase with increasing speed. If the models were correct, the ratios would be independent of speed.

This chapter presents the development of a new building wake diffusion model. The development is based on the ground-level release data because they cover a wider range of atmospheric conditions than the elevated data. It begins by examining the relationship between observed concentrations and distance, wind speed, and atmospheric stability. A general model form relating concentrations to projected building area, distance, wind speed and stability is assumed on the basis of this examination. Then, multiple linear regression is used to evaluate model parameters. The chapter ends with an examination of results of the regression analysis and an analysis of the sensitivity of the concentration predictions to variations in the parameter values. The next chapter extends the model to give it more reasonable asymptotic behavior and include elevated releases.

OBSERVED CHARACTERISTICS OF WAKE DIFFUSION

Existing building wake diffusion models estimate the maximum concentration in wakes as a function of building size, wind speed, atmospheric stability, and distance from the release point. In this section, the data for ground-level releases are used to examine the relationships between concentration, distance and wind speed. The effects of building dimensions are not examined here because the buildings used in the wake diffusion experiments were, with one exception, nearly the same size.

The normalized, plume centerline concentrations the ground-release data set are plotted as a function of distance in Figures 5 through 7 for three wind speed ranges. Figure 5 shows data for experiments with low wind speeds; Figure 6 shows data for experiments with moderate wind speeds, and Figure 7 shows data for experiments with high wind speeds. Each figure contains lines with slopes of -1, -3/2, and -2 for reference. In general, the data indicate that the normalized concentrations tend to decrease at a rate less than distance to the -3/2 power. This decrease is slower than the decrease found in the Gaussian model at distances of less than 1000 m using the Pasquill-Gifford diffusion coefficients. Thus, if concentrations are lower in building wakes, there must be a rapid initial diffusion related to the building that is not shown in the data. Once this initial diffusion occurs, the diffusion slows until at some distance downwind normal diffusion processes become dominant.

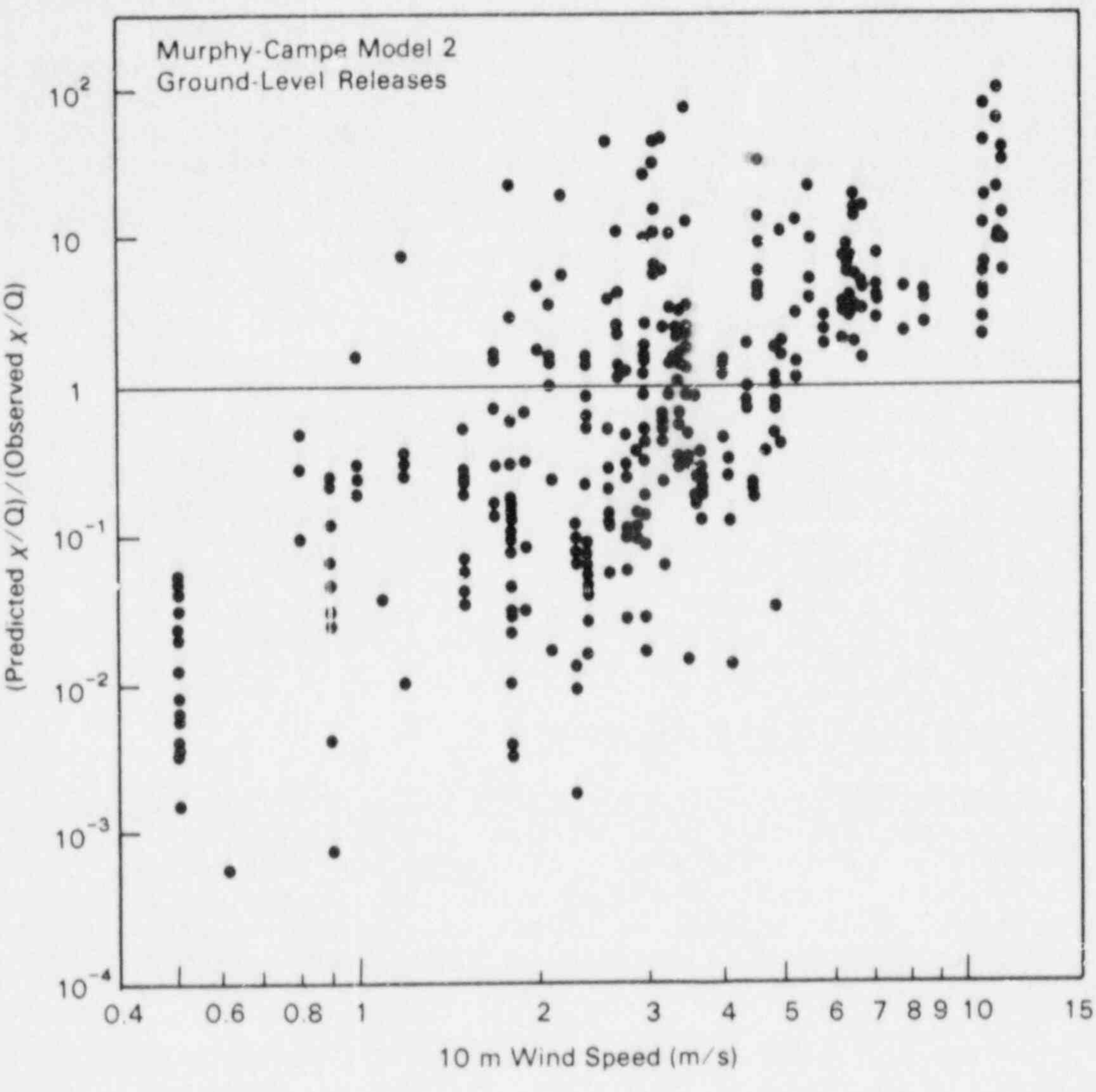

FIGURE 4. Variation of the Ratio of Observed Concentrations to Concentrations Predicted by Murphy-Campe Model 2 for Ground-Level Releases as a Function of the 10-m Wind Speed

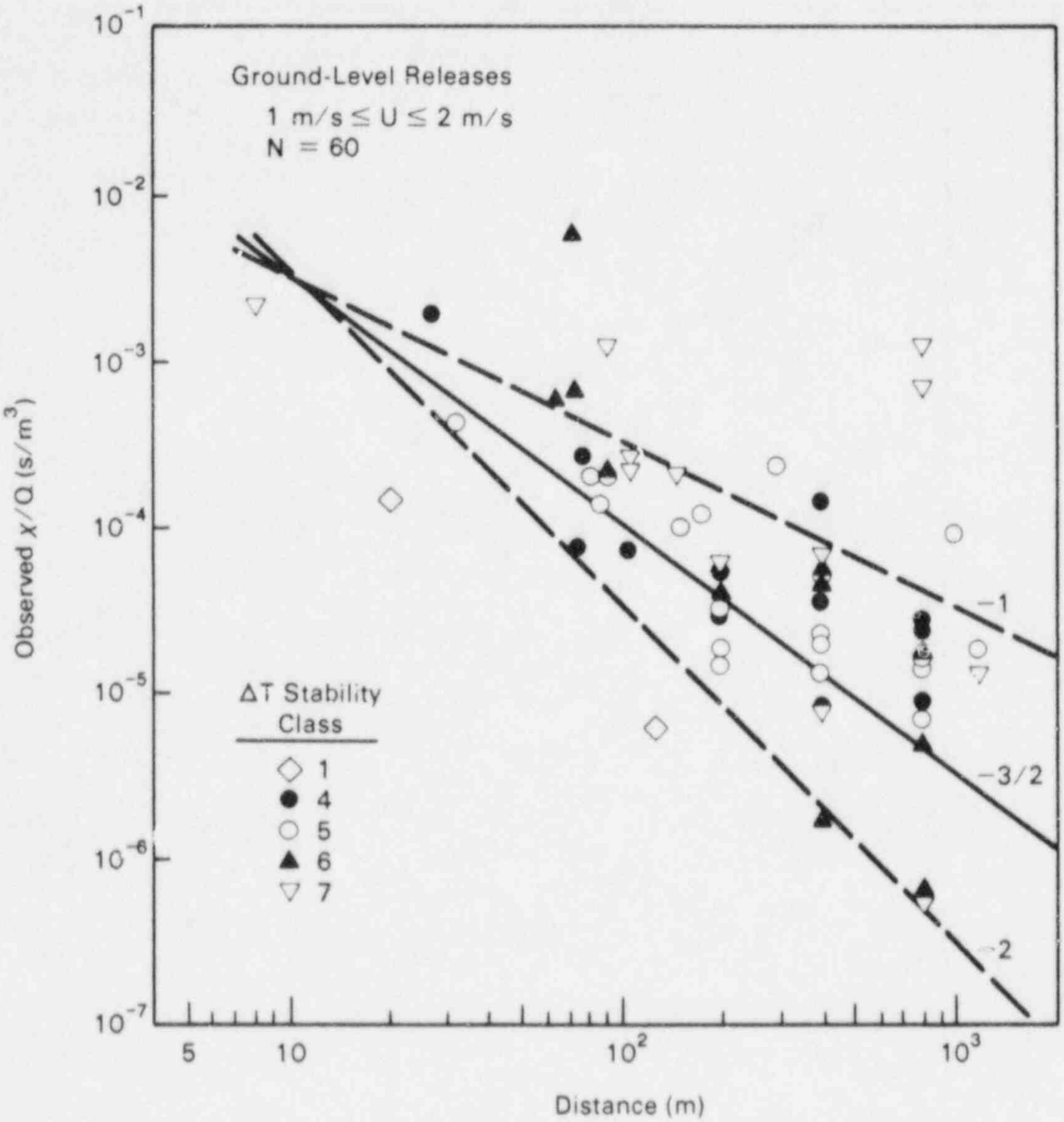

FIGURE 5. Variation of Normalized Concentrations Observed in Building Wakes as a Function of Distance from the Release Point During Low Wind Speed Conditions

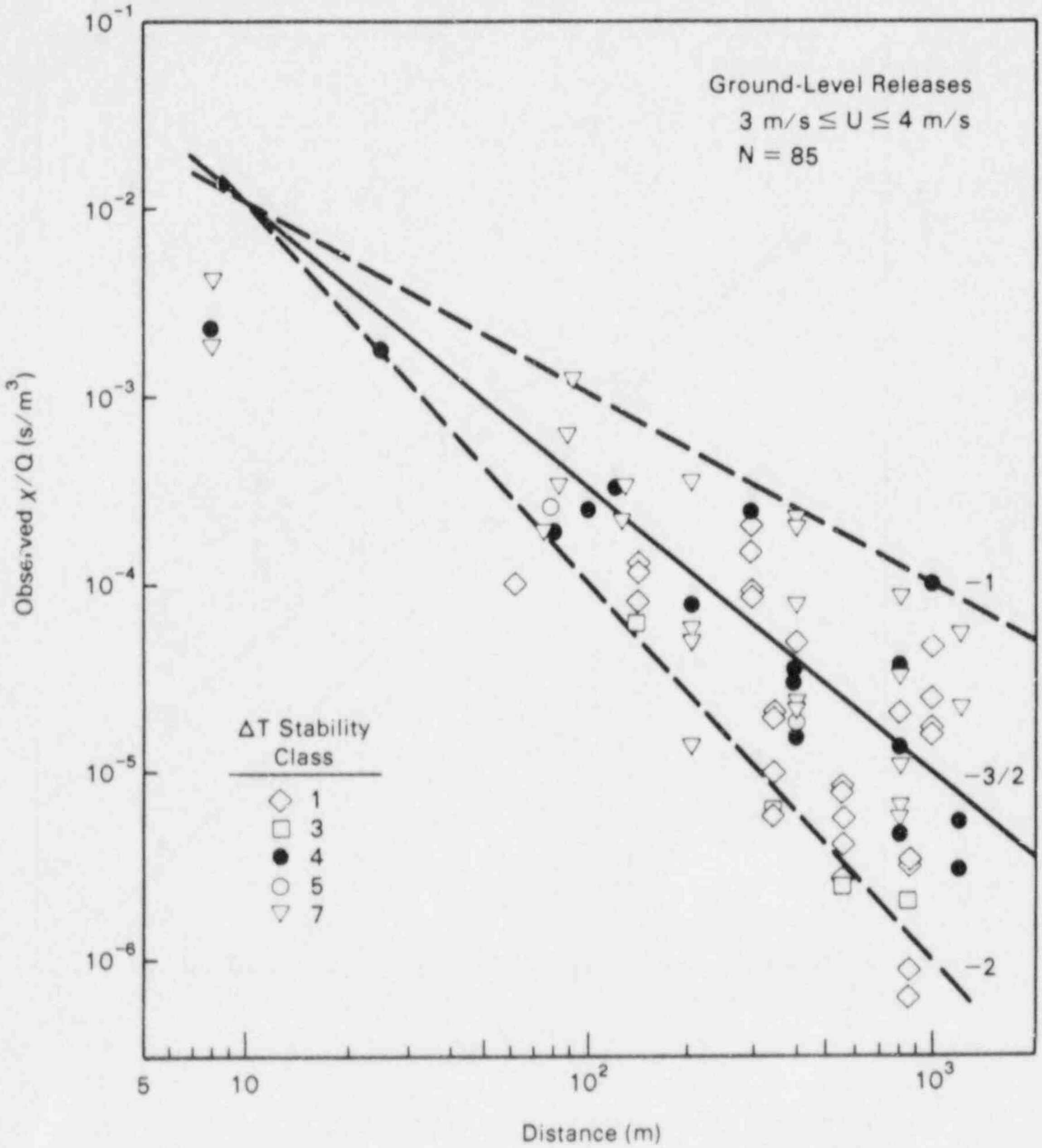

FIGURE 6. Variation of Normalized Concentrations Observed in Building Wakes as a Function of Distance from the Release Point During Moderate Wind Speed Conditions

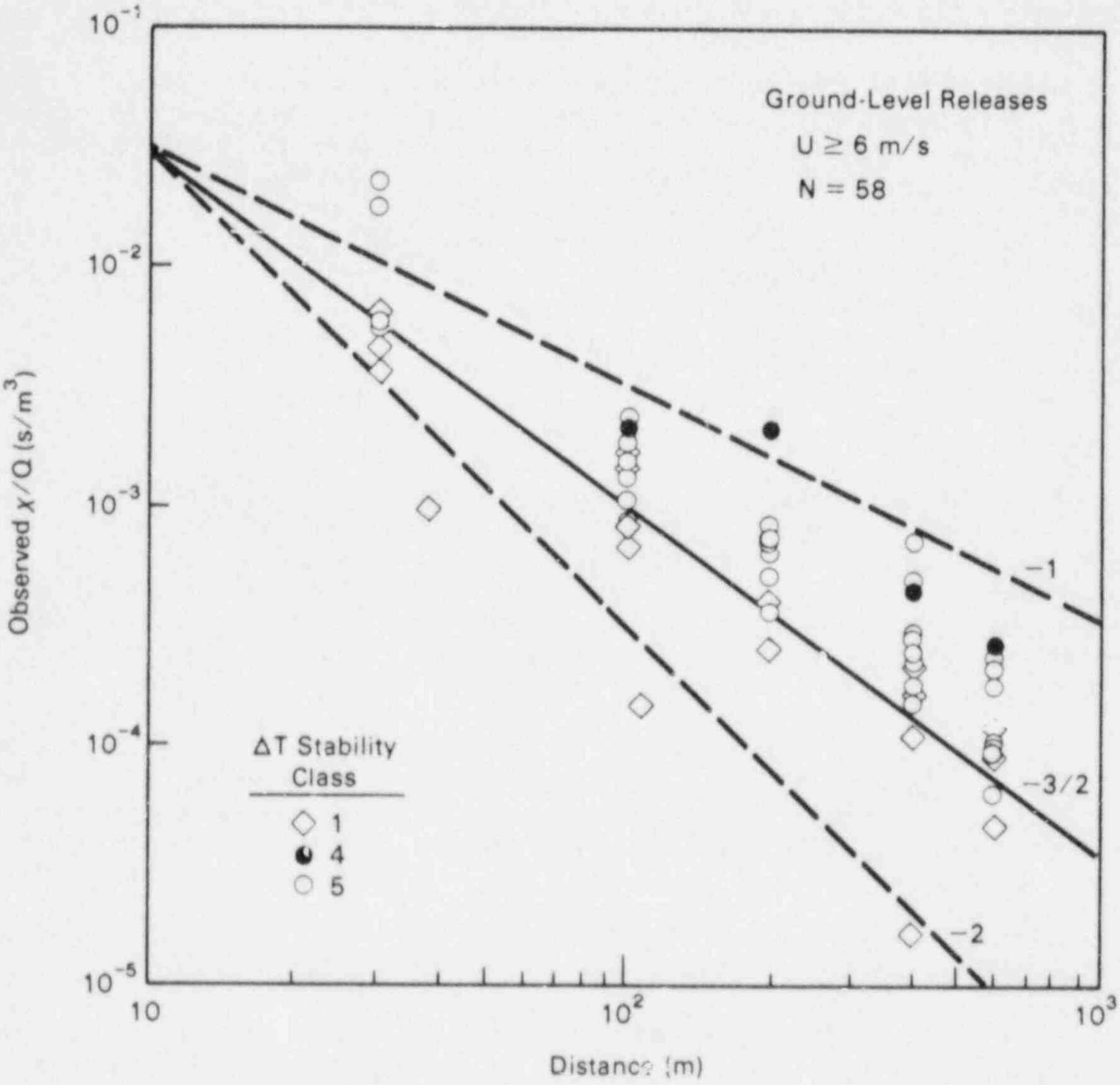

FIGURE 7. Variation of Normalized Concentrations Observed in Building Wakes as a Function of Distance from the Release Point During High Wind Speed Conditions

The data in Figures 5 through 7 are plotted by atmospheric stability class. None of these figures indicates that stability has a large effect on diffusion in building wakes, although some small effects may be evident in the higher wind speed data shown in Figure 7.

The variation of normalized concentrations with wind speed is shown in Figures 8 through 10 for three distance ranges. The data shown in Figure 8 were observed in the building wakes near the release points, those shown in Figure 9 were observed near the downwind end of the wakes, and those shown in Figure 10 were observed downwind of the wakes. In the current wake diffusion models, concentrations are inversely related to wind speed. This relationship is indicated in the figures by the lines with slopes of -1. The data in Figures 8 and 9 clearly do not support the inverse relationship. Rather, they tend to support a relationship in which concentrations increase with increasing speed, for example a relationship such as shown by the lines with slopes of +1. The data in Figure 10 do not support either a direct or an inverse relationship between concentration and wind speed.

If the direct relationship between concentration and wind speed shown in Figures 8 and 9 is correct near the release point, and if the Gaussian plume model correctly describes diffusion at distances well downwind of buildings, then there must be a transition region in which concentration appears not to be a function of wind speed. Thus, Figure 10 may be interpreted as supporting the direct relationship shown in Figures 8 and 9 and providing an indication of the region in which the transition occurs.

The data in Figures 8 through 10 are plotted by stability as they were in Figures 5 through 7. Again, there is no conclusive evidence of an effect of stability on concentrations. However, in Figure 8 there does appear to be an indication that stability has some effect. On the average, the data for stability classes 1 and 3 tend to fall below the data for stability classes 6 and 7.

A NEW BUILDING-WAKE DIFFUSION MODEL

On the basis of the preceding discussion, it is reasonable to conclude that the Murphy-Campe and PAVAN models do not adequately represent diffusion in building wakes. Figure 4 and Figures 8 through 10 suggest that the way in which these models account for the effects of wind speed is a factor in their inadequacies. However, the scatter of the data in the figures makes it difficult to select a relationship between the normalized concentration and the variables. Further, there does not appear to be a current theoretical basis that would explain the observed variation of concentration with wind speed. Therefore, multiple linear regression (cf. Brownlee 1965) has been used to develop a new building-wake diffusion model instead of modifying an existing model.

The general form of the model selected is shown in Equation (7).

$$\chi/Q = k\ x^{a}\ A^{b}\ U^{c}\ S^{d} \tag{7}$$

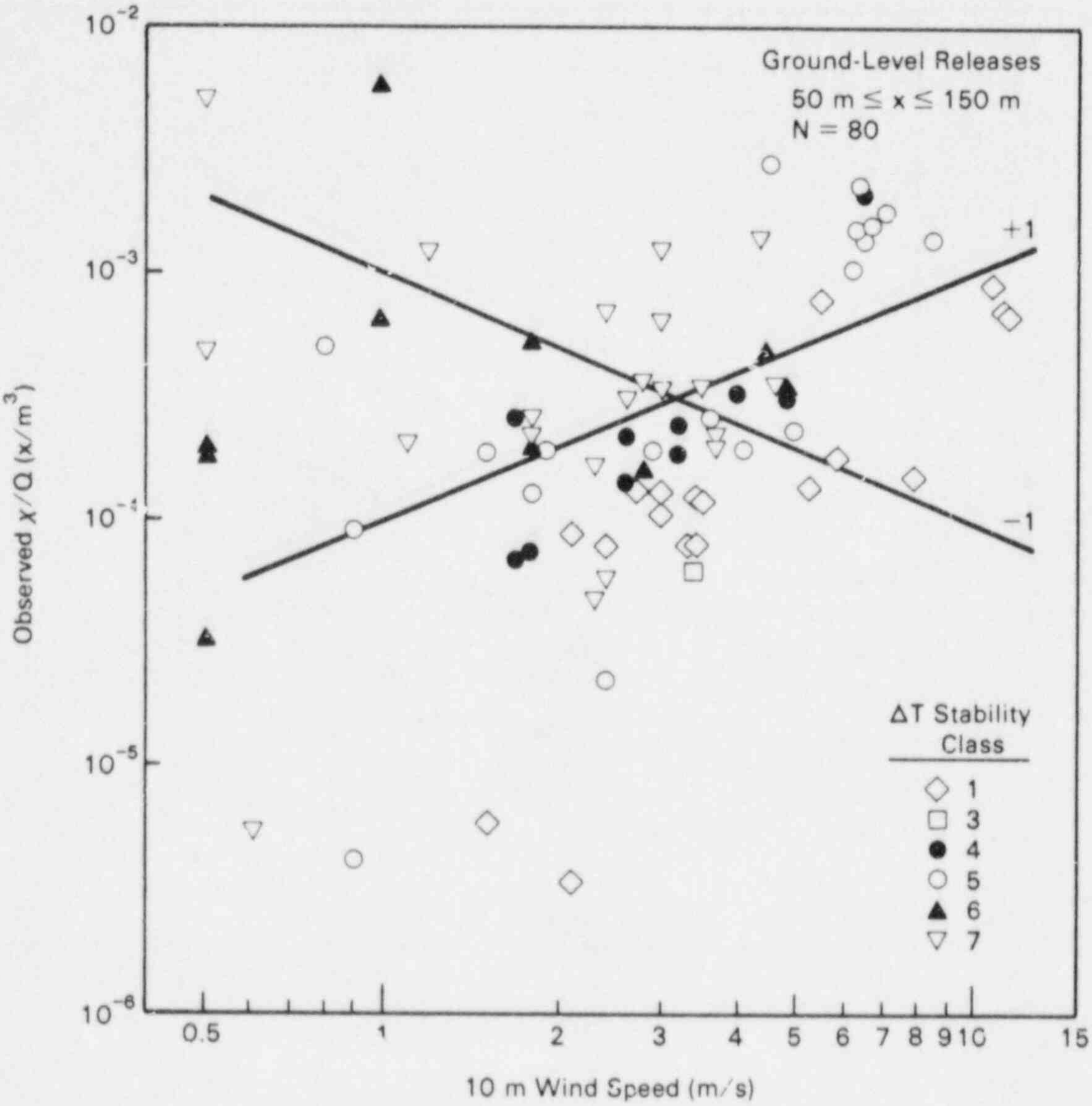

FIGURE 8. Variation of Normalized Concentrations Observed in Building Wakes as a Function of Wind Speed

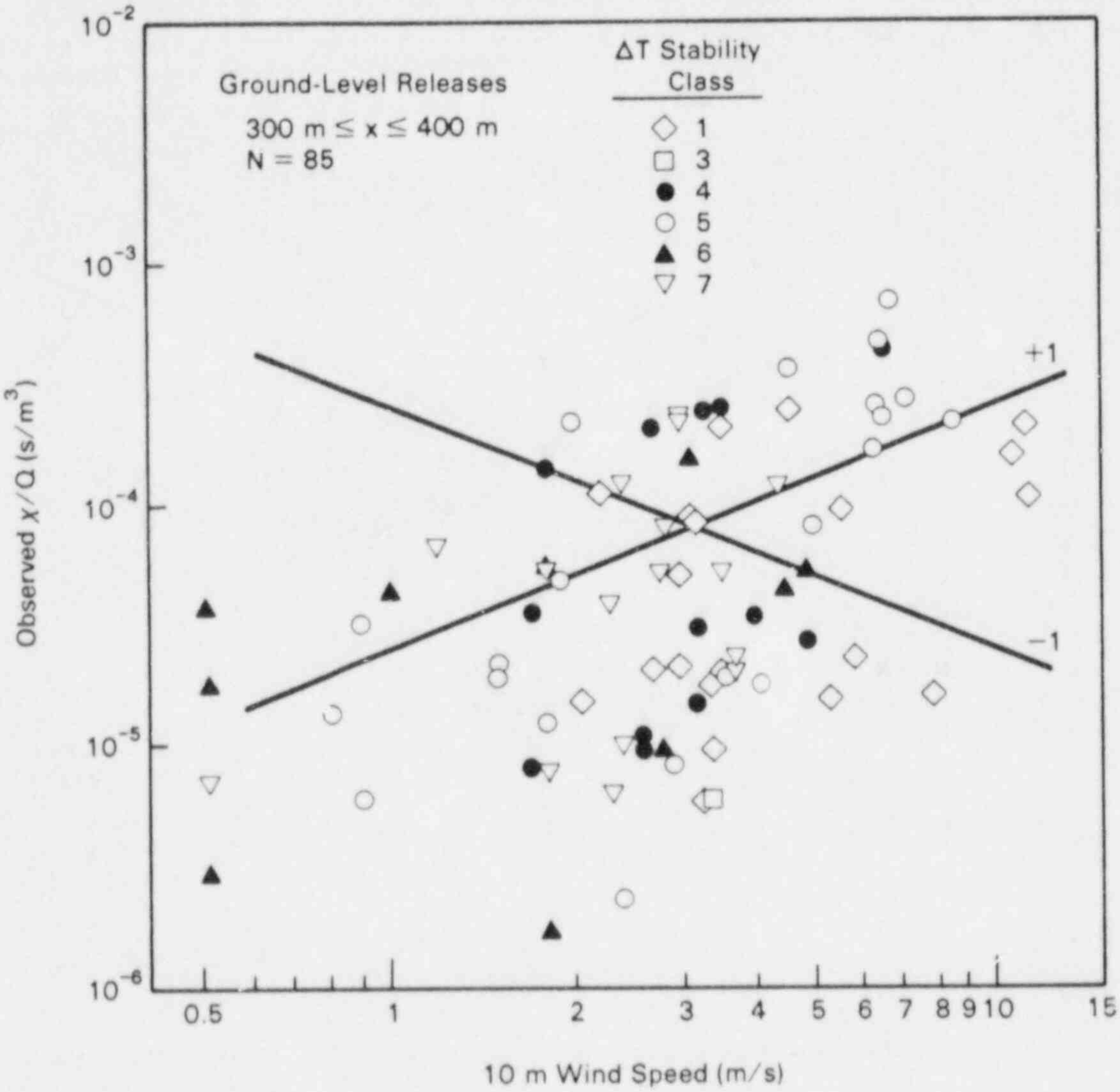

FIGURE 9. Variation of Normalized Concentrations Observed Near the End of Building Wakes as a Function of Wind Speed

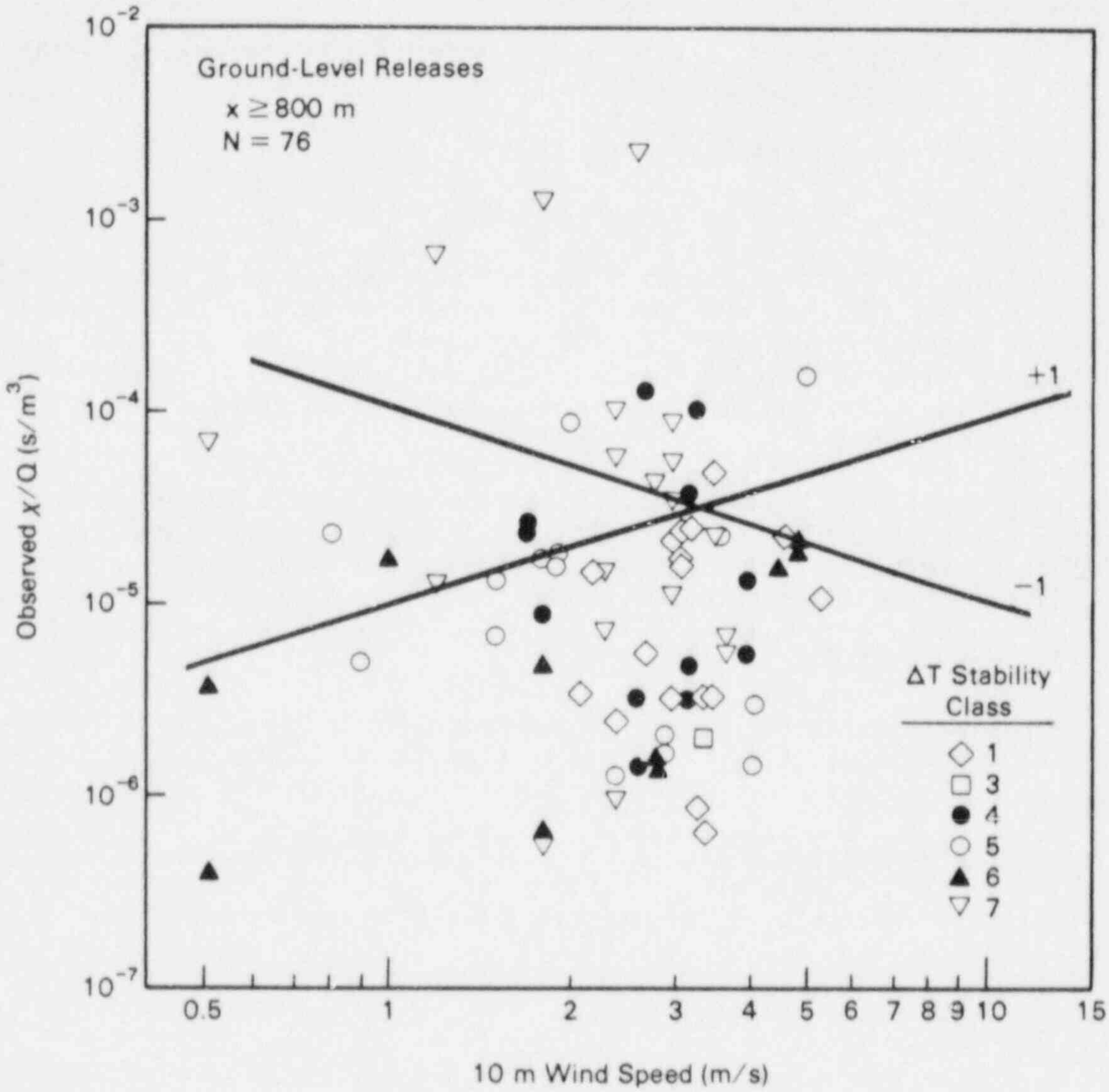

FIGURE 10. Variation of Normalized Concentrations Observed Beyond the End of Building Wakes as a Function of Wind Speed

where x = distance from the release point (m)

A = projected building area (m^2)

U = wind speed at 10 m in the undisturbed flow upwind of the building complex (m/s)

S = atmospheric stability class; 1 = A, 2 = B, ...

k, a, b, c, d = parameters to be determined.

This model includes the same variables that have been included in previous models. However, it does not specify the way in which each of the variables enters the model. For example, if the parameter c has a positive value, χ/Q will be directly proportional to wind speed, while if it has a negative value, χ/Q will be inversely proportional to wind speed as is the case with the current wake diffusion models.

The ground-level building wake diffusion data were selected for use in the evaluation of the new wake model parameter values because modeling ground-level releases should be more tractable than modeling elevated releases. In addition, the climatological distribution of the atmospheric conditions under which these ground-level release data were collected is better than that for the elevated releases.

To estimate parameter values for Equation (7) using multiple linear regression techniques it is necessary to transform Equation (7) to a linear form. This is easily accomplished by taking logarithms

$$\log(\chi/Q) = \log(k) + a \log(x) + b \log(A) + c \log(U) + d \log(S). \quad (8)$$

Each of the parameters to be estimated except k is now a coefficient of a linear equation.

Parameter value estimates from the regression are listed in Table 8. The values for a, b, and d have signs that are consistent with the manner in which distance, projected area, and stability enter current building-wake diffusion models. The sign of c is consistent with the indications of Figures 8 through 10; it is inconsistent with the manner in which wind speed enters current models.

Each of the variables contributes significantly to the model. The significance of the contributions distance and wind speed and the parameter values for these variables are in accord with the qualitative results of Figures 5 through 10. The significance of the projected area is consistent with expectations based on previous models. However, the significance of atmospheric stability is somewhat surprising given the minimal evidence in Figures 5 through 10 to support stability effects. The significance of stability was confirmed when the results of regressions with and without stability were compared. Using an F-test on the ratio of residual variances with and without stability,

TABLE 8. Multiple Linear Regression Parameter Estimates for the Building Wake Diffusion Model

Parameter	Estimated Value	90% Confidence Limit Lower	Upper	Student's t
k	97.49	89.06	106.7	50.64
a	-1.223	-1.329	-1.116	-18.91
b	-1.211	-1.549	-0.8729	-5.894
c	0.6771	0.4653	0.8890	5.259
d	0.4885	0.3224	0.6546	4.839

the contribution of stability to the regression was determined to be significant at a confidence level of greater than 99.5%.

As whole, the linear regression model accounts for almost 65% of variability in the observed data. In contrast, the Murphy-Campe and PAVAN models only accounted for about 30% of the observed variability. The magnitude of the improvement in predictive ability is further evidence that the current models do not treat wind speed correctly.

The concentrations predicted by Equation (7) with parameter values listed in Table 8 are compared with corresponding observed values in Figure 11. The improvement in the regression model over Murphy-Campe Model 1 is evident when Figures 11 is compared with Figure 1. There is much less scatter in Figure 11. However, there are seven instances in which the observed χ/Q is underpredicted by more than an order of magnitude. The differences between observed concentrations and the concentrations predicted by the regression model are examined in Figures 12 and 13. Neither figure shows a systematic error in the model in the sense that Figure 4 indicated that there is a systematic error in Murphy-Campe Model 2.

Regression analysis frequently results in leading coefficients that have fractional dimensions that are not physically realistic. That is the case if the parameter values estimated by the regression are used in Equation (7). The predictive skill of the regression model is not particularly sensitive to variations in parameter values. Therefore, it may be possible to develop a wake model that has a better physical basis which will account for much of the observed variation in concentrations.

Appendix E contains additional details on the results of the regression and the examination of the sensitivity of the model to variation in parameter values.

The results of a regression analysis do not imply a strict cause and effect relationship. However, the implicit dimensions of the lead constant

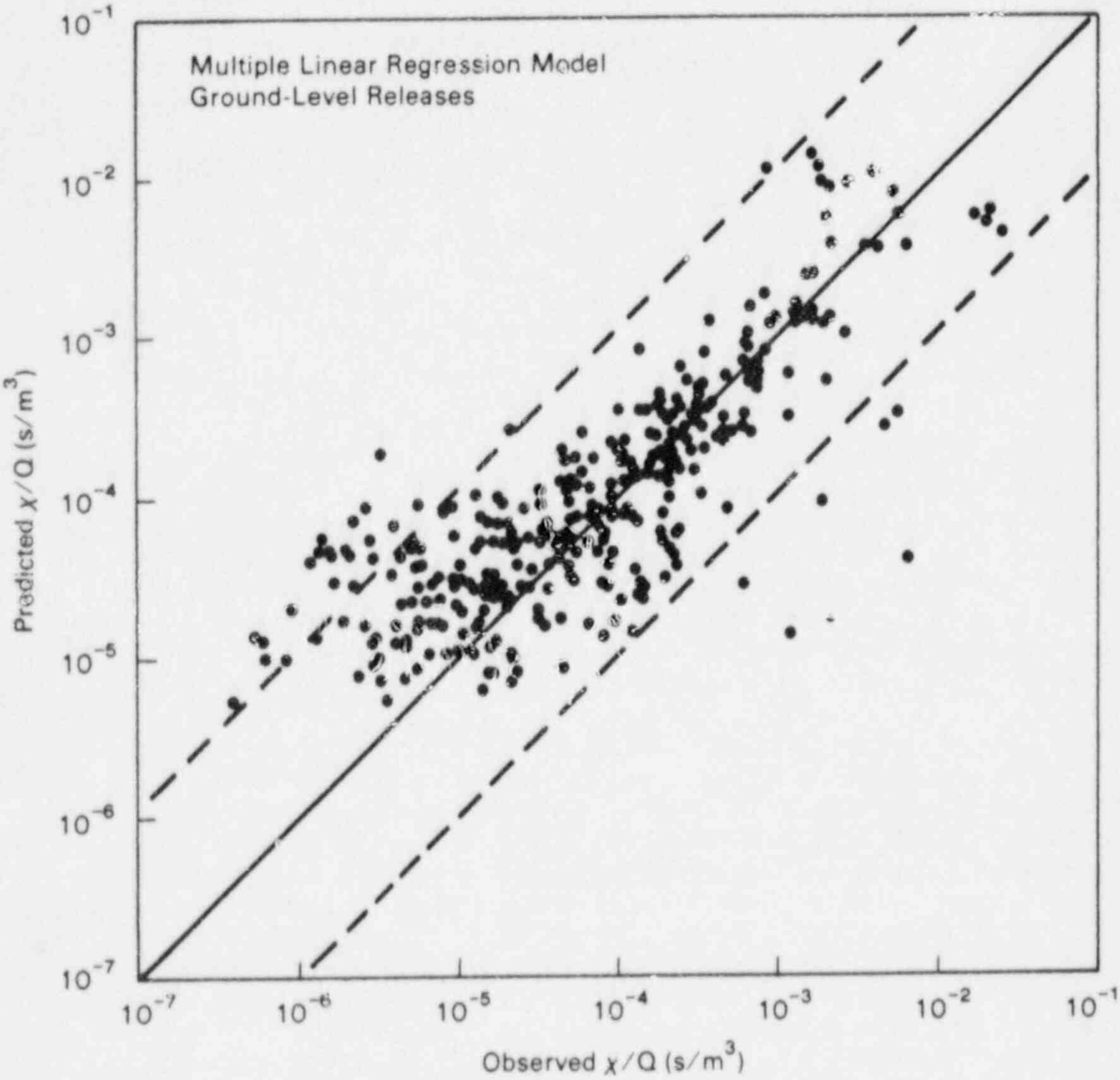

FIGURE 11. Comparison of Normalized Concentrations Predicted by Multiple Linear Regression for Ground-Level Releases with Observed Concentrations

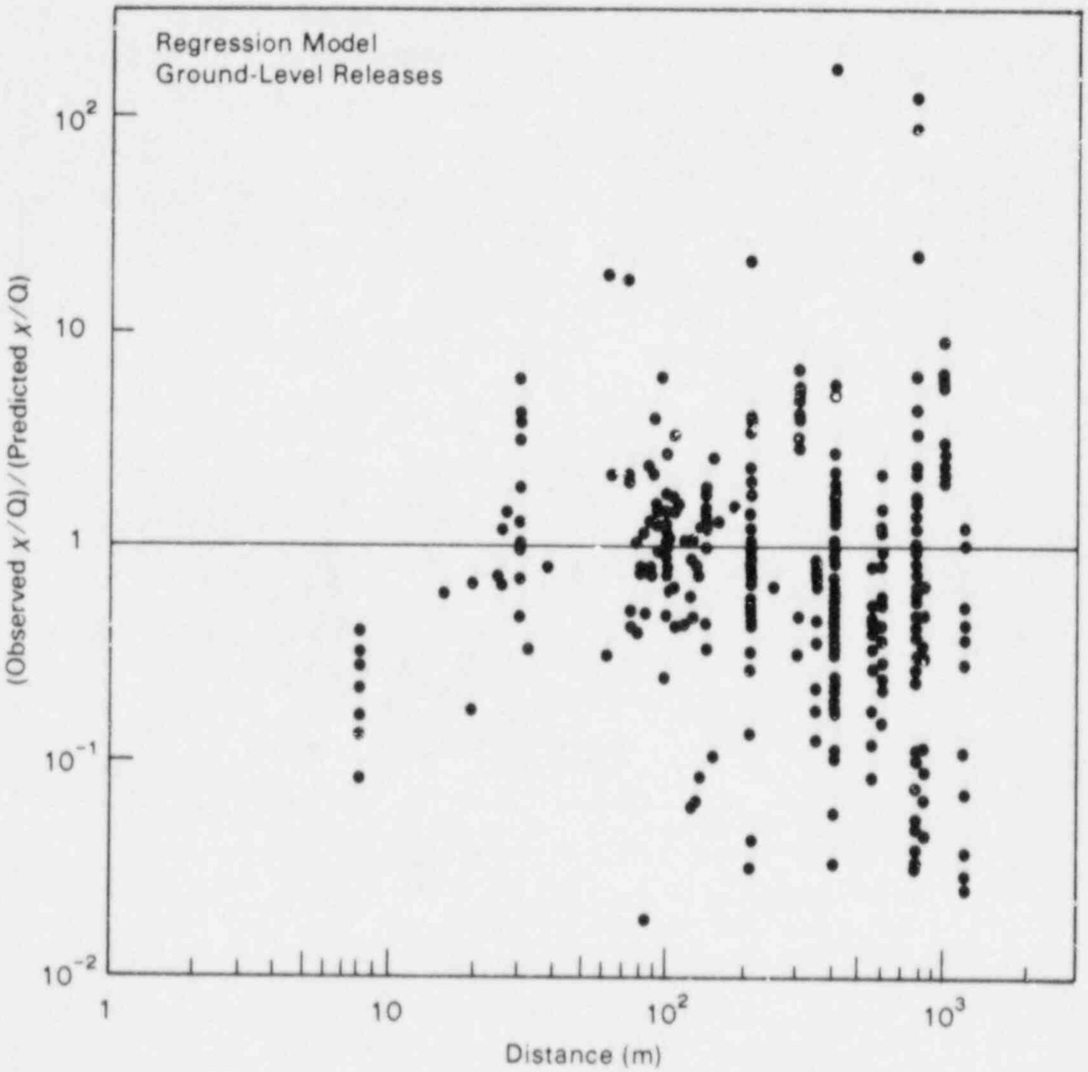

FIGURE 12. Variation of the Ratio of Observed Concentrations to Concentrations Predicted by the Multiple Linear Regression Model for Ground-Level Releases as a Function of Distance from the Release Point

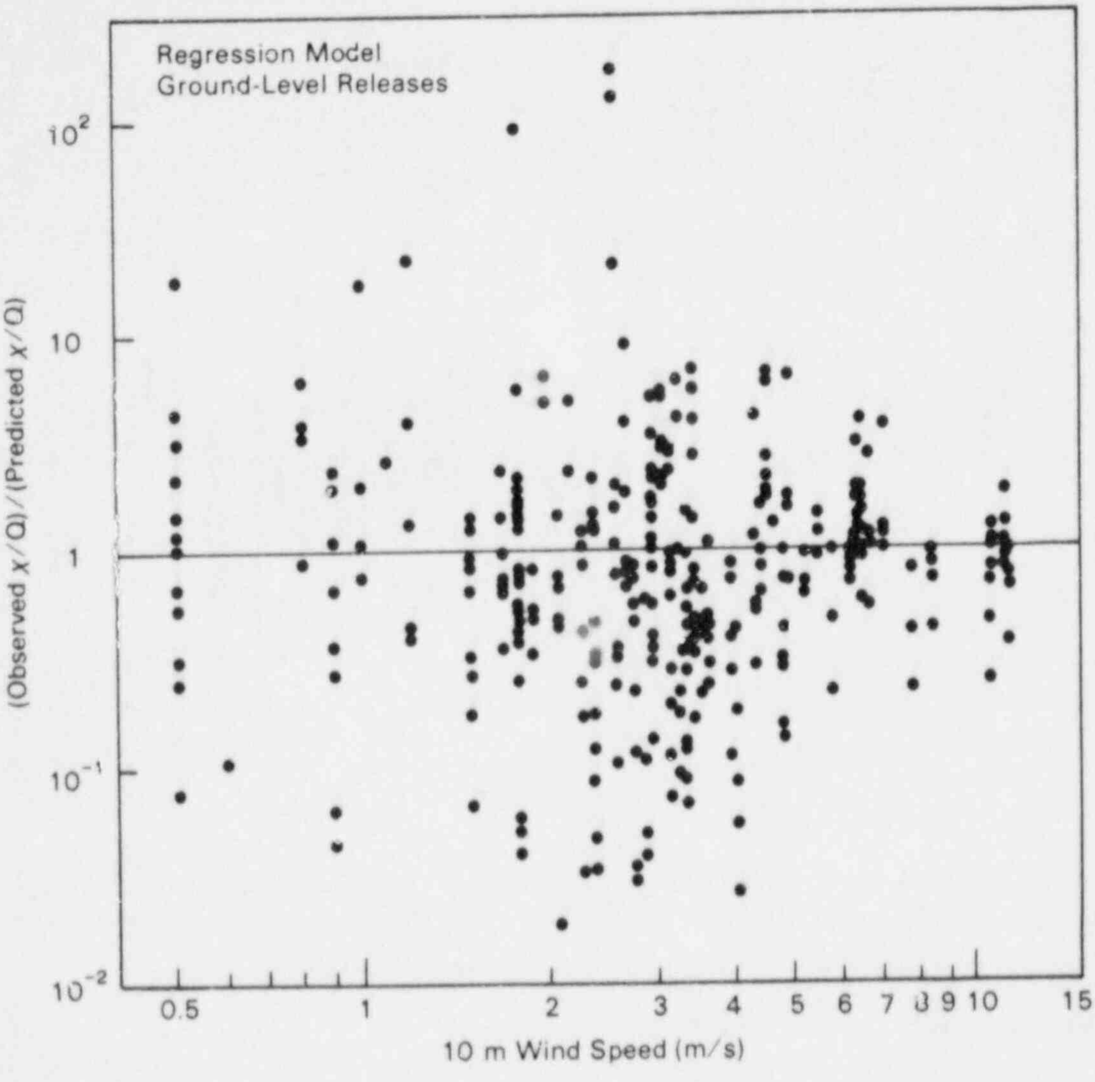

FIGURE 13. Variation of the Ratio of Observed Concentrations to Concentrations Predicted by the Multiple Linear Regression Model for Ground-Level Releases as a Function of the 10-m Wind Speed

in the model may lead to avenues for further research. It is possible that k could be related to characteristics of the building complex and atmospheric conditions. For example, if k has units of T^2, it might be proportional to some function of A/U^2 has a possible interpretation as being a scale associated with the square of inverse of the wind speed gradient across the wake immediately downwind of the building. Similarly, if k has units of T^2/L, it may be related to $A^{1/2}/U$, which has a possible physical interpretation as a scale associated with the inverse of a gradient of kinetic energy. These gradients are counter to the crosswind concentration gradient and become stronger as the freestream wind speed increases. Thus, on cursory evaluation, it seems reasonable that increasing the wind speed might decrease the rate of lateral diffusion out of the wake, and that this reduction might lead to U appearing in the numerator in the regression model. Of course, as suggested initially, both explanations are speculative and are designed to challenge the theorists.

At the present time there is no theoretical basis on which to select a set of parameter values to replace the regression estimates. As a result, the following parameter values are suggested:

k = 100
a = -1.2
b = -1.2
c = 0.68
d = 0.5.

Other sets of parameter values that yield about the same correlation between predicted and observed concentrations are listed in Table E.2 in Appendix E.

Throughout the remainder of this report, the regression model with these parameter values will be referred as the new building-wake diffusion model. This model is appropriate for use in estimating maximum concentrations in building wakes from ground-level releases as long as the release flow rate is small. Elevated releases and releases associated with large flows rates are discussed in the next chapter. A value of k of 150 is suggested in the next chapter when a composite model is developed that includes consideration of elevated releases and releases with large flow rates.

BUILDING-WAKE DIFFUSION MODEL EXTENSIONS

The generality of the regression model is limited by the range of variables represented in the experimental data. This chapter deals with model modifications and extensions needed to obtain realistic asymptotic behavior as the model variables approach their upper and lower limits. It also extends the model to elevated releases and covers alternative definitions of the variable is the model. Finally, it ends with a discussion of adaptation of the model for use in regulatory applications where conservative concentration estimates are desired.

COMPOSITE WAKE MODEL FOR GROUND-LEVEL RELEASES

The model and parameters developed in the last chapter describe diffusion in building wakes. However, the model does not have the correct behavior as the variables included in the model approach their asymptotic limits. For example, the concentration becomes undefined as the distance approaches zero. Similarly, the range of projected building areas (or heights, or widths) is too small to expect the regression model to give accurate concentration estimates for buildings significantly outside of the experimental range. This section describes modification to the regression model to obtain desired asymptotic behavior as distance, wind speed, and building area approach limiting values. In general, the model extensions required to obtain the desired asymptotic properties are indepenuent of specific values of the coefficient and exponents in the regression model.

The first variable to be considered is distance. In the asymptotic limit as the distance from the source decreases, the concentration in the plume must not be greater than the concentration at the release point. This concentration may be given as

$$\chi = Q/F_o \tag{9}$$

where χ = the concentration
Q = the release rate
F_o = the volumetric flow at the release point.

If χ/Q is considered to be inversely related to a characteristic flow in the wake, i.e.,

$$\chi/Q = 1 / F_w = k\ x^a\ A^b\ U^c\ S^d \tag{10}$$

where $F_w = 1 / (\ k\ x^a\ A^b\ U^c\ S^d\ )$, (11)

then, the initial flow and characteristic flow in the wake may be added to give a total volume flow in which the effluent is dispersed. The concentration in the combined flows may then be estimated by

$$\chi/Q = 1 / (\ F_o + F_w\ ). \tag{12}$$

Given Equation (12), as the downwind distance decreases, a point is reached where the initial flow dominates the diffusion and further decreases in distance do not lead to increases in concentration.

In addition to giving the wake model the correct behavior as the downwind distance approaches zero, this modification allows the model to handle a second limiting case correctly. The second case involves a release from a small opening near an air intake. If the flow at the release is less than the flow through the intake, the maximum concentration in the intake is not Q/F_o, rather it is Q/F_i where F_i is the flow in the intake. To encompass this additional case it is only necessary to redefine F_o. The redefinition allows F_o to be the larger of the flows at the release point and the intake. In both cases the material being released is uniformly mixed in the flow and the concentration is just total mass flow divided by volume flow

As the distance from the release point increases, the effect of the building wake on overall diffusion should decrease. Eventually, the effect of the building should become minimal, and barring other external factors, the concentration standard Gaussian plume model should describe the diffusion. This behavior can be imposed on the model in a manner that follows the imposition of the constraint for small distances. If it is assumed that the normalized concentration is inversely related to a flow, and that the flow characteristic of a Gaussian plume is

$$\chi/Q = (F_p)^{-1} = (\pi U \sigma_y \sigma_z)^{-1} \tag{13}$$

then, F_p may be added to F_o and F_w to get

$$\chi/Q = 1 / (F_o + F_p + F_w). \tag{14}$$

The initial flow, F_o, is constant and does not contribute significantly at large distances. However, both F_p and F_w continue to increase as x increases. If the model is to asymptotically approach the Gaussian plume model at large distances, the wake induced diffusion must be limited. This can be accomplished by placing an upper limit on the distance used in the wake model. Turbulence research has shown that excess turbulence induced by buildings decreases as the distance from the building increases. The choice of a limit is somewhat arbitrary, but the limit should be related to building size. According to Hosker and Pendergrass (1986), 10 to 20 building heights downwind of a building, the turbulence is indistinguishable from the upwind turbulence.

The effects of various limits on the predictive ability of the model were examined. In general, making the limits on distance more restrictive reduced model performance. Ultimately, the distance in the wake model was limited to 20 times the square-root of the projected building area. This distance is consistent with distances associated with the persistence of wake turbulence. The use of other characteristic lengths associated with buildings, such as building height, was examined, but none gave a better result than the square-root of the projected area.

It should be noted that the addition of the F_p does not change the asymptotic behavior of the model as the distance decreases because both diffusion coefficients tend to zero as distance approaches zero.

The combination of the initial dilution, Gaussian plume and wake terms in the composite model result in a tendency for the model to overestimate diffusion. This tendency can be countered by increasing magnitude of the coefficient in the wake term. If the coefficient is increased to 150, about as many concentrations are underestimated as are overestimated.

The predictive ability of the composite model for ground-level releases is shown in Figure 14. Comparing the scatter shown in Figure 14 with the scatter shown in Figure 11, it is clear that the addition of the terms required to achieve the desired asymptotic behavior decreased the predictive ability. Quantitatively, this decrease is represented by a decrease in the square of the overall correlation coefficient between predicted and observed concentrations from 0.64 to 0.56. However, when the composite model is compared with Murphy-Campe Model 1, the improvement represented in the composite model is significant. This can be seen by comparing Figures 1 and 14.

As the projected building area approaches zero, the F_w term in the composite model goes to zero, and it reverts to a Gaussian plume model with a correction term to account for initial dilution. As the area increases, the distance to which wake diffusion dominates normal diffusion increases. As a practical matter the increase in the projected area is limited by construction considerations. It would seem inappropriate to apply the composite model to diffusion in the wakes of buildings that have projected areas that are much larger than the largest area in the data set (2050 m^2). It would also be questionable to apply the model to buildings that have height to width ratios much outside the experimental range of 0.4 to 1.1.

The Gaussian diffusion model and current wake models become undefined as the wind speed approaches zero. The wake factor in the composite model changes this asymptotic behavior. As the wind speed approaches zero in the composite model, the concentration also approaches zero because the wake diffusion term increases without bound. The decrease in concentration with decreasing wind speeds can be limited by placing a lower limit on wind speeds. Physically, the increase in the wake term is unreal because the wake should disappear at some low speed. The lower limit of the data used in development of the wake model is 0.5 m/s, and the lower limit of the data in the elevated-release data set is 0.3 m/s. Either of these values would be a reasonable lower limit for the wake model.

As wind speed increases, the flow associated with the wake decreases and the flow associated with the plume increases. As a result, the asymptotic behavior at high wind speeds is determined by the plume model. There is no reason to place an upper limit on the speed used in the model because the atmosphere effectively places an upper limit on the speed. Models used to estimate extreme winds (e.g., Ramsdell et al. 1986, 1987) indicate that the

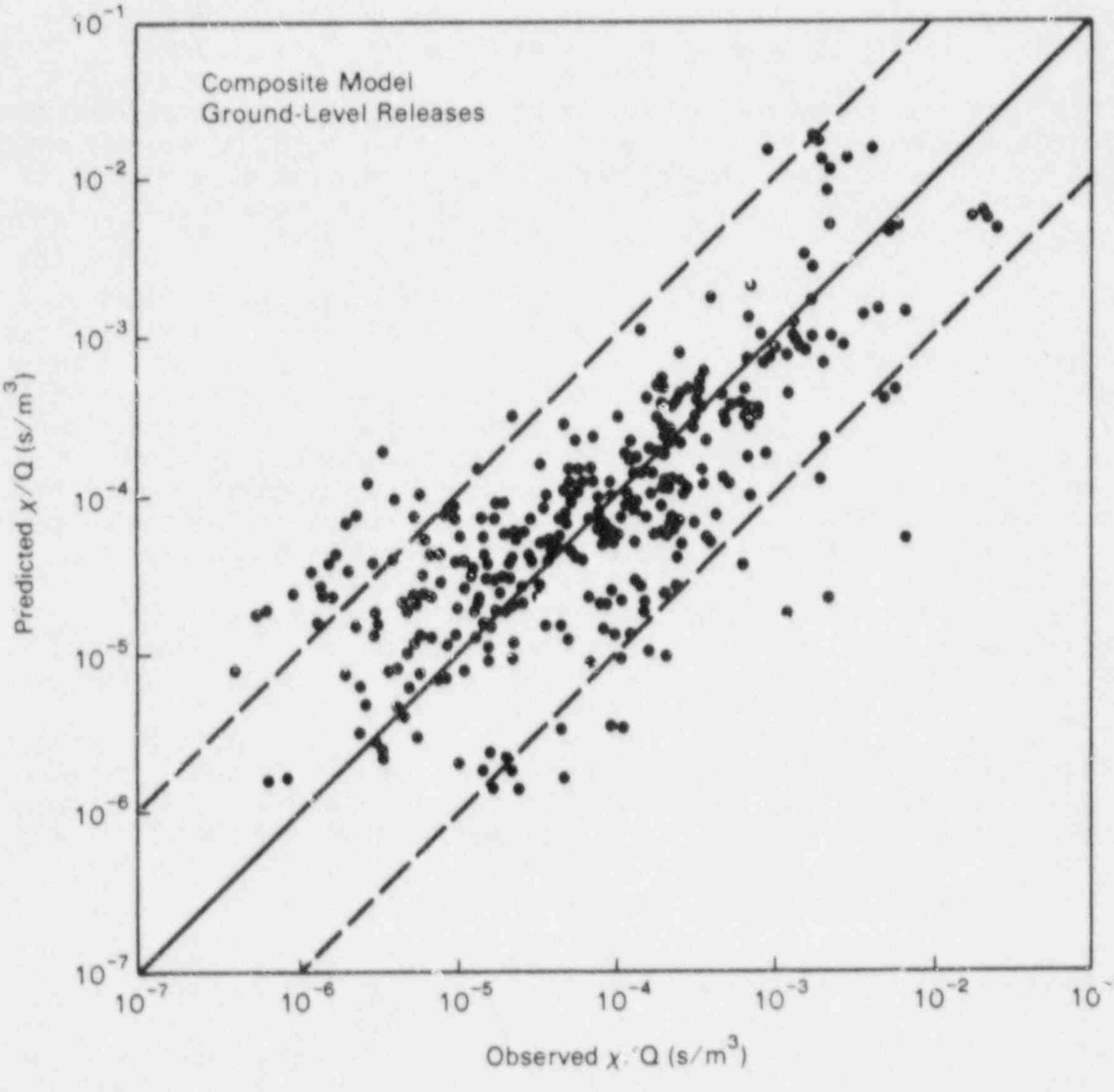

FIGURE 14. Comparison of Normalized Concentrations Predicted by the Composite Model for Ground-Level Releases with Observed Concentrations

probability of occurrence of high speeds decreases much more rapidly than 1/U. Doubling the speed from 20 m/s to 40 m/s will only reduce the concentration by a factor of 2, but the probability of a 40 m/s wind is several orders of magnitude less than that of a 20 m/s wind.

With the limitations on distance and wind speed in the building wake term, the model defined by Equation (14) has the desired asymptotic behavior with respect to distance from the source. Near the source the concentrations have an upper limit associated with the release or intake flow. As the distance from the source increases, the wake and plume models control the concentration. Eventually, the term associated with the building wake becomes a constant. Beyond this point, diffusion is controlled by the normal atmospheric turbulence and the Gaussian plume model.

ELEVATED RELEASES

The conservative approach to estimating the concentrations downwind of short stacks and roof-top vents is to assume that a release takes place at ground level unless the release point is 2.5 times the building height. However, there is a significant body of literature to support a less conservative assumption. For example, Davies and Moore (1964), Martin (1965), Munn and Cole (1967), and Rodliffe and Fraser (1971) present experimental evidence that the behavior of plumes released from short stacks and roof-top vents depends on the ratio between the vertical velocity of the effluent and the wind speed at release height. When the ratio is large, plumes escape the wake; when it is small they remain in the wake, and when the ratio has an intermediate value, the plumes escape the wake part of the time and are entrained in the wake the rest of the time.

Following the Millstone experiments, Johnson et al. (1975) suggested a model, which they called a Split-H model, that attempted to account for this behavior of elevated releases. A modified version of the Split-H model is included in Regulatory Guide 1.111 (NRC 1977) and is implemented in the XOQDOQ model (Sagendorf, Goll, and Sandusky 1982), which is used in the evaluation of the consequences of routine releases from nuclear power plants. However, the results of the Duane Arnold Energy Center diffusion experiments (Thuillier and Mancuso 1980) were not entirely consistent with the results of the Millstone experiments. This inconsistency led to a re-evaluation of the Split-H concept and development of a revised model (Ramsdell 1983).

The Split-H concept was tentatively used in estimating concentrations in the wakes for the experiments that are included in the elevated-release data set. The standard Gaussian model for elevated releases was used to estimate concentrations in the wake when the plume was elevated, and the composite wake model was used estimate concentrations when the plume was entrained in the wake. Figure 15 compares the concentrations predicted using this combination with the observed concentrations for the elevated release data set. This figure corresponds with Figure 2, which compares Murphy-Campe Model 2 concentration predictions with the observed data. A large portion of the concentrations are overpredicted in both cases, and neither approach appears

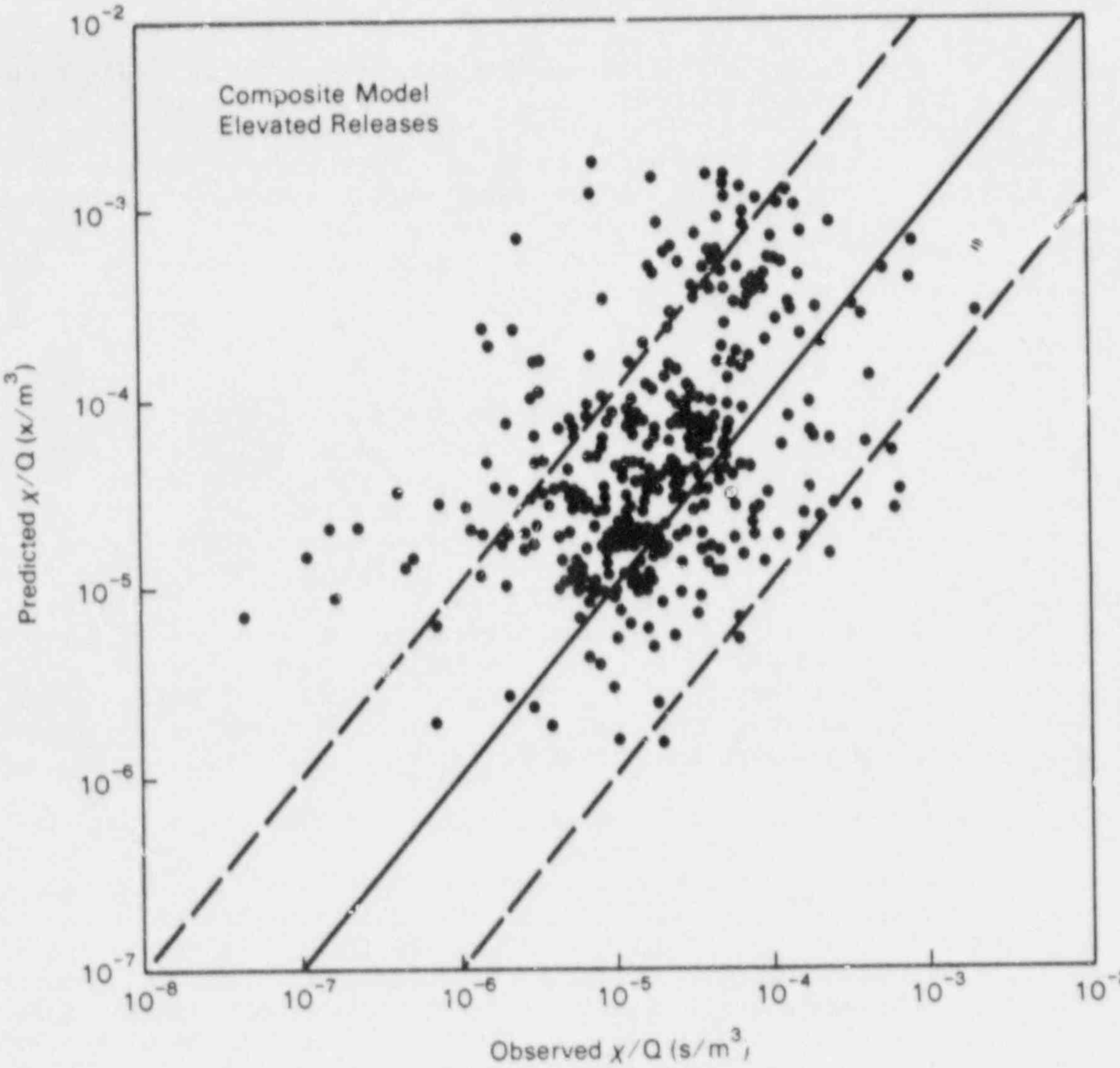

FIGURE 15. Comparison of Normalized Concentrations Predicted by the Composite Model for Elevated Releases with Observed Concentrations

to be particularly skilled. Nevertheless, on the average, the Split-H approach appears to be better, i.e., the bias and scatter appear to be less, than Murphy-Campe Model 2. The predictive abilities of the two approaches, as measured by the square of the correlation coefficient between predicted and observed concentrations, are 0.207 for the Split-H approach with the composite wake model and 0.133 for Murphy-Campe Model 2. This difference, although small, is significant.

All three forms of the Split-H model (Johnson et al. 1975; Regulatory Guide 1.111; and Ramsdell 1983) were evaluated. Changing the form of the Split-H model did not result in significant changes in the ability predict concentrations. Consequently, there is no need to change the current NRC implementation of the Split-H model.

In the NRC implementation, the Split-H model is applied to releases in which the actual release height is equal to or greater than the height of the tallest building in the area. Assuming that this condition is met, a release is considered to be elevated, when the ratio of vertical velocity to wind speed is equal to or greater than 5. If the ratio is less than 1, the release is considered to be ground-level, and if the ratio is between 1 and 5, the concentration is computed assuming that a portion of the release is elevated and the remainder is at ground level.

The exact form of the NRC implementation of the model is

$$(\chi/Q) = M\,(\chi/Q)_{entr} + (1 - M)\,(\chi/Q)_{elev} \tag{15}$$

where (χ/Q) = the normalized concentration predicted by the Split-H model

M = the fraction of the time that the plume is entrained in the building wake

$(\chi/Q)_{entr}$ = the normalized concentration in the building wake predicted for a ground-level release

$(\chi/Q)_{elev}$ = the normalized concentration at ground level predicted for an elevated release.

The fraction of the time that the plume is entrained in the wake is estimated from the ratio of the effluent vertical velocity (W_0) to the release height wind speed (U_r) according to:

$$M = \begin{cases} 1 & W_0/U_r < 1.0 \\ 2.58 - 1.58\,(W_0/U_r) & 1.0 <= W_0/U_r < 1.5 \\ 0.3 - 0.06\,(W_0/U_r) & 1.5 <= W_0/U_r < 5.0 \\ 0 & W_0/U_r >= 5.0. \end{cases} \tag{16}$$

This form of the Split-H model differs from the form suggested by Johnson et al. (1975) only in the values of the constants used in the definition of M.

The elevated-release data were divided into two subsets to examine the models more closely. The division of the data was made on the basis of vertical velocity of the release. One subset included the data for the releases that were made without significant vertical velocity, and the other subset included the data for releases made from stacks and vents that had flow with a significant vertical velocity. Of the 421 elevated release data points, 265 were included in the first subset. These data were obtained in the EOCR, Rancho Seco, Duane Arnold experiments. The other subset included 146 data points, most of which were obtained in the Millstone experiments. There were also a few data points in this second group from the Duane Arnold Experiment.

Table 9 lists the predictive abilities of the composite wake model Split-H model combination, Murphy-Campe Model 2, and the new wake model without the Split-H model for the complete elevated-release data set and for each of the subsets. The new wake model is clearly better than Murphy-Campe Model 2 for elevated releases that have an initial vertical velocity. However, it is slightly worse than Murphy-Campe Model 2 for releases with no initial vertical velocity. The composite model and Murphy-Campe Model 2 have the same predictive ability for elevated releases with no vertical velocity, but the composite model clearly outperforms the Murphy-Campe model when releases have a significant vertical velocity.

TABLE 9. Predictive Ability (r^2) of the Composite, Murphy-Campe, New Wake Diffusion Models for Elevated Releases.

Model	Elevated Release Data Set		
	All	$W_0 = 0$	$W_0 > 0$
Composite	0.203	0.225	0.412
Murphy-Campe Model 2	0.133	0.231	0.011
New Wake	0.189	0.191	0.266

A large part of the difference in performance of these two models is the result of the addition of Split-H model to the composite model. However, a comparison of the performance of the new wake model and the Murphy-Campe model indicates that some of the difference in performance between the composite and Murphy-Campe models is also the result of the difference in the treatment of diffusion within the wake.

The statistics in Table 9 indicate that none of the models is particularly adept at estimating concentrations in building wakes from elevated releases where plume rise is not a significant factor. The maximum r^2 of 0.231 for the elevated data subset with no initial vertical velocity is small compared with the corresponding maximum values for the other elevated release subset and for the ground-level data set. The statistics also indicate that failure to account for possible plume rise results in lower predictive ability in cases where plume rise is not a potential factor as well as in those cases where it is.

Neither the Murphy-Campe model nor the new wake model considers potential plume rise effects. Yet, the new wake model shows about the same amount of skill with both elevated release data subsets, while Murphy-Campe Model 2 only shows skill with the data subset in which plume rise is not a factor. The difference in performance of the two models may be attributed to the manner in which they account for the effect of wind. In the Murphy-Campe model increasing wind speed results in decreasing concentrations, but increasing the wind speed increases concentrations in the new wake model. If the composite model is considered, increasing the wind speed causes increased concentrations by decreasing the fraction of the time that the plume escapes wake and by increasing concentrations when the plume is in the wake.

The Split-H procedure accounts for plume rise and tends to reduce the bias in the composite model concentration estimates. This reduction in bias is clearly seen when Figure 15 is compared with Figure 2. However, this reduction in bias is accompanied by an increase in the number of observed concentrations that are underpredicted. The Split-H procedure may results in a few gross concentrations underestimates. These underestimates occur when the plume is assumed to escape the wake but doesn't. Six of the data points obtained during releases with significant vertical velocity were underestimated by more than an order of magnitude, and all were obtained in the Duane Arnold experiments.

The four largest underpredictions of centerline concentrations occurred at a distance of 300 m in stable atmospheric conditions with wind speeds of less than 1 m/s. In each of these cases the plume should have escaped the wake according to the Split-H criteria. Thus, the normalized concentrations predicted by the model were small. The largest of the observed concentrations for these cases was 3.5×10^{-7} s/m^3, which is well below the maximum concentration expected at 300 m in the wake from a ground-level release. Of the possible explanations for these underestimates, two come to mind immediately. The first is that the Split-H criteria do not adequately determine when plumes escape wakes, and the second is that the turbulence caused by buildings may result in enhanced vertical diffusion even if a plume initially escapes the wake. Neither explanation has been examined in detail. The other two concentrations that were underestimated by more than an order of magnitude were underestimated by slightly over an order of magnitude. These cases occurred at 300 and 1000 m in neutral and unstable conditions during moderate winds. The largest normalized concentration in these cases is 6.3×10^{-5} s/m^3. As with the other cases of gross concentration underestimates, the observed concentrations are well below concentrations that would be predicted by the model under other realistic atmospheric conditions.

For the remainder of the report, references to the composite model include the Split-H model if they are related to elevated releases. A FORTRAN computer code for computing centerline concentrations in wakes using the composite model is presented in Appendix F.

MODEL VARIABLE DEFINITIONS

As the new models were being developed, different methods of determining values for these variables were evaluated. This section summarizes the results of those evaluations.

Wind Speed

The Murphy-Campe models and PAVAN use the 10 m wind speed in estimating the concentration in building wakes, although the wind speed at the release height has been used in modeling building-wake diffusion in many studies. The revised building-wake model was tested using both the 10 m and release height winds. Table 10 contains the square of the correlation coefficient between observed concentrations and concentrations predicted by the wake model for each of the data sets for both wind measurement heights. Model performance was slightly better when the 10-m wind was used than when the release height wind was used. Consequently, it is appropriate to use 10-m wind speeds in the new models. However, when the Split-H procedure is used, the release height wind should be used to determine fraction of the time that the release is in the wake and in estimating diffusion when the plume escapes the wake.

TABLE 10. Comparison of the Predictive Ability (r^2) of the Wake Diffusion Model with Different Wind Speed Measurement Heights

Measurement Height	Data Set				
	Ground-level Releases	Elevated Releases: All	Elevated Releases: $W_0 = 0$	Elevated Releases: $W_0 > 0$	Receptors on or Adjacent to Buildings
10 Meters	0.637	0.186	0.186	0.268	0.069
Release Height	0.637	0.174	0.178	0.229	0.045

Stability Class Estimation

In the development of the wake model, the stability class determination was based on the vertical temperature gradient. Addition of the Gaussian plume term to the composite model makes it possible to specify different stability classes for horizontal and vertical diffusion. Established NRC guidance (NRC 1972) recognizes the use of vertical temperature gradient to

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TABLE 12. Comparison of the Predictive Ability (r^2) of the New Wake Diffusion Model with Different Distance Measures

Distance Measure	Data Set: Ground-level Releases	Elevated Releases: All	Elevated Releases: $W_0 = 0$	Elevated Releases: $W_0 > 0$	Receptors on or Adjacent to Buildings
Horizontal	0.638	0.188	0.191	0.265	0.010
Slant Range	0.638	0.189	0.191	0.266	0.043
Stretched-String	0.637	0.186	0.186	0.268	0.069

release is postulated. When estimating concentrations at other receptor locations any of the distances may be used.

REGULATORY APPLICATIONS

The Murphy-Campe models and PAVAN were chosen for use in regulatory applications because they were thought to tend to overestimate concentrations, i.e., that they were conservative. The use of conservative models is appropriate in regulatory applications where safety and health are concerned. However, the extent to which a model is conservative should be known. It is difficult to quantitatively evaluate how conservative current regulatory models are because they have been developed using a series of conservative assumptions. Another alternative to developing regulatory models is to develop the best unbiased model possible and then add a known bias to achieve a desired level of conservatism. The composite wake model has been developed to give "best estimates" of the concentration. Consequently, it is not surprising to find that it underestimates concentrations more frequently than the Murphy-Campe models and PAVAN. The following discussion demonstrates modification of the composite wake model to make it arbitrarily conservative.

The square of the correlation coefficient between the predicted and observed concentrations has been used as a measure of a model's predictive ability. More precisely this statistic should be interpreted as the fraction of the variation in the observed values that is accounted for by a model. It does not indicate how accurate a model is. All concentrations estimated by a model may be multiplied by a constant without affecting the correlation between predicted and observed values. In contrast, the accuracy of the estimated concentrations is affected when the concentrations are multiplied by a constant. Thus, wake concentration for regulatory applications may be estimated from the composite model as

$$(\chi/Q)_{reg} = C\ (\chi/Q)_c \qquad (17)$$

where $(\chi/Q)_{reg}$ = a normalized concentration estimated for regulatory applications

C = a constant chosen to make the model conservative

$(\chi/Q)_c$ = the normalized concentration estimated with the composite model

The following two examples show one method for selecting a value for the constant. The first step in selecting a value for C is to define a desired level of conservatism. For the purpose of this discussion, a model will be considered conservative if it underestimates concentrations less than 10% of the time. Following the procedure outlined below, the NRC regulatory staff may adjust the value of C if it feels a different definition of conservative is more appropriate.

Figure 16 shows cumulative frequency distributions for ratios of observed to predicted concentrations for the new wake, composite, and Murphy-Campe models for the ground-level release data. None of the models of the models is conservative because 40 to 50% of the observed concentrations are underestimated by each model. The factor required to make each model conservative can be determined from the cumulative frequency distributions. To make the Murphy-Campe model conservative, it would be necessary to multiply the concentrations by a factor of ten. To obtain the value of ten, a vertical line is extended upward from the 10% exceeded mark on the horizontal axis until it intersects the line formed by the Murphy-Campe Model 1 data points. This intersection occurs at a concentration ratio of 10 as read from the vertical axis. Similarly, the factor required to make the composite model conservative is 6, and that for the new wake model is about 3.5. The dashed line in Figure 16 shows the cumulative distribution of observed to predicted concentrations for the composite model when the predicted concentrations are multiplied by 6. Had conservative been defined as underestimating concentrations 5% of the time or less, the multiplicative factors for the three models would be about 22, 11, and 5.5, respectively.

Figure 17 shows cumulative distributions of the observed to predicted concentration ratios for the elevated-release data. In this case, the composite model, Murphy-Campe Models 2 and 3, and PAVAN were used to predict the concentrations. Murphy-Campe Model 2 is conservative according to the preceding definition, and multiplicitive factors of 1.3, 3 and 24 are needed, respectively to make PAVAN, the composite model, and Murphy-Campe Model 3 conservative. The dashed line shows the cumulative frequency distribution for the observed to predicted concentration ratio for the composite model after multiplying the predicted concentrations by a factor of 3.

The next chapter summarizes the building wake model recommendations. These recommendations cover both models and methods for determining values for the model variables. The following chapter presents guidelines for use in evaluating intake locations without the use of models.

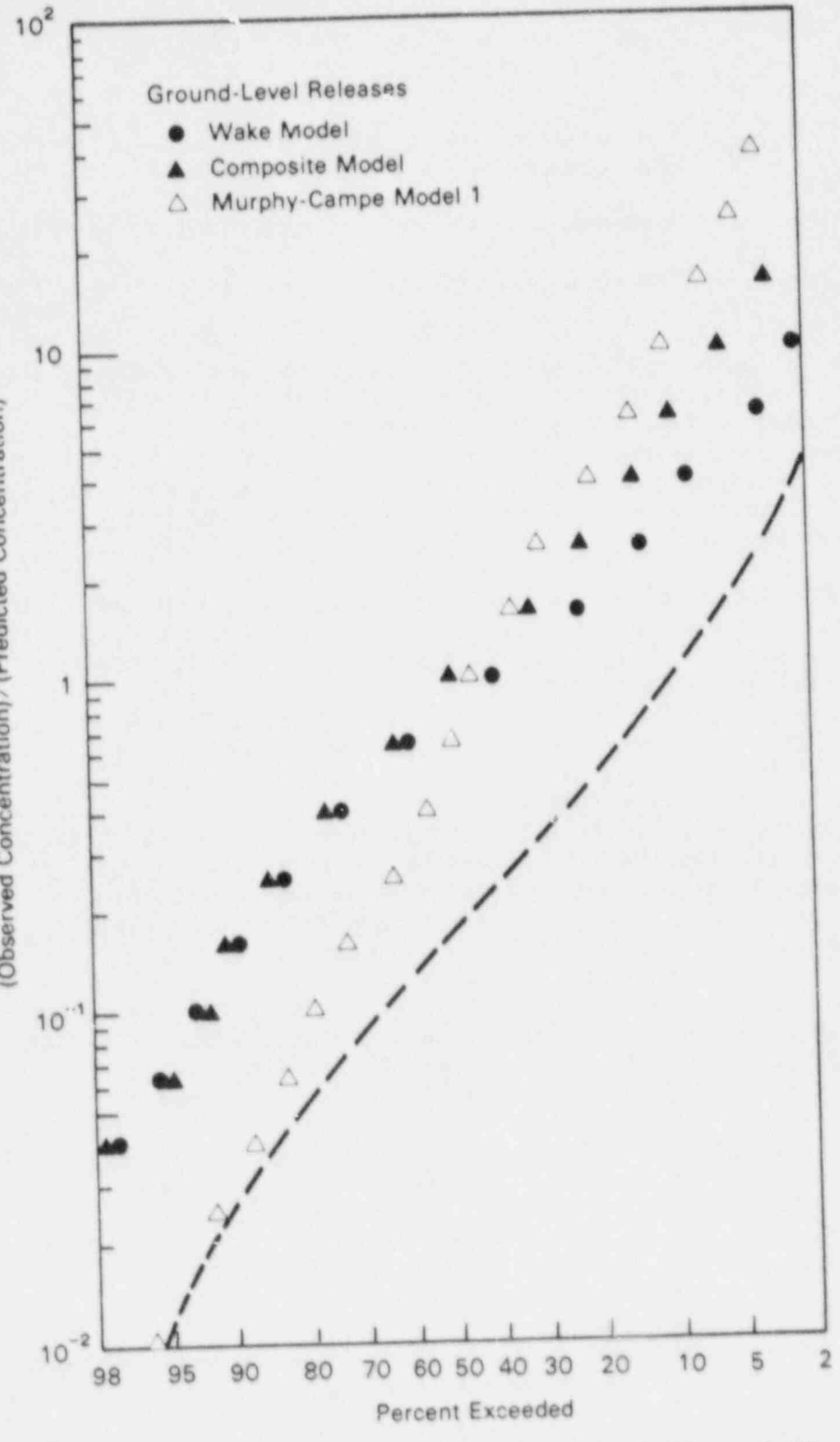

FIGURE 16. Cumulative Frequency Distributions for the Ratios of Observed Concentrations to Concentrations Predicted by the New Wake and Composite Models and Murphy-Campe Model 1 for the Ground-Level Release Data

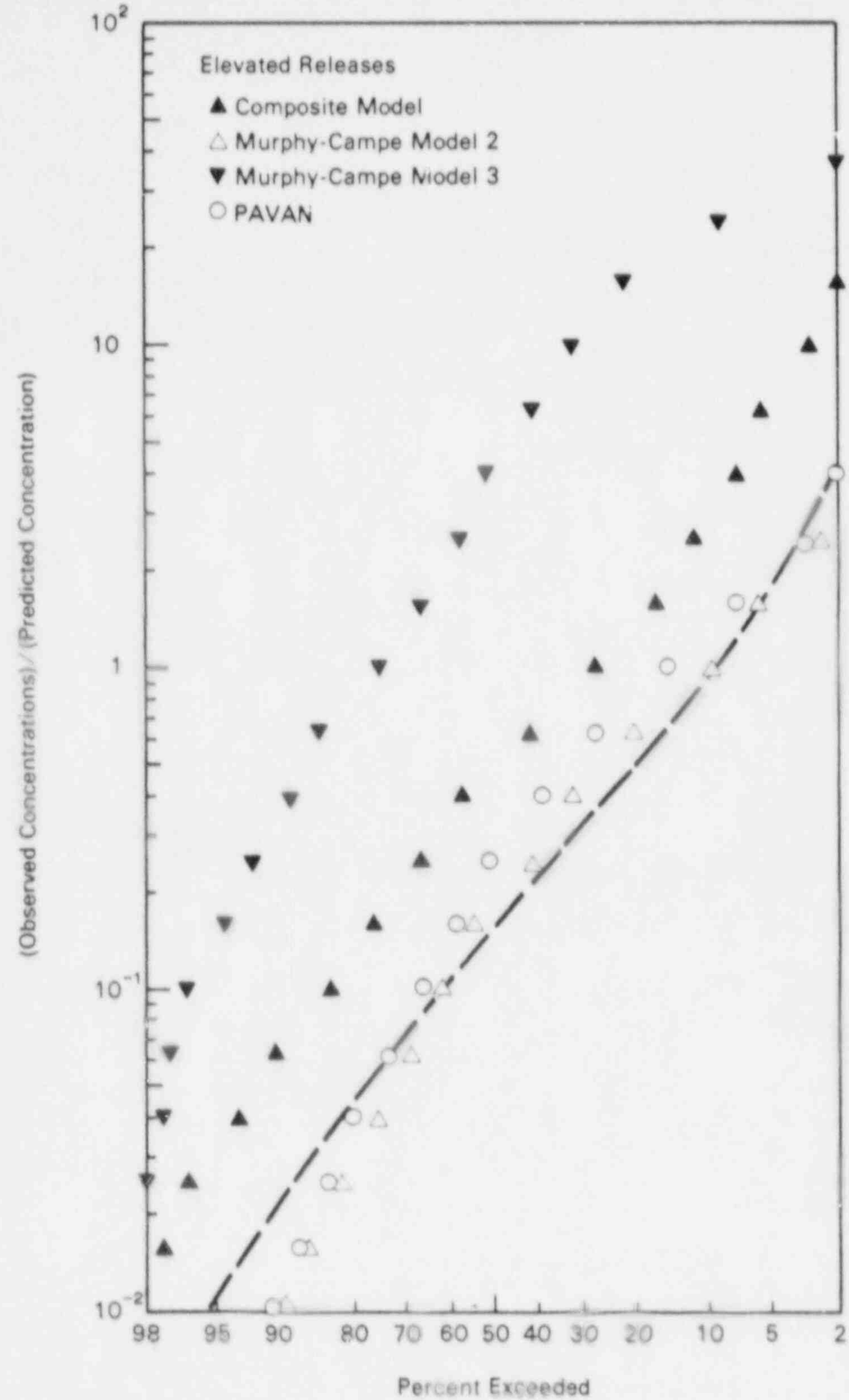

FIGURE 17. Cumulative Frequency Distributions for the Ratios of Observed Concentrations to Concentrations Predicted by the Composite Model, Murphy-Campe Models 2 and 3, and PAVAN for the Elevated Release Data

BUILDING-WAKE MODEL RECOMMENDATIONS

The last two chapters described the observed characteristics of diffusion in building wakes and developed models for estimating centerline concentrations in wakes. The first model, which is based on ground-level release data, is referred to as the "new wake" model. It differs significantly from previous wake models in the manner in which wind speed is incorporated in the model. The second model is an extension of the first model to improve asymptotic behavior and include consideration of the mitigating effect of plume rise on concentrations. It is referred to as the "composite" model and is more generally applicable than the "new wake" model. This chapter presents a final comparison between the new models and the Murphy-Campe models and PAVAN and makes recommendations for use of the models.

FINAL COMPARISONS

The previous comparisons between the new models and the Murphy-Campe models and PAVAN have been made using either the ground-level or elevated release data. In this section, the initial comparison is based on a combination of the data from these two sets. A second comparison is made using the data collected on and adjacent to the buildings.

The cumulative frequency distribution for the observed to predicted concentration ratios for each of the models is shown in Figure 18. The 10-m wind speed and "stretched string" distance were used in the new wake model, and in the wake portion of the composite model. In the Gaussian plume portions of the composite model, horizontal distance was used, and the release height wind was used to estimate the fractional entrainment of elevated plumes in the wake and in the elevated plume model. The new wake and composite models have about the same tendency to underpredict concentrations as the Murphy-Campe models and PAVAN. At the opposite extreme, the two new models have less tendency for large overpredictions. The dashed line in the figure shows the effect of increasing the composite model concentrations by a factor of 4 to make the model more conservative. When this is done, lower probability of underestimating concentrations is reduced significantly, but the frequency of overestimating the concentration is increased.

Cumulative frequency distributions for observed-to-predicted concentration ratios for receptors on and adjacent to building surfaces for the composite model, all three Murphy-Campe models, and PAVAN are shown in Figure 19. The data used for this comparison were obtained in the EOCR, Rancho Seco, and Duane Arnold experiments at a limited number of sampling locations. As a result, there is no assurance that the data represent maximum concentrations. Therefore, these distributions cannot be used to prove that models are correct. However, they can show that a model has significant problems. Specifically, the distribution of the ratios for Murphy-Campe Model 3 shows that the model underestimated more than 50% of the observed concentrations. This is a clear indication that it is not conservative to use Murphy-Campe Model 3.

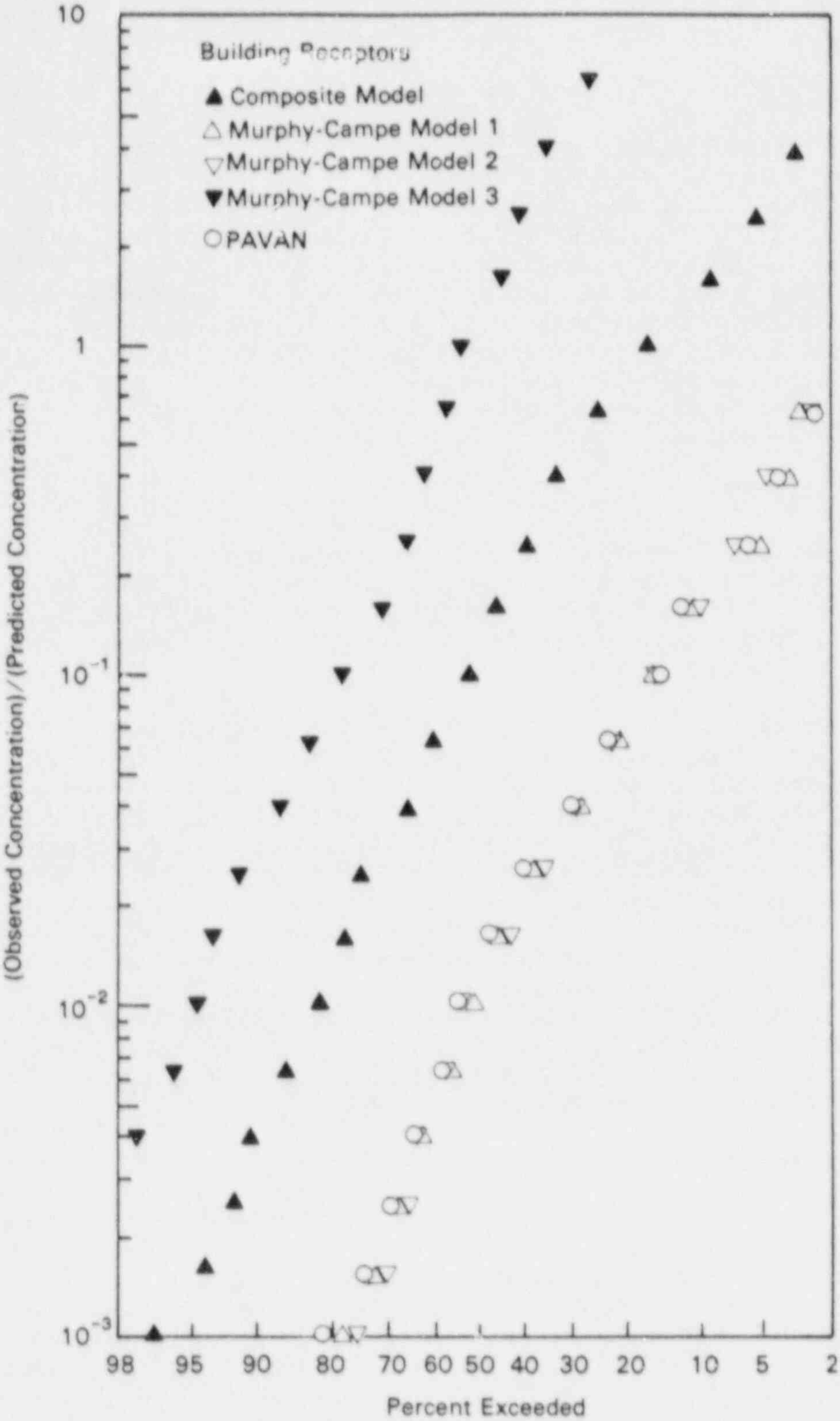

FIGURE 18. Cumulative Frequency Distributions for the Ratio of Observed Concentrations to Concentrations Predicted by the New Wake and Composite Models, Murphy-Campe Models 1 and 2, and PAVAN for the Combined Ground-Level and Elevated Release Data

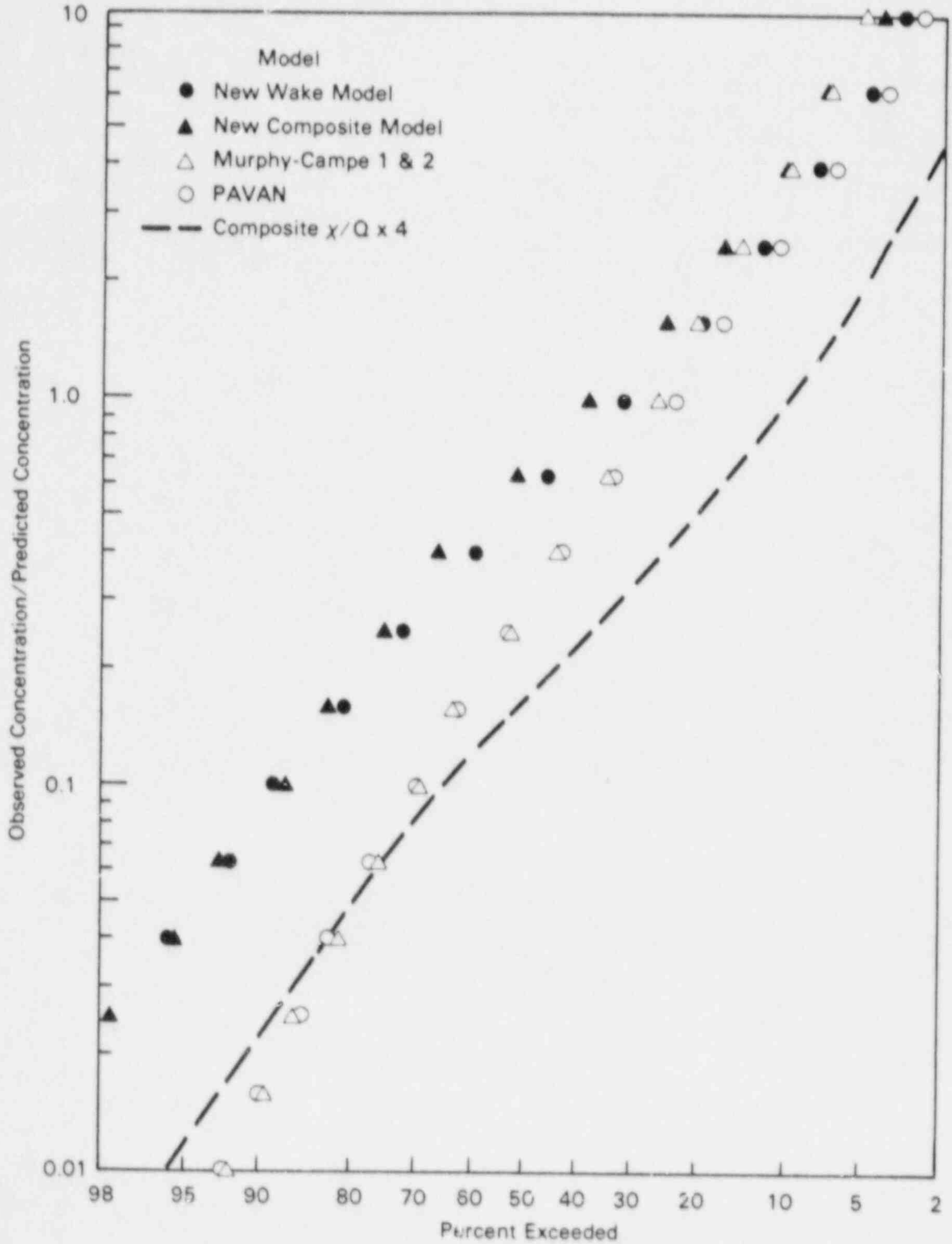

FIGURE 19. Cumulative Frequency Distributions for the Ratios of Observed Concentrations to Concentrations Predicted by the Composite Model, the Murphy-Campe Models and PAVAN for Receptors Located on or Adjacent to Building Surfaces

The predictive abilities of the new models, the Murphy-Campe models, and PAVAN for each of the data sets are summarized in Table 13. The new models clearly outperform the current models for ground-level releases and for elevated releases with initial upward velocity, but their performance for elevated releases with no upward velocity is no better than that of the current model. The statistics in Table 13 generally indicate that additional work is needed to improve understanding of diffusion from short stacks and elevated vents. The data are not sufficient to determine if there are significant differences in model skill in estimating concentrations at receptors on or adjacent to buildings.

TABLE 13. Comparison of the Predictive Ability (r^2) of the Recommended Wake Diffusion Model with the Murphy-Campe and PAVAN Wake Models

Model	Data Set: Ground-level Releases	Elevated Releases: All	Elevated Releases: $W_0 = 0$	Elevated Releases: $W_0 > 0$	Receptors on or Adjacent to Buildings
New Wake	0.637	0.186	0.186	0.268	0.069
Composite	0.558	0.203	0.225	0.412	0.044
Murphy-Campe	0.310	0.133	0.231	0.011	0.049/0.019
PAVAN	0.293	0.134	0.224	0.006	0.075

MODEL RECOMMENDATIONS

The development of new building wake diffusion models and the comparison of the new models with wake models currently used by the NRC staff is now complete. This section deals with the application of the new models. It concludes the discussion of wake models.

The composite wake model (Equation (14) with the Split-H procedure) is recommended for general use. Its overall performance is better than the new wake model (Equation (7) with the regression parameter estimates), although the new model is better for ground-level releases. If the combination of the ground-level and elevated release data are considered to represent reasonable cross section of atmospheric and release conditions, the composite model is slightly conservative and estimates maximum concentrations within an order of magnitude about 85% of the time. If a postulated release point is at or near ground level and the receptor of concern is within 50 to 100 m of the release point, it may be more appropriate to use the new wake model, correcting for the initial effluent or intake flow than to use the composite model. Either model is better than the current models.

When a conservative model is desired for a specific set of conditions, concentrations should be estimated using the composite model and then increased by a factor chosen to give an appropriate level of conservatism. The experimental data indicate that if a composite model estimate is multiplied by a factor of 4 there is only about a 10% chance that the maximum concentration would exceed the estimate.

The new models indicate that it is no longer appropriate to assume that maximum concentrations in building wakes occur during low wind speed conditions. Concentrations near the release point increase with increasing wind speeds when the release is at ground level. To determine an appropriate normalized concentration for building-wakes for regulatory applications, it is necessary to consider the wind speed distribution. For elevated releases, the concentration depends on both wind speed and stability. In this case, it is necessary to consider the joint frequency distribution of wind speed and stability in selecting an appropriate normalized concentration. If the uncertainty in the estimates of the new models is neglected, a frequency distribution of normalized concentrations in building wakes can be estimated using the procedure followed in PAVAN estimating short-term χ/Q values. The procedure in PAVAN neglects the uncertainty in normal diffusion computations. It would be possible to develop a procedure, similar to the procedure in PAVAN, that takes the uncertainty in building-wake diffusion estimates into account. However, the added complexity of such a procedure is probably not justifiable given the limitations of the data used to develop the models.

GUIDELINES FOR EVALUATING CONTROL ROOM AIR INTAKE LOCATIONS

At nuclear power plants it is generally necessary to place control room air intakes near vents where radioactive effluents may be released. However, it is also necessary to ensure that the control room remains habitable during accidents even if radioactive effluents are released. The following guidelines are offered for use in evaluating potential control room air intake locations. It should be possible to distinguish between good and bad locations by following the guidelines, but it may not be possible to determine which of several similar locations is best or worst. In that sense, the guidelines cannot be relied upon to identify optimum control room air intake locations.

1. The distance between intakes and release locations should be maximized.

2. The frequency with which a control room air intake is downwind of likely release locations (short stacks, vents, etc.) should be minimized.

3. Intakes should be located lower on a building than vents.

4. Intakes should not be located in sheltered positions where contaminated air may stagnate.

The remainder of this section elaborates on these guidelines.

The new building wake diffusion model indicates, as do other wake models, that the decrease in concentrations in building wakes is proportional to the distance between the release point and the receptor. Thus, when control room intakes are near vents or short stacks, an increase in the separation between the vent and intake will result in a reduction in concentrations in the control room, thereby improving control room habitability. The distance used in assessing concentrations at control room air intakes should be the minimum path length between the vent and the intake, not just the horizontal separation. For example, if a vent in the middle of a flat roof is the release point and the intake is on the side of the same building, the distance should be the sum of the horizontal and vertical separations. If the intake is not on the same structure as the release point, the composite model should be used in the evaluation.

Wind direction distributions can be used to assess probabilities that effluents from specific vents will impact various actual or potential intake locations. However, the circulation in building wakes tends to distribute the effluents entering the wake more widely than normal atmospheric diffusion. Therefore, relatively wide wind direction sectors (perhaps as wide as 90°) should be used in this evaluation. Building wake diffusion data indicate that the plume centerline concentrations within the building wake tend to increase as the wind speed increases. This tendency is reflected in the new wake model. In addition, as wind speed and atmospheric stability increase, plume rise, which might carry effluents from vents and short stacks out of the building wake, is reduced. Therefore, wind speed and atmospheric stability should be considered along with wind direction in evaluating intake locations.

Kot and Lam (1985) released tracer material from two vents on the roof of a 6-story building at the University of Hong Kong and studied concentrations at an air intake between the vents. As constructed, the top of the vents were even with the building parapet. During the experiments short stacks (~1.25 m) were added to the vents. These short stacks decreased the concentrations at the intake by about a factor of 3. Although these results are not conclusive, they do indicate that even short stacks are of value in minimizing intake concentrations.

When a single building in a reactor complex is significantly larger than the other buildings, it may be reasonable to attempt to evaluate intake locations based on studies of simple shapes. The results of wind tunnel studies of simple building shapes are summarized by Hosker (1982). In these studies, the concentrations on building roofs and sides near vents and short stacks are related to specific building geometry, the orientation of the building relative to the wind, the ratio of release height to building height, and the ratio of effluent vertical velocity to the wind speed. If the ratios of release height to building height and effluent velocity to wind speed fall below minimum values, the effluent will diffuse within the building wake, contaminating various potential intake locations. These minimum values appear to be functions of the building height, width, and length. They are also functions of the direction of the wind relative to the building.

Qualitatively, these studies indicate that if a building is long and narrow, the effluents will be more widely distributed over the building surfaces when the wind direction is perpendicular to the long side than when it is parallel to the long side. However, the maximum concentrations on the building surface are likely to be higher when the wind is parallel to the long side, although the region of high concentrations may be small. Further, the studies indicate that diagonal flow across a building tends to enhance downwash behind the building.

The two primary implications of these studies are: 1) there may be some advantage to placing an intake in the middle of the long side of a long, narrow building rather than placing it on the roof at the same distance from the vent or short stack, and 2) building corners may not be optimum locations for intakes, particularly if the wind frequently blows diagonally across the building so that the intake is near the downwind corner.

The effects of specific release location and building orientation on the concentration patterns decrease as the distance from the buildings increases. In general, according to Hatcher et al. (1978) the rate of dispersion becomes independent of release position and building orientation by eight building heights downwind, although the effects of the buildings on diffusion may be seen as far as 15 building heights downwind.

Simplified diagrams of airflow within building wakes appear to show a larger portion of the building surface where air is ascending than where it is descending. In addition, under light wind conditions, thermodynamic effects related to heating of the air by the building will tend to cause air near the building surfaces to rise. These effects, which should be particularly pronounced on the eastern side of buildings in early mornings and on the western side in late afternoons, explain some of the cases in which the building wake diffusion model overestimates concentrations in the wake. The implication of this observation is that intakes should be lower than vents.

Finally, as a matter of common sense, intakes should not be located in sheltered locations where contaminated air might stagnate.

These guidelines are stated for application to evaluation of intakes and vents located on the same building. They are based on studies of diffusion around simple shapes and are appropriate for evaluating intake locations on isolated buildings and buildings that are large compared to other buildings in a complex. However, they should also generally apply in the case of vents on one building and intakes located on another. The guidelines may not be reliable for the evaluation of intake locations on buildings in a building complex under other conditions. For example, they may not be reliable if the building on which the intake is located is not significantly larger than other buildings in the complex. Wind tunnel studies of diffusion in the wakes of building clusters that are typical of reactors (e.g., Hatcher et al. 1978; Allwine, Meroney and Peterka 1978; Hosker and Pendergrass 1986) indicate that the presence or absence of surrounding buildings, minor changes in topography, and building orientation significantly alter concentration patterns.

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APPENDIX A

EBR-II EXPERIMENTAL DATA

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EBR-II EXPERIMENTAL DATA

This appendix summarizes the maximum concentration and wind speed data for the 1967 diffusion experiments conducted in the wake of the EBR-II reactor at the National Reactor Testing Station (now the Idaho National Engineering Laboratory) at Idaho Falls, Idaho. The data are from the personal notes of Mr. E. H. Markee. They were made available through Mr. Irwin Spickler of the NRC.

SAMPLER ARC

TEST	30 m XU/Q(a,b)	30 m U(c)	100 m XU/Q	100 m U	200 m XU/Q	200 m U	400 m XU/Q	400 m U	600 m XU/Q	600 m U
2	-	-	2.15E-3	2.8	1.32E-3	4.8	4.49E-4	4.8	3.46E-4	5.0
3	-	-	8.46E-3	4.1	5.76E-3	5.1	2.66E-3	6.1	1.49E-3	6.1
4	-	-	5.81E-3	3.9	2.31E-3	4.6	1.43E-3	5.5	1.19E-3	5.7
5	-	-	5.80E-3	4.3	3.75E-3	5.4	1.38E-3	6.1	6.73E-4	6.2
6	-	-	3.61E-3	3.5	2.56E-3	5.2	9.29E-4	5.5	9.69E-4	5.6
7	-	-	7.60E-3	5.5	3.80E-3	5.8	1.45E-3	7.2	7.51E-4	8.0
8	2.19E-2	3.7	6.67E-3	4.3	3.57E-3	5.1	1.87E-3	5.7	6.09E-4	6.0
9	5.76E-2	2.2	7.42E-3	2.7	2.46E-3	3.1	1.38E-3	3.8	1.23E-3	4.0
10	6.41E-2	3.7	9.77E-3	4.3	4.00E-3	5.0	2.66E-3	5.6	1.[illegible]E-3	4.8
11	2.97E-2	5.4	5.65E-3	6.5	2.90E-3	7.9	1.40E-3	9.0	5.94E-4	9.6
12	2.12E-2	4.7	5.48E-3	6.2	3.05E-3	8.0	1.50E-3	9.4	9.14E-4	9.7
13	2.00E-2	5.5	4.60E-3	6.9	2.19E-3	8.6	1.00E-3	9.3	4.65E-4	10.4
14	3.32E-2	5.0	4.53E-3	6.6	3.09E-3	7.7	1.61E-3	7.6	1.14E-3	10.2
15	3.49E-2	1.7	3.02E-3	2.2	7.70E-4	2.7	3.98E-4	3.4	1.89E-4	3.9
16	4.67E-2	2.1	6.53E-3	3.7	2.57E-3	3.6	1.33E-3	4.9	1.48E-3	6.4

(a) XU/Q has units of m^{-2}.
(b) Q for all releases was 75 g in 1800 s.
(c) The wind speeds reported are in the wake of the reactor at the sampling arc in units of m/s that were used to normalize the concentrations. Wind speeds at 10 m in the undisturbed flow are given in Appendix B.

APPENDIX B

GROUND-LEVEL RELEASE DATA

APPENDIX B

GROUND-LEVEL RELEASE DATA

Site	Test	Rht(a)	W0(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EBR	8	1.0	0.0	6.8	5	4	30.0	1.0	5.92E-03
EBR	9	1.0	0.0	4.6	5	4	30.0	1.0	2.62E-02
EBR	10	1.0	0.0	6.5	5	5	30.0	1.0	1.73E-02
EBR	11	1.0	0.0	10.7	5	4	30.0	1.0	5.50E-03
EBR	12	1.0	0.0	10.8	1	4	30.0	1.0	4.51E-03
EBR	13	1.0	0.0	11.6	1	4	30.0	1.0	3.64E-03
EBR	14	1.0	0.0	11.4	1	4	30.0	1.0	6.64E-03
EBR	15	1.0	0.0	4.4	7	3	30.0	1.0	2.05E-02
EBR	16	1.0	0.0	7.2	5	5	30.0	1.0	2.22E-02
EOCR	3F	1.0	0.0	0.5	6	0	26.0	1.0	8.14E-04
EOCR	4F	1.0	0.0	3.6	5	4	26.0	1.0	1.57E-03
EOCR	5F	1.0	0.0	8.0	1	3	38.0	1.0	9.42E-04
EOCR	6F	1.0	0.0	1.7	4	1	27.0	1.0	1.77E-03
EOCR	7F	1.0	0.0	0.5	7	0	61.0	1.0	4.88E-03
EOCR	8F	1.0	0.0	1.0	6	1	72.0	1.0	5.72E-03
EOCR	11B	1.0	0.0	1.5	1	1	20.0	1.0	1.43E-04
EOCR	12B	1.0	0.0	2.4	5	3	30.0	1.0	7.13E-04
EOCR	13B	1.0	0.0	2.1	1	1	20.0	1.0	6.95E-04
EOCR	14S	1.0	0.0	1.9	5	4	32.0	1.0	4.02E-04
EOCR	15S	1.0	0.0	4.0	4	2	25.0	1.0	1.78E-03
EOCR	16S	1.0	0.0	3.2	4	2	8.0	1.0	2.29E-03
EOCR	17S	1.0	0.0	1.2	7	1	8.0	1.0	2.17E-03
EOCR	18S	1.0	0.0	4.9	6	3	8.0	1.0	1.78E-03
EOCR	19S	1.0	0.0	2.4	7	3	8.0	1.0	2.91E-03
EOCR	20S	1.0	0.0	3.5	7	3	8.0	1.0	1.90E-03
EOCR	21S	1.0	0.0	3.0	7	3	8.0	1.0	4.18E-03
EOCR	22S	1.0	0.0	4.1	5	4	8.0	1.0	9.17E-04
EOCR	23S	1.0	0.0	2.9	5	3	16.0	1.0	2.26E-03
EOCR	24S	1.0	0.0	2.8	6	2	8.0	1.0	2.02E-03
MTR	1	1.0	0.0	5.9	1	3	100.0	1.0	1.73E-04
MTR	2	1.0	0.0	4.9	4	2	100.0	1.0	3.06E-04
MTR	3	1.0	0.0	3.3	1	1	140.0	1.0	7.79E-05
MTR	4	1.0	0.0	3.4	1	0	140.0	1.0	7.74E-05
MTR	5	1.0	0.0	3.4	3	1	140.0	1.0	6.26E-05
MTR	6	1.0	0.0	3.0	1	3	140.0	1.0	1.27E-04
MTR	7	1.0	0.0	4.7	7	4	140.0	1.0	3.49E-04
MTR	8	1.0	0.0	3.5	1	3	140.0	1.0	1.16E-04
MTR	9	1.0	0.0	3.4	1	3	140.0	1.0	1.22E-04
MTR	10	1.0	0.0	2.4	7	1	140.0	1.0	5.71E-05
MTR	11	1.0	0.0	2.4	1	3	140.0	1.0	7.78E-05
MTR	12	1.0	0.0	2.7	1	3	140.0	1.0	1.29E-04
MTR	13	1.0	0.0	2.1	1	0	140.0	1.0	8.61E-05
EBR	2	1.0	0.0	5.6	1	5	100.0	1.0	7.68E-04

Ground-Level Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EBR	3	1.0	0.0	6.6	4	4	100.0	1.0	2.06E-03
EBR	4	1.0	0.0	6.4	5	4	100.0	1.0	1.49E-03
EBR	5	1.0	0.0	6.6	5	5	100.0	1.0	1.35E-03
EBR	6	1.0	0.0	6.3	5	4	100.0	1.0	1.03E-03
EBR	7	1.0	0.0	8.6	5	5	100.0	1.0	1.38E-03
EBR	8	1.0	0.0	6.8	5	4	100.0	1.0	1.55E-03
EBR	9	1.0	0.0	4.6	5	4	100.0	1.0	2.75E-03
EBR	10	1.0	0.0	6.5	5	5	100.0	1.0	2.27E-03
EBR	11	1.0	0.0	10.7	5	4	100.0	1.0	8.69E-04
EBR	12	1.0	0.0	10.8	1	4	100.0	1.0	8.84E-04
EBR	13	1.0	0.0	11.6	1	4	100.0	1.0	6.67E-04
EBR	14	1.0	0.0	11.4	1	4	100.0	1.0	6.86E-04
EBR	15	1.0	0.0	4.4	7	3	100.0	1.0	1.37E-03
EBR	16	1.0	0.0	7.2	5	5	100.0	1.0	1.77E-03
TMI	7	1.0	0.0	1.1	7	5	149.0	1.0	1.99E-04
TMI	10	1.0	0.0	0.6	7	5	149.0	1.0	5.36E-06
RS	4F	4.0	0.0	2.3	7	5	99.0	1.0	4.64E-05
RS	5S	4.0	0.0	1.8	7	1	107.0	1.0	2.14E-04
RS	5F	4.0	0.0	1.8	7	1	107.0	1.0	2.57E-04
RS	6F	4.0	0.0	3.2	4	3	80.0	1.0	1.84E-04
RS	7F	4.0	0.0	5.3	1	3	92.0	1.0	1.33E-04
RS	8F	4.0	0.0	2.6	7	2	107.0	1.0	3.03E-04
RS	9F	4.0	0.0	1.8	4	1	74.0	1.0	7.23E-05
RS	10F	4.0	0.0	4.5	6	0	92.0	1.0	4.78E-04
RS	11F	4.0	0.0	5.0	5	3	88.0	1.0	2.27E-04
RS	12F	4.0	0.0	1.8	5	2	88.0	1.0	1.27E-04
RS	13F	4.0	0.0	0.8	5	1	95.0	1.0	5.03E-04
RS	14F	4.0	0.0	2.3	7	4	134.0	1.0	1.64E-04
RS	15F	4.0	0.0	1.7	4	1	107.0	1.0	6.84E-05
RS	16S	4.0	0.0	0.9	5	1	125.0	1.0	4.11E-06
RS	16F	4.0	0.0	0.9	5	1	103.0	1.0	9.12E-05
RS	17S	4.0	0.0	3.0	7	4	87.0	1.0	6.25E-04
RS	17F	4.0	0.0	3.0	7	4	82.0	1.0	3.31E-04
RS	18S	4.0	0.0	0.5	6	1	62.0	1.0	3.29E-05
RS	18F	4.0	0.0	0.5	6	1	107.0	1.0	1.90E-04
RS	19S	4.0	0.0	1.5	5	1	154.0	1.0	9.36E-05
RS	19F	4.0	0.0	1.5	5	1	92.0	1.0	1.87E-04
RS	21S	4.0	0.0	3.7	7	1	125.0	1.0	2.18E-04
RS	21F	4.0	0.0	3.7	7	1	74.0	1.0	1.89E-04
RS	22S	4.0	0.0	2.6	4	0	113.0	1.0	2.11E-04
RS	22F	4.0	0.0	2.6	4	0	117.0	1.0	1.38E-04
RS	23S	4.0	0.0	1.8	6	0	64.0	1.0	5.34E-04
RS	23F	4.0	0.0	1.8	6	0	92.0	1.0	2.03E-04
EOCR	3F	1.0	0.0	0.5	6	0	77.0	1.0	1.98E-04
EOCR	4F	1.0	0.0	3.6	5	4	78.0	1.0	2.56E-04

Ground-Level Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	5F	1.0	0.0	8.0	1	3	107.0	1.0	1.45E-04
EOCR	6F	1.0	0.0	1.7	4	1	79.0	1.0	2.54E-04
EOCR	7F	1.0	0.0	0.5	7	0	73.0	1.0	4.70E-04
EOCR	8F	1.0	0.0	1.0	6	1	73.0	1.0	6.48E-04
EOCR	9F	1.0	0.0	2.8	7	1	100.0	1.0	3.58E-04
EOCR	10F	1.0	0.0	3.0	1	1	61.0	1.0	1.05E-04
EOCR	11B	1.0	0.0	1.5	1	1	128.0	1.0	5.78E-06
EOCR	12B	1.0	0.0	2.4	5	3	132.0	1.0	2.22E-05
EOCR	13B	1.0	0.0	2.1	1	1	84.0	1.0	3.39E-06
EOCR	14S	1.0	0.0	1.9	5	4	83.0	1.0	1.92E-04
EOCR	15S	1.0	0.0	4.0	4	2	122.0	1.0	3.17E-04
EOCR	16S	1.0	0.0	3.2	4	2	102.0	1.0	2.41E-04
EOCR	17S	1.0	0.0	1.2	7	1	90.0	1.0	1.20E-03
EOCR	18S	1.0	0.0	4.9	6	3	131.0	1.0	3.39E-04
EOCR	19S	1.0	0.0	2.4	7	3	86.0	1.0	6.84E-04
EOCR	20S	1.0	0.0	3.5	7	3	128.0	1.0	3.37E-04
EOCR	21S	1.0	0.0	3.0	7	3	90.0	1.0	1.22E-03
EOCR	22S	1.0	0.0	4.1	5	4	117.0	1.0	1.90E-04
EOCR	23S	1.0	0.0	2.9	5	3	122.0	1.0	1.92E-04
EOCR	24S	1.0	0.0	2.8	6	2	125.0	1.0	1.59E-04
TMI	8	1.0	0.0	1.8	5	4	177.0	1.0	1.12E-04
TMI	9	1.0	0.0	0.9	7	1	244.0	1.0	2.40E-05
TMI	11	1.0	0.0	0.9	7	4	204.0	1.0	2.00E-06
RS	4F	4.0	0.0	2.3	7	5	200.0	1.0	2.70E-06
RS	5S	4.0	0.0	1.8	7	1	200.0	1.0	5.14E-05
RS	5F	4.0	0.0	1.8	7	1	200.0	1.0	5.71E-05
RS	6F	4.0	0.0	3.2	4	3	200.0	1.0	7.64E-05
RS	7F	4.0	0.0	5.3	1	3	200.0	1.0	3.96E-05
RS	8F	4.0	0.0	2.6	7	2	200.0	1.0	1.96E-03
RS	9F	4.0	0.0	1.8	4	1	200.0	1.0	2.83E-05
RS	10F	4.0	0.0	4.5	6	0	200.0	1.0	1.21E-04
RS	11F	4.0	0.0	5.0	5	3	200.0	1.0	2.15E-04
RS	12F	4.0	0.0	1.8	5	2	200.0	1.0	3.47E-05
RS	13F	4.0	0.0	0.8	5	1	200.0	1.0	1.32E-04
RS	14F	4.0	0.0	2.3	7	4	200.0	1.0	7.17E-05
RS	15F	4.0	0.0	1.7	4	1	200.0	1.0	4.94E-05
RS	16S	4.0	0.0	0.9	5	1	200.0	1.0	1.02E-05
RS	16F	4.0	0.0	0.9	5	1	200.0	1.0	8.89E-05
RS	17S	4.0	0.0	3.0	7	4	200.0	1.0	3.51E-04
RS	17F	4.0	0.0	3.0	7	4	200.0	1.0	1.35E-05
RS	18S	4.0	0.0	0.5	6	1	200.0	1.0	1.51E-05
RS	18F	4.0	0.0	0.5	6	1	200.0	1.0	2.83E-05
RS	19S	4.0	0.0	1.5	5	1	200.0	1.0	1.74E-05
RS	19F	4.0	0.0	1.5	5	1	200.0	1.0	1.41E-05
RS	21S	4.0	0.0	3.7	7	1	200.0	1.0	5.04E-05

Ground-Level Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
RS	21F	4.0	0.0	3.7	7	1	200.0	1.0	5.70E-05
RS	22S	4.0	0.0	2.6	4	0	200.0	1.0	1.38E-04
RS	22F	4.0	0.0	2.6	4	0	200.0	1.0	5.26E-05
RS	23S	4.0	0.0	1.8	6	0	200.0	1.0	3.75E-05
RS	23F	4.0	0.0	1.8	6	0	200.0	1.0	5.19E-05
EBR	2	1.0	0.0	5.6	1	5	200.0	1.0	2.75E-04
EBR	3	1.0	0.0	6.6	4	4	200.0	1.0	2.06E-03
EBR	4	1.0	0.0	6.4	5	4	200.0	1.0	5.02E-04
EBR	5	1.0	0.0	6.6	5	5	200.0	1.0	6.94E-04
EBR	6	1.0	0.0	6.3	5	4	200.0	1.0	4.92E-04
EBR	7	1.0	0.0	8.6	5	5	200.0	1.0	6.55E-04
EBR	8	1.0	0.0	6.8	5	4	200.0	1.0	7.00E-04
EBR	9	1.0	0.0	4.6	5	4	200.0	1.0	7.94E-04
EBR	10	1.0	0.0	6.5	5	5	200.0	1.0	8.00E-04
EBR	11	1.0	0.0	10.7	5	4	200.0	1.0	3.67E-04
EBR	12	1.0	0.0	10.8	1	4	200.0	1.0	3.81E-04
EBR	13	1.0	0.0	11.6	1	4	200.0	1.0	2.55E-04
EBR	14	1.0	0.0	11.4	1	4	200.0	1.0	4.01E-04
EBR	15	1.0	0.0	4.4	7	3	200.0	1.0	2.85E-04
EBR	16	1.0	0.0	7.2	5	5	200.0	1.0	7.14E-04
DAEC	34	1.0	0.0	3.3	4	3	300.0	1.0	2.38E-04
DAEC	35	1.0	0.0	2.7	4	3	300.0	1.0	1.99E-04
DAEC	36	1.0	0.0	2.0	5	2	300.0	1.0	2.21E-04
DAEC	37	1.0	0.0	4.6	1	4	300.0	1.0	2.41E-04
DAEC	38	1.0	0.0	3.5	4	4	300.0	1.0	2.45E-04
DAEC	39	1.0	0.0	3.5	1	3	300.0	1.0	2.04E-04
DAEC	40	1.0	0.0	2.2	1	2	300.0	1.0	1.08E-04
DAEC	41	1.0	0.0	3.2	1	2	300.0	1.0	8.22E-05
DAEC	42	1.0	0.0	3.1	1	4	300.0	1.0	1.44E-04
DAEC	43	1.0	0.0	3.1	1	2	300.0	1.0	8.84E-05
DAEC	44	1.0	0.0	3.1	1	2	300.0	1.0	1.51E-04
MTR	1	1.0	0.0	5.9	1	3	300.0	1.0	2.28E-05
MTR	2	1.0	0.0	4.9	4	2	300.0	1.0	2.65E-05
MTR	3	1.0	0.0	3.3	1	1	350.0	1.0	5.83E-06
MTR	4	1.0	0.0	3.4	1	0	350.0	1.0	9.64E-06
MTR	5	1.0	0.0	3.4	3	1	350.0	1.0	5.99E-06
MTR	6	1.0	0.0	3.0	1	3	350.0	1.0	2.06E-05
MTR	8	1.0	0.0	3.5	1	3	350.0	1.0	1.97E-05
MTR	9	1.0	0.0	3.4	1	3	350.0	1.0	1.78E-05
MTR	10	1.0	0.0	2.4	7	1	350.0	1.0	9.88E-06
MTR	11	1.0	0.0	2.4	1	3	350.0	1.0	9.93E-06
MTR	12	1.0	0.0	2.7	1	3	350.0	1.0	2.01E-05
MTR	13	1.0	0.0	2.1	1	0	350.0	1.0	1.48E-05
EBR	2	1.0	0.0	5.6	1	5	400.0	1.0	9.35E-05
EBR	3	1.0	0.0	6.6	4	4	400.0	1.0	4.36E-04

Ground-Level Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EBR	4	1.0	0.0	6.4	5	4	400.0	1.0	2.60E-04
EBR	5	1.0	0.0	6.6	5	5	400.0	1.0	2.26E-04
EBR	6	1.0	0.0	6.3	5	4	400.0	1.0	1.69E-04
EBR	7	1.0	0.0	8.6	5	5	400.0	1.0	2.14E-04
EBR	8	1.0	0.0	6.8	5	4	400.0	1.0	7.00E-04
EBR	9	1.0	0.0	4.6	5	4	400.0	1.0	3.63E-04
EBR	10	1.0	0.0	6.5	5	5	400.0	1.0	4.75E-04
EBR	11	1.0	0.0	10.7	5	4	400.0	1.0	1.56E-04
EBR	12	1.0	0.0	10.8	1	4	400.0	1.0	1.60E-04
EBR	13	1.0	0.0	11.6	1	4	400.0	1.0	1.08E-04
EBR	14	1.0	0.0	11.4	1	4	400.0	1.0	2.12E-04
EBR	15	1.0	0.0	4.4	7	3	400.0	1.0	1.16E-04
EBR	16	1.0	0.0	7.2	5	5	400.0	1.0	2.71E-04
RS	4F	4.0	0.0	2.3	7	5	400.0	1.0	6.24E-06
RS	5S	4.0	0.0	1.[illegible]	7	1	400.0	1.0	5.14E-05
RS	5F	4.0	0.0	1.8	7	1	400.0	1.0	7.76E-06
RS	6F	4.0	0.0	3.2	4	3	400.0	1.0	2.96E-05
RS	7F	4.0	0.0	5.3	1	3	400.0	1.0	1.55E-05
RS	8F	4.0	0.0	2.6	7	2	400.0	1.0	6.70E-03
RS	9F	4.0	0.0	1.8	4	1	400.0	1.0	1.36E-04
RS	10F	4.0	0.0	4.5	6	0	400.0	1.0	4.45E-05
RS	11F	4.0	0.0	5.0	5	3	400.0	1.0	8.14E-05
RS	12F	4.0	0.0	1.8	5	2	400.0	1.0	1.25E-05
RS	13F	4.0	0.0	0.8	5	1	400.0	1.0	1.35E-05
RS	14F	4.0	0.0	2.3	7	4	400.0	1.0	3.82E-05
RS	15F	4.0	0.0	1.7	4	1	400.0	1.0	7.91E-06
RS	16S	4.0	0.0	0.9	5	1	400.0	1.0	5.89E-06
RS	16F	4.0	0.0	0.9	5	1	400.0	1.0	3.19E-05
RS	17S	4.0	0.0	3.0	7	4	400.0	1.0	2.25E-04
RS	17F	4.0	0.0	3.0	7	4	400.0	1.0	7.80E-05
RS	18S	4.0	0.0	0.5	6	1	400.0	1.0	3.03E-06
RS	18F	4.0	0.0	0.5	6	1	400.0	1.0	1.79E-05
RS	19S	4.0	0.0	1.5	5	1	400.0	1.0	2.16E-05
RS	19F	4.0	0.0	1.5	5	1	400.0	1.0	1.93E-05
RS	21S	4.0	0.0	3.7	7	1	400.0	1.0	2.34E-05
RS	21F	4.0	0.0	3.7	7	1	400.0	1.0	1.99E-05
RS	22S	4.0	0.0	2.6	4	0	400.0	1.0	9.79E-06
RS	22F	4.0	0.0	2.6	4	0	400.0	1.0	1.06E-05
RS	23S	4.0	0.0	1.8	6	0	400.0	1.0	1.69E-06
RS	23F	4.0	0.0	1.8	6	0	400.0	1.0	5.44E-05
EOCR	3F	1.0	0.0	0.5	6	0	400.0	1.0	3.80E-05
EOCR	4F	1.0	0.0	3.6	5	4	400.0	1.0	1.95E-05
EOCR	5F	1.0	0.0	8.0	1	3	400.0	1.0	1.59E-05
EOCR	6F	1.0	0.0	1.7	4	1	400.0	1.0	3.45E-05
EOCR	7F	1.0	0.0	0.5	7	0	400.0	1.0	6.88E-06

Ground-Level Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	8F	1.0	0.0	1.0	6	1	400.0	1.0	4.43E-05
EOCR	9F	1.0	0.0	2.8	7	1	400.0	1.0	5.08E-05
EOCR	10F	1.0	0.0	3.0	1	1	400.0	1.0	5.00E-05
EOCR	12B	1.0	0.0	2.4	5	3	400.0	1.0	2.32E-06
EOCR	14S	1.0	0.0	1.9	5	4	400.0	1.0	4.82E-05
EOCR	15S	1.0	0.0	4.0	4	2	400.0	1.0	3.37E-05
EOCR	16S	1.0	0.0	3.2	4	2	400.0	1.0	1.46E-05
EOCR	17S	1.0	0.0	1.2	7	1	400.0	1.0	6.68E-05
EOCR	18S	1.0	0.0	4.9	6	3	400.0	1.0	5.29E-05
EOCR	19S	1.0	0.0	2.4	7	3	400.0	1.0	1.20E-04
EOCR	20S	1.0	0.0	3.5	7	3	400.0	1.0	5.09E-05
EOCR	21S	1.0	0.0	3.0	7	3	400.0	1.0	2.13E-04
EOCR	22S	1.0	0.0	4.1	5	4	400.0	1.0	1.75E-05
EOCR	23S	1.0	0.0	2.9	5	3	400.0	1.0	8.37E-06
EOCR	24S	1.0	0.0	2.8	6	2	400.0	1.0	9.56E-06
MTR	1	1.0	0.0	5.9	1	3	600.0	1.0	4.54E-06
MTR	2	1.0	0.0	4.9	4	2	600.0	1.0	5.47E-06
MTR	3	1.0	0.0	3.3	1	1	550.0	1.0	2.66E-06
MTR	4	1.0	0.0	3.4	1	0	550.0	1.0	4.19E-06
MTR	5	1.0	0.0	3.4	3	1	550.0	1.0	2.30E-06
MTR	6	1.0	0.0	3.0	1	3	550.0	1.0	5.69E-06
MTR	8	1.0	0.0	3.5	1	3	550.0	1.0	7.53E-06
MTR	9	1.0	0.0	3.4	1	3	550.0	1.0	8.29E-06
MTR	10	1.0	0.0	2.4	7	1	550.0	1.0	3.96E-06
MTR	11	1.0	0.0	2.4	1	3	550.0	1.0	4.13E-06
MTR	12	1.0	0.0	2.7	1	3	550.0	1.0	1.08E-05
MTR	13	1.0	0.0	2.1	1	0	550.0	1.0	4.95E-06
EBR	2	1.0	0.0	5.6	1	5	600.0	1.0	6.92E-05
EBR	3	1.0	0.0	6.6	4	4	600.0	1.0	2.44E-04
EBR	4	1.0	0.0	6.4	5	4	600.0	1.0	2.09E-04
EBR	5	1.0	0.0	6.6	5	5	600.0	1.0	1.08E-04
EBR	6	1.0	0.0	6.3	5	4	600.0	1.0	1.73E-04
EBR	7	1.0	0.0	8.6	5	5	600.0	1.0	9.39E-05
EBR	8	1.0	0.0	6.8	5	4	600.0	1.0	1.02E-04
EBR	9	1.0	0.0	4.6	5	4	600.0	1.0	3.08E-04
EBR	10	1.0	0.0	6.5	5	5	600.0	1.0	2.27E-04
EBR	11	1.0	0.0	10.7	5	4	600.0	1.0	6.19E-05
EBR	12	1.0	0.0	10.8	1	4	600.0	1.0	9.42E-05
EBR	13	1.0	0.0	11.6	1	4	600.0	1.0	4.47E-05
EBR	14	1.0	0.0	11.4	1	4	600.0	1.0	1.12E-04
EBR	15	1.0	0.0	4.4	7	3	600.0	1.0	4.85E-05
EBR	16	1.0	0.0	7.2	5	5	600.0	1.0	2.31E-04
RS	4F	4.0	0.0	2.3	7	5	800.0	1.0	1.39E-05
RS	5S	4.0	0.0	1.8	7	1	800.0	1.0	5.44E-07
RS	5F	4.0	0.0	1.8	7	1	800.0	1.0	1.21E-03

Ground-Level Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
RS	6F	4.0	0.0	3.2	4	3	800.0	1.0	3.61E-05
RS	7F	4.0	0.0	5.3	1	3	800.0	1.0	1.04E-05
RS	8F	4.0	0.0	2.6	7	2	800.0	1.0	2.20E-03
RS	9F	4.0	0.0	1.8	4	1	800.0	1.0	8.47E-06
RS	10F	4.0	0.0	4.5	6	0	800.0	1.0	1.52E-05
RS	11F	4.0	0.0	5.0	5	3	800.0	1.0	1.47E-04
RS	12F	4.0	0.0	1.8	5	2	800.0	1.0	1.61E-05
RS	13F	4.0	0.0	0.8	5	1	800.0	1.0	2.24E-05
RS	14F	4.0	0.0	2.3	7	4	800.0	1.0	6.87E-06
RS	15F	4.0	0.0	1.7	4	1	800.0	1.0	2.32E-05
RS	16F	4.0	0.0	0.9	5	1	800.0	1.0	4.84E-06
RS	17S	4.0	0.0	3.0	7	4	800.0	1.0	1.08E-05
RS	17F	4.0	0.0	3.0	7	4	800.0	1.0	3.30E-05
RS	18S	4.0	0.0	0.5	6	1	800.0	1.0	4.00E-07
RS	18F	4.0	0.0	0.5	6	1	800.0	1.0	3.59E-06
RS	19S	4.0	0.0	1.5	5	1	800.0	1.0	6.74E-06
RS	19F	4.0	0.0	1.5	5	1	800.0	1.0	1.29E-05
RS	21S	4.0	0.0	3.7	7	1	800.0	1.0	5.30E-06
RS	21F	4.0	0.0	3.7	7	1	800.0	1.0	6.61E-06
RS	22S	4.0	0.0	2.6	4	0	800.0	1.0	1.35E-06
RS	22F	4.0	0.0	2.6	4	0	800.0	1.0	3.11E-06
RS	23S	4.0	0.0	1.8	6	0	800.0	1.0	6.25E-07
RS	23F	4.0	0.0	1.8	6	0	800.0	1.0	4.80E-06
EOCR	4F	1.0	0.0	3.6	5	4	800.0	1.0	2.17E-05
EOCR	6F	1.0	0.0	1.7	4	1	800.0	1.0	2.57E-05
EOCR	7F	1.0	0.0	0.5	7	0	800.0	1.0	6.78E-05
EOCR	8F	1.0	0.0	1.0	6	1	800.0	1.0	1.73E-05
EOCR	9F	1.0	0.0	2.8	7	1	800.0	1.0	4.23E-05
EOCR	10F	1.0	0.0	3.0	1	1	800.0	1.0	2.06E-05
EOCR	12B	1.0	0.0	2.4	5	3	800.0	1.0	1.23E-06
EOCR	14S	1.0	0.0	1.9	5	4	800.0	1.0	1.53E-05
EOCR	15S	1.0	0.0	4.0	4	2	800.0	1.0	1.29E-05
EOCR	16S	1.0	0.0	3.2	4	2	800.0	1.0	4.60E-06
EOCR	17S	1.0	0.0	1.2	7	1	800.0	1.0	6.37E-04
EOCR	18S	1.0	0.0	4.9	6	3	800.0	1.0	2.14E-05
EOCR	19S	1.0	0.0	2.4	7	3	800.0	1.0	9.71E-05
EOCR	20S	1.0	0.0	3.5	7	3	800.0	1.0	2.28E-05
EOCR	21S	1.0	0.0	3.0	7	3	800.0	1.0	8.54E-05
EOCR	22S	1.0	0.0	4.1	5	4	800.0	1.0	2.90E-06
EOCR	23S	1.0	0.0	2.9	5	3	800.0	1.0	2.09E-06
EOCR	24S	1.0	0.0	2.8	6	2	800.0	1.0	1.59E-06
MTR	3	1.0	0.0	3.3	1	1	850.0	1.0	8.47E-07
MTR	4	1.0	0.0	3.4	1	0	850.0	1.0	6.40E-07
MTR	5	1.0	0.0	3.4	3	1	850.0	1.0	1.96E-06
MTR	6	1.0	0.0	3.0	1	3	850.0	1.0	3.09E-06

Ground-Level Release Data (cont.)

Site	Test	Rht[a]	WO[b]	U[c]	S1[d]	S2[e]	X[f]	Oht[g]	X/Q[h]
MTR	8	1.0	0.0	3.5	1	3	850.0	1.0	3.29E-06
MTR	9	1.0	0.0	3.4	1	3	850.0	1.0	3.25E-06
MTR	10	1.0	0.0	2.4	7	1	850.0	1.0	9.32E-07
MTR	11	1.0	0.0	2.4	1	3	850.0	1.0	2.37E-06
MTR	12	1.0	0.0	2.7	1	3	850.0	1.0	5.51E-06
MTR	13	1.0	0.0	2.1	1	0	850.0	1.0	3.29E-06
DAEC	34	1.0	0.0	3.3	4	3	1000.0	1.0	9.91E-05
DAEC	35	1.0	0.0	2.7	4	3	1000.0	1.0	1.27E-04
DAEC	36	1.0	0.0	2.0	5	2	1000.0	1.0	8.40E-05
DAEC	37	1.0	0.0	4.6	1	4	1000.0	1.0	2.20E-05
DAEC	38	1.0	0.0	3.5	4	4	1000.0	1.0	4.57E-05
DAEC	39	1.0	0.0	3.5	1	3	1000.0	1.0	4.66E-05
DAEC	40	1.0	0.0	2.2	1	2	1000.0	1.0	1.45E-05
DAEC	41	1.0	0.0	3.2	1	2	1000.0	1.0	2.40E-05
DAEC	42	1.0	0.0	3.1	1	4	1000.0	1.0	1.56E-05
DAEC	43	1.0	0.0	3.1	1	2	1000.0	1.0	1.67E-05
DAEC	44	1.0	0.0	3.1	1	2	1000.0	1.0	2.39E-05
EOCR	14S	1.0	0.0	1.9	5	4	1200.0	1.0	1.73E-05
EOCR	15S	1.0	0.0	4.0	4	2	1200.0	1.0	5.30E-06
EOCR	16S	1.0	0.0	3.2	4	2	1200.0	1.0	2.97E-06
EOCR	17S	1.0	0.0	1.2	7	1	1200.0	1.0	1.24E-05
EOCR	18S	1.0	0.0	4.9	6	3	1200.0	1.0	1.90E-05
EOCR	19S	1.0	0.0	2.4	7	3	1200.0	1.0	5.66E-05
EOCR	20S	1.0	0.0	3.5	7	3	1200.0	1.0	2.21E-05
EOCR	21S	1.0	0.0	3.0	7	3	1200.0	1.0	5.35E-05
EOCR	22S	1.0	0.0	4.1	5	4	1200.0	1.0	1.40E-06
EOCR	23S	1.0	0.0	2.9	5	3	1200.0	1.0	1.63E-06
EOCR	24S	1.0	0.0	2.8	6	2	1200.0	1.0	1.36E-06

(a) Nominal release height (m)
(b) Vertical velocity of release (m/s)
(c) Wind speed at 10 m (m/s)
(d) Delta-T stability class; 1 = Pasquill-Gifford Class A, etc.
(e) Sigma-Theta stability class; 0 = missing, 1 = Pasquill-Gifford Class A, etc.
(f) Distance to centerline receptor (m)
(g) Concentration measurement height (m)
(h) Normalized concentration (s/m_3)

APPENDIX C

ELEVATED RELEASE DATA

APPENDIX C

ELEVATED RELEASE DATA

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	3S	30.0	0.0	0.5	6	0	49.0	1.0	2.50E-05
EOCR	3B	23.0	0.0	0.5	6	0	37.0	1.0	4.38E-05
EOCR	4S	30.0	0.0	3.6	5	4	23.0	1.0	4.25E-05
EOCR	4B	23.0	0.0	3.6	5	4	37.0	1.0	1.38E-04
EOCR	5S	30.0	0.0	8.0	1	3	23.0	1.0	2.56E-04
EOCR	5B	23.0	0.0	8.0	1	3	37.0	1.0	1.06E-04
EOCR	6S	30.0	0.0	1.7	4	1	43.0	1.0	1.15E-04
EOCR	6B	23.0	0.0	1.7	4	1	37.0	1.0	8.65E-04
EOCR	7S	30.0	0.0	0.5	7	0	24.0	1.0	5.63E-04
EOCR	7B	23.0	0.0	0.5	7	0	37.0	1.0	8.23E-04
EOCR	8S	30.0	0.0	1.0	6	1	23.0	1.0	1.11E-04
EOCR	8B	23.0	0.0	1.0	6	1	37.0	1.0	2.24E-03
EOCR	11S	30.0	0.0	1.5	1	1	45.0	1.0	2.40E-06
EOCR	11F	23.0	0.0	1.5	1	1	37.0	1.0	7.27E-05
EOCR	12S	30.0	0.0	2.4	5	3	48.0	1.0	2.56E-06
EOCR	12F	23.0	0.0	2.4	5	3	37.0	1.0	7.09E-05
EOCR	13S	30.0	0.0	2.1	1	1	42.0	1.0	2.46E-05
EOCR	13F	23.0	0.0	2.1	1	1	37.0	1.0	8.16E-05
EOCR	14F	30.0	0.0	1.9	5	4	40.0	1.0	1.08E-04
EOCR	14B	23.0	0.0	1.9	5	4	37.0	1.0	2.01E-05
EOCR	15F	30.0	0.0	4.0	4	2	47.0	1.0	3.55E-05
EOCR	15B	23.0	0.0	4.0	4	2	37.0	1.0	1.56E-04
EOCR	16B	23.0	0.0	3.2	4	2	37.0	1.0	7.31E-05
EOCR	17B	23.0	0.0	1.2	7	1	37.0	1.0	1.73E-04
EOCR	18F	30.0	0.0	4.9	6	3	26.0	1.0	7.97E-06
EOCR	18B	23.0	0.0	4.9	6	3	37.0	1.0	5.45E-05
EOCR	19B	23.0	0.0	2.4	7	3	37.0	1.0	5.60E-05
EOCR	20F	30.0	0.0	3.5	7	3	40.0	1.0	7.79E-06
EOCR	20B	23.0	0.0	3.5	7	3	37.0	1.0	1.91E-05
EOCR	21F	30.0	0.0	3.0	7	3	51.0	1.0	5.08E-05
EOCR	21B	23.0	0.0	3.0	7	3	37.0	1.0	5.55E-05
EOCR	22B	23.0	0.0	4.1	5	4	37.0	1.0	7.02E-05
EOCR	23F	30.0	0.0	2.9	5	3	44.0	1.0	7.15E-05
EOCR	23B	23.0	0.0	2.9	5	3	37.0	1.0	1.21E-04
EOCR	24B	23.0	0.0	2.8	6	2	37.0	1.0	8.84E-05
RS	1S	43.0	0.0	1.8	1	1	100.0	1.0	8.73E-06
RS	1F	18.5	0.0	1.8	1	1	95.0	1.0	2.51E-05
RS	2S	43.0	0.0	2.1	7	1	100.0	1.0	7.62E-06
RS	2F	18.5	0.0	2.1	7	1	134.0	1.0	3.28E-06
RS	3S	43.0	0.0	1.8	7	2	100.0	1.0	3.54E-06
RS	3F	18.5	0.0	1.8	7	2	140.0	1.0	2.70E-04
RS	4S	43.0	0.0	2.3	7	5	100.0	1.0	1.67E-06
RS	6S	18.5	0.0	3.2	4	3	69.0	1.0	2.08E-04
RS	7S	18.5	0.0	5.3	1	3	87.0	1.0	5.61E-05

Elevated Release Data (cont.)

Site	Test	Rht[a]	WO[b]	U[c]	S1[d]	S2[e]	X[f]	Oht[g]	X/Q[h]
RS	8S	18.5	0.0	2.6	7	2	102.0	1.0	5.48E-05
RS	9S	43.0	0.0	1.8	4	1	100.0	1.0	3.07E-05
RS	10S	18.5	0.0	4.6	6	0	91.0	1.0	9.29E-05
RS	11S	18.5	0.0	5.0	5	3	87.0	1.0	6.27E-05
RS	12S	18.5	0.0	1.8	5	2	86.0	1.0	1.66E-05
RS	13S	18.5	0.0	0.8	5	1	63.0	1.0	1.38E-05
RS	14S	18.5	0.0	2.3	7	4	104.0	1.0	2.37E-05
RS	15S	18.5	0.0	1.7	4	1	90.0	1.0	1.31E-05
EOCR	3S	30.0	0.0	0.5	6	0	100.0	1.0	5.98E-05
EOCR	3B	23.0	0.0	0.5	6	0	88.0	1.0	5.29E-05
EOCR	4S	30.0	0.0	3.6	5	4	95.0	1.0	9.80E-05
EOCR	4B	23.0	0.0	3.6	5	4	88.0	1.0	1.26E-04
EOCR	5S	30.0	0.0	8.0	1	3	74.0	1.0	2.20E-05
EOCR	5B	23.0	0.0	8.0	1	3	88.0	1.0	7.65E-05
EOCR	6S	30.0	0.0	1.7	4	1	94.0	1.0	1.16E-04
EOCR	6B	23.0	0.0	1.7	4	1	88.0	1.0	1.45E-04
EOCR	7S	30.0	0.0	0.5	7	0	73.0	1.0	1.64E-04
EOCR	7B	23.0	0.0	0.5	7	0	88.0	1.0	9.93E-05
EOCR	8S	30.0	0.0	1.0	6	1	74.0	1.0	1.38E-04
EOCR	8B	23.0	0.0	1.0	6	1	88.0	1.0	2.12E-03
EOCR	9S	30.0	0.0	2.8	7	1	86.0	1.0	6.59E-05
EOCR	9B	23.0	0.0	2.8	7	1	88.0	1.0	4.69E-05
EOCR	10S	30.0	0.0	3.0	1	1	76.0	1.0	6.32E-05
EOCR	10B	23.0	0.0	3.0	1	1	88.0	1.0	2.43E-05
EOCR	11S	30.0	0.0	1.5	1	1	102.0	1.0	3.55E-06
EOCR	11F	23.0	0.0	1.5	1	1	88.0	1.0	4.50E-04
EOCR	12S	30.0	0.0	2.4	5	3	100.0	1.0	9.26E-06
EOCR	12F	23.0	0.0	2.4	5	3	88.0	1.0	8.12E-05
EOCR	13S	30.0	0.0	2.1	1	1	92.0	1.0	2.27E-05
EOCR	13F	23.0	0.0	2.1	1	1	88.0	1.0	6.89E-05
EOCR	14F	30.0	0.0	1.9	5	4	102.0	1.0	3.56E-04
EOCR	14B	23.0	0.0	1.9	5	4	88.0	1.0	3.36E-05
EOCR	15F	30.0	0.0	4.0	4	2	92.0	1.0	7.82E-05
EOCR	15B	23.0	0.0	4.0	4	2	88.0	1.0	8.77E-05
EOCR	16F	30.0	0.0	3.2	4	2	97.0	1.0	1.40E-04
EOCR	16B	23.0	0.0	3.2	4	2	88.0	1.0	5.47E-05
EOCR	17F	30.0	0.0	1.2	7	1	102.0	1.0	4.04E-04
EOCR	17B	23.0	0.0	1.2	7	1	88.0	1.0	3.49E-05
EOCR	18F	30.0	0.0	4.9	6	3	97.0	1.0	1.83E-05
EOCR	18B	23.0	0.0	4.9	6	3	88.0	1.0	4.82E-05
EOCR	19F	30.0	0.0	2.4	7	3	93.0	1.0	1.94E-05
EOCR	19B	23.0	0.0	2.4	7	3	88.0	1.0	4.52E-05
EOCR	20F	30.0	0.0	3.5	7	3	84.0	1.0	2.29E-05
EOCR	20B	23.0	0.0	3.5	7	3	88.0	1.0	2.53E-05
EOCR	21F	30.0	0.0	3.0	7	3	92.0	1.0	2.75E-05

Elevated Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	21B	23.0	0.0	3.0	7	3	88.0	1.0	4.39E-05
EOCR	22F	30.0	0.0	4.1	5	4	94.0	1.0	5.11E-05
EOCR	22B	23.0	0.0	4.1	5	4	88.0	1.0	5.13E-05
EOCR	23F	30.0	0.0	2.9	5	3	95.0	1.0	7.94E-05
EOCR	23B	23.0	0.0	2.9	5	3	88.0	1.0	1.63E-04
EOCR	24F	30.0	0.0	2.8	6	2	94.0	1.0	4.25E-05
EOCR	24B	23.0	0.0	2.8	6	2	88.0	1.0	4.03E-05
RS	1S	43.0	0.0	1.8	1	1	200.0	1.0	9.31E-06
RS	1F	18.5	0.0	1.8	1	1	200.0	1.0	2.51E-05
RS	2S	43.0	0.0	2.1	7	1	200.0	1.0	1.03E-05
RS	2F	18.5	0.0	2.1	7	1	200.0	1.0	3.10E-06
RS	3S	43.0	0.0	1.8	7	2	200.0	1.0	2.68E-05
RS	3F	18.5	0.0	1.8	7	2	200.0	1.0	1.86E-04
RS	6S	18.5	0.0	3.2	4	3	200.0	1.0	7.10E-05
RS	7S	18.5	0.0	5.3	1	3	200.0	1.0	2.67E-05
RS	8S	18.5	0.0	2.6	7	2	200.0	1.0	1.75E-05
RS	9S	43.0	0.0	1.8	4	1	200.0	1.0	1.74E-05
RS	10S	18.5	0.0	4.6	6	0	200.0	1.0	4.84E-05
RS	11S	18.5	0.0	5.0	5	3	200.0	1.0	3.27E-05
RS	12S	18.5	0.0	1.8	5	2	200.0	1.0	1.64E-05
RS	13S	18.5	0.0	0.8	5	1	200.0	1.0	3.68E-06
RS	14S	18.5	0.0	2.3	7	4	200.0	1.0	1.85E-05
RS	15S	18.5	0.0	1.7	4	1	200.0	1.0	8.85E-06
DAEC	1	23.5	0.0	0.7	4	1	300.0	1.0	8.73E-05
DAEC	2	23.5	0.0	1.7	4	2	300.0	1.0	5.50E-05
DAEC	3	23.5	0.0	1.7	4	3	300.0	1.0	6.82E-05
DAEC	4	23.5	0.0	0.5	5	1	300.0	1.0	1.70E-04
DAEC	5	23.5	0.0	1.5	4	1	300.0	1.0	3.50E-05
DAEC	6	23.5	0.0	1.7	3	1	300.0	1.0	4.10E-05
DAEC	7	23.5	0.0	2.0	4	1	300.0	1.0	7.00E-05
DAEC	8	23.5	0.0	1.4	3	1	300.0	1.0	2.61E-05
DAEC	9	23.5	0.0	2.6	5	2	300.0	1.0	4.18E-04
DAEC	10	23.5	0.0	3.5	4	3	300.0	1.0	3.58E-05
DAEC	11	23.5	0.0	3.3	4	3	300.0	1.0	1.26E-04
DAEC	12	23.5	0.0	3.1	5	3	300.0	1.0	1.96E-04
DAEC	13	23.5	0.0	1.6	2	1	300.0	1.0	7.91E-05
DAEC	14	23.5	0.0	1.4	4	1	300.0	1.0	2.83E-05
DAEC	15	23.5	0.0	1.2	4	2	300.0	1.0	1.43E-05
DAEC	16	23.5	0.0	1.3	4	1	300.0	1.0	4.78E-05
DAEC	17	45.7	10.8	2.8	4	1	300.0	1.0	6.26E-05
DAEC	18	45.7	10.8	2.9	2	2	300.0	1.0	7.91E-05
DAEC	19	45.7	10.8	2.7	1	2	300.0	1.0	6.10E-05
DAEC	20	45.7	10.8	3.0	2	1	300.0	1.0	4.28E-05
DAEC	25	45.7	10.2	2.7	3	4	300.0	1.0	1.15E-04
DAEC	26	45.7	10.2	2.8	4	3	300.0	1.0	6.40E-05

Elevated Release Data (cont.)

Site	Test	Rht[a]	WO[b]	U[c]	S1[d]	S2[e]	X[f]	Oht[g]	X/Q[h]
DAEC	27	45.7	10.2	3.3	3	3	300.0	1.0	9.37E-05
DAEC	28	45.7	10.2	3.8	1	2	300.0	1.0	8.12E-05
DAEC	30	45.7	10.2	0.6	5	1	300.0	1.0	1.50E-07
DAEC	31	45.7	10.2	0.3	6	1	300.0	1.0	3.50E-07
DAEC	32	45.7	10.2	0.4	5	1	300.0	1.0	3.50E-07
DAEC	33	45.7	10.2	0.8	5	1	300.0	1.0	2.00E-07
MS	1S	48.3	8.7	7.2	4	5	350.0	1.0	3.97E-05
MS	2S	48.3	8.7	6.6	4	5	350.0	1.0	3.19E-05
MS	3S	48.3	8.7	6.4	1	5	350.0	1.0	3.04E-05
MS	4S	48.3	8.7	6.9	3	5	350.0	1.0	2.83E-05
MS	5S	48.3	8.3	4.8	4	5	350.0	1.0	1.67E-05
MS	6S	48.3	8.3	4.5	4	5	350.0	1.0	2.19E-05
MS	8S	48.3	8.1	6.8	5	6	350.0	1.0	2.50E-05
MS	9S	48.3	8.1	5.2	5	6	350.0	1.0	3.49E-05
MS	10S	48.3	8.1	6.2	5	6	350.0	1.0	3.13E-05
MS	11S	48.3	8.7	7.9	4	5	350.0	1.0	5.61E-05
MS	11F	27.6	10.5	7.9	4	5	350.0	1.0	3.55E-05
MS	12S	48.3	8.7	8.5	3	6	350.0	1.0	5.11E-05
MS	12F	27.6	10.5	8.5	3	6	350.0	1.0	4.25E-05
MS	13S	48.3	8.7	8.3	4	5	350.0	1.0	4.52E-05
MS	13F	27.6	10.5	8.3	4	5	350.0	1.0	3.37E-05
MS	14S	48.3	8.7	9.5	4	5	350.0	1.0	4.51E-05
MS	14F	27.6	10.5	9.5	4	5	350.0	1.0	3.07E-05
MS	15S	48.3	8.7	10.3	4	6	350.0	1.0	3.07E-05
MS	15F	27.6	10.5	10.3	4	6	350.0	1.0	3.26E-05
MS	16S	48.3	8.7	10.1	4	6	350.0	1.0	4.38E-05
MS	16F	27.6	10.5	10.1	4	6	350.0	1.0	2.91E-05
MS	17S	48.3	8.7	10.2	4	5	350.0	1.0	3.78E-05
MS	17F	27.6	10.5	10.2	4	5	350.0	1.0	3.57E-05
MS	18S	48.3	8.7	9.9	4	6	350.0	1.0	2.75E-05
MS	18F	27.6	10.5	9.9	4	6	350.0	1.0	3.54E-05
MS	28S	48.3	4.8	3.0	5	6	350.0	1.0	5.27E-05
MS	28F	27.6	10.5	3.0	5	6	350.0	1.0	6.16E-05
MS	29S	48.3	4.6	3.7	5	5	350.0	1.0	4.60E-05
MS	29F	27.6	10.5	3.7	5	5	350.0	1.0	4.71E-05
MS	30S	48.3	4.6	2.9	4	5	350.0	1.0	3.61E-05
MS	30F	27.6	10.5	2.9	4	5	350.0	1.0	3.97E-05
MS	31S	48.3	4.6	3.1	4	5	350.0	1.0	5.91E-05
MS	31F	27.6	10.5	3.1	4	5	350.0	1.0	5.50E-05
MS	32S	48.3	4.6	3.1	4	5	350.0	1.0	3.83E-05
MS	32F	27.6	10.5	3.1	4	5	350.0	1.0	3.53E-05
MS	36S	48.3	5.8	3.7	4	5	350.0	1.0	1.69E-05
MS	36F	27.6	10.5	3.7	4	5	350.0	1.0	3.76E-05
MS	45S	48.3	8.6	7.2	4	5	350.0	1.0	4.36E-05
MS	45F	27.6	10.5	7.2	4	5	350.0	1.0	2.64E-05

Elevated Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
MS	46S	48.3	8.6	8.1	3	5	350.0	1.0	6.62E-05
MS	46F	27.6	10.5	8.1	3	5	350.0	1.0	3.56E-05
MS	47S	48.3	8.6	9.5	2	5	350.0	1.0	5.81E-05
MS	47F	27.6	10.5	9.5	2	5	350.0	1.0	2.74E-05
MS	48S	48.3	8.6	9.2	4	5	350.0	1.0	4.30E-05
MS	48F	27.6	10.5	9.2	4	5	350.0	1.0	2.43E-05
MS	49S	48.3	8.6	9.5	4	5	350.0	1.0	4.53E-05
MS	49F	27.6	10.5	9.5	4	5	350.0	1.0	4.07E-05
MS	50S	48.3	8.6	9.8	4	5	350.0	1.0	4.39E-05
MS	50F	27.6	10.5	9.8	4	5	350.0	1.0	1.90E-05
MS	51S	48.3	8.6	10.3	4	5	350.0	1.0	4.60E-05
MS	51F	27.6	10.5	10.3	4	5	350.0	1.0	1.37E-05
MS	52S	48.3	8.68	11.2	4	6	350.0	1.0	3.70E-05
MS	52F	27.6	10.5	11.2	4	6	350.0	1.0	1.38E-05
MS	53S	48.3	8.6	10.9	4	6	350.0	1.0	3.66E-05
MS	53F	27.6	10.5	10.9	4	6	350.0	1.0	1.48E-05
MS	54S	48.3	8.6	10.6	4	6	350.0	1.0	4.35E-05
MS	54F	27.6	10.5	10.6	4	6	350.0	1.0	1.36E-05
MS	57S	48.3	8.6	3.6	4	5	350.0	1.0	1.70E-05
MS	57F	27.6	10.5	3.6	4	5	350.0	1.0	5.07E-05
MS	58S	48.3	8.6	3.6	4	5	350.0	1.0	1.63E-05
MS	58F	27.6	10.5	3.6	4	5	350.0	1.0	4.32E-05
MS	59S	48.3	8.6	3.4	4	5	350.0	1.0	9.25E-06
RS	1S	43.0	0.0	1.8	1	1	400.0	1.0	7.66E-06
RS	1F	18.5	0.0	1.8	1	1	400.0	1.0	4.86E-06
RS	2S	43.0	0.0	2.1	7	1	400.0	1.0	2.02E-05
RS	2F	18.5	0.0	2.1	7	1	400.0	1.0	1.08E-05
RS	3S	43.0	0.0	1.8	7	2	400.0	1.0	1.82E-05
RS	3F	18.5	0.0	1.8	7	2	400.0	1.0	4.99E-05
RS	4S	43.0	0.0	2.3	7	5	400.0	1.0	1.64E-06
RS	6S	18.5	0.0	3.2	4	3	400.0	1.0	2.53E-05
RS	7S	18.5	0.0	5.3	1	3	400.0	1.0	1.35E-05
RS	8S	18.5	0.0	2.6	7	2	400.0	1.0	3.67E-05
RS	9S	43.0	0.0	1.8	4	1	400.0	1.0	7.89E-06
RS	10S	18.5	0.0	4.6	6	0	400.0	1.0	2.00E-05
RS	11S	18.5	0.0	5.0	5	3	400.0	1.0	1.64E-05
RS	12S	18.5	0.0	1.8	5	2	400.0	1.0	5.86E-06
RS	13S	18.5	0.0	0.8	5	1	400.0	1.0	1.63E-07
RS	14S	18.5	0.0	2.3	7	4	400.0	1.0	5.43E-05
RS	15S	18.5	0.0	1.7	4	1	400.0	1.0	5.73E-06
EOCR	3S	30.0	0.0	0.5	6	0	400.0	1.0	3.86E-05
EOCR	3B	23.0	0.0	0.5	6	0	400.0	1.0	1.42E-05
EOCR	4S	30.0	0.0	3.6	5	4	400.0	1.0	5.59E-05
EOCR	4B	23.0	0.0	3.6	5	4	400.0	1.0	2.70E-05
EOCR	5S	30.0	0.0	8.0	1	3	400.0	1.0	2.07E-05

Elevated Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	5B	23.0	0.0	8.0	1	3	400.0	1.0	7.09E-06
EOCR	6S	30.0	0.0	1.7	4	1	400.0	1.0	2.33E-05
EOCR	6B	23.0	0.0	1.7	4	1	400.0	1.0	1.08E-05
EOCR	7S	30.0	0.0	0.5	7	0	400.0	1.0	1.19E-05
EOCR	7B	23.0	0.0	0.5	7	0	400.0	1.0	2.93E-05
EOCR	8S	30.0	0.0	1.0	6	1	400.0	1.0	8.17E-06
EOCR	8B	23.0	0.0	1.0	6	1	400.0	1.0	6.06E-04
EOCR	9S	30.0	0.0	2.8	7	1	400.0	1.0	9.39E-06
EOCR	9B	23.0	0.0	2.8	7	1	400.0	1.0	7.05E-06
EOCR	10S	30.0	0.0	3.0	1	1	400.0	1.0	5.24E-06
EOCR	10B	23.0	0.0	3.0	1	1	400.0	1.0	6.65E-06
EOCR	11S	30.0	0.0	1.5	1	1	400.0	1.0	1.15E-07
EOCR	11F	23.0	0.0	1.5	1	1	400.0	1.0	2.47E-04
EOCR	12S	30.0	0.0	2.4	5	3	400.0	1.0	5.94E-06
EOCR	12F	23.0	0.0	2.4	5	3	400.0	1.0	4.44E-05
EOCR	13S	30.0	0.0	2.1	1	1	400.0	1.0	9.57E-06
EOCR	13F	23.0	0.0	2.1	1	1	400.0	1.0	2.76E-05
EOCR	14F	30.0	0.0	1.9	5	4	400.0	1.0	1.88E-04
EOCR	14B	23.0	0.0	1.9	5	4	400.0	1.0	1.25E-05
EOCR	15F	30.0	0.0	4.0	4	2	400.0	1.0	2.41E-05
EOCR	15B	23.0	0.0	4.0	4	2	400.0	1.0	1.39E-05
EOCR	16F	30.0	0.0	3.2	4	2	400.0	1.0	2.49E-05
EOCR	16B	23.0	0.0	3.2	4	2	400.0	1.0	7.31E-06
EOCR	17F	30.0	0.0	1.2	7	1	400.0	1.0	2.50E-04
EOCR	17B	23.0	0.0	1.2	7	1	400.0	1.0	3.18E-06
EOCR	18F	30.0	0.0	4.9	6	3	400.0	1.0	2.62E-05
EOCR	18B	23.0	0.0	4.9	6	3	400.0	1.0	1.41E-04
EOCR	19F	30.0	0.0	2.4	7	3	400.0	1.0	1.26E-05
EOCR	19B	23.0	0.0	2.4	7	3	400.0	1.0	7.19E-06
EOCR	20F	30.0	0.0	3.5	7	3	400.0	1.0	1.32E-05
EOCR	20B	23.0	0.0	3.5	7	3	400.0	1.0	9.02E-06
EOCR	21F	30.0	0.0	3.0	7	3	400.0	1.0	5.57E-05
EOCR	21B	23.0	0.0	3.0	7	3	400.0	1.0	1.39E-05
EOCR	22F	30.0	0.0	4.1	5	4	400.0	1.0	1.33E-05
EOCR	22B	23.0	0.0	4.1	5	4	400.0	1.0	5.54E-06
EOCR	23F	30.0	0.0	2.9	5	3	400.0	1.0	5.97E-06
EOCR	23B	23.0	0.0	2.9	5	3	400.0	1.0	6.00E-06
EOCR	24F	30.0	0.0	2.8	6	2	400.0	1.0	4.62E-06
EOCR	24B	23.0	0.0	2.8	6	2	400.0	1.0	2.15E-06
RS	1S	43.0	0.0	1.8	1	1	800.0	1.0	3.11E-06
RS	1F	18.5	0.0	1.8	1	1	800.0	1.0	1.90E-05
RS	2S	43.0	0.0	2.1	7	1	800.0	1.0	2.82E-06
RS	2F	18.5	0.0	2.1	7	1	800.0	1.0	2.17E-06
RS	3S	43.0	0.0	1.8	7	2	800.0	1.0	2.27E-05
RS	3F	18.5	0.0	1.8	7	2	800.0	1.0	1.69E-04

Elevated Release Data (cont.)

Site	Test	Rht[a]	WO[b]	U[c]	S1[d]	S2[e]	X[f]	Oht[g]	X/Q[h]
RS	4S	43.0	0.0	2.3	7	5	800.0	1.0	1.25E-06
RS	6S	18.5	0.0	3.2	4	3	800.0	1.0	5.32E-07
RS	7S	18.5	0.0	5.3	1	3	800.0	1.0	3.96E-06
RS	8S	18.5	0.0	2.6	7	2	800.0	1.0	7.84E-06
RS	9S	43.0	0.0	1.8	4	1	800.0	1.0	2.12E-06
RS	10S	18.5	0.0	4.6	6	0	800.0	1.0	6.35E-06
RS	11S	18.5	0.0	5.0	5	3	800.0	1.0	3.18E-06
RS	12S	18.5	0.0	1.8	5	2	800.0	1.0	4.95E-06
RS	13S	18.5	0.0	0.8	5	1	800.0	1.0	1.75E-07
RS	14S	18.5	0.0	2.3	7	4	800.0	1.0	3.32E-06
RS	15S	18.5	0.0	1.7	4	1	800.0	1.0	5.88E-06
EOCR	4S	30.0	0.0	3.6	5	4	800.0	1.0	2.05E-05
EOCR	6S	30.0	0.0	1.7	4	1	800.0	1.0	9.32E-06
EOCR	6B	23.0	0.0	1.7	4	1	800.0	1.0	5.31E-06
EOCR	7S	30.0	0.0	0.5	7	0	800.0	1.0	1.29E-05
EOCR	7B	23.0	0.0	0.5	7	0	800.0	1.0	2.20E-04
EOCR	8S	30.0	0.0	1.0	6	1	800.0	1.0	1.19E-06
EOCR	8B	23.0	0.0	1.0	6	1	800.0	1.0	2.61E-04
EOCR	9S	30.0	0.0	2.8	7	1	800.0	1.0	5.76E-06
EOCR	9B	23.0	0.0	2.8	7	1	800.0	1.0	1.47E-05
EOCR	10S	30.0	0.0	3.0	1	1	800.0	1.0	7.39E-07
EOCR	12S	30.0	0.0	2.4	5	3	800.0	1.0	6.23E-06
EOCR	12F	23.0	0.0	2.4	5	3	800.0	1.0	2.82E-05
EOCR	13S	30.0	0.0	2.1	1	1	800.0	1.0	2.14E-06
EOCR	14F	30.0	0.0	1.9	5	4	800.0	1.0	1.84E-04
EOCR	14B	23.0	0.0	1.9	5	4	800.0	1.0	5.03E-06
EOCR	15F	30.0	0.0	4.0	4	2	800.0	1.0	9.14E-06
EOCR	15B	23.0	0.0	4.0	4	2	800.0	1.0	2.01E-06
EOCR	16F	30.0	0.0	3.2	4	2	800.0	1.0	2.68E-05
EOCR	16B	23.0	0.0	3.2	4	2	800.0	1.0	1.48E-06
EOCR	17F	30.0	0.0	1.2	7	1	800.0	1.0	6.76E-04
EOCR	17B	23.0	0.0	1.2	7	1	800.0	1.0	1.83E-06
EOCR	18F	30.0	0.0	4.9	6	3	800.0	1.0	6.10E-06
EOCR	18B	23.0	0.0	4.9	6	3	800.0	1.0	5.49E-06
EOCR	19F	30.0	0.0	2.4	7	3	800.0	1.0	6.76E-05
EOCR	19B	23.0	0.0	2.4	7	3	800.0	1.0	1.30E-05
EOCR	20F	30.0	0.0	3.5	7	3	800.0	1.0	5.36E-06
EOCR	20B	23.0	0.0	3.5	7	3	800.0	1.0	3.30E-06
EOCR	21F	30.0	0.0	3.0	7	3	800.0	1.0	7.72E-05
EOCR	21B	23.0	0.0	3.0	7	3	800.0	1.0	3.39E-06
EOCR	22F	30.0	0.0	4.1	5	4	800.0	1.0	1.28E-05
EOCR	22B	23.0	0.0	4.1	5	4	800.0	1.0	4.43E-07
EOCR	23F	30.0	0.0	2.9	5	3	800.0	1.0	6.58E-06
EOCR	24F	30.0	0.0	2.8	6	2	800.0	1.0	3.07E-06
MS	1S	48.3	8.7	7.2	4	5	800.0	1.0	1.67E-05

Elevated Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
MS	2S	48.3	8.7	6.6	4	5	800.0	1.0	1.50E-05
MS	3S	48.3	8.7	6.4	1	5	800.0	1.0	9.86E-06
MS	4S	48.3	8.7	6.9	3	5	800.0	1.0	1.24E-05
MS	5S	48.3	8.3	4.8	4	5	800.0	1.0	6.25E-06
MS	6S	48.3	8.3	4.5	4	5	800.0	1.0	6.61E-06
MS	8S	48.3	8.1	6.8	5	6	800.0	1.0	4.35E-06
MS	9S	48.3	8.1	5.2	5	6	800.0	1.0	3.41E-05
MS	10S	48.3	8.1	6.2	5	6	800.0	1.0	9.95E-05
MS	11S	48.3	8.7	7.9	4	5	800.0	1.0	1.99E-05
MS	11F	27.6	10.5	7.9	4	5	800.0	1.0	1.35E-05
MS	12S	48.3	8.7	8.5	3	6	800.0	1.0	1.55E-05
MS	12F	27.6	10.5	8.5	3	6	800.0	1.0	1.86E-05
MS	13S	48.3	8.7	8.3	4	5	800.0	1.0	1.80E-05
MS	13F	27.6	10.5	8.3	4	5	800.0	1.0	1.18E-05
MS	14S	48.3	8.7	9.5	4	5	800.0	1.0	1.36E-05
MS	14F	27.6	10.5	9.5	4	5	800.0	1.0	1.23E-05
MS	15S	48.3	8.7	10.3	4	6	800.0	1.0	1.34E-05
MS	15F	27.6	10.5	10.3	4	6	800.0	1.0	1.41E-05
MS	16S	48.3	8.7	10.1	4	6	800.0	1.0	1.63E-05
MS	16F	27.6	10.5	10.1	4	6	800.0	1.0	1.42E-05
MS	17S	48.3	8.7	10.2	4	5	800.0	1.0	1.68E-05
MS	17F	27.6	10.5	10.2	4	5	800.0	1.0	1.99E-05
MS	18S	48.3	8.7	9.9	4	6	800.0	1.0	1.24E-05
MS	18F	27.6	10.5	9.9	4	6	800.0	1.0	1.16E-05
MS	28S	48.3	4.8	3.0	5	6	800.0	1.0	1.08E-05
MS	28F	27.6	10.5	3.0	5	6	800.0	1.0	1.24E-05
MS	29S	48.3	4.6	3.7	5	5	800.0	1.0	4.00E-06
MS	29F	27.6	10.5	3.7	5	5	800.0	1.0	2.49E-05
MS	30S	48.3	4.6	2.9	4	5	800.0	1.0	2.21E-05
MS	30F	27.6	10.5	2.9	4	5	800.0	1.0	1.82E-05
MS	31S	48.3	4.6	3.1	4	5	800.0	1.0	2.26E-05
MS	31F	27.6	10.5	3.1	4	5	800.0	1.0	2.41E-05
MS	32S	48.3	4.6	3.1	4	5	800.0	1.0	3.81E-05
MS	32F	27.6	10.5	3.1	4	5	800.0	1.0	2.19E-05
MS	36S	48.3	5.8	3.7	4	5	800.0	1.0	9.41E-06
MS	36F	27.6	10.5	3.7	4	5	800.0	1.0	1.75E-05
MS	45S	48.3	8.6	7.2	4	5	800.0	1.0	2.01E-05
MS	45F	27.6	10.5	7.2	4	5	800.0	1.0	1.59E-05
MS	46S	48.3	8.6	8.1	3	5	800.0	1.0	1.63E-05
MS	46F	27.6	10.5	8.1	3	5	800.0	1.0	1.45E-05
MS	47S	48.3	8.6	9.5	2	5	800.0	1.0	1.65E-05
MS	47F	27.6	10.5	9.5	2	5	800.0	1.0	1.33E-05
MS	48S	48.3	8.6	9.2	4	5	800.0	1.0	1.55E-05
MS	48F	27.6	10.5	9.2	4	5	800.0	1.0	1.08E-05
MS	49S	48.3	8.6	9.5	4	5	800.0	1.0	1.42E-05

Elevated Release Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
MS	49F	27.6	10.5	9.5	4	5	800.0	1.0	1.37E-05
MS	50S	48.3	8.6	9.8	4	5	800.0	1.0	1.53E-05
MS	50F	27.6	10.5	9.8	4	5	800.0	1.0	6.92E-06
MS	51S	48.3	8.6	10.3	4	5	800.0	1.0	1.19E-05
MS	51F	27.6	10.5	10.3	4	5	800.0	1.0	8.76E-06
MS	52S	48.3	8.6	11.2	4	6	800.0	1.0	1.36E-05
MS	[illegible]	27.6	10.5	11.2	4	6	800.0	1.0	1.10E-05
MS	[illegible]	48.3	8.6	10.9	4	6	800.0	1.0	1.31E-05
MS	[illegible]	27.6	10.5	10.9	4	6	800.0	1.0	1.19E-05
MS	[illegible]	48.3	8.6	10.6	4	6	800.0	1.0	1.30E-05
MS	54F	27.6	10.5	10.6	4	6	800.0	1.0	1.04E-05
MS	57S	48.3	8.6	3.6	4	5	800.0	1.0	1.74E-05
MS	57F	27.6	10.5	3.6	4	5	800.0	1.0	2.00E-05
MS	58S	48.3	8.6	3.6	4	5	800.0	1.0	1.25E-05
MS	58F	27.6	10.5	[illegible]	4	5	800.0	1.0	9.25E-06
MS	59S	48.3	8.6	[illegible]	4	5	800.0	1.0	5.75E-06
DAEC	1	23.5	0.0	[illegible]	4	1	1000.0	1.0	1.16E-05
DAEC	2	23.5	0.0	1.7	4	2	1000.0	1.0	7.90E-06
DAEC	3	23.5	0.0	1.7	4	3	1000.0	1.0	9.41E-06
DAEC	4	23.5	0.0	0.5	5	1	1000.0	1.0	3.50E-05
DAEC	5	23.5	0.0	1.5	4	1	1000.0	1.0	4.54E-06
DAEC	6	23.5	0.0	1.7	3	1	1000.0	1.0	6.14E-06
DAEC	7	23.5	0.0	2.0	4	1	1000.0	1.0	1.06E-05
DAEC	8	23.5	0.0	1.4	3	1	1000.0	1.0	4.71E-08
DAEC	9	23.5	0.0	2.6	5	2	1000.0	1.0	4.18E-05
DAEC	10	23.5	0.0	3.5	4	3	1000.0	1.0	4.60E-05
DAEC	11	23.5	0.0	3.3	4	3	1000.0	1.0	4.87E-05
DAEC	12	23.5	0.0	3.1	5	3	1000.0	1.0	6.98E-05
DAEC	13	23.5	0.0	1.6	2	1	1000.0	1.0	1.88E-05
DAEC	14	23.5	0.0	1.4	4	1	1000.0	1.0	6.17E-06
DAEC	15	23.5	0.0	1.2	4	2	1000.0	1.0	1.39E-05
DAEC	16	23.5	0.0	1.3	4	1	1000.0	1.0	1.48E-05
DAEC	17	45.7	10.8	2.8	2	1	1000.0	1.0	7.02E-06
DAEC	18	45.7	10.8	2.9	2	2	1000.0	1.0	1.09E-05
DAEC	19	45.7	10.8	2.7	1	2	1000.0	1.0	1.08E-05
DAEC	20	45.7	10.8	3.0	2	1	1000.0	1.0	8.30E-06
DAEC	25	45.7	10.2	2.7	3	4	1000.0	1.0	3.76E-05
DAEC	26	45.7	10.2	2.8	4	3	1000.0	1.0	2.78E-05
DAEC	27	45.7	10.2	3.3	3	3	1000.0	1.0	3.74E-05
DAEC	28	45.7	10.2	2.8	1	2	1000.0	1.0	2.12E-05
DAEC	32	45.7	10.2	0.4	5	1	1000.0	1.0	4.75E-07
DAEC	33	45.7	10.2	0.8	5	1	1000.0	1.0	7.50E-07
EOCR	14F	30.0	0.0	1.9	5	4	1200.0	1.0	6.56E-04
EOCR	14B	23.0	0.0	1.9	5	4	1200.0	1.0	3.88E-05
EOCR	15F	30.0	0.0	4.0	4	2	1200.0	1.0	1.05E-05

Elevated Rclease Data (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	15B	23.0	0.0	4.0	4	2	1200.0	1.0	7.33E-06
EOCR	16F	30.0	0.0	3.2	4	2	1200.0	1.0	1.83E-05
EOCR	16B	23.0	0.0	3.2	4	2	1200.0	1.0	1.44E-06
EOCR	17F	30.0	0.0	1.2	7	1	1200.0	1.0	3.69E-04
EOCR	17B	23.0	0.0	1.2	7	1	1200.0	1.0	8.00E-07
EOCR	18F	30.0	0.0	4.9	6	3	1200.0	1.0	8.78E-06
EOCR	18B	23.0	0.0	4.9	6	3	1200.0	1.0	4.69E-06
EOCR	19F	30.0	0.0	2.4	7	3	1200.0	1.0	6.04E-06
EOCR	19B	23.0	0.0	2.4	7	3	1200.0	1.0	1.96E-05
EOCR	20F	30.0	0.0	3.5	7	3	1200.0	1.0	7.16E-06
EOCR	20B	23.0	0.0	3.5	7	3	1200.0	1.0	3.57E-06
EOCR	21F	30.0	0.0	3.0	7	3	1200.0	1.0	9.10E-06
EOCR	21B	23.0	0.0	3.0	7	3	1200.0	1.0	2.33E-06
EOCR	22F	30.0	0.0	4.1	5	4	1200.0	1.0	3.77E-05
EOCR	22B	23.0	0.0	4.1	5	4	1200.0	1.0	2.50E-07
EOCR	23F	30.0	0.0	2.9	5	3	1200.0	1.0	1.35E-05
EOCR	24F	30.0	0.0	2.8	6	2	1200.0	1.0	2.80E-06

(a) Nominal release height (m)
(b) Vertical velocity of release (m/s)
(c) Wind speed at 10 m (m/s)
(d) Delta-T stability class; 1 = Pasquill-Gifford Class A, etc.
(e) Sigma-Theta stbility class; 0 = missing, 1 = Pasquill-Gifford Class A, etc.
(f) Distance to centerline receptor (m)
(g) Concentration measurement height (m)
(h) Normalized concentration (s/m^3)

APPENDIX D

DATA FOR RECEPTORS ON OR ADJACENT TO BUILDING SURFACES

APPENDIX D

DATA FOR RECEPTORS ON OR ADJACENT TO BUILDING SURFACES

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	11S	30.0	0.0	1.5	1	1	22.0	4.0	1.58E-05
EOCR	11S	30.0	0.0	1.5	1	1	9.0	4.0	2.25E-05
EOCR	11S	30.0	0.0	1.5	1	1	21.0	4.0	2.63E-07
EOCR	11S	30.0	0.0	1.5	1	1	12.0	4.0	4.64E-06
EOCR	11F	23.0	0.0	1.5	1	1	15.0	4.0	6.73E-05
EOCR	11F	23.0	0.0	1.5	1	1	15.0	4.0	5.25E-05
EOCR	11F	23.0	0.0	1.5	1	1	23.0	4.0	1.53E-04
EOCR	11F	23.0	0.0	1.5	1	1	23.0	4.0	9.20E-06
EOCR	11B	1.0	0.0	1.5	1	1	41.0	8.0	5.53E-06
EOCR	11B	1.0	0.0	1.5	1	1	26.0	8.0	3.01E-05
EOCR	11B	1.0	0.0	1.5	1	1	6.0	8.0	1.03E-05
EOCR	12F	23.0	0.0	2.4	5	3	15.0	4.0	2.41E-05
EOCR	12F	23.0	0.0	2.4	5	3	15.0	4.0	1.02E-05
EOCR	12F	23.0	0.0	2.4	5	3	23.0	4.0	1.25E-05
EOCR	12B	1.0	0.0	2.4	5	3	41.0	8.0	1.18E-05
EOCR	12B	1.0	0.0	2.4	5	3	26.0	8.0	1.60E-04
EOCR	12B	1.0	0.0	2.4	5	3	37.0	8.0	5.61E-07
EOCR	13S	30.0	0.0	2.1	1	1	22.0	4.0	1.48E-05
EOCR	13S	30.0	0.0	2.1	1	1	9.0	4.0	2.68E-06
EOCR	13S	30.0	0.0	2.1	1	1	21.0	4.0	1.35E-05
EOCR	13S	30.0	0.0	2.1	1	1	12.0	4.0	2.02E-06
EOCR	13F	23.0	0.0	2.1	1	1	15.0	4.0	1.45E-04
EOCR	13F	23.0	0.0	2.1	1	1	15.0	4.0	8.37E-05
EOCR	13F	23.0	0.0	2.1	1	1	23.0	4.0	5.63E-05
EOCR	13F	23.0	0.0	2.1	1	1	23.0	4.0	2.67E-05
EOCR	13B	1.0	0.0	2.1	1	1	41.0	8.0	2.92E-05
EOCR	13B	1.0	0.0	2.1	1	1	26.0	8.0	2.94E-05
EOCR	13B	1.0	0.0	2.1	1	1	37.0	8.0	4.18E-05
EOCR	13B	1.0	0.0	2.1	1	1	6.0	8.0	9.10E-05
EOCR	14S	1.0	0.0	1.9	5	4	41.0	5.0	5.03E-06
EOCR	14F	30.0	0.0	1.9	5	4	12.0	4.0	1.02E-04
EOCR	14F	30.0	0.0	1.9	5	4	22.0	4.0	1.50E-05
EOCR	14F	30.0	0.0	1.9	5	4	21.0	4.0	5.56E-06
EOCR	14B	23.0	0.0	1.9	5	4	15.0	4.0	3.73E-05
EOCR	14B	23.0	0.0	1.9	5	4	23.0	4.0	2.43E-05
EOCR	15S	1.0	0.0	4.0	4	2	6.0	8.0	4.34E-04
EOCR	15S	1.0	0.0	4.0	4	2	26.0	8.0	3.48E-04
EOCR	15S	1.0	0.0	4.0	4	2	41.0	8.0	4.47E-04
EOCR	15S	1.0	0.0	4.0	4	2	37.0	8.0	2.03E-06
EOCR	15F	30.0	0.0	4.0	4	2	9.0	4.0	2.47E-05
EOCR	15B	23.0	0.0	4.0	4	2	15.0	4.0	1.65E-04
EOCR	15B	23.0	0.0	4.0	4	2	15.0	4.0	1.69E-05
EOCR	16S	1.0	0.0	3.2	4	2	6.0	8.0	5.10E-04

Data for Receptors on or Adjacent to Building Surfaces (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
EOCR	16S	1.0	0.0	3.2	4	2	26.0	8.0	9.71E-05
EOCR	16S	1.0	0.0	3.2	4	2	41.0	8.0	7.16E-05
EOCR	16S	1.0	0.0	3.2	4	2	37.0	8.0	5.16E-04
EOCR	16B	23.0	0.0	3.2	4	2	15.0	4.0	1.31E-05
EOCR	16B	23.0	0.0	3.2	4	2	15.0	4.0	1.93E-06
EOCR	16B	23.0	0.0	3.2	4	2	23.0	4.0	1.73E-04
EOCR	17S	1.0	0.0	1.2	7	1	6.0	8.0	4.83E-06
EOCR	17S	1.0	0.0	1.2	7	1	26.0	8.0	3.31E-04
EOCR	17S	1.0	0.0	1.2	7	1	41.0	8.0	4.15E-04
EOCR	17S	1.0	0.0	1.2	7	1	37.0	8.0	5.63E-06
EOCR	17F	30.0	0.0	1.2	7	1	12.0	4.0	1.66E-05
EOCR	17F	30.0	0.0	1.2	7	1	21.0	4.0	2.26E-05
EOCR	18S	1.0	0.0	4.9	6	3	6.0	8.0	2.27E-04
EOCR	18S	1.0	0.0	4.9	6	3	26.0	8.0	4.46E-04
EOCR	18S	1.0	0.0	4.9	6	3	41.0	8.0	6.27E-04
EOCR	18S	1.0	0.0	4.9	6	3	37.0	8.0	4.80E-06
EOCR	18F	30.0	0.0	4.9	6	3	12.0	4.0	1.71E-05
EOCR	18F	30.0	0.0	4.9	6	3	21.0	4.0	1.90E-05
EOCR	18B	23.0	0.0	4.9	6	3	23.0	4.0	4.26E-06
EOCR	18B	23.0	0.0	4.9	6	3	15.0	4.0	6.65E-06
EOCR	18B	23.0	0.0	4.9	6	3	23.0	4.0	1.95E-06
EOCR	19S	1.0	0.0	2.4	7	3	6.0	8.0	6.83E-06
EOCR	19S	1.0	0.0	2.4	7	3	26.0	8.0	2.38E-05
EOCR	19S	1.0	0.0	2.4	7	3	37.0	8.0	5.64E-05
EOCR	19F	30.0	0.0	2.4	7	3	21.0	4.0	1.00E-05
EOCR	19B	23.0	0.0	2.4	7	3	15.0	4.0	5.69E-05
EOCR	19B	23.0	0.0	2.4	7	3	23.0	4.0	7.50E-05
EOCR	20S	1.0	0.0	3.5	7	3	6.0	8.0	6.63E-04
EOCR	20S	1.0	0.0	3.5	7	3	26.0	8.0	6.37E-04
EOCR	20S	1.0	0.0	3.5	7	3	41.0	8.0	6.01E-04
EOCR	20S	1.0	0.0	3.5	7	3	37.0	8.0	5.27E-04
EOCR	20B	23.0	0.0	3.5	7	3	15.0	4.0	4.62E-06
EOCR	20B	23.0	0.0	3.5	7	3	23.0	4.0	1.34E-05
EOCR	21S	1.0	0.0	3.0	7	3	6.0	8.0	1.15E-04
EOCR	21S	1.0	0.0	3.0	7	3	26.0	8.0	5.23E-06
EOCR	21S	1.0	0.0	3.0	7	3	41.0	8.0	1.16E-04
EOCR	21S	1.0	0.0	3.0	7	3	34.0	8.0	1.07E-04
EOCR	21F	30.0	0.0	3.0	7	3	22.0	4.0	1.41E-05
EOCR	21F	30.0	0.0	3.0	7	3	15.0	4.0	1.94E-05
EOCR	21B	23.0	0.0	3.0	7	3	15.0	4.0	1.05E-04
EOCR	21B	23.0	0.0	3.0	7	3	14.0	4.0	1.03E-04
EOCR	22S	1.0	0.0	4.1	5	4	6.0	8.0	9.54E-05
EOCR	22S	1.0	0.0	4.1	5	4	26.0	8.0	3.45E-04
EOCR	22S	1.0	0.0	4.1	5	4	41.0	8.0	2.55E-04
EOCR	22S	1.0	0.0	4.1	5	4	37.0	8.0	2.73E-04
EOCR	22F	30.0	0.0	4.1	5	4	12.0	4.0	6.23E-06
EOCR	22F	30.0	0.0	4.1	5	4	22.0	4.0	7.49E-06

Data for Receptors on or Adjacent to Building Surfaces (cont.)

Site	Test	Rht[a]	WO[b]	U[c]	S1[d]	S2[e]	X[f]	Oht[g]	X/Q[h]
EOCR	22F	30.0	0.0	4.1	5	4	21.0	4.0	8.85E-06
EOCR	22B	23.0	0.0	4.1	5	4	15.0	4.0	8.22E-07
EOCR	22B	23.0	0.0	4.1	5	4	15.0	4.0	1.98E-05
EOCR	23S	1.0	0.0	2.9	5	3	6.0	8.0	5.14E-04
EOCR	23S	1.0	0.0	2.9	5	3	26.0	8.0	9.74E-04
EOCR	23S	1.0	0.0	2.9	5	3	41.0	8.0	6.42E-04
EOCR	23S	1.0	0.0	2.9	5	3	37.0	8.0	5.15E-04
EOCR	23F	30.0	0.0	2.9	5	3	21.0	4.0	1.38E-05
EOCR	23B	23.0	0.0	2.9	5	3	15.0	4.0	2.38E-05
EOCR	23B	23.0	0.0	2.9	5	3	23.0	4.0	4.75E-05
EOCR	24S	1.0	0.0	2.8	6	2	6.0	8.0	6.78E-04
EOCR	24S	1.0	0.0	2.8	6	2	26.0	8.0	7.78E-04
EOCR	24S	1.0	0.0	2.8	6	2	41.0	8.0	6.22E-04
EOCR	24S	1.0	0.0	2.8	6	2	37.0	8.0	6.50E-04
EOCR	24B	23.0	0.0	2.8	6	2	15.0	4.0	1.12E-05
EOCR	24B	23.0	0.0	2.8	6	2	23.0	4.0	3.87E-05
RS	1S	43.0	0.0	1.8	1	1	25.0	16.5	1.26E-05
RS	1S	43.0	0.0	1.8	1	1	37.0	16.5	2.17E-06
RS	1F	16.5	0.0	1.8	1	1	6.0	16.5	1.38E-06
RS	1F	16.5	0.0	1.8	1	1	17.0	16.5	8.81E-05
RS	1F	16.5	0.0	1.8	1	1	31.0	16.5	4.36E-05
RS	4S	43.0	0.0	2.3	7	5	25.0	16.5	4.48E-04
RS	4S	43.0	0.0	2.3	7	5	37.0	16.5	1.41E-05
RS	4S	43.0	0.0	2.3	7	5	49.0	16.5	6.83E-06
RS	4F	1.0	0.0	2.3	7	5	18.0	16.5	5.03E-04
RS	4F	1.0	0.0	2.3	7	5	27.0	16.5	6.65E-05
RS	4F	1.0	0.0	2.3	7	5	41.0	16.5	3.53E-04
RS	5S	1.0	0.0	1.8	7	1	18.0	16.5	9.49E-04
RS	5S	1.0	0.0	1.8	7	1	27.0	16.5	8.31E-04
RS	5S	1.0	0.0	1.8	7	1	49.0	16.5	3.90E-04
RS	5F	1.0	0.0	1.8	7	1	18.0	16.5	2.41E-03
RS	5F	1.0	0.0	1.8	7	1	27.0	16.5	9.14E-04
RS	5F	1.0	0.0	1.8	7	1	49.0	16.5	4.76E-04
RS	6S	16.5	0.0	3.2	4	3	6.0	16.5	5.13E-03
RS	6S	16.5	0.0	3.2	4	3	17.0	16.5	2.97E-04
RS	6S	16.5	0.0	3.2	4	3	31.0	16.5	9.26E-05
RS	7S	16.5	0.0	5.3	1	3	6.0	16.5	1.78E-03
RS	7S	16.5	0.0	5.3	1	3	17.0	16.5	6.94E-04
RS	7S	16.5	0.0	5.3	1	3	31.0	16.5	1.15E-06
RS	8F	1.0	0.0	2.6	7	2	41.0	16.5	1.12E-04
RS	9F	1.0	0.0	1.8	4	1	18.0	16.5	6.80E-05
RS	10S	16.5	0.0	4.6	6	0	6.0	16.5	3.73E-04
RS	10S	16.5	0.0	4.6	6	0	17.0	16.5	2.65E-04
RS	10S	16.5	0.0	4.6	6	0	31.0	16.5	3.41E-04
RS	10F	1.0	0.0	4.6	6	0	41.0	16.5	2.50E-04
RS	11S	16.5	0.0	5.0	5	3	6.0	16.5	1.59E-03
RS	11S	16.5	0.0	5.0	5	3	17.0	16.5	6.23E-04

Data for Receptors on or Adjacent to Building Surfaces (cont.)

Site	Test	Rht(a)	WO(b)	U(c)	S1(d)	S2(e)	X(f)	Oht(g)	X/Q(h)
RS	11S	16.5	0.0	5.0	5	3	31.0	16.5	4.56E-04
RS	12S	16.5	0.0	1.8	5	2	6.0	16.5	2.85E-03
RS	12S	16.5	0.0	1.8	5	2	17.0	16.5	7.53E-04
RS	12S	16.5	0.0	1.8	5	2	31.0	16.5	1.89E-04
RS	13S	16.5	0.0	0.8	5	1	6.0	16.5	1.03E-03
RS	13S	16.5	0.0	0.8	5	1	31.0	16.5	2.48E-05
RS	13F	1.0	0.0	0.8	5	1	18.0	16.5	2.11E-03
RS	13F	1.0	0.0	0.8	5	1	41.0	16.5	2.00E-04
RS	14S	16.5	0.0	2.3	7	4	6.0	16.5	8.57E-06
RS	14S	16.5	0.0	2.3	7	4	17.0	16.5	2.84E-06
RS	14S	16.5	0.0	2.3	7	4	31.0	16.5	5.00E-07
RS	14F	1.0	0.0	2.3	7	4	18.0	16.5	4.79E-05
RS	14F	1.0	0.0	2.3	7	4	27.0	16.5	3.62E-05
RS	14F	1.0	0.0	2.3	7	4	41.0	16.5	1.14E-05
RS	15S	16.5	0.0	1.7	4	1	6.0	16.5	1.10E-03
RS	15S	16.5	0.0	1.7	4	1	17.0	16.5	5.88E-04
RS	15F	1.0	0.0	1.7	4	1	18.0	16.5	1.99E-03
RS	15F	1.0	0.0	1.7	4	1	27.0	16.5	3.53E-04
RS	16S	1.0	0.0	0.9	5	1	60.0	16.5	2.56E-03
RS	16S	1.0	0.0	0.9	5	1	68.0	16.5	5.81E-04
RS	16S	1.0	0.0	0.9	5	1	84.0	16.5	1.37E-03
RS	17S	1.0	0.0	3.0	7	4	60.0	16.5	1.39E-05
RS	17S	1.0	0.0	3.0	7	4	68.0	16.5	5.00E-07
RS	17S	1.0	0.0	3.0	7	4	84.0	16.5	1.24E-05
RS	17F	1.0	0.0	3.0	7	4	18.0	16.5	2.52E-04
RS	17F	1.0	0.0	3.0	7	4	27.0	16.5	1.30E-04
RS	17F	1.0	0.0	3.0	7	4	41.0	16.5	6.15E-05
RS	18S	1.0	0.0	0.5	6	1	60.0	16.5	2.84E-03
RS	18S	1.0	0.0	0.5	6	1	68.0	16.5	1.96E-04
RS	18S	1.0	0.0	0.5	6	1	84.0	16.5	1.59E-03
RS	19S	1.0	0.0	1.5	5	1	60.0	16.5	2.77E-04
RS	19S	1.0	0.0	1.5	5	1	68.0	16.5	3.15E-04
RS	19S	1.0	0.0	1.5	5	1	84.0	16.5	1.33E-04
RS	19F	1.0	0.0	1.5	5	1	18.0	16.5	5.98E-04
RS	19F	1.0	0.0	1.5	5	1	41.0	16.5	7.47E-05
RS	21S	1.0	0.0	3.7	7	1	60.0	16.5	8.73E-06
RS	21S	1.0	0.0	3.7	7	1	68.0	16.5	8.14E-07
RS	21S	1.0	0.0	3.7	7	1	84.0	16.5	9.50E-07
RS	21F	1.0	0.0	3.7	7	1	18.0	16.5	7.27E-05
RS	21F	1.0	0.0	3.7	7	1	27.0	16.5	1.12E-06
RS	21F	1.0	0.0	3.7	7	1	41.0	16.5	1.50E-05
RS	22S	1.0	0.0	2.6	4	0	60.0	16.5	7.26E-05
RS	22S	1.0	0.0	2.6	4	0	68.0	16.5	3.42E-05
RS	22S	1.0	0.0	2.6	4	0	84.0	16.5	1.77E-05
RS	22F	1.0	0.0	2.6	4	0	18.0	16.5	7.95E-04
RS	22F	1.0	0.0	2.6	4	0	27.0	16.5	8.11E-04
RS	22F	1.0	0.0	2.6	4	0	41.0	16.5	4.59E-04

Data for Receptors on or Adjacent to Building Surfaces (cont.)

Site	Test	Rht[a]	WO[b]	U[c]	S1[d]	S2[e]	X[f]	Oht[g]	X/Q[h]
RS	23S	1.0	0.0	1.8	6	0	68.0	16.5	7.61E-05
RS	23S	1.0	0.0	1.8	6	0	84.0	16.5	4.56E-05
RS	23F	1.0	0.0	1.8	6	0	27.0	16.5	5.79E-04
RS	23F	1.0	0.0	1.8	6	0	41.0	16.5	4.48E-04
DAEC	1	23.5	0.0	0.7	4	1	34.0	18.1	7.01E-04
DAEC	3	23.5	0.0	1.7	4	3	34.0	18.1	8.68E-04
DAEC	4	23.5	0.0	0.5	5	1	34.0	18.1	2.25E-06
DAEC	5	23.5	0.0	1.5	4	1	34.0	18.1	6.47E-04
DAEC	6	23.5	0.0	1.7	3	1	34.0	18.1	5.14E-04
DAEC	7	23.5	0.0	2.0	4	1	34.0	18.1	7.25E-04
DAEC	8	23.5	0.0	1.4	3	1	34.0	18.1	1.84E-05
DAEC	10	23.5	0.0	3.5	4	3	34.0	18.1	4.73E-04
DAEC	11	23.5	0.0	3.3	4	3	34.0	18.1	4.20E-04
DAEC	13	23.5	0.0	1.6	2	1	34.0	18.1	4.35E-04
DAEC	15	23.5	0.0	1.2	4	2	34.0	18.1	1.19E-04
DAEC	17	45.7	10.8	2.8	4	1	25.0	18.1	6.53E-05
DAEC	19	45.7	10.8	2.7	1	2	25.0	18.1	8.07E-05
DAEC	20	45.7	10.8	3.0	2	1	25.0	18.1	8.19E-05
DAEC	25	45.7	10.2	2.7	3	4	25.0	18.1	2.35E-04
DAEC	26	45.7	10.2	2.8	4	3	25.0	18.1	9.67E-05
DAEC	27	45.7	10.2	3.3	3	3	25.0	18.1	7.63E-05
DAEC	28	45.7	10.2	3.8	1	2	25.0	18.1	1.98E-04
DAEC	30	45.7	10.2	0.6	5	1	25.0	18.1	2.75E-07
DAEC	31	45.7	10.2	0.3	6	1	25.0	18.1	6.50E-07
DAEC	32	45.7	10.2	0.4	5	1	25.0	18.1	8.25E-07
DAEC	33	45.7	10.2	0.8	5	1	25.0	18.1	6.25E-07
DAEC	34	1.0	0.0	3.3	4	3	91.0	18.1	1.52E-04
DAEC	35	1.0	0.0	2.7	4	3	91.0	18.1	1.80E-04
DAEC	36	1.0	0.0	2.0	5	2	91.0	18.1	5.30E-04
DAEC	38	1.0	0.0	4.6	1	4	91.0	18.1	2.94E-04
DAEC	39	1.0	0.0	3.5	4	4	91.0	18.1	1.65E-04
DAEC	40	1.0	0.0	2.2	1	3	91.0	18.1	6.18E-04
DAEC	41	1.0	0.0	3.2	1	2	91.0	18.1	1.23E-04
DAEC	42	1.0	0.0	3.1	1	4	91.0	18.1	2.36E-04
DAEC	43	1.0	0.0	3.1	1	2	91.0	18.1	1.67E-04
RS	1S	43.0	0.0	1.8	1	1	53.0	1.0	1.21E-05
RS	1F	16.5	0.0	1.8	1	1	75.0	1.0	9.05E-06
RS	2S	43.0	0.0	2.1	7	1	88.0	1.0	4.28E-06
RS	2F	16.5	0.0	2.1	7	1	84.0	1.0	4.62E-06
RS	3S	43.0	0.0	1.8	7	2	53.0	1.0	5.71E-06
RS	3F	16.5	0.0	1.8	7	2	68.0	1.0	1.32E-04
RS	4S	43.0	0.0	2.3	7	5	25.0	1.0	1.60E-05
RS	4F	1.0	0.0	2.3	7	5	6.0	1.0	2.12E-03
RS	5S	1.0	0.0	1.8	7	1	25.0	1.0	8.64E-04
RS	5F	1.0	0.0	1.8	7	1	25.0	1.0	1.81E-03
RS	6S	16.5	0.0	3.2	4	3	45.0	1.0	3.58E-04
RS	6F	1.0	0.0	3.2	4	3	6.0	1.0	7.75E-04

Data for Receptors on or Adjacent to Building Surfaces (cont.)

Site	Test	Rht[a]	WO[b]	U[c]	S1[d]	S2[e]	X[f]	Oht[g]	X/Q[h]
RS	7S	16.5	0.0	5.3	1	3	41.0	1.0	3.29E-05
RS	7F	1.0	0.0	5.3	1	3	6.0	1.0	2.91E-03
RS	8S	16.5	0.0	2.6	7	2	84.0	1.0	5.72E-05
RS	8F	1.0	0.0	2.6	7	2	25.0	1.0	2.18E-04
RS	9S	43.0	0.0	1.8	4	1	25.0	1.0	1.01E-05
RS	9F	1.0	0.0	1.8	4	1	6.0	1.0	5.77E-03
RS	10S	16.5	0.0	4.6	6	0	55.0	1.0	1.34E-04
RS	10F	1.0	0.0	4.6	6	0	6.0	1.0	2.11E-03
RS	11S	16.5	0.0	5.0	5	3	48.0	1.0	5.85E-05
RS	11F	1.0	0.0	5.0	5	3	6.0	1.0	4.95E-03
RS	12S	16.5	0.0	1.8	5	2	23.0	1.0	3.87E-05
RS	12F	1.0	0.0	1.8	5	2	6.0	1.0	4.78E-03
RS	13S	16.5	0.0	0.8	5	1	82.0	1.0	4.70E-06
RS	13F	1.0	0.0	0.8	5	1	49.0	1.0	1.93E-04
RS	14S	16.5	0.0	2.3	7	4	80.0	1.0	7.00E-06
RS	14F	1.0	0.0	2.3	7	4	6.0	1.0	4.34E-03
RS	15S	16.5	0.0	1.7	4	1	23.0	1.0	1.94E-05
RS	15F	1.0	0.0	1.7	4	1	6.0	1.0	5.00E-03
RS	16S	1.0	0.0	0.9	5	1	19.0	1.0	4.40E-04
RS	16F	1.0	0.0	0.9	5	1	6.0	1.0	5.56E-03
RS	17S	1.0	0.0	3.0	7	4	47.0	1.0	2.13E-03
RS	17F	1.0	0.0	3.0	7	4	25.0	1.0	1.98E-03
RS	18S	1.0	0.0	0.5	6	1	19.0	1.0	2.76E-04
RS	18F	1.0	0.0	0.5	6	1	6.0	1.0	3.56E-03
RS	19S	1.0	0.0	1.5	5	1	19.0	1.0	3.24E-03
RS	19F	1.0	0.0	1.5	5	1	6.0	1.0	4.32E-03
RS	20S	1.0	0.0	2.1	7	0	23.0	1.0	1.54E-03
RS	20F	1.0	0.0	2.1	7	0	6.0	1.0	3.38E-03
RS	21S	1.0	0.0	3.7	7	1	31.0	1.0	3.72E-04
RS	21F	1.0	0.0	3.7	7	1	6.0	1.0	3.95E-03
RS	22S	1.0	0.0	2.6	4	0	23.0	1.0	3.64E-04
RS	22F	1.0	0.0	2.6	4	0	6.0	1.0	1.01E-03
RS	23S	1.0	0.0	1.8	6	0	23.0	1.0	2.80E-03
RS	23F	1.0	0.0	1.8	6	0	6.0	1.0	2.65E-03

(a) Nominal release height (m)
(b) Vertical velocity of release (m/s)
(c) Wind speed at 10 m (m/s)
(d) Delta-T stability class; 1 = Pasquill-Gifford Class A, etc.
(e) Sigma-Theta stbility class; 0 = missing, 1 = Pasquill-Gifford Class A, etc.
(f) Distance to centerline receptor (m)
(g) Concentration measurement height (m). Some heights have been adjusted to give proper vertical separation from release point.
(h) Normalized concentration (s/m_3)

APPENDIX E

CORRELATIONS BETWEEN MODEL VARIABLES AND MODEL SENSITIVITY

APPENDIX E

CORRELATIONS BETWEEN MODEL VARIABLES AND MODEL SENSITIVITY

The correlations found to exist among the variables in the ground-level release data set are shown in Table E-1. The correlation between distance and speed, and between distance and stability are small and are not significantly different from zero. The correlation between speed and stability is significant, but the 95% confidence interval for the correlation ranges from about 0.05 to 0.3. Finally, the correlations between area and the other variables are artifacts of the distribution of experimental conditions. These correlations would not be expected to exist if the each set of experiments covered a full range of meteorological conditions.

TABLE E.1. Partial Correlation Coefficients from Multiple Linear Regression Analysis

Variable	Distance	Area	Speed	Stability
Distance	1.0000	-0.1988	-0.0761	0.0485
Area		1.0000	0.5721	0.1831
Speed			1.0000	0.3649
Stability				1.0000

The sensitivity of the model to variations in parameter values has been examined by selecting fractional exponents for the model variables that yield dimensions for the leading constant (k) that are rational and might have physically real bases and then comparing predicted and observed concentrations in each case. The parameter values and the square of the correlation coefficient between predicted and observed concentrations for each case are given in Table E.2. The regression parameter values and r^2 are listed first for reference.

In cases 1 through 5 the exponents were selected so that k would have dimensions of time squared. In each case the values selected are within the 90% confidence limits. The exponent for S was not varied because it doesn't effect dimensions, and value k was not varied because it doesn't affect the correlation. Despite the wide variation in exponent values, the correlation doesn't change significantly. In each case the value of r^2 indicates that the model accounts for more than 64% of the observed variability in the normalized centerline concentrations. In case 6, the parameter values were chosen to give k dimensions of time squared divided by length, and k was given a geometric mean determined from the data. The minimal reduction in r^2 should be noted because the values given to the exponents on A and U are outside of their respective 90% confidence intervals.

TABLE E.2. New Building Wake Model Sensitivity Variations in Parameter Values

Case	Parameter k	a	b	c	d	r^2
Regression	97.5	-1.223	-1.211	0.6771	0.4885	0.6469
1	100.	-5/4	-9/8	1/2	1/2	0.6420
2	100.	-6/5	-6/5	3/5	1/2	0.6463
3	100.	-4/3	-7/6	2/3	1/2	0.6456
4	100.	-5/4	-5/4	3/4	1/2	0.6465
5	100.	-7/5	-6/5	4/5	1/2	0.6460
6	4.34	-1.	-1.	1.	1/2	0.6282

APPENDIX F

FORTRAN PROGRAM ELEMENTS FOR ESTIMATING NORMALIZED CENTERLINE CONCENTRATIONS IN BUILDING WAKES

APPENDIX F

FORTRAN PROGRAM ELEMENTS FOR ESTIMATING NORMALIZED CENTERLINE CONCENTRATIONS IN BUILDING WAKES

This appendix contains a FORTRAN-77 implementation of the composite building wake model. The implementation consists of a function named WMOD and two subroutines. When WMOD is called from a program, it calls subroutine SSIGMA to determine the diffusion coefficients for the Gaussian plume portions of the composite model. If the height of the release point is at or above the roof of the building and the vertical velocity of the effluent is greater than zero, WMOD calls subroutine PROFILE to estimate the wind speed at the release height for use in the Split-H procedure.

All input to WMOD and the subroutines is via argument lists. The individual arguments are described at the beginning of each program element. The output of the subroutines is also passed through the formal arguments. The estimate of normalized concentration in the building wake is passed to the program element calling WMOD through the value assigned to the name WMOD in the function.

```
      FUNCTION WMOD( AREA,BHT,RHT,WO,FO,DIST,OHT,U10,IST1,IST2 )

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     FUNCTION WMOD
C
C     Function to compute diffusion estimates for releases made in
C     building wakes
C
C     J. V. RAMSDELL
C     PACIFIC NORTHWEST LABORATORY
C     P.O. BOX 999
C     RICHLAND, WASHINGTON  99352
C
C     CREATED:  July 10, 1987
C
C     DESCRIPTION:  The function WMOD estimates normalized
C       concentrations (X/Q) resulting from releases made in building
C       wakes.  The function is an implementation of the building wake
C       diffusion model developed for the U.S. Nuclear Regulatory
C       Commisssion by J. V. Ramsdell.  The model was developed using
C       building wake diffusion data obtained in experiments conducted
C       at 7 reactors.
C
C     INPUT:
C       Building area (m2)                               ==>     AREA
C       Building height (m)                              ==>     BHT
C
C       Release height (m)                               ==>     RHT
C       Effluent vertical velocity (m/s)                 ==>     WO
C       Flow (m3/s)                                      ==>     FO
C
C       Horizontal distance to receptor (m)              ==>     DIST
C       Receptor height(m)                               ==>     OHT
C
C       Wind speed at 10 m (m/s)                         ==>     U10
C       Vertical diffusion class                         ==>     IST1
C       Horizontal diffusion class                       ==>     IST2
C
C     OUTPUT:
C       Normalized Concentration (s/m3)                  ==>     WMOD
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      PI = 3.14159

C     WAKE MODEL CONSTANTS

      CO = 150.
      CX = -1.2
```

```
      CU = 0.68
      CA = -1.2

C     GET DIFFUSION COEFFICIENTS FOR GAUSSIAN PLUME

      CALL SSIGMA( DIST, IST1, IST2, SIGMAZ, SIGMAY )

C     COMPUTE DENOMINATOR OF GAUSSIAN PLUME MODEL

      PLUMED = PI * SIGMAY * SIGMAZ * U10

C     ***********  BUILDING WAKE MODEL  ***************

C     COMPUTE LIMITING DISTANCE FOR WAKE ENHANCEMENT TO DIFFUSION RATE

      CL = SQRT( AREA )

C     COMPUTE 'STRETCHED STRING DISTANCE'

      XS = DIST + ABS( RHT - OHT )

C     LIMIT XS TO WAKE ENHANCEMENT LIMITING DISTANCE

      XSL = AMIN1( XS, 20.0*CL )

C     COMPUTE BUILDING SURFACE RELEASE X/Q

      BMOD = CO * U10**CU * SQRT( FLOAT( IST1 ) ) * AREA**CA * XSL**CX

C     COMPUTE COMPOSITE WAKE X/Q

      WXOQ = 1.0 / ( FO + PLUMED + 1.0 / BMOD )

      IF( WO .GT. 0.0 .AND. RHT .GE. BHT ) THEN

C     NRC XOQDOQ SPLIT-H MODEL

C     COMPUTE X/Q FROM ELEVATED PLUME

        CALL PROFILE( U10, IST1, RHT, RHU )
        PLUMED = PI * SIGMAY * SIGMAZ * RHU
        VEXP = EXP( -0.5 * ( RHT / SIGMAZ )**2 )
        EMOD = VEXP / PLUMED

        WR = WO / RHU

        IF( WR .GT. 1.0 ) THEN

C     COMPUTE FRACTION OF TIME PLUME IS IN WAKE

          IF( WR .LE. 1.5 ) THEN
```

```
          WF = 2.58 - 1.58 * WR
        ELSE IF( WR .LT. 5.0 ) THEN
          WF = 0.3 - 0.06 * WR
        ELSE
          WF = 0.0
        ENDIF
C     COMBINE WAKE AND ELEVATED PLUME CONCENTRATIONS
        WMOD = ( 1.0 - WF ) * EMOD + WF * WXOQ
      ELSE
C     PLUME IS IN WAKE 100% OF THE TIME
        WMOD = WXOQ
      ENDIF
    ELSE
C     PLUME IS ENTRAINED IN WAKE
      WMOD = WXOQ
    ENDIF
    RETURN
    END
```

```
      SUBROUTINE SSIGMA (X, STABZ, STABY, SIGMAZ, SIGMAY)

C******************************************************************
C
C     SUBROUTINE SSIGMA
C
C     Diffusion curves used in the NRC XOQDOQ and PAVAN models
C
C     J. V. RAMSDELL,
C     PACIFIC NORTHWEST LABORATORY
C     P.O. BOX 999
C     RICHLAND, WASHINGTON  99352
C
C     CREATED: May 1987
C
C     DESCRIPTION:  Subroutine SSIGMA computes diffusion coefficients
C       given the distance from the source and atmospheric stability
C       using the split-sigma approach.  If sigma theta stability class
C       is not given or it is out of range, the delta-T stability class
C       is used for both sigma-y and sigma-z computations
C
C     INPUT:
C
C       Distance (m)                                ==>  X
C       Delta-T stability class                     ==>  STABZ
C       Sigma theta stability class                 ==>  STABY
C
C     OUTPUT:
C
C        Vertical diffusion coefficient             ==>  SIGMAZ
C        Horizontal diffusion coefficient           ==>  SIGMAY
C
C******************************************************************

      REAL AY(7), AZ(7,3), BZ(7,3), CZ(7,3)
      INTEGER STABZ, STABY

      DATA AY/ 0.3658, 0.2751,0.2089,0.1471,0.1046,0.0722,0.0481/
      DATA AZ/ 0.192,  0.156, 0.116, 0.079, 0.063, 0.053, 0.032,
     +         0.00066,0.0382,0.113, 0.222, 0.211, 0.086, 0.052,
     +         0.00024,0.055, 0.113, 1.26,  6.73, 18.05, 10.83 /
      DATA BZ/ 0.936, 0.922, 0.905, 0.881, 0.871, 0.814, 0.814,
     +         1.941,  1.149, 0.911, 0.725, 0.678, 0.74,  0.74,
     +         2.094,  1.098, 0.911, 0.516, 0.305, 0.18,  0.18 /
      DATA CZ/ 0.0,    0.0,   0.0,   0.0,   0.0,   0.0,   0.0,
     +         9.27,   3.3,   0.0,  -1.7,  -1.3,  -0.35, -0.21,
     +        -9.6,    2.0,   0.0, -13.,  -34.0, -48.6, -29.2  /

      ISY = STABY
      IF( STABY .LT. 1 .OR. STABY .GT. 7 ) ISY = STABZ
```

```
SIGMAY = AY(ISY) *  X ** 0.9031
IF ( X .LE. 100.0 ) THEN
  SIGMAZ = AZ(STABZ,1) * X ** BZ(STABZ,1)
ELSE IF ( X .LE. 1000.0 ) THEN
  SIGMAZ = AZ(STABZ,2) * X ** BZ(STABZ,2) + CZ(STABZ,2)
ELSE IF ( X .GT. 1000.0 ) THEN
  SIGMAZ = AZ(STABZ,3) * X ** BZ(STABZ,3) + CZ(STABZ,3)
ENDIF

RETURN
END
```

```
      SUBROUTINE PROFILE(SPD,IST,SHGHT,RSPD)

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     SUBROUTINE TO COMPUTE RELEASE HEIGHT WINDS FROM 10 M WINDS
C
C     J. V. RAMSDELL
C     BATTELLE, PACIFIC NORTHWEST LABORATORY
C     P.O. BOX 999
C     RICHLAND, WA 99352
C
C     CREATED: December 12, 1986
C
C     DESCRIPTION:  Subroutine estimates the release height wind
C       using a diabatic wind profile -- see Panofsky and Dutton (1984)
C       Section 6.5 -- from the 10 m wind speed and atmospheric
C       stability.  The specific profile form is determined by the
C       stability class.  The surface roughness length is assumed to
C       be 0.1 m.
C
C     INPUT:
C
C       10 m wind speed (m/s)                          ==>     SPD
C       Atmospheric stability class                    ==>     IST
C       Release height (m)                             ==>     SHGHT
C
C     OUTPUT:
C
C       Release height wind speed (m/s)                ==>     RSPD
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      DIMENSION MOL(7)

C     MOL IS MONIN-OBUKOV LENGTH USED IN DIABATIC WIND PROFILES

      DATA MOL/-8,-14,-25,-1000,100,40,20/

      PI = 3.14159

      IF(IST .LE. 3) THEN

C       UNSTABLE CONDITIONS

        Y = (1 - 16 * SHGHT / MOL(IST) )**0.25
        PSI = ALOG( (0.5+Y*Y/2) * (0.5+Y/2)**2 ) - 2*ATAN(Y) + PI/2
        Y1 = (1 - 16 * 10.0 / MOL(IST) )**0.25
        PSI1 = ALOG( (0.5+Y1*Y1/2) * (0.5+Y1/2)**2 ) - 2*ATAN(Y1) + PI/2
        RSPD = SPD * (ALOG(SHGHT/0.1) - PSI)
     +          / (ALOG(10.0/0.1) - PSI1 )
```

```
      ELSE IF(IST .GE. 5) THEN

C        STABLE CONDITIONS

         RSPD = SPD * ( ALOG(SHGHT/0.1) + 5.0*SHGHT/MOL(IST) )
     +                / ( ALOG(10.0/0.1) + 5.0*10.0/MOL(IST) )

      ELSE

C        NEUTRAL CONDITIONS

         RSPD = SPD * ALOG(SHGHT/0.1) / ALOG(10.0/0.1)

      ENDIF

      RETURN
      END
```

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This report presents the results of an evaluation of the procedure used by the NRC staff to assess nuclear reactor control room habitability. The evaluation is based on experimental data collected in seven sets of field experiments at nuclear power plant sites. The procedure is generally conservative, but the models in the procedure show little skill in predicting the effects of different atmospheric conditions on maximum effluent concentrations in building wakes. Two alternative building-wake models have been developed using the experimental data. The first model differs significantly from current models in the manner in which wind speed enters the model. The second model is an extension of the first model that has more desirable asymptotic behavior and includes consideration of the mitigating effect of plume rise on concentrations in building wakes. A set of non-mathematical guidelines is offered for use in evaluating potential control room air intake locations.

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