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VERIFICATION OF VENTSAR XL - A SPREADSHEET VERSION OF VENTSAR

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May 1996

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ABSTRACT

VENTSAR is a computer model that analyzes flow patterns of pollutants on or near buildings. Plume rise may be considered. VENTSAR has been modified to allow for execution on a Macintosh using Microsoft Excel. This new version is called VENTSAR XL. All methodologies are identical to those within VENTSAR. This report provides verification of all models within VENTSAR XL. Strict comparisons were made with VENTSAR to ensure consistency between the two models.

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VERIFICATION OF VENTSAR XL - A SPREADSHEET VERSION OF VENTSAR

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1.0 INTRODUCTION

The VENTSAR code is an upgraded and improved version of the VENTX code (Smith and Weber 1983), which estimates contaminant concentrations on or near a building from a release at a nearby location. The code calculates the concentrations for a given meteorological exceedance probability or for a given stability and wind speed combination. A single building can be modeled and a penthouse can be added to the top of the building. Plume rise also may be considered. Contaminant release types can be chemical or radioactive. Downwind concentrations are determined at user-specified incremental distances.

VENTSAR resides on the IBM Mainframe at SRS. For ease in calculations, VENTSAR methodologies were transferred to a Microsoft Excel Spreadsheet. The new version is entitled VENTSAR XL. Use of a spreadsheet model will allow for immediate display of output as well as ease in input preparation.

2.0 THEORETICAL MODELS

This section discusses the theoretical models and data files that are employed within VENTSAR XL. For a complete set of user instructions refer to Simpkins (1996). The only difference between VENTSAR and VENTSAR XL is the removal of the additional vent height increment option. These calculations can be accomplished by executing the spreadsheet for each of the requested vent heights. This feature typically was not used.

2.1 Gaussian Plume Model

The pollutant dispersion calculations in the VENTSAR XL code are based on a reflecting Gaussian plume model (Hanna 1982). Along the plume centerline, the dispersion factor or relative air concentration, defined as the ratio of the pollutant concentration χ (kg/m^3 or Ci/m^3) to the source strength Q (kg/sec or Ci/sec), is given by the equation:

$$\frac{\chi}{Q}=\frac{1}{2\pi\sigma_y\sigma_z U_S}\left[e^{-\left(\frac{(z-h_e)^2}{2\sigma_z^2}\right)}+e^{-\left(\frac{(z+h_e)^2}{2\sigma_z^2}\right)}\right] \quad (1)$$

where:

χ/Q	the dispersion factor (sec/m^3)
z	height above the ground surface (m)
h_e	effective release height (m)
U_S	wind speed at the release height,(m/sec)
σ_y	the standard deviation of the concentration distribution in the horizontal cross-plume direction (m)
σ_z	the standard deviation of the concentration distribution in the vertical direction (m)

Annual averaged values of χ/Q are calculated as:

$$annual(\overline{\chi / Q}) = \sum_{i,j}^{6,7} P_{ij}\left(\frac{\chi}{Q}\right)_{ij} \quad (2)$$

where:

i	wind speed category
j	stability class
$(\chi/Q)_i$	relative air concentration for meteorological condition (i,j)
P_i	the probability of a particular meteorological condition (i,j) occurring within a five-year time period

2.1.1 Meteorological Data Files

Meteorological data files for use with VENTSAR XL exist for the following areas onsite: A, C, D, F, H, K, L, and P. The meteorological data are obtained from hourly averages of measurements made at 1.5 seconds intervals. The files contain joint frequency distributions and reciprocal average wind velocities categorized by wind direction, speed, and stability class. Reciprocal average wind speeds are utilized since air concentration is inversely proportional to wind speed. Table 1 provides wind speed category definitions. Validation of the meteorological data are the responsibility of the Environmental Transport Group. See Parker (1992) and Weber (1993) for more details on the wind statistics obtained from the SRS area meteorological towers. VENTSAR XL accesses meteorological data for the period of 1987-1991. The quality assurance of this data is handled by the Environmental Transport Group.

Table 1. Wind Speed Category Ranges

Speed Category	Range (m/sec)
1	$0<U\leq2$
2	$2<U\leq4$
3	$4<U\leq6$
4	$6<U\leq8$
5	$8<U\leq12$
6	$U\geq12$

Atmospheric stability is classified by standard deviations of the lateral or azimuthal wind direction. Area meteorological towers contain instrumentation at 61 m (200 ft) that measures horizontal (azimuth) and vertical (elevation) wind directions. Also, direct measurements of turbulence, expressed as standard deviations of fluctuations about mean azimuth (noted either as σ_a or σ_θ) and elevation (σ_e) angles, are made at 61 m.

For calculational purposes within the spreadsheet, an assumed average value of σ_θ is chosen for the atmospheric stability class of interest. Ranges for σ_θ and the values that are used within VENTSAR XL are shown in Table 2.

Table 2. Classification of Atmospheric Stability

Pasquill Category	Range for σ_θ (degrees)	σ_θ Used in VENTSAR XL (degrees)
A	$23\leq\sigma_\theta$	27.5
B	$18\leq\sigma_\theta<23$	22.5
C	$13\leq\sigma_\theta<18$	17.5
D	$8\leq\sigma_\theta<13$	12.5
E	$4\leq\sigma_\theta<8$	7.5
F	$2\leq\sigma_\theta<4$	3.75
G	$\sigma_\theta<2$	2.00

2.1.2 Pasquill-Briggs Dispersion Coefficients

The lateral and vertical dispersion coefficients within VENTSAR XL are those derived by Pasquill (1976) and Briggs (1973), respectively. The equation representing Pasquill's lateral dispersion coefficients is

$$\sigma_y = \sigma_\theta X f(X) \tag{3}$$

where:

σ_θ standard deviation of lateral wind direction (radians) [See Table 2]

X downwind distance (km)

$f(X)$ function of distance, X (km), as discussed below

Pasquill developed formulations for $f(X)$ with a table of values for distances less than 10 km and the following equation for distances greater than 10 km:

$$f(X) = 0{:}33\left[\frac{10}{X}\right]^{0.5} \tag{4}$$

For distances less than 10 km, the following equation was derived from the table of values with X in kilometers:

$$f(X) = \frac{1}{1 + 0.031(1000X)^{0.46}} \tag{5}$$

Pasquill (1976) gives a detailed description on how the coefficients were developed using data from experiments at various sites.

The vertical diffusion coefficients defined by Briggs (1973) and then refined by Briggs and published in Hanna (1982) for open-country conditions are represented in Table 3 as a function of Pasquill's atmospheric stability classes. For these equations the units of X should be meters.

2.2 Plume Rise

Plume rise models are based on fundamental laws of fluid mechanics, conservation of mass, potential density, and momentum. The quantities across the plume are referred to as "top-hat" meaning that discontinuities in temperature, speed and etc. are assumed at the plume boundary. Therefore, for the models employed here, constant values are assumed inside the plume, and another set of constant values is assumed outside of the plume. VENTSAR XL considers plume rise due to both buoyancy and momentum effects.

Table 3. Brigg's Vertical Diffusion Coefficient Formulas

Pasquill Stability Category	σ_z (X in meters)
A	$0.20X$
B	$0.12X$
C	$0.08X(1 + 0.0002X)^{-0.5}$
D	$0.06X(1 + 0.0015X)^{-0.5}$
E	$0.03X(1 + 0.0003X)^{-1}$
F	$0.02X(1 + 0.0003X)^{-1}$
G	$0.01X(1 + 0.0003X)^{-1}$

Several different mechanisms can increase or decrease the height of the plume at downwind distances. Plume rise due to momentum and buoyancy effects can increase the height of the plume while downwash can decrease the height of the plume. The effective plume height at a given distance, X, downwind is

$$h(X) = h_s - \Delta h_D + \Delta h_B(X) + \Delta h_M(X) \tag{6}$$

where:

h_S initial height of the source

Δh_D source height change due to downwash

Δh_B source height change due to buoyancy effects

Δh_M source height change due to momentum effects

2.2.1 Downwash

Downwash occurs when the plume is drawn downward due to low pressure in the wake of the stack. Downwash will *not* occur if the velocity of the effluent (V_e,) is a significantly greater than the wind speed (U). Downwash is generally recognized to occur when V_e/U is less than 1.5 (Briggs 1973). When the ratio is less than 1.5 the following equation is applied to determine the effects of downwash (Hanna 1982):

$$\Delta h_D = 2\left(\frac{V_e}{U} - 1.5\right)D \tag{7}$$

where

D the internal stack diameter (m)

V_e effluent velocity (m/s)

U crosswind velocity (m/s)

Recent work by Snyder (1991) suggests that downwash seldom has consequences due to the fact that conditions are typically associated with small diameters, and the change in stack height due to downwash is only of a few diameters. Snyder states that "serious downwash will occur only for sources with: $V_eD<0.5(60{,}000)(0.15cm^2s^{-1})\sim0.5\ m^2s^{-1}$."

2.2.2 Buoyancy Effects

For most plumes the primary contributor to rise is buoyancy, which results from density differences between the effluent and the atmosphere (Briggs 1984). The initial buoyancy flux for a plume is determined by (Hanna 1982):

$$F_o = g(DRHO)(CMS) \tag{8}$$

where:

F_o buoyancy flux (m^4/s^3)

g acceleration due to gravity (9.8 m/s^2)

CMS volume flux at the stack exit (m^3/s)

$DRHO$ density ratio (unitless), defined below

Plumes are considered dense when the density ratio, *DRHO*, is greater than zero (Meroney 1982a). *DRHO* is determined using the following equation:

$$DRHO = \frac{MW_aT_e - MW_eT_a}{2MW_aT_e} \tag{9}$$

where:

MW_e molecular weight of the effluent

MW_a molecular weight of the air (28.9)

T_e temperature of effluent (K)

T_a temperature of air (K)

The Froude number (*Fr*) is used to represent the ratio of inertial forces to buoyancy forces (Snyder 1972). If DRHO≤0, the plume is lighter than air and the Froude number is not determined. The plume falls to the ground close to the source when the Froude number is less than 7.7 (Meroney 1982a). The Froude number is calculated as follows:

$$Fr = \frac{U}{\sqrt{g * DRHO * D}} \tag{10}$$

where:

Fr Froude number (unitless)

U wind speed (m/s)

D plume exit diameter (m)

For the vertical motion of the plume, the environmental stability parameter, *S*, plays an important role for unstable conditions. *The stability parameter is set to unity for all classes except E, F and G where*

$$S = \frac{g * \frac{\partial T_a}{\partial z}}{T_a} \tag{11}$$

where:

S stability parameter (s^{-2})

$\frac{\partial T_a}{\partial z}$ = 0.02 for E, 0.03 for F, and 0.04 °C/100 m for G stability (Hanna 1982).

Now that many of the initializing parameters have been determined, the increase in plume height due to buoyancy can be calculated. For unstable to neutral conditions buoyancy is limited to a distance *XSTR* from the source using the following formulations (Briggs 1969):

For $F_o > 55\ m^4/s^3$

$$XSTR = 120.7 F_o^{0.4} (m) \tag{12}$$

For $F_o \le 55\ m^4/s^3$

$$XSTR = 49.0 F_o^{0.625} (m) \tag{13}$$

Using the above determined distances, the increase in plume height due to buoyancy effects for unstable to neutral conditions where $X<XSTR$ is determined using the following equation (Briggs 1969):

$$\Delta h_B = 1.6\frac{F_o^{1/3}X^{2/3}}{U} \tag{14}$$

For distances greater than *XSTR* for unstable to neutral conditions, the same equation is used, except X is set to a constant value of *XSTR*.

For stability classes E, F and G with calm winds (given below) the increase in plume height is determined by the following (Briggs 1969):

$$\Delta h_B = 5.0\left[\frac{F_o}{S^{3/2}}\right]^{1/4} \tag{15}$$

For stability classes E, F and G with the wind speed greater than the calm wind speed, and for distances greater than or equal to $XTST=2.07U/SP$ buoyancy is less dominating and the increase in plume height is given by the following (Hanna 1982):

$$\Delta h_B = 2.6\left[\frac{F_o}{(U)S}\right]^{1/3} \tag{16}$$

For distances less than *XSTR,* Equation 14 is applied.

By setting equations 15 and 16 equal and solving for U, calm winds are given by the following relationship:

$$U< 0.141*(F_o*S^{1/2})^{0.25}\text{ m/s} \tag{17}$$

2.2.3 Momentum Effects

Plume rise may also occur because the initial vertical velocity of the effluent is great enough to elevate the plume. Plume rise due to momentum effects near the source for unstable to neutral weather conditions (Stability Classes A-D) is determined by the following equation (Briggs 1976):

$$\Delta h_M = \left[\frac{3\pi}{4\beta^2}\right]^{1/3}\left[\frac{DW_eM_o}{U}\right]^{2/3}X^{1/3} \tag{18}$$

where:

β $=0.4+1.2U/V_e$, (unitless),

U wind speed (m/s)

V_e effluent velocity (m/s)

D diameter of the stack (m)

M_o measure of relative density of effluent plume to that of air:

$$M_0 = \left[\frac{MW_e T_a}{MW_a T_e}\right]^{1/2} \tag{19}$$

X downwind distance (m)

For ease in calculation within the spreadsheet the equation is rewritten as

$$\Delta h_M = \left[B1 * X * DHMOM^2\right]^{1/3} \tag{20}$$

where

$$B1 = \frac{0.75 * \pi}{(0.4 + 1.2U/V_e)^2} \tag{21}$$

$$DHMOM = D * \frac{V_e}{U} M_o \tag{22}$$

with all terms previously defined.

The above equation is applicable for all distances less than XTEST where

$$XTEST = \frac{27.0\,DHMOM}{B1} \tag{23}$$

For distances where X≥XTEST the increase in plume height due to momentum effects is given by the following equation (Briggs 1969):

$$\Delta h_M = 3DHMOM \tag{24}$$

For stable weather conditions (Stability Classes E, F, and G) the change in plume height due to momentum effects is equal to the minimum of the following two equations (Briggs 1969):

$$\Delta h_M = 4.0\sqrt{\frac{DHMOM*U}{2S^{1/2}}} \tag{25}$$

$$\Delta h_M = 1.5\left(\frac{DHMOM^2U}{4S^{1/2}}\right)^{1/3} \tag{26}$$

2.3 Building Wake Effects

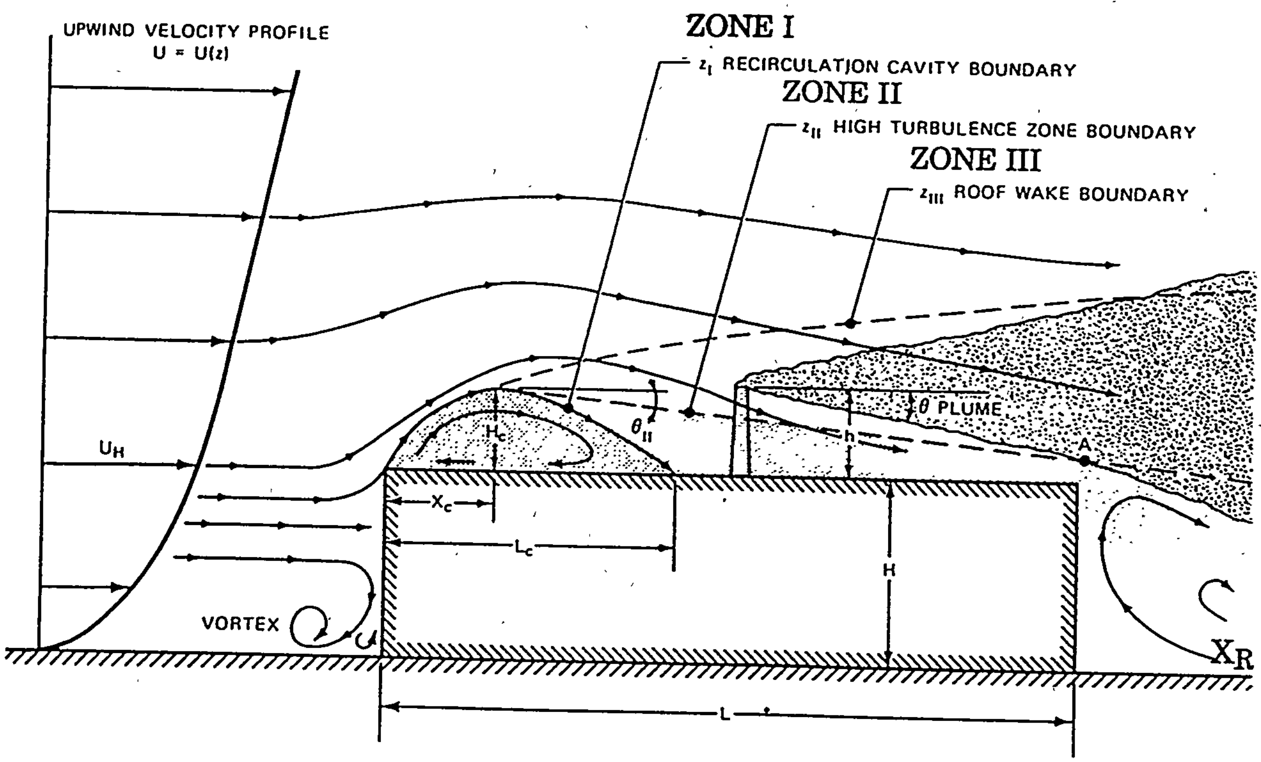
An exact mathematical solution to the plume interaction with air flow does not exist. However, a great deal of useful quantitative information has been obtained using wind-tunnel simulations of flow around model buildings, and a limited number of measurements around full-scale buildings of relatively simple geometry. Semi-empirical models consolidating these simulations and experiments are available for estimating pollutant concentrations around buildings. A summary of the methods available for determining flow patterns and pollutant concentrations near buildings with a simple block-like structure has been prepared by Hanna (1982).

Wind passing over and around buildings creates a complicated dispersion pattern. A recirculation cavity and zones of high turbulence are created on the building roof with a roof cavity region produced downwind of the structure. These regions may trap effluent material and produce high ground- or roof-level concentrations. Models that neglect turbulence effects near structures will usually underestimate pollutant concentrations on building roofs or near buildings. Since air-intake vents may be located on building roofs or near the ground downwind of a release source, an estimation of pollutant concentrations on or near a structure is important in determining expected pollutant levels. Therefore, a methodology was adapted to determine the effect of plume interaction with the air-flow pattern around buildings. This provides a useful tool for determining heights of new stacks so that acceptable pollutant levels near the source and downwind buildings can be assured.

Figure 1 (Wilson 1979) shows a cross-section of the flow over a building with the wind perpendicular to the face of the building. The recirculation cavity (Zone I) is created due to the separation of the flow from the upwind edge of the roof. The flow recirculates and the turbulence levels are very high. Only if the roof is long enough will the flow reattach to the roof. The boundary of the high turbulence region (Zone II) is not precisely defined. Turbulence generated in the shear layers at the edge of the recirculation cavity result in accelerated diffusion to the roof level of any gases. Zone II is defined such that it also includes Zone I. The roof wake region (Zone III) is depicted in Figure 1 in an exaggerated form. This region's boundary is essentially straight and parallel with the flow. Gases that are released in this region will have some downwash and more rapid spreading than the gases above Zone III. Zone III also includes Zones I and II.

Analytical models have been associated with the regions discussed previously. Building effects are included in the model using the techniques presented by Wilson (1979). The dimensions of recirculation zones, high turbulence zones, and wake cavities associated with the building and any penthouse structure are determined based on building dimensions. If the plume is not over the building or the downwind wake cavity, the height above the ground, z, is set equal to zero to give ground-level concentrations.

Figure 1. Recirculation Zones for Building Wake Effects Calculations



Various fluid modeling experiments have led to the development of models to predict the behavior of wind flow around buildings. The dimensional parameters describing the building of interest in VENTSAR XL are shown in Figure 2. These dimensions are consistent with the wind being perpendicular to the building face. When ratios of L/H (where L and H correspond to the length and height of the building or penthouse) are greater than one, reattachment of streamlines to the roof and sides is expected. This however, may not be the case if W/H is very large. The length the recirculation cavity zone (Zone I) extends from the upwind edge of the building is given by the following expression:

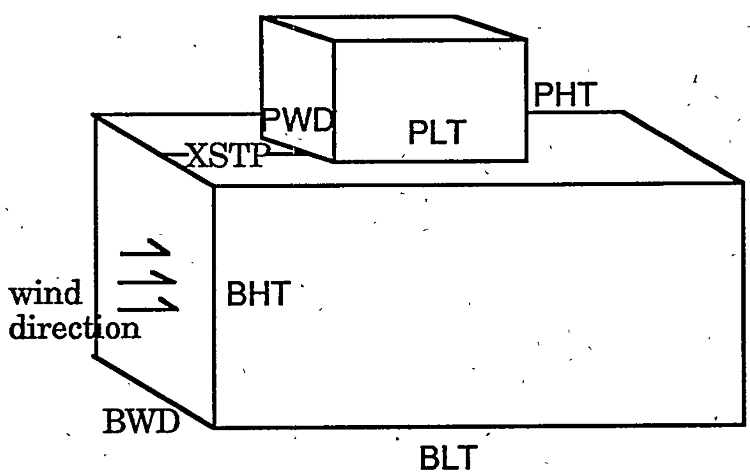
$$L_c \approx 0.9R \qquad (27)$$

where:

$$R \approx (B_{min})^{2/3}(B_{max})^{1/3} \qquad (28)$$

where B_{min} is the smaller of H or W and B_{max} is the larger. The length of the cavity zone should be calculated for both the building and penthouse separately and then summed. All building dimension units are in meters.

Figure 2. Dimensions of Building and Penthouse used with VENTSAR XL



The maximum height of the recirculation zone (Zone I) is

$$H_c \approx 0.22R \qquad (29)$$

and is assumed to occur at a distance of $R/2$ from the edge of the building. The length of the cavity zone is defined for both the building and the penthouse.

The distance beyond the building where plumes may be caught and mixed to the ground is called the wake cavity. The empirical formula for the length of the wake cavity is (Hanna 1982):

$$X_r = \frac{A*W}{1+B(W/H)} \tag{30}$$

where

W the building width,

H the building height, and

A and B are discussed below.

Separate values for A and B are used depending on whether the flow reattaches to the roof and sides of the building. Cases of reattachment occur when L/H≥1. For this case

$$A = 1.75 \tag{31}$$

$$B = 0.25 \tag{32}$$

For cases where the flow does not reattach to the building

$$A = -2.0 + 0.37\left(\frac{L}{H}\right)^{1/3} \tag{33}$$

$$B = -0.15 + 0.305\left(\frac{L}{H}\right)^{1/3} \tag{34}$$

When the recirculation cavity does not reattach to the building roof, calculation of the effective release height is altered. Following Briggs, if the adjusted release height h' is less than the building height H, then the adjusted effective height is given by (Briggs 1973):

$$h_{eff} = h' - 1.5B_{min} \tag{35}$$

where

h_{eff} the effective plume,

h' the release height adjusted by downwash and plume rise, and

B_{min} the smaller of the width or height of the building.

If the emission height at the building is such that $H < h' < H + 1.5\ B_{min}$, then the adjusted effective release height is:

$$h_{eff} = 2h' - (H + 1.5B_{min}) \tag{36}$$

If $h' \geq H + 1.5B_{min}$, the plume is out of the wake of the building and no effects from the building are seen, therefore, $h_{eff} = h'$.

When there is a change in elevation on the building roof, three separate flow regimes must be considered. Let X_s be the distance from the leading edge of the building to the step change in roof elevation. R_u and R_s are the scaling lengths given by Equation 28 for the building and penthouse upwind faces, respectively. The following three flow regimes can occur:

(i) $X_s < 0.5\ (R_u + R_s)$. The leading edge of the building is connected in a straight line to the top of the penthouse to form a recirculation cavity. Roof cavity heights and turbulence zone boundaries are calculated using $R = (R_u + R_s)$;

(ii) $0.5\ (R_u + R_s) < X_s < 2\ (R_u + R_s)$. The recirculation cavity height H_c and location X_c on the upwind portion of the roof are calculated using $R = R_u + R_s$. The top of this cavity region is joined in a straight line with the top of the penthouse to form a high turbulence zone. The cavity height on the penthouse roof and the downwind high turbulence zone boundary are then calculated using R_s as a scale length; or

(iii) $X_s > 2(R_u + R_s)$. The upwind roof and penthouse roof are treated as two separate buildings with scaling lengths R_u and R_s, respectively.

Using the R values determined above for a given point, the height of cavity Zone I is determined (Wilson 1979).

For downwind distances less than 0.5R:

$$Z = 0.28R\left(\frac{X}{R}\right)^{1/3} \tag{37}$$

where

R determined above based on building dimensions, and

X downwind distance.

For downwind distance X where 0.5R<X≤L:

$$Z = 0.27R - 0.1X \tag{38}$$

For use within the code, the value of Z calculated above is added to the height of the building to determine the relative air concentration. Beyond the building Z=0.

When building wake effects are considered, adjustments must be made to the relative air concentration equation. Some fraction (f) of the effluent plume will be entrained into the wake cavity. For the model used in VENTSAR XL, this fraction is estimated as the ratio of χ/Q evaluated at the top of the cavity when it first forms to the value of χ/Q at the plume centerline. The material trapped within the wake cavity behaves as if it originates from an area source of building dimensions. Meroney (1982b) has shown that a simple expression useful for estimating pollutant concentrations within the cavity is:

$$\left(\frac{\chi}{Q}\right)_{cav} = \frac{f}{HWU_s} \tag{39}$$

Equation 39 assumes that the effluent rapidly mixes in a uniform volume within the cavity. Turbulence within the wake cavity will produce a relatively constant pollutant concentration within this region. Experimental evidence indicates that this assumption will give conservative predictions of ground-level concentrations in most cases.

For distances beyond the wake cavity, surface χ/Q values will contain a component from the elevated plume $(\chi/Q)_E$ (see Eq. 1) and from the area source of material trapped within the cavity $(\chi/Q)_T$. Following Hosker (1984), this is expressed as:

$$\frac{\chi}{Q} = (1-f)\left(\frac{\chi}{Q}\right)_E + f\left(\frac{\chi}{Q}\right)_T \tag{40}$$

Meroney (1982b) proposed an empirical expression for $(\chi/Q)_T$ as:

$$\left(\frac{\chi}{Q}\right)_T = \left(\frac{\chi}{Q}\right)_0 \exp\left[-0.5\left(\frac{\chi}{Q}\right)_0 \pi HWU_s\left(\frac{h}{H}\right)^2\right] \tag{41}$$

where the centerline ground-level plume concentration is

$$\left(\frac{\chi}{Q}\right)_0 = \frac{1}{U_s\left(\pi\sigma_y\sigma_z + 0.5HW\right)} \tag{42}$$

In Equation 42, σ_y and σ_z are evaluated using Pasquill and Briggs formulations with x equal to the distance from the start of the wake cavity. Initial values for σ_y and σ_z in Equation 42 are taken to be the minimum building cross-sectional dimensions.

3.0 VERIFICATION OF CALCULATIONS

Strict comparisons were made between VENTSAR and VENTSAR XL to ensure proper application of methodologies within the spreadsheet model. First, each of the test cases previously used for VENTSAR were duplicated using VENTSAR XL. Input for each of the test cases is shown in Appendix A. An additional set of four test cases were executed using VENTSAR XL and the results were compared with results from VENTSAR. These additional test cases are shown in Appendix B. Hand calculations also were performed to demonstrate certain aspects of the code.

3.1 Comparison with Original Test Cases

Results from VENTSAR XL are compared with results from VENTSAR test cases. VENTSAR had a default number of increments set at 200. Results are shown here for a select number of points. Positions were chosen in relation to building structure. If a smaller number of increments are used results may not be identical beyond the end of the building. The results may differ because the fraction of the plume that is trapped in the building wake cavity is determined at the point just beyond the building and this fraction is used within the remainder of the cavity zone (See Section 3.3).

In Appendix A, the results for test case 1 are shown in their entirety for the first two release heights. This test case was chosen for a complete comparison because it exercises both the plume rise and building wake effects methodologies.

Looking closely at Appendix A, differences are less than 1% for all distances except 505.0 m downwind which is 5.61% different for the first release height. This difference can be explained due to the difference in division in FORTRAN and Excel Macros. The minimum and maximum distance of interest was 10 m and 1000 m, respectively, for test case one. With 200 increments the x increment (Δx) is equal to (1000-10)/200 which equals 4.95. With VENTSAR on the IBM Mainframe, FORTRAN determined this value to be 4.949999. Therefore, at increments number 100, VENTSAR and VENTSAR XL determine the distance as follows:

VENTSAR	VENTSAR XL
D=min+No. increments*Δx	D=min+No. increments*Δx
D=10+100*4.949999	D=10+100*4.95
D=504.9999m	D=505.0 m

While this difference may seem inconsequential, it is used to determine whether or not D is still on top of the building. Within VENTSAR on the IBM Mainframe, D<505.0 and therefore is on top of the building. In VENTSAR XL, D is not less than 505.0 and therefore is past the building. As a result different values of z are used by VENTSAR and VENTSAR XL for this particular point and thus different answers. For all test cases, this was the only instance that this difference occurred.

Table 4 shows the results of the comparison between VENTSAR and VENTSAR XL for test case number two at several downwind distances. Both the annual average air concentration and the 99.5% air concentration are shown.

Table 4. Comparison of VENTSAR and VENTSAR XL for Test Case 2

Downwind Distance (m)	VENTSAR 99.5% χ/Q (s/m**3)	VENTSAR Annual χ/Q (s/m**3)	VENTSAR XL 99.5% χ/Q (s/m**3)	VENTSAR XL Annual χ/Q (s/m**3)	% Diff 99.5% χ/Q (%)	% Diff Annual χ/Q (%)
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00%
109	9.40E-41	7.85E-32	9.34E-41	7.82E-32	0.69%	0.41%
208	4.39E-20	1.34E-17	4.37E-20	1.34E-17	0.40%	-0.03%
307	1.01E-12	1.07E-13	1.01E-12	1.07E-13	-0.11%	0.35%
406	5.59E-10	4.00E-12	5.59E-10	4.00E-12	-0.07%	0.10%
505	9.46E-09	3.98E-11	9.43E-09	3.98E-11	-0.01%	-0.06%
604	4.01E-08	1.53E-10	4.01E-08	1.53E-10	-0.03%	0.05%
703	8.99E-08	3.45E-10	8.99E-08	3.45E-10	0.05%	0.11%
802	1.45E-07	5.99E-10	1.45E-07	5.99E-10	0.34%	-0.03%
901	1.93E-07	9.11E-10	1.93E-07	9.11E-10	-0.11%	0.01%

The results for the remaining test cases are shown in Appendix A. Differences were less than 1% for all distances. If a specific stability class and wind speed was selected then only the χ/Q corresponding to the particular combination is shown because no annual average is calculated.

3.2 Comparison with Additional Test Cases

Four additional test cases were developed to test various aspects of the spreadsheet. The input for these test cases is shown in Appendix B. The results of the comparison also are shown in Appendix B. Differences were less than 0.01% for all distances.

3.3 Plume Rise Hand Calculations

Table 5 shows the input parameters that were used in the spreadsheet to verify the plume rise module. Variables were chosen at random within the ranges of validity. Table 6 shows a comparison of hand calculations and VENTSAR XL results for several downwind distances. Differences are less than 1% for all distances shown. See Appendix C Section 1 for the actual hand calculations.

Table 5. Input parameters for Plume Rise Verification.

Parameter	Input
Area or Release Location	A
Building Height	0.0 m
Building Width	0.0 m
Building Length	0.0 m
Penthouse Height	0.0 m
Penthouse Width	0.0 m
Penthouse Length	0.0 m
Penthouse Distance	0.0 m
Minimum Distance of Interest	10 m
Maximum Distance of Interest	1010 m
Number of Increments	100
Compass Sector of Building Location	3
Distance of Vent from Roof Edge	0.0
Vent Height	20.0 m
Radioactive Calculation?	No
Release Rate	0
Mole Fraction of Pollutant	1.8E-03
Vent Gas Flow Rate	50 m^3/s
Averaging Option	No
Wind Speed	6 m/s
Stability Class	4(D)
Vent Diameter	1.0 m
Vent Gas Molecular Weight	78.12
Vent Gas Air Temperature	40 C
Air Temperature	20 C

Table 6. Hand Calculations for Plume Rise Verification

Downwind Distance (m)	Relative Air Concentration (s/m^3) VENTSAR XL	Relative Air Concentration (s/m^3) Hand Calculations	Percent Difference
10	0.00E+00	0.00E+00	0.0%
200	8.16E-17	8.22E-17	-0.7%
1000	4.40E-07	4.41E-07	-0.2%

3.4 Building Wake Effects Verification

Table 7 shows the input parameters that were used to verify the building wake effects module. Figure 3 shows a side view of the building and the places at which calculations were performed to verify the concentrations. These locations were selected to ensure all zones were considered. Table 8 shows the results of the comparison. Differences are less than 1%. See Appendix A, Section 2 for the hand calculations.

Table 7. Input parameters for Building Wake Effects Verification

Parameter	Input
Area or Release Location	K
Building Height	10.0 m
Building Width	20.0 m
Building Length	30.0 m
Penthouse Height	5.0 m
Penthouse Width	10.0 m
Penthouse Length	10.0 m
Penthouse Distance	10.0 m
Minimum Distance of Interest	10 m
Maximum Distance of Interest	50 m
Number of Increments	8
Compass Sector of Building Location	3
Distance of Vent from Roof Edge	-10.0
Vent Height	20.0 m
Radioactive Calculation?	Yes
Release Rate	1 Ci/min
Mole Fraction of Pollutant	0
Vent Gas Flow Rate	0
Averaging Option	No
Wind Speed	6 m/s
Stability Class	4 (D)
Vent Diameter	0.1 m
Vent Gas Molecular Weight	78.12
Vent Gas Temperature	0
Ambient Air Temperature	0

Figure 3. Concentration locations for Building Wake Effects Verification

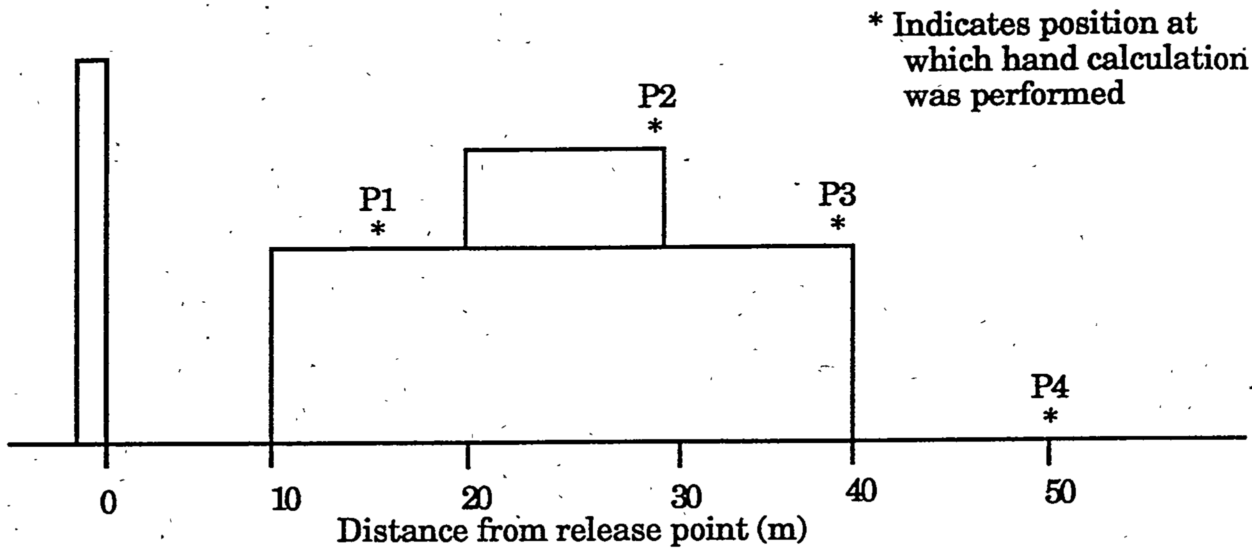


Table 8. Hand Calculations for Building Wake Effects Verification

Downwind Distance (m) (Position)	Relative Air Concentration (s/m^3) VENTSAR XL	Relative Air Concentration (s/m^3) Hand Calculations	Percent Difference
15 (P1)	1.13E-14	1.13E-14	0.0%
30 (P2)	4.69E-05	4.68E-05	0.2 %
40 (P3)	3.16E-19	3.16E-19	0.0 %
50 (P4)	8.42E-14	8.36E-14	0.7 %

3.5 Verification of Plume Rise and Building Options Combined

A case with both a simple building and plume rise was analyzed. The input parameters for this comparison are shown in Table 9. The results of the hand calculations compared with the actual code output are shown in Table 10. The differences were 2% or less for all of the positions selected. These differences are due to rounding. When the results are large negative exponents slight differences in the exponents can result in magnified differences in the results. See Appendix C, Section 3 for an example of the hand calculations.

Table 9. Input parameters for Building Wake Effects and PR Verification

Parameter	Input
Area or Release Location	A
Building Height	10.0 m
Building Width	20.0 m
Building Length	30.0 m
Penthouse Height	0.0 m
Penthouse Width	0.0 m
Penthouse Length	0.0 m
Penthouse Distance	0.0 m
Minimum Distance of Interest	10 m
Maximum Distance of Interest	1010 m
Number of Increments	200
Compass Sector of Building Location	3
Distance of Vent from Roof Edge	-10.0
Vent Height	0.0 m
Radioactive Calculation?	Yes
Release Rate	1 Ci/min
Mole Fraction of Pollutant	0
Vent Gas Flow Rate	50
Averaging Option	No
Wind Speed	4 m/s
Stability Class	3 (C)
Vent Diameter	1 m
Vent Gas Molecular Weight	78.12
Vent Gas Temperature	40 C
Ambient Air Temperature	20 C

Table 10. Hand Calculations for Building Wake Effects and PR Verification

Downwind Distance (m)	Relative Air Concentration (s/m^3) VENTSAR XL	Relative Air Concentration (s/m^3) Hand Calculations	Percent Difference
30	7.78E-73	7.66E-73	1.5%
45	9.60E-69	9.51E-69	1.0%
100	9.82E-23	9.70E-23	1.2%
500	1.89E-07	1.88E-07	0.5%

4.0 CONCLUSIONS

VENTSAR XL has been verified and is operating as expected. Comparisons with VENTSAR and hand calculations demonstrate that the spreadsheet is utilizing the same methods as VENTSAR. Use of the spreadsheet version will allow for ease in input preparation and immediate display of output.

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APPENDIX A. ORIGINAL TEST CASE DEMONSTRATION

APPENDIX A. ORIGINAL TEST CASE DEMONSTRATION

Each of the VENTSAR Test cases were executed using VENTSAR XL to ensure that all MACROS had been coded properly. Table A1 shows the input parameters used for each of the test cases.

Tables A2 and A3 show the results of the comparison for test case 1 for the first two release heights respectively. The results are shown in their entirety. Percentage differences between VENTSAR and VENTSAR XL are also shown. Table A4 shows the results of the remaining test cases for a selected number of user distances. All numbers were compared but only the selected distances are shown here.

Table A1. VENTSAR Test Cases

Parameter*	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	CASE 8
Consider Plume Rise$	YES	YES	NO	YES	NO	NO	YES	NO
Area of Release	P	D	H	C	A	K	F	OTHER#
Building Height	10	0	5	20	15	8	10	12
Building Width	20	0	30	100	200	200	10	30
Building Length	30	0	100	30	200	10	10	15
Penthouse Height	1	0	3	6	7	3	5	6
Penthouse Width	2	0	5	10	200	150	5	20
Penthouse Length	3	0	5	10	100	8	5	10
Bldg. to Penthouse	5	0	20	0	100	2	0	1
Min. Vent to Receptor	10	10	10	10	10	10	10	10
Max. Vent to Receptor	1000	1000	1000	1000	1000	1000	1000	1000
Compass Sector	NNW	S	N	NE	WNW	SSE	ENE	E
Vent to Roof Edge	-500	0	-100	10	-10	500	100	-30
Vent Height	50	25	5	0	100	50	5	0
Radioactive Release?	NO	NO	YES	NO	YES	YES	NO	YES
Rlease Rate (Ci/min)	-	-	1	-	1	1	-	1
Pollutant Mole Fraction	0.000001	0.000001	-	0.000001	-	-	0.000001	-
Vent-Gas Flow Rate (m^3/s)	500	750	1000	100	500	750	1000	100
Met. Averaging?	YES	YES	NO	NO	NO	YES	YES	NO
Probability Level	0.005	0.005	-	-	-	0.005	0.005	-
Wind Speed (m/s)	-	-	2	1	4	-	-	3
Stability Class	-	-	D	F	B	-	-	A
Vent Diameter	3	2	3	1	3	2	2	1
Vent-Gas Molecular Weight	210	200	200	190	200	180	230	220
Vent-Gas Temp(C)	20	17	17	18	17	17	19	14
Ambient Air Temp(C)	15	17	17	12	17	17	16	13
Vent Height Increment	5	0	0	1	5	0	0	5

* unit are in meters unless otherwise stated

$ plume rise only for chemical release (with pollutant mole fraction)

Release Coordinates at center of site: E58000; N 62000

Table A2. Results for Test Case 1 (Release Height =50 m)

Downwind Distance	VENTSAR 99.50% X/Q	VENTSAR Annual Average	VENTSAR XL 99.50% X/Q	VENTSAR XL Annual Average	% Diff X/Q	% Diff Ann Ave
10.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**	**
14.95	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**	**
19.90	0.00E+00	0.00E+00	0.00E+00	1.58E-202	**	**
24.85	0.00E+00	0.00E+00	0.00E+00	6.93E-146	**	**
29.80	0.00E+00	0.00E+00	4.56E-214	1.80E-112	**	**
34.75	0.00E+00	0.00E+00	5.39E-169	7.26E-91	**	**
39.70	0.00E+00	5.86E-76	4.16E-138	5.83E-76	**	0.53%
44.65	0.00E+00	3.58E-65	7.01E-116	3.56E-65	**	0.43%
49.60	0.00E+00	4.51E-57	2.86E-99	4.49E-57	**	0.43%
54.55	0.00E+00	8.29E-51	1.77E-86	8.26E-51	**	0.39%
59.50	0.00E+00	7.59E-46	1.27E-105	7.57E-46	**	0.27%
64.45	0.00E+00	7.76E-42	8.73E-95	7.73E-42	**	0.32%
69.40	0.00E+00	1.53E-38	1.16E-85	1.52E-38	**	0.47%
74.35	0.00E+00	8.50E-36	5.26E-78	8.47E-36	**	0.30%
79.30	1.59E-71	1.76E-33	1.58E-71	1.76E-33	0.46%	0.18%
84.25	5.47E-66	1.67E-31	5.44E-66	1.66E-31	0.59%	0.49%
89.20	3.25E-61	8.37E-30	3.23E-61	8.35E-30	0.48%	0.20%
94.15	4.61E-57	2.51E-28	4.59E-57	2.51E-28	0.43%	0.14%
99.10	2.00E-53	4.92E-27	1.99E-53	4.91E-27	0.29%	0.15%
104.05	1.51E-49	1.12E-25	1.51E-49	1.12E-25	0.02%	0.04%
109.00	5.29E-46	2.05E-24	5.29E-46	2.05E-24	0.04%	-0.18%
113.95	6.79E-43	2.62E-23	6.79E-43	2.62E-23	0.02%	-0.10%
118.90	3.75E-40	2.47E-22	3.75E-40	2.47E-22	0.07%	-0.02%
123.85	1.01E-37	1.80E-21	1.01E-37	1.80E-21	-0.19%	0.09%
128.80	1.49E-35	1.05E-20	1.49E-35	1.05E-20	0.32%	-0.11%
133.75	1.29E-33	5.09E-20	1.29E-33	5.09E-20	-0.12%	0.02%
138.70	7.15E-32	2.09E-19	7.15E-32	2.09E-19	0.01%	-0.21%
143.65	2.67E-30	7.49E-19	2.67E-30	7.49E-19	-0.12%	0.05%
148.60	7.10E-29	2.37E-18	7.10E-29	2.37E-18	0.00%	0.14%
153.55	1.40E-27	6.72E-18	1.40E-27	6.72E-18	0.21%	0.00%
158.50	2.11E-26	1.74E-17	2.11E-26	1.74E-17	-0.05%	0.24%
163.45	2.53E-25	4.12E-17	2.53E-25	4.12E-17	0.15%	-0.12%
168.40	2.46E-24	9.11E-17	2.46E-24	9.11E-17	0.10%	0.05%
173.35	1.99E-23	1.88E-16	1.99E-23	1.88E-16	0.11%	-0.13%
178.30	1.36E-22	3.67E-16	1.36E-22	3.67E-16	-0.27%	-0.04%
183.25	8.07E-22	6.80E-16	8.07E-22	6.80E-16	0.00%	0.04%
188.20	4.18E-21	1.20E-15	4.18E-21	1.20E-15	-0.04%	-0.13%
193.15	1.92E-20	2.04E-15	1.92E-20	2.04E-15	-0.11%	0.12%
198.10	7.93E-20	3.33E-15	7.93E-20	3.33E-15	0.04%	0.02%
203.05	2.96E-19	5.26E-15	2.96E-19	5.26E-15	-0.12%	-0.04%
208.00	1.01E-18	8.07E-15	1.01E-18	8.07E-15	-0.33%	-0.04%
212.95	3.19E-18	1.21E-14	3.19E-18	1.21E-14	-0.13%	0.33%
217.90	9.35E-18	1.76E-14	9.35E-18	1.76E-14	0.02%	0.06%
222.85	2.56E-17	2.51E-14	2.56E-17	2.51E-14	0.15%	-0.04%

** Value in VENTSAR Printed as zero since below cutoff.

227.80	6.57E-17	3.52E-14	6.57E-17	3.52E-14	0.04%	0.11%
232.75	1.59E-16	4.84E-14	1.59E-16	4.84E-14	-0.23%	0.03%
237.70	3.67E-16	6.55E-14	3.67E-16	6.55E-14	0.04%	-0.08%
242.65	8.05E-16	8.75E-14	8.05E-16	8.75E-14	0.05%	-0.05%
247.60	1.69E-15	1.15E-13	1.69E-15	1.15E-13	0.17%	-0.36%
252.55	3.39E-15	1.50E-13	3.39E-15	1.50E-13	-0.13%	-0.23%
257.50	6.57E-15	1.94E-13	6.57E-15	1.94E-13	-0.03%	0.14%
262.45	1.23E-14	2.47E-13	1.23E-14	2.47E-13	0.17%	-0.05%
267.40	2.22E-14	3.12E-13	2.22E-14	3.12E-13	0.02%	-0.08%
272.35	3.89E-14	3.91E-13	3.89E-14	3.91E-13	-0.01%	-0.02%
277.30	6.63E-14	4.86E-13	6.63E-14	4.86E-13	0.05%	0.06%
282.25	1.10E-13	5.98E-13	1.10E-13	5.98E-13	0.10%	-0.08%
287.20	1.78E-13	7.32E-13	1.78E-13	7.32E-13	0.14%	0.02%
292.15	2.81E-13	8.89E-13	2.81E-13	8.89E-13	0.05%	0.05%
297.10	4.34E-13	1.07E-12	4.34E-13	1.07E-12	-0.05%	-0.12%
302.05	6.58E-13	1.28E-12	6.58E-13	1.28E-12	0.04%	-0.24%
307.00	9.77E-13	1.53E-12	9.77E-13	1.53E-12	-0.03%	0.20%
311.95	4.58E-15	1.81E-12	4.58E-15	1.81E-12	0.07%	0.22%
316.90	7.75E-15	2.12E-12	7.75E-15	2.12E-12	-0.04%	-0.16%
321.85	1.28E-14	2.48E-12	1.28E-14	2.48E-12	-0.30%	-0.09%
326.80	2.08E-14	2.89E-12	2.08E-14	2.89E-12	-0.05%	0.14%
331.75	3.31E-14	3.34E-12	3.31E-14	3.34E-12	0.14%	0.08%
336.70	5.15E-14	3.84E-12	5.15E-14	3.84E-12	-0.02%	0.02%
341.65	7.88E-14	4.40E-12	7.88E-14	4.40E-12	-0.04%	0.11%
346.60	1.19E-13	5.01E-12	1.19E-13	5.01E-12	0.33%	0.05%
351.55	1.76E-13	5.68E-12	1.76E-13	5.68E-12	0.23%	0.02%
356.50	2.56E-13	6.41E-12	2.56E-13	6.41E-12	0.00%	-0.03%
361.45	3.68E-13	7.21E-12	3.68E-13	7.21E-12	0.04%	0.01%
366.40	5.21E-13	8.07E-12	5.21E-13	8.07E-12	-0.06%	-0.02%
371.35	7.29E-13	9.00E-12	7.29E-13	9.00E-12	-0.03%	-0.03%
376.30	1.01E-12	1.00E-11	1.01E-12	1.00E-11	0.25%	-0.03%
381.25	1.38E-12	1.11E-11	1.38E-12	1.11E-11	0.33%	0.24%
386.20	1.86E-12	1.22E-11	1.86E-12	1.22E-11	0.17%	-0.14%
391.15	2.48E-12	1.34E-11	2.48E-12	1.34E-11	0.00%	-0.24%
396.10	3.28E-12	1.47E-11	3.28E-12	1.47E-11	0.05%	-0.15%
401.05	4.29E-12	1.61E-11	4.29E-12	1.61E-11	-0.05%	0.10%
406.00	5.57E-12	1.75E-11	5.57E-12	1.75E-11	0.04%	-0.13%
410.95	7.16E-12	1.90E-11	7.16E-12	1.90E-11	0.02%	-0.18%
415.90	9.13E-12	2.06E-11	9.13E-12	2.06E-11	0.05%	-0.10%
420.85	1.15E-11	2.23E-11	1.15E-11	2.23E-11	-0.35%	0.09%
425.80	1.45E-11	2.40E-11	1.45E-11	2.40E-11	0.13%	-0.05%
430.75	1.80E-11	2.58E-11	1.80E-11	2.58E-11	-0.21%	-0.07%
435.70	2.23E-11	2.77E-11	2.23E-11	2.77E-11	-0.05%	0.01%
440.65	2.74E-11	2.96E-11	2.74E-11	2.96E-11	-0.03%	-0.15%
445.60	3.35E-11	3.17E-11	3.35E-11	3.17E-11	0.14%	0.11%
450.55	4.06E-11	3.38E-11	4.06E-11	3.38E-11	0.06%	0.14%
455.50	4.89E-11	3.59E-11	4.89E-11	3.59E-11	-0.05%	-0.03%
460.45	5.87E-11	3.81E-11	5.87E-11	3.81E-11	0.07%	-0.09%
465.40	6.99E-11	4.04E-11	6.99E-11	4.04E-11	-0.06%	-0.05%

470.35	8.30E-11	4.28E-11	8.30E-11	4.28E-11	0.06%	0.06%
475.30	9.79E-11	4.52E-11	9.79E-11	4.52E-11	0.01%	0.02%
480.25	1.15E-10	4.77E-11	1.15E-10	4.77E-11	0.04%	0.06%
485.20	1.34E-10	5.02E-11	1.34E-10	5.02E-11	-0.27%	-0.02%
490.15	1.56E-10	5.28E-11	1.56E-10	5.28E-11	-0.22%	-0.02%
495.10	1.81E-10	5.55E-11	1.81E-10	5.55E-11	-0.08%	0.05%
500.05	2.84E-10	6.06E-11	2.84E-10	6.06E-11	0.08%	-0.03%
505.00	3.42E-10	6.39E-11	3.23E-10	6.34E-11	5.61%	0.74%
509.95	3.66E-10	6.33E-11	3.66E-10	6.33E-11	-0.02%	0.02%
514.90	4.14E-10	6.61E-11	4.14E-10	6.61E-11	0.04%	-0.02%
519.85	4.66E-10	6.90E-11	4.66E-10	6.90E-11	-0.06%	0.02%
524.80	5.24E-10	7.19E-11	5.24E-10	7.19E-11	0.06%	-0.02%
529.75	5.86E-10	7.49E-11	5.86E-10	7.49E-11	-0.08%	0.01%
534.70	5.12E-10	7.87E-11	5.12E-10	7.87E-11	-0.07%	-0.05%
539.65	5.75E-10	8.19E-11	5.75E-10	8.19E-11	0.06%	0.02%
544.60	6.43E-10	8.51E-11	6.43E-10	8.51E-11	0.07%	0.02%
549.55	7.16E-10	8.83E-11	7.16E-10	8.83E-11	-0.06%	-0.04%
554.50	7.96E-10	8.78E-11	7.96E-10	8.78E-11	-0.06%	0.02%
559.45	8.83E-10	9.10E-11	8.83E-10	9.10E-11	-0.02%	-0.04%
564.40	9.77E-10	9.43E-11	9.77E-10	9.43E-11	0.03%	-0.03%
569.35	1.08E-09	9.77E-11	1.08E-09	9.77E-11	0.24%	0.03%
574.30	1.19E-09	1.01E-10	1.19E-09	1.01E-10	0.36%	-0.07%
579.25	1.30E-09	1.05E-10	1.30E-09	1.05E-10	-0.13%	0.46%
584.20	1.43E-09	1.08E-10	1.43E-09	1.08E-10	0.30%	-0.01%
589.15	1.56E-09	1.12E-10	1.56E-09	1.12E-10	0.12%	0.40%
594.10	1.70E-09	1.15E-10	1.70E-09	1.15E-10	0.04%	-0.13%
599.05	1.85E-09	1.19E-10	1.85E-09	1.19E-10	0.04%	0.17%
604.00	2.01E-09	1.22E-10	2.01E-09	1.22E-10	0.07%	-0.41%
608.95	2.18E-09	1.26E-10	2.18E-09	1.26E-10	0.13%	-0.19%
613.90	2.36E-09	1.30E-10	2.36E-09	1.30E-10	0.19%	-0.03%
618.85	2.54E-09	1.34E-10	2.54E-09	1.34E-10	-0.15%	0.08%
623.80	2.74E-09	1.38E-10	2.74E-09	1.38E-10	-0.08%	0.15%
628.75	2.95E-09	1.42E-10	2.95E-09	1.42E-10	-0.03%	0.18%
633.70	3.17E-09	1.46E-10	3.17E-09	1.46E-10	-0.01%	0.17%
638.65	3.40E-09	1.50E-10	3.40E-09	1.50E-10	-0.01%	0.13%
643.60	3.64E-09	1.54E-10	3.64E-09	1.54E-10	-0.04%	0.06%
648.55	3.89E-09	1.58E-10	3.89E-09	1.58E-10	-0.09%	-0.04%
653.50	4.16E-09	1.62E-10	4.16E-09	1.62E-10	0.07%	-0.17%
658.45	4.43E-09	1.67E-10	4.43E-09	1.67E-10	-0.04%	0.27%
663.40	4.72E-09	1.71E-10	4.72E-09	1.71E-10	0.04%	0.08%
668.35	5.02E-09	1.75E-10	5.02E-09	1.75E-10	0.08%	-0.13%
673.30	5.33E-09	1.80E-10	5.33E-09	1.80E-10	0.08%	0.20%
678.25	5.65E-09	1.84E-10	5.65E-09	1.84E-10	0.05%	-0.07%
683.20	5.98E-09	1.89E-10	5.98E-09	1.89E-10	-0.01%	0.19%
688.15	6.33E-09	1.93E-10	6.33E-09	1.93E-10	0.06%	-0.12%
693.10	6.68E-09	1.98E-10	6.68E-09	1.98E-10	-0.05%	0.07%
698.05	7.05E-09	2.03E-10	7.05E-09	2.03E-10	-0.04%	0.23%
703.00	7.43E-09	2.07E-10	7.43E-09	2.07E-10	-0.05%	-0.13%
707.95	7.83E-09	2.12E-10	7.83E-09	2.12E-10	0.03%	-0.03%

712.90	8.39E-09	2.19E-10	8.39E-09	2.19E-10	0.05%	-0.07%
717.85	9.01E-09	2.27E-10	9.01E-09	2.27E-10	0.00%	0.00%
722.80	9.67E-09	2.35E-10	9.67E-09	2.35E-10	0.05%	-0.01%
727.75	1.04E-08	2.43E-10	1.04E-08	2.43E-10	0.46%	-0.11%
732.70	1.11E-08	2.52E-10	1.11E-08	2.52E-10	0.26%	0.12%
737.65	1.18E-08	2.60E-10	1.18E-08	2.60E-10	-0.18%	-0.13%
742.60	1.26E-08	2.69E-10	1.26E-08	2.69E-10	-0.04%	-0.07%
747.55	1.34E-08	2.78E-10	1.34E-08	2.78E-10	-0.16%	-0.08%
752.50	1.43E-08	2.87E-10	1.43E-08	2.87E-10	0.21%	-0.17%
757.45	1.52E-08	2.97E-10	1.52E-08	2.97E-10	0.30%	0.02%
762.40	1.61E-08	3.07E-10	1.61E-08	3.07E-10	0.18%	0.12%
767.35	1.70E-08	3.16E-10	1.70E-08	3.16E-10	-0.13%	-0.16%
772.30	1.80E-08	3.27E-10	1.80E-08	3.27E-10	-0.03%	0.13%
777.25	1.90E-08	3.37E-10	1.90E-08	3.37E-10	-0.13%	0.03%
782.20	2.01E-08	3.47E-10	2.01E-08	3.47E-10	0.11%	-0.12%
787.15	2.12E-08	3.58E-10	2.12E-08	3.58E-10	0.16%	-0.04%
792.10	2.23E-08	3.69E-10	2.23E-08	3.69E-10	0.06%	-0.02%
797.05	2.34E-08	3.80E-10	2.34E-08	3.80E-10	-0.18%	-0.06%
802.00	2.46E-08	3.92E-10	2.46E-08	3.92E-10	-0.13%	0.11%
806.95	2.59E-08	4.03E-10	2.59E-08	4.03E-10	0.17%	-0.03%
811.90	2.71E-08	4.15E-10	2.71E-08	4.15E-10	-0.04%	0.03%
816.85	2.84E-08	4.27E-10	2.84E-08	4.27E-10	-0.01%	0.03%
821.80	2.97E-08	4.39E-10	2.97E-08	4.39E-10	-0.08%	0.00%
826.75	3.11E-08	4.51E-10	3.11E-08	4.51E-10	0.06%	-0.09%
831.70	3.25E-08	4.64E-10	3.25E-08	4.64E-10	0.10%	0.01%
836.65	3.39E-08	4.77E-10	3.39E-08	4.77E-10	0.04%	0.06%
841.60	3.53E-08	4.90E-10	3.53E-08	4.90E-10	-0.11%	0.06%
846.55	3.68E-08	5.03E-10	3.68E-08	5.03E-10	-0.06%	0.03%
851.50	3.83E-08	5.16E-10	3.83E-08	5.16E-10	-0.09%	-0.03%
856.45	3.99E-08	5.30E-10	3.99E-08	5.30E-10	0.06%	0.06%
861.40	4.14E-08	5.43E-10	4.15E-08	5.43E-10	-0.12%	-0.07%
866.35	4.31E-08	5.57E-10	4.31E-08	5.57E-10	0.11%	-0.05%
871.30	4.47E-08	5.71E-10	4.47E-08	5.71E-10	0.04%	-0.06%
876.25	4.63E-08	5.86E-10	4.63E-08	5.86E-10	-0.08%	0.07%
881.20	4.80E-08	6.00E-10	4.80E-08	6.00E-10	-0.05%	0.00%
886.15	4.97E-08	6.15E-10	4.97E-08	6.15E-10	-0.07%	0.07%
891.10	5.15E-08	6.29E-10	5.15E-08	6.29E-10	0.05%	-0.04%
896.05	5.32E-08	6.44E-10	5.32E-08	6.44E-10	-0.07%	-0.02%
901.00	5.50E-08	6.59E-10	5.50E-08	6.59E-10	-0.04%	-0.03%
905.95	5.68E-08	6.74E-10	5.68E-08	6.74E-10	-0.06%	-0.05%
910.90	5.87E-08	6.90E-10	5.87E-08	6.90E-10	0.06%	0.04%
915.85	6.05E-08	7.05E-10	6.05E-08	7.05E-10	-0.04%	-0.02%
920.80	6.24E-08	7.21E-10	6.24E-08	7.21E-10	0.00%	0.03%
925.75	6.43E-08	7.36E-10	6.43E-08	7.37E-10	0.00%	-0.07%
930.70	6.62E-08	7.52E-10	6.62E-08	7.52E-10	-0.03%	-0.05%
935.65	6.82E-08	7.68E-10	6.82E-08	7.68E-10	0.06%	-0.05%
940.60	7.01E-08	7.84E-10	7.01E-08	7.84E-10	-0.02%	-0.06%
945.55	7.21E-08	8.01E-10	7.21E-08	8.01E-10	0.02%	0.04%
950.50	7.41E-08	8.17E-10	7.41E-08	8.17E-10	0.03%	0.00%

955.45	7.61E-08	8.33E-10	7.61E-08	8.33E-10	0.02%	-0.06%
960.40	7.81E-08	8.50E-10	7.81E-08	8.50E-10	-0.01%	0.00%
965.35	8.01E-08	8.67E-10	8.01E-08	8.67E-10	-0.06%	0.04%
970.30	8.22E-08	8.83E-10	8.22E-08	8.83E-10	0.01%	-0.04%
975.25	8.43E-08	9.00E-10	8.43E-08	9.00E-10	0.05%	-0.02%
980.20	8.63E-08	9.17E-10	8.63E-08	9.17E-10	-0.04%	-0.01%
985.15	8.84E-08	9.34E-10	8.84E-08	9.34E-10	-0.03%	-0.01%
990.10	9.05E-08	9.51E-10	9.05E-08	9.51E-10	-0.03%	-0.02%
995.05	9.26E-08	9.68E-10	9.26E-08	9.68E-10	-0.03%	-0.03%

Table A3. Results for Test Case 1 (Release Height =55 m)

	VENTSAR 99.50% X/Q	Annual Average	VENTSAR XL 99.50% X/Q	Annual Average	% Diff X/Q	% Diff Ann Ave
10.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**	**
14.95	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**	**
19.90	0.00E+00	0.00E+00	0.00E+00	3.40E-219	**	**
24.85	0.00E+00	0.00E+00	0.00E+00	4.22E-157	**	**
29.80	0.00E+00	0.00E+00	2.28E-233	1.34E-120	**	**
34.75	0.00E+00	0.00E+00	1.21E-183	4.65E-97	**	**
39.70	0.00E+00	0.00E+00	1.18E-149	7.37E-81	**	**
44.65	0.00E+00	3.71E-69	3.03E-125	3.69E-69	**	0.59%
49.60	0.00E+00	2.18E-60	4.87E-107	2.17E-60	**	0.31%
54.55	0.00E+00	1.29E-53	4.84E-93	1.29E-53	**	0.33%
59.50	0.00E+00	2.93E-48	5.17E-82	2.92E-48	**	0.26%
64.45	0.00E+00	6.16E-44	3.83E-73	6.14E-44	**	0.31%
69.40	0.00E+00	2.17E-40	6.91E-66	2.17E-40	**	0.22%
74.35	0.00E+00	1.95E-37	3.65E-82	1.94E-37	**	0.28%
79.30	1.97E-75	6.02E-35	1.96E-75	6.00E-35	0.60%	0.29%
84.25	1.41E-69	7.96E-33	1.40E-69	7.94E-33	0.93%	0.27%
89.20	1.71E-64	5.32E-31	1.70E-64	5.31E-31	0.80%	0.25%
94.15	4.61E-60	2.04E-29	4.59E-60	2.03E-29	0.44%	0.31%
99.10	3.55E-56	4.94E-28	3.53E-56	4.93E-28	0.59%	0.27%
104.05	4.55E-52	1.37E-26	4.55E-52	1.37E-26	0.09%	0.04%
109.00	2.60E-48	3.00E-25	2.60E-48	3.00E-25	0.12%	-0.06%
113.95	5.13E-45	4.48E-24	5.13E-45	4.48E-24	0.05%	0.00%
118.90	4.14E-42	4.84E-23	4.14E-42	4.84E-23	0.11%	-0.01%
123.85	1.56E-39	3.98E-22	1.56E-39	3.98E-22	-0.15%	0.03%
128.80	3.09E-37	2.59E-21	3.09E-37	2.59E-21	-0.04%	-0.03%
133.75	3.51E-35	1.38E-20	3.51E-35	1.38E-20	-0.01%	-0.10%
138.70	2.47E-33	6.20E-20	2.47E-33	6.20E-20	0.05%	0.01%
143.65	1.15E-31	2.40E-19	1.15E-31	2.40E-19	0.39%	0.18%
148.60	3.70E-30	8.13E-19	3.70E-30	8.13E-19	0.06%	0.03%
153.55	8.68E-29	2.46E-18	8.68E-29	2.46E-18	-0.05%	0.00%
158.50	1.54E-27	6.73E-18	1.54E-27	6.73E-18	-0.12%	-0.07%
163.45	2.14E-26	1.69E-17	2.14E-26	1.69E-17	0.13%	0.13%
168.40	2.38E-25	3.91E-17	2.38E-25	3.91E-17	0.05%	-0.02%
173.35	2.18E-24	8.45E-17	2.18E-24	8.45E-17	0.12%	-0.03%
178.30	1.67E-23	1.72E-16	1.67E-23	1.72E-16	-0.21%	0.16%
183.25	1.10E-22	3.30E-16	1.10E-22	3.30E-16	0.01%	-0.03%
188.20	6.28E-22	6.04E-16	6.28E-22	6.04E-16	0.01%	0.01%
193.15	3.16E-21	1.06E-15	3.16E-21	1.06E-15	0.08%	0.26%
198.10	1.42E-20	1.78E-15	1.42E-20	1.78E-15	0.31%	0.07%
203.05	5.72E-20	2.89E-15	5.72E-20	2.89E-15	0.02%	0.06%
208.00	2.10E-19	4.54E-15	2.10E-19	4.54E-15	-0.09%	-0.07%
212.95	7.09E-19	6.94E-15	7.09E-19	6.94E-15	0.04%	-0.06%
217.90	2.21E-18	1.03E-14	2.21E-18	1.03E-14	0.04%	0.27%
222.85	6.41E-18	1.51E-14	6.41E-18	1.51E-14	0.03%	0.14%

227.80	1.74E-17	2.15E-14	1.74E-17	2.15E-14	0.00%	-0.14%
232.75	4.45E-17	3.00E-14	4.45E-17	3.00E-14	0.06%	-0.08%
237.70	1.08E-16	4.13E-14	1.08E-16	4.13E-14	0.45%	0.00%
242.65	2.47E-16	5.60E-14	2.47E-16	5.60E-14	0.05%	-0.03%
247.60	5.41E-16	7.48E-14	5.41E-16	7.48E-14	0.07%	0.00%
252.55	1.13E-15	9.87E-14	1.13E-15	9.87E-14	-0.27%	0.25%
257.50	2.28E-15	1.29E-13	2.28E-15	1.29E-13	-0.01%	0.03%
262.45	4.42E-15	1.66E-13	4.42E-15	1.66E-13	0.02%	0.05%
267.40	8.27E-15	2.12E-13	8.27E-15	2.12E-13	0.00%	-0.01%
272.35	1.50E-14	2.68E-13	1.50E-14	2.68E-13	0.13%	-0.01%
277.30	2.63E-14	3.36E-13	2.63E-14	3.36E-13	-0.09%	-0.01%
282.25	4.50E-14	4.18E-13	4.50E-14	4.18E-13	0.08%	0.05%
287.20	7.48E-14	5.15E-13	7.48E-14	5.15E-13	-0.01%	-0.06%
292.15	1.21E-13	6.31E-13	1.21E-13	6.31E-13	-0.35%	0.02%
297.10	1.93E-13	7.67E-13	1.93E-13	7.67E-13	0.22%	0.04%
302.05	2.99E-13	9.25E-13	2.99E-13	9.25E-13	0.04%	-0.05%
307.00	4.55E-13	1.11E-12	4.55E-13	1.11E-12	0.10%	0.04%
311.95	6.78E-13	1.32E-12	6.78E-13	1.32E-12	-0.03%	-0.14%
316.90	9.94E-13	1.57E-12	9.94E-13	1.57E-12	0.01%	0.31%
321.85	1.43E-12	1.84E-12	1.43E-12	1.84E-12	-0.16%	-0.12%
326.80	2.03E-12	2.16E-12	2.03E-12	2.16E-12	-0.08%	0.19%
331.75	2.84E-12	2.51E-12	2.84E-12	2.51E-12	0.05%	0.04%
336.70	3.91E-12	2.90E-12	3.91E-12	2.90E-12	-0.02%	-0.16%
341.65	5.32E-12	3.35E-12	5.32E-12	3.35E-12	0.06%	0.14%
346.60	7.14E-12	3.83E-12	7.14E-12	3.83E-12	0.03%	-0.10%
351.55	9.47E-12	4.37E-12	9.47E-12	4.37E-12	0.01%	-0.07%
356.50	1.24E-11	4.96E-12	1.24E-11	4.96E-12	-0.17%	-0.10%
361.45	1.61E-11	5.61E-12	1.61E-11	5.61E-12	-0.12%	-0.04%
366.40	2.07E-11	6.32E-12	2.07E-11	6.32E-12	-0.05%	0.05%
371.35	2.64E-11	7.08E-12	2.64E-11	7.08E-12	0.17%	-0.01%
376.30	3.32E-11	7.91E-12	3.32E-11	7.91E-12	-0.10%	0.04%
381.25	4.15E-11	8.79E-12	4.15E-11	8.79E-12	-0.12%	-0.06%
386.20	5.15E-11	9.75E-12	5.15E-11	9.75E-12	-0.04%	0.02%
391.15	6.34E-11	1.08E-11	6.34E-11	1.08E-11	0.03%	0.31%
396.10	7.74E-11	1.19E-11	7.74E-11	1.19E-11	-0.01%	0.41%
401.05	9.39E-11	1.30E-11	9.39E-11	1.30E-11	0.04%	-0.03%
406.00	1.13E-10	1.42E-11	1.13E-10	1.42E-11	-0.05%	-0.17%
410.95	1.35E-10	1.55E-11	1.35E-10	1.55E-11	-0.22%	-0.08%
415.90	1.61E-10	1.69E-11	1.61E-10	1.69E-11	0.04%	0.18%
420.85	1.90E-10	1.83E-11	1.90E-10	1.83E-11	-0.17%	0.02%
425.80	2.24E-10	1.98E-11	2.24E-10	1.98E-11	0.09%	0.04%
430.75	2.62E-10	2.14E-11	2.62E-10	2.14E-11	0.08%	0.21%
435.70	3.05E-10	2.30E-11	3.05E-10	2.30E-11	0.11%	0.06%
440.65	3.53E-10	2.47E-11	3.53E-10	2.47E-11	0.04%	0.05%
445.60	4.07E-10	2.65E-11	4.07E-10	2.65E-11	0.06%	0.18%
450.55	4.67E-10	2.83E-11	4.67E-10	2.83E-11	0.04%	0.05%
455.50	5.33E-10	3.02E-11	5.33E-10	3.02E-11	-0.08%	0.06%
460.45	6.07E-10	3.21E-11	6.07E-10	3.21E-11	-0.01%	-0.14%
465.40	6.88E-10	3.42E-11	6.88E-10	3.42E-11	-0.03%	0.08%

470.35	7.77E-10	3.63E-11	7.77E-10	3.63E-11	-0.02%	0.11%
475.30	8.75E-10	3.84E-11	8.75E-10	3.84E-11	0.05%	-0.03%
480.25	9.81E-10	4.06E-11	9.81E-10	4.06E-11	0.03%	-0.06%
485.20	1.10E-09	4.29E-11	1.10E-09	4.29E-11	0.35%	0.01%
490.15	1.22E-09	4.52E-11	1.22E-09	4.52E-11	-0.09%	-0.06%
495.10	1.36E-09	4.76E-11	1.36E-09	4.76E-11	0.27%	-0.03%
500.05	1.92E-10	5.22E-11	1.92E-10	5.22E-11	0.08%	0.01%
505.00	2.32E-10	5.52E-11	2.20E-10	5.47E-11	5.25%	0.84%
509.95	2.51E-10	5.50E-11	2.51E-10	5.50E-11	-0.03%	-0.03%
514.90	2.86E-10	5.76E-11	2.86E-10	5.76E-11	0.09%	0.03%
519.85	3.24E-10	6.02E-11	3.24E-10	6.02E-11	-0.02%	0.00%
524.80	3.66E-10	6.29E-11	3.66E-10	6.29E-11	-0.09%	0.04%
529.75	4.13E-10	6.56E-11	4.13E-10	6.56E-11	0.05%	0.00%
534.70	2.85E-09	6.87E-11	2.85E-09	6.87E-11	0.06%	-0.01%
539.65	3.09E-09	7.16E-11	3.09E-09	7.16E-11	-0.05%	0.03%
544.60	3.35E-09	7.45E-11	3.35E-09	7.45E-11	0.04%	0.00%
549.55	3.62E-09	7.75E-11	3.62E-09	7.75E-11	0.01%	0.04%
554.50	3.90E-09	7.75E-11	3.90E-09	7.75E-11	0.05%	0.01%
559.45	4.20E-09	8.05E-11	4.20E-09	8.05E-11	0.07%	0.03%
564.40	4.51E-09	8.35E-11	4.51E-09	8.35E-11	-0.02%	-0.02%
569.35	4.84E-09	8.66E-11	4.84E-09	8.66E-11	0.01%	0.00%
574.30	5.18E-09	8.97E-11	5.18E-09	8.97E-11	-0.05%	-0.04%
579.25	5.54E-09	9.29E-11	5.54E-09	9.29E-11	-0.02%	-0.02%
584.20	5.92E-09	9.61E-11	5.92E-09	9.61E-11	0.08%	-0.05%
589.15	6.30E-09	9.94E-11	6.30E-09	9.94E-11	-0.07%	-0.03%
594.10	6.71E-09	1.03E-10	6.71E-09	1.03E-10	0.02%	0.23%
599.05	7.13E-09	1.06E-10	7.13E-09	1.06E-10	0.02%	-0.13%
604.00	7.56E-09	1.10E-10	7.56E-09	1.10E-10	-0.06%	0.39%
608.95	8.02E-09	1.13E-10	8.02E-09	1.13E-10	0.06%	-0.04%
613.90	8.48E-09	1.17E-10	8.48E-09	1.17E-10	-0.03%	0.36%
618.85	8.96E-09	1.20E-10	8.96E-09	1.20E-10	-0.05%	-0.13%
623.80	9.46E-09	1.24E-10	9.46E-09	1.24E-10	-0.02%	0.18%
628.75	9.98E-09	1.27E-10	9.98E-09	1.27E-10	0.04%	-0.36%
633.70	1.05E-08	1.31E-10	1.05E-08	1.31E-10	-0.04%	-0.14%
638.65	1.10E-08	1.35E-10	1.10E-08	1.35E-10	-0.44%	0.03%
643.60	1.16E-08	1.39E-10	1.16E-08	1.39E-10	-0.06%	0.16%
648.55	1.22E-08	1.43E-10	1.22E-08	1.43E-10	0.15%	0.24%
653.50	1.28E-08	1.47E-10	1.28E-08	1.47E-10	0.23%	0.28%
658.45	1.34E-08	1.51E-10	1.34E-08	1.51E-10	0.19%	0.29%
663.40	1.40E-08	1.55E-10	1.40E-08	1.55E-10	0.04%	0.26%
668.35	1.46E-08	1.59E-10	1.46E-08	1.59E-10	-0.18%	0.20%
673.30	1.53E-08	1.63E-10	1.53E-08	1.63E-10	0.17%	0.12%
678.25	1.59E-08	1.67E-10	1.59E-08	1.67E-10	-0.23%	0.00%
683.20	4.81E-09	1.71E-10	4.81E-09	1.71E-10	-0.10%	-0.13%
688.15	5.11E-09	1.76E-10	5.11E-09	1.76E-10	0.08%	0.28%
693.10	5.41E-09	1.80E-10	5.41E-09	1.80E-10	0.04%	0.09%
698.05	5.72E-09	1.84E-10	5.72E-09	1.84E-10	-0.02%	-0.13%
703.00	6.04E-09	1.89E-10	6.04E-09	1.89E-10	-0.08%	0.18%
707.95	6.38E-09	1.93E-10	6.38E-09	1.93E-10	0.00%	-0.08%

712.90	6.85E-09	2.00E-10	6.85E-09	2.00E-10	-0.06%	0.12%
717.85	7.39E-09	2.07E-10	7.39E-09	2.07E-10	0.06%	-0.02%
722.80	7.94E-09	2.14E-10	7.94E-09	2.14E-10	-0.05%	-0.23%
727.75	8.53E-09	2.22E-10	8.53E-09	2.22E-10	-0.02%	-0.07%
732.70	9.15E-09	2.30E-10	9.15E-09	2.30E-10	0.02%	0.00%
737.65	9.79E-09	2.38E-10	9.79E-09	2.38E-10	-0.04%	-0.01%
742.60	1.05E-08	2.46E-10	1.05E-08	2.46E-10	0.30%	-0.10%
747.55	1.12E-08	2.55E-10	1.12E-08	2.55E-10	0.23%	0.13%
752.50	3.13E-08	2.63E-10	3.13E-08	2.63E-10	-0.03%	-0.12%
757.45	3.27E-08	2.72E-10	3.27E-08	2.72E-10	-0.08%	-0.05%
762.40	3.42E-08	2.81E-10	3.42E-08	2.81E-10	0.08%	-0.05%
767.35	3.57E-08	2.90E-10	3.57E-08	2.90E-10	0.12%	-0.13%
772.30	3.72E-08	3.00E-10	3.72E-08	3.00E-10	0.07%	0.07%
777.25	3.87E-08	3.09E-10	3.87E-08	3.09E-10	-0.05%	-0.14%
782.20	4.03E-08	3.19E-10	4.03E-08	3.19E-10	0.00%	-0.08%
787.15	4.19E-08	3.29E-10	4.19E-08	3.29E-10	-0.02%	-0.09%
792.10	4.36E-08	3.40E-10	4.36E-08	3.40E-10	0.11%	0.14%
797.05	4.52E-08	3.50E-10	4.52E-08	3.50E-10	-0.05%	0.01%
802.00	4.69E-08	3.61E-10	4.69E-08	3.61E-10	-0.05%	0.11%
806.95	4.87E-08	3.71E-10	4.87E-08	3.71E-10	0.10%	-0.12%
811.90	5.04E-08	3.82E-10	5.04E-08	3.82E-10	-0.02%	-0.12%
816.85	5.22E-08	3.94E-10	5.22E-08	3.94E-10	0.01%	0.07%
821.80	5.40E-08	4.05E-10	5.40E-08	4.05E-10	-0.02%	-0.04%
826.75	5.58E-08	4.17E-10	5.58E-08	4.17E-10	-0.09%	0.05%
831.70	5.77E-08	4.29E-10	5.77E-08	4.29E-10	-0.02%	0.09%
836.65	5.96E-08	4.41E-10	5.96E-08	4.41E-10	0.00%	0.08%
841.60	6.15E-08	4.53E-10	6.15E-08	4.53E-10	-0.02%	0.04%
846.55	6.34E-08	4.65E-10	6.35E-08	4.65E-10	-0.08%	-0.05%
851.50	6.54E-08	4.78E-10	6.54E-08	4.78E-10	-0.01%	0.04%
856.45	6.74E-08	4.91E-10	6.74E-08	4.91E-10	0.02%	0.09%
861.40	6.94E-08	5.04E-10	6.94E-08	5.04E-10	0.02%	0.10%
866.35	7.14E-08	5.17E-10	7.14E-08	5.17E-10	-0.01%	0.07%
871.30	7.34E-08	5.30E-10	7.34E-08	5.30E-10	-0.07%	0.01%
876.25	7.55E-08	5.43E-10	7.55E-08	5.43E-10	-0.01%	-0.07%
881.20	7.76E-08	5.57E-10	7.76E-08	5.57E-10	0.02%	-0.01%
886.15	7.97E-08	5.71E-10	7.97E-08	5.71E-10	0.03%	0.03%
891.10	8.18E-08	5.84E-10	8.18E-08	5.85E-10	0.02%	-0.14%
896.05	8.39E-08	5.99E-10	8.39E-08	5.99E-10	-0.01%	0.02%
901.00	8.60E-08	6.13E-10	8.60E-08	6.13E-10	-0.05%	-0.03%
905.95	8.82E-08	6.28E-10	8.82E-08	6.28E-10	0.01%	0.06%
910.90	9.04E-08	6.42E-10	9.04E-08	6.42E-10	0.05%	-0.03%
915.85	9.25E-08	6.57E-10	9.25E-08	6.57E-10	-0.03%	0.02%
920.80	9.47E-08	6.72E-10	9.47E-08	6.72E-10	-0.02%	0.04%
925.75	9.69E-08	6.87E-10	9.69E-08	6.87E-10	-0.01%	0.04%
930.70	9.91E-08	7.02E-10	9.91E-08	7.02E-10	-0.01%	0.03%
935.65	1.01E-07	7.17E-10	1.01E-07	7.17E-10	-0.32%	-0.01%
940.60	1.04E-07	7.32E-10	1.04E-07	7.32E-10	0.44%	-0.06%
945.55	1.06E-07	7.48E-10	1.06E-07	7.48E-10	0.22%	0.01%
950.50	1.08E-07	7.63E-10	1.08E-07	7.63E-10	0.00%	-0.06%

955.45	1.10E-07	7.79E-10	1.10E-07	7.79E-10	-0.22%	-0.02%
960.40	1.12E-07	7.95E-10	1.12E-07	7.95E-10	-0.43%	0.00%
965.35	1.15E-07	8.11E-10	1.15E-07	8.11E-10	0.24%	0.01%
970.30	1.17E-07	8.27E-10	1.17E-07	8.27E-10	0.02%	0.01%
975.25	1.19E-07	8.43E-10	1.19E-07	8.43E-10	-0.19%	0.00%
980.20	1.21E-07	8.59E-10	1.21E-07	8.59E-10	-0.39%	-0.03%
985.15	1.24E-07	8.75E-10	1.24E-07	8.75E-10	0.22%	-0.06%
990.10	1.26E-07	8.92E-10	1.26E-07	8.92E-10	0.02%	0.02%
995.05	1.28E-07	9.08E-10	1.28E-07	9.08E-10	-0.18%	-0.03%

Table A4. Test Cases 3 through 8

TEST CASE # 3

Downwind Distance (m)	VENTSAR X/Q (s/m**3)	VENTSAR XL X/Q (s/m**3)	% Diff X/Q (%)
10	3.66E-17	3.66E-17	0.00%
109	8.69E-04	8.69E-04	0.00%
208	3.93E-04	3.93E-04	0.00%
307	2.11E-04	2.11E-04	0.00%
406	1.35E-04	1.35E-04	0.00%
505	9.51E-05	9.51E-05	0.00%
604	7.18E-05	7.18E-05	0.00%
703	5.67E-05	5.67E-05	0.00%
802	4.63E-05	4.63E-05	0.00%
901	3.88E-05	3.88E-05	0.00%

TEST CASE # 4

Downwind Distance (m)	VENTSAR X/Q (s/m**3)	VENTSAR XL X/Q (s/m**3)	% Diff X/Q (%)
10	0.00E+00	0.00E+00	
109	0.00E+00	0.00E+00	
208	0.00E+00	9.83E-300	
307	0.00E+00	3.82E-147	
406	0.00E+00	3.19E-90	
505	1.14E-62	1.13E-62	0.47%
604	3.73E-47	3.72E-47	0.31%
703	1.67E-37	1.66E-37	0.41%
802	4.59E-31	4.58E-31	0.18%
901	1.55E-26	1.55E-26	0.06%

TEST CASE # 5

Downwind Distance (m)	VENTSAR X/Q (s/m**3)	VENTSAR XL X/Q (s/m**3)	% Diff X/Q (%)
10	0.00E+00	0.00E+00	
109	1.76E-12	1.76E-12	0.00%
208	2.01E-07	2.01E-07	0.00%
307	6.43E-07	6.43E-07	0.00%
406	1.86E-06	1.86E-06	0.00%
505	2.62E-06	2.62E-06	0.00%
604	2.84E-06	2.84E-06	0.00%
703	2.76E-06	2.76E-06	0.00%
802	2.56E-06	2.56E-06	0.00%
901	2.32E-06	2.32E-06	0.00%

TEST CASE # 6

Downwind Distance (m)	VENTSAR 99.5% X/Q (s/m**3)	VENTSAR Annual X/Q (s/m**3)	VENTSAR XL 99.5% X/Q (s/m**3)	VENTSAR XL Annual X/Q (s/m**3)	% Diff 99.5% X/Q (%)	% Diff Annual X/Q (%)
10	0.00E+00	0.00E+00	3.46E-138	2.74E-140		
109	1.40E-05	1.11E-07	1.40E-05	1.11E-07	0.00%	0.00%
208	2.00E-05	2.63E-07	2.00E-05	2.63E-07	0.00%	0.00%
307	1.48E-05	2.43E-07	1.48E-05	2.43E-07	0.00%	0.00%
406	1.29E-05	2.14E-07	1.29E-05	2.14E-07	0.00%	0.00%
505	1.06E-05	1.91E-07	1.06E-05	1.91E-07	0.00%	0.00%
604	9.21E-06	1.73E-07	9.21E-06	1.73E-07	0.00%	0.00%
703	8.43E-06	1.60E-07	8.43E-06	1.60E-07	0.00%	0.00%
802	8.39E-06	1.50E-07	8.39E-06	1.50E-07	0.00%	0.00%
901	7.30E-06	1.42E-07	7.30E-06	1.42E-07	0.00%	0.00%

TEST CASE # 7

Downwind Distance (m)	VENTSAR 99.5% X/Q (s/m**3)	VENTSAR Annual X/Q (s/m**3)	VENTSAR XL 99.5% X/Q (s/m**3)	VENTSAR XL Annual X/Q (s/m**3)	% Diff 99.5% X/Q (%)	% Diff Annual X/Q (%)
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
109	0.00E+00	2.86E-28	1.05E-96	2.85E-28		0.22%
208	6.78E-45	1.56E-16	6.78E-45	1.56E-16	0.00%	-0.12%
307	5.89E-32	1.93E-13	5.89E-32	1.93E-13	0.01%	-0.15%
406	1.76E-27	2.40E-12	1.76E-27	2.40E-12	0.09%	-0.14%
505	2.30E-17	7.98E-12	2.30E-17	7.98E-12	0.02%	0.01%
604	1.27E-14	1.61E-11	1.27E-14	1.61E-11	0.27%	0.07%
703	6.47E-13	2.61E-11	6.47E-13	2.61E-11	0.04%	0.08%
802	1.09E-11	4.03E-11	1.09E-11	4.03E-11	-0.40%	-0.08%
901	1.01E-10	6.40E-11	1.01E-10	6.40E-11	-0.37%	0.08%

TEST CASE # 8

Downwind Distance (m)	VENTSAR 99.5% X/Q (s/m**3)	VENTSAR XL 99.5% X/Q (s/m**3)	% Diff 99.5% X/Q (%)
10	1.17E-02	1.17E-02	-0.37%
109	1.18E-04	1.18E-04	0.04%
208	3.48E-05	3.48E-05	0.08%
307	1.68E-05	1.68E-05	0.04%
406	1.00E-05	1.00E-05	0.01%
505	6.69E-06	6.69E-06	0.03%
604	4.82E-06	4.82E-06	0.07%
703	3.65E-06	3.65E-06	-0.02%
802	2.87E-06	2.87E-06	-0.10%
901	2.33E-06	2.33E-06	0.14%

APPENDIX B ADDITIONAL TEST CASE DEMONSTRATION

APPENDIX B. ADDITIONAL TEST CASE DEMONSTRATION

Four additional test cases were created to ensure proper application of methodologies. Parameters for the additional test cases are shown in Table B1. Results for test cases 9-12 are shown in Table B2 for selected downwind distances. Differences are less than 0.01% for all receptor distances.

Table B1. Test Cases Parameters

Parameter*	Case 9	Case 10	Case 11	Case 12
Consider Plume Rise	NO	NO	YES	NO
Area of Release	#	#	C	A
Building Height	10	10	40	10
Building Width	100	100	30	10
Building Length	100	100	100	10
Penthouse Height	5	5	5	5
Penthouse Width	90	90	10	5
Penthouse Length	90	90	30	5
Bldg. to Penthouse	5	5	70	1
Min. Vent to Receptor	10	10	10	1
Max. Vent to Receptor	510	510	1010	101
Number of Increments	200	200	200	200
Compass Sector	S	S	SSE	E
Vent to Roof Edge	-10	-10	70	20
Vent Height	10	10	0	0
Radioactive Release?	YES	YES	NO	YES
Release Rate (Ci/min)	1	1	-	1
Pollutant Mole Fraction	0.000001	0.000001	-	0.000001
Vent-Gas Flow Rate (m^3/s)	500	500	1000	500
Met. Averaging?	YES	NO	YES	NO
Probability Level	0.005	-	0.005	-
Wind Speed (m/s)	-	4.5	-	3
Stability Class	-	D	-	B
Vent Diameter	1	1	1	1
Vent-Gas Molecular Weight	29	29	190	30
Vent-Gas Temp(C)	30	30	100	20
Ambient Air Temp(C)	30	30	20	20

Release Coordinates at center of site: E58000; N 62000

Table B2. Comparison of VENTSAR XL and VENTSAR for Additional Test Cases

TEST CASE # 9

Downwind Distance (m)	VENTSAR 99.5% X/Q (s/m**3)	VENTSAR Annual X/Q (s/m**3)	VENTSAR XL 99.5% X/Q (s/m**3)	VENTSAR XL Annual X/Q (s/m**3)	% Diff 99.5% X/Q (%)	% Diff Annual X/Q (%)
10	9.14E-18	9.66E-10	9.14E-08	9.66E-10		0.00%
60	8.42E-04	2.45E-05	8.42E-04	2.45E-05	0.00%	0.00%
110	2.38E-04	4.59E-06	2.38E-04	4.59E-06	0.00%	0.00%
160	8.38E-05	1.84E-06	8.38E-05	1.84E-06	0.00%	0.00%
210	7.61E-05	1.52E-06	7.61E-05	1.52E-06	0.00%	0.00%
260	5.61E-05	1.23E-06	5.61E-05	1.23E-06	0.00%	0.00%
310	6.12E-05	1.00E-06	6.12E-05	1.00E-06	0.00%	0.00%
360	4.97E-05	8.36E-07	4.97E-05	8.36E-07	0.00%	0.00%
410	4.08E-05	7.15E-07	4.08E-05	7.15E-07	0.00%	0.00%
460	3.65E-05	6.21E-07	3.65E-05	6.21E-07	0.00%	0.00%

TEST CASE # 10

Downwind Distance (m)	VENTSAR X/Q (s/m**3)	VENTSAR XL X/Q (s/m**3)	% Diff X/Q (%)
10	3.17E-63	3.17E-63	0.00%
60	9.39E-04	9.39E-04	0.00%
110	1.60E-04	1.60E-04	0.00%
160	2.87E-05	2.87E-05	0.00%
210	4.13E-05	4.13E-05	0.00%
260	4.98E-05	4.98E-05	0.00%
310	5.20E-05	5.20E-05	0.00%
360	4.99E-05	4.99E-05	0.00%
410	4.60E-05	4.60E-05	0.00%
460	4.15E-05	4.15E-05	0.00%

Table B2. Cont. Comparison of VENTSAR XL and VENTSAR for Additional Test Cases

TEST CASE #11

Downwind Distance (m)	VENTSAR 99.5% X/Q (s/m**3)	VENTSAR Annual X/Q (s/m**3)	VENTSAR XL 99.5% X/Q (s/m**3)	VENTSAR XL Annual X/Q (s/m**3)	% Diff 99.5% X/Q (%)	% Diff Annual X/Q (%)
10	0.00E+00	0.00E+00	0.00E+00	1.39E-116	**	**
110	0.00E+00	1.64E-31	4.29E-96	1.64E-31	**	0.00%
210	2.19E-42	1.08E-17	2.19E-42	1.08E-17	0.00%	0.00%
310	2.31E-25	2.68E-14	2.31E-25	2.68E-14	0.00%	0.00%
410	1.21E-18	4.89E-13	1.21E-18	4.89E-13	0.00%	0.00%
510	2.94E-15	1.90E-12	2.94E-15	1.90E-12	0.00%	0.00%
610	2.72E-13	3.97E-12	2.72E-13	3.97E-12	0.00%	0.00%
710	4.82E-12	6.34E-12	4.82E-12	6.34E-12	0.00%	0.00%
810	3.38E-11	9.16E-12	3.38E-11	9.16E-12	0.00%	0.00%
910	1.35E-10	1.29E-11	1.35E-10	1.29E-11	0.00%	0.00%

TEST CASE # 12

Downwind Distance (m)	VENTSAR X/Q (s/m**3)	VENTSAR XL X/Q (s/m**3)	% Diff X/Q (%)
10	2.35E-03	2.35E-03	0.00%
20	1.57E-03	1.57E-03	0.00%
30	1.10E-03	1.10E-03	0.00%
40	8.05E-04	8.05E-04	0.00%
50	6.09E-04	6.09E-04	0.00%
60	4.75E-04	4.75E-04	0.00%
70	3.81E-04	3.81E-04	0.00%
80	3.11E-04	3.11E-04	0.00%
90	2.59E-04	2.59E-04	0.00%
100	2.19E-04	2.19E-04	0.00%

**Value determined in VENTSAR is below threshold value for printout.

APPENDIX C. HAND CALCULATIONS

APPENDIX C. HAND CALCULATIONS

Independent hand calculations were performed to demonstrate that VENTSAR XL was correctly applying the methodologies previously discussed.

1.0 Plume Rise Options

For a downwind distance of 10 m, the following calculations were performed to verify plume rise methodologies using the parameters shown in Table 5.

Buoyancy Effects

$$DRHO = \frac{MW_a T_e - MW_e T_a}{2MW_a T_e}$$

$$MW_e = MFCT \times MW_e + (1 - MFCT)MW_a$$
$$MW_e = 1.8\text{E}-06 \times 78.12 + (1 - 1.8\text{E}-06)28.9$$
$$MW_e = 28.90$$

Using all other known parameters the following is determined.

$DRHO$= 0.0319

The buoyancy flux, F_o, is then calculated using the following equation:

$$F_o = 2.0 \times G \times DRHO \times CMS$$

$$F_o = 2.0 \times 9.8(\frac{m}{s^2}) \times 0.0319 \times 50(\frac{m^3}{s}) = 31.26 m^4/s^3$$

Since the buoyancy flux is less than 55.0, XSTR is calculated as follows:

$$XSTR = 49.0 \times F_o^{0.625} = 49.0 \times 31.26^{0.625} = 421.3m$$

Since the weather conditions are neutral (D stability) the value of the stability parameter, S, is one. Increase in release height due to buoyancy is:

$$\Delta h_B = 1.6\frac{F_o^{1/3} X^{2/3}}{U} = 1.6\frac{31.26^{1/3} 10^{2/3}}{6} = 3.90\text{m}$$

Momentum Effects

The velocity of the plume, V_e, is calculated as follows:

$$V_e = CMS / AREA$$

$$V_e = 50\frac{m^3}{s} / [\pi(0.5m)^2] = 63.66\frac{m^3}{s}$$

$$B1 = \frac{0.75\times\pi}{(0.4+1.2\times U / V_e)^2} = \frac{0.75\times\pi}{(0.4+1.2\times 6.0\frac{m}{s} / 63.66\frac{m^3}{s})^2} = 8.95$$

$$M_o = [\frac{MW_e T_a}{MW_a T_e}]^{0.5} = [\frac{28.9\times 293}{28.9\times 313}]^{0.5} = 0.97$$

$$DHMOM = \frac{D\times V_e M_o}{U} = \frac{1m\times 63.66\frac{m}{s}\times 0.97}{6\frac{m}{s}} = 10.29$$

Using the above parameters, XTEST can be calculated as follows:

$$XTEST = \frac{27.0*DHMOM}{B1} = \frac{27.0*10.29}{8.95} = 31.04\text{m}$$

Since X is less than XTEST

$$\Delta h_m = \left(B1*X*DHMOM^2\right)^{1/3} = \left(8.95*10*10.29^2\right)^{1/3} = 21.15\text{m}$$

There is no downwash since $V_e/U > 1.5$.

The effective change in plume height is

$$h(x) = h_s - \Delta h_D + \Delta h_B(x) + \Delta h_M(x)$$

$$h(x) = 20.0 - 0.00 + 3.90 + 21.15 = 44.99\text{m}$$

The concentration is calculated as follows:

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z U_S}\left[e^{-\left(\frac{(z-h_e)^2}{2\sigma_z^2}\right)} + e^{-\left(\frac{(z+h_e)^2}{2\sigma_z^2}\right)}\right]$$

For D stability 10 m downwind of release location

$$\sigma_y = \frac{\sigma_\theta x}{1 + 0.031(x)^{0.46}} \qquad \sigma_z = 0.06x(1 + 0.0015x)^{-0.5}$$

$$\sigma_y = \frac{0.218 * 10\ m}{1 + 0.031(10\ )^{0.46}} \qquad \sigma_z = 0.06 * 10\ m(1 + 0.0015 * 10)^{-0.5}$$

$$\sigma_y = 2.001\ m \qquad \sigma_z = 0.596\ m$$

$$\frac{\chi}{Q} = \frac{e^{-0.5(44.99/0.596)^2} + e^{-0.5(44.99/0.596)^2}}{2 * 3.14 * 2.001\ m * 0.596\ m * 6\ m/s} = 0.0E{+}00\ s/m^3$$

The following hand calculation is for a downwind distance of X=200 m.

Using the same constants as above and since X<XSTR

$$\Delta h_B = 1.6\frac{F_o^{1/3}X^{2/3}}{U} = 1.6\frac{29.91^{1/3}200^{2/3}}{6} = 28.31\text{m}$$

For momentum effects, X>XTEST yielding

$$\Delta h_m = 3 * DHMOM = 3 * 10.28 = 30.80\text{m}$$

$$h(x) = 20.0 - 0.00 + 28.31 + 30.84 = 79.11\text{m}$$

For D stability 200 m downwind of release location

$$\sigma_y = \frac{\sigma_\theta x}{1 + 0.031(x)^{0.46}} \qquad \sigma_z = 0.06x(1 + 0.0015x)^{-0.5}$$

$$\sigma_y = \frac{0.218 * 200\ m}{1 + 0.031(200\ )^{0.46}} \qquad \sigma_z = 0.06 * 200\ m(1 + 0.0015 * 200)^{-0.5}$$

$$\sigma_y = 32.21\ m \qquad \sigma_z = 10.52\ m$$

$$\frac{\chi}{Q} = \frac{e^{-0.5(79.11/10.52)^2} + e^{-0.5(79.11/10.52)^2}}{2 * 3.14 * 32.21\ m * 10.52\ m * 6\ m/s} = 8.22E{-}17\ s/m^3$$

The following hand calculation is for a downwind distance of X=1000 m.

Since X>XSTR the same equation is used as above except X is replaced with the value of XSTR.

$$\Delta h_B = 1.6\frac{F_o^{1/3} XSTR^{2/3}}{U}$$

$$\Delta h_B = 1.6\frac{29.91^{1/3} 409.79^{2/3}}{6} = 45.67\text{m}$$

For momentum effects, X>XTEST yielding

$$\Delta h_m = 3 * DHMOM = 3 * 10.28 = 30.80\text{m}$$

$$h(x) = 20.0 - 0.00 + 45.67 + 30.84 = 96.47\text{m}$$

Using the same equation as above, the pollutant concentration was calculated to be 4.41E-07 s/m^3.

2.0 Building Wake Effects

The building wake effects will be verified using the input that was specified in Table 7 of the text.

For a downwind distance of 15 m, the length that the recirculation cavity zone extends from the upwind edge of the building is determined using the following expression:

$L_c \approx 0.9R$

where

$R \approx (B_{min})^{0.667}(B_{max})^{0.333}$

where B_{min} is the smaller of H and W and B_{max} is the larger.

For the building

$R_u \approx (10)^{0.667}(20)^{0.333}$

$R_u \approx 12.6$ m

For the penthouse

$R_s \approx (5)^{0.667}(10)^{0.333}$

$R_s \approx 6.3$ m

The total is 18.9 m.

Next a series of tests must be performed as shown in Section 2.3 to determine the correct characteristic length to use for the remainder of the equations. The variable X_S is equal to the length from the release point to the nearest edge of the building (10 m).

The conditions for this problem fell into the second set of criteria which are shown as follows.

(ii) $0.5\,(R_u + R_S) < X_S < 2\,(R_u + R_S)$.
0.5(18.9)<10<2(18.9) is true therefore the recirculation cavity height H_c and location X_c on the upwind portion of the roof are calculated using $R = R_u + R_S$. The top of this cavity region is joined in a straight line with the top of the penthouse to form a high turbulence zone. The cavity height on the Penthouse roof and the downwind high turbulence zone boundary are then calculated using R_S as a scale length.

Since the position that has been chosen is on the upwind portion of the penthouse, R_{total} will be used to determine the cavity height and length as follows:

$H_c = 0.22R_{total}$	$X_c = 0.5R_{total}$
$H_c = 0.22*18.86\text{m}$	$X_c = 0.5*18.86\text{ m}$
$H_c = 4.15\text{ m}$	$X_c = 9.43\text{ m}$

The empirical formula for the length of the wake cavity is:

$$X_r = \frac{A * W}{1 + B\,(W/H)}$$

Two separate combinations of values for A and B are used depending on whether the flow reattaches to the roof and sides of the building. Cases of reattachment occur when the roof cavity length (L_c) is less than the length of the building.

Test to see if $0.9R_{total} < X_c$

0.9 * 18.86 < 20 is true.

For this case A = 1.75 and B = 0.25.

Using

$$X_r = \frac{1.75 * 20\text{ m}}{1 + 0.25\,(20/10)}$$

$X_r = 23.33$ m

Since $X_s < 0.5$ R

$$Z = 0.28 * R * \left[\frac{X}{R}\right]^{0.333}$$

$$Z = 0.28 * 18.86 \text{ m} * \left[\frac{5}{18.86}\right]^{0.333}$$

$Z = 3.39$ m

$Z_{tot} = Z + BHT = 3.39 \text{ m} + 10 \text{ m} = 13.39$ m

Now to determine the relative air concentration

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z U_S}\left[e^{-\left(\frac{(z-h_s)^2}{2\sigma_z^2}\right)} + e^{-\left(\frac{(z+h_s)^2}{2\sigma_z^2}\right)}\right]$$

For D stability 15 m downwind of release location

$$\sigma_y = \frac{\sigma_\theta x}{1 + 0.031(x)^{0.46}} \qquad \sigma_z = 0.06x(1 + 0.0015x)^{-0.5}$$

$$\sigma_y = \frac{0.218 * 15 \text{ m}}{1 + 0.031(15)^{0.46}} \qquad \sigma_z = 0.06 * 15 \text{ m}(1 + 0.0015 * 15)^{-0.5}$$

$$\sigma_y = 2.954 \text{ m} \qquad \sigma_z = 0.890 \text{ m}$$

$$\frac{\chi}{Q} = \frac{e^{-0.5((13.4-20)/0.89)^2} + e^{-0.5((13.4+20)/0.89)^2}}{2 * 3.14 * 2.954 \text{ m} * 0.890 \text{ m} * 6 \text{ m/s}} = 1.13\text{E-}14 \text{ s/m}^3$$

At the remaining distances the calculations are performed in a similar manner. Different equations may be used due to various tests and checks that are performed.

3.0 Building Wake Effects and Plume Rise Verification

A simple building was analyzed along with the effects of plume rise for this hand calculation. For input see Table 9 of text. The calculations for several of the parameters are not shown. The user can refer to the first section of this appendix for sample calculations of these parameters. Determination of all other parameters follows:

Downwind Distance of 30 m.

Plume Rise

Since Fo≤55 and X≤XSTR the increase in plume height is equal to the following:

$$\Delta h_B = 1.6\frac{F_o^{1/3}X^{2/3}}{U} = 1.6\frac{31.33^{1/3}30^{2/3}}{4} = 12.17\text{m}$$

For plume rise due to momentum,

$$XTEST = \frac{27.0*DHMOM}{B1} = \frac{27.0*15.4}{10.4} = 39.88m$$

Since X is less than XTEST

$$\Delta h_m = \left(B1*X*DHMOM^2\right)^{1/3} = \left(10.4*30*15.40^2\right)^{1/3} = 42.02m$$

For a ground level release with no downwash

$$\Delta h = 42.02 + 12.17 = 54.19m$$

Building Effects

Test to see if $0.9R_{total} < X_c$

0.9 * 12.6 < 30 is true.

For this case A = 1.75 and B = 0.25.

Using

$$X_r = \frac{1.75 * 20 \text{ m}}{1 + 0.25\ (20/10)}$$

X_r = 23.33 m

For downwind distances less than the length of the building:

$$Z = 0.27R - 0.1X$$

$$Z = 0.27 * 12.6 - 0.1 * 20 = 1.4\text{m}$$

Z_{tot}=Z+BHT = 10.0 + 1.4 = 11.4 m

The relative air concentration is determined using the following equation:

$$\frac{\chi}{Q}=\frac{1}{2\pi\sigma_y\sigma_z U_S}\left[e^{-\left(\frac{(z-h_e)^2}{2\sigma_z^2}\right)}+e^{-\left(\frac{(z+h_e)^2}{2\sigma_z^2}\right)}\right]$$

For C stability 30 m downwind of release location

$$\sigma_y=\frac{\sigma_\theta x}{1+0.031(x)^{0.46}} \qquad \sigma_z=0.06x(1+0.0002x)^{-0.5}$$

$$\sigma_y=\frac{0.305 * 30\text{ m}}{1+0.031(30)^{0.46}} \qquad \sigma_z=0.08 * 30\text{ m}(1+0.0002 * 30)^{-0.5}$$

$$\sigma_y=7.98\text{ m} \qquad \sigma_z=2.39\text{ m}$$

$$\frac{\chi}{Q}=\frac{e^{-0.5((11.4-54.19)/2.39)^2}+e^{-0.5((11.4+54.19)/2.39)^2}}{2 * 3.14 * 2.39\text{ m} * 7.98\text{ m} * 4\text{ m/s}}=7.66\text{E-73 s/m}^3$$

For a downwind distance of 45 m which is just beyond the building, the calculations are shown below.

For plume rise due to buoyancy with $Fo \leq 55$ and $X \leq XSTR$, the increase in height is

$$\Delta h_B=1.6\frac{F_o^{1/3}X^{2/3}}{U}=1.6\frac{31.31^{1/3}45^{2/3}}{4}=15.95\text{m}$$

Since X>XTEST

$$\Delta h_m=3\times DHMOM=3\times 15.4=46.2m$$

$$\Delta h=15.95m+46.2m=62.15m$$

Building Wake Effects

Since the point X is beyond the building, Z=0.

Now to determine the relative air concentration

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z U_S}\left[e^{-\left(\frac{(z-h_e)^2}{2\sigma_z^2}\right)} + e^{-\left(\frac{(z+h_e)^2}{2\sigma_z^2}\right)}\right]$$

For C stability 45 m downwind of release location

$$\sigma_y = \frac{\sigma_\theta\, x}{1 + 0.031(x)^{0.46}} \qquad \sigma_z = 0.06x(1 + 0.0002x)^{-0.5}$$

$$\sigma_y = \frac{0.305 * 45\ \text{m}}{1 + 0.031(45)^{0.46}} \qquad \sigma_z = 0.08 * 45\ \text{m}(1 + 0.0002 * 45)^{-0.5}$$

$$\sigma_y = 11.66\ \text{m} \qquad \sigma_z = 3.58\ \text{m}$$

$$\frac{\chi}{Q} = \frac{e^{-0.5((62.15)/3.58)^2} + e^{-0.5((62.15)/3.58)^2}}{2 * 3.14 * 3.58\ \text{m} * 11.66\ \text{m} * 4\ \text{m/s}} = 9.51\text{E-69 s/m}^3$$

For a downwind distance of 100 m.

For plume rise due to buoyancy and since Fo≤55 and X≤XSTR the increase in plume height is

$$\Delta h_B = 1.6\frac{F_o^{1/3}X^{2/3}}{U} = 1.6\frac{31.31^{1/3}100^{2/3}}{4} = 27.16\text{m}$$

Since X>XTEST

$$\Delta h_m = 3 \times \text{DHMOM} = 3 \times 15.4 = 46.2\text{m}$$

$$\Delta h = 27.16\text{m} + 46.2\text{m} = 73.36\text{m}$$

Building Wake Effects

Since the point X is beyond the building, Z=0.

Now to determine the relative air concentration

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z U_S}\left[e^{-\left(\frac{(z-h_e)^2}{2\sigma_z^2}\right)} + e^{-\left(\frac{(z+h_e)^2}{2\sigma_z^2}\right)}\right]$$

For C stability 100 m downwind of release location

$$\sigma_y = \frac{\sigma_\theta x}{1 + 0.031(x)^{0.46}} \qquad \sigma_z = 0.06x(1 + 0.0002x)^{-0.5}$$

$$\sigma_y = \frac{0.305 * 100\ m}{1 + 0.031(100)^{0.46}} \qquad \sigma_z = 0.08 * 100\ m(1 + 0.0002 * 100)^{-0.5}$$

$$\sigma_y = 24.28\ m \qquad \sigma_z = 7.92\ m$$

$$\frac{\chi}{Q} = \frac{e^{-0.5((73.36)/7.92)^2} + e^{-0.5((73.36)/7.92)^2}}{2 * 3.14 * 7.92\ m * 24.28\ m * 4\ m/s} = 9.70E\text{-}23\ s/m^3$$

For a downwind distance of 500 m.

For plume rise due to buoyancy, using the parameters shown in Figure A2 and since $Fo \leq 55$ and $X \geq XSTR$

$$\Delta h_B = 1.6\frac{F_o^{1/3} XSTR^{2/3}}{U} = 1.6\frac{31.31^{1/3} 421.69^{2/3}}{4} = 70.90m$$

Since X>XTEST

$$\Delta h_m = 3 \times DHMOM = 3 \times 15.4 = 46.19m$$

$$\Delta h = 70.90m + 46.19m = 117.09m$$

Building Wake Effects

Since the point X is beyond the building, Z=0.

Now to determine the relative air concentration

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z U_S}\left[e^{-\left(\frac{(z-h_e)^2}{2\sigma_z^2}\right)} + e^{-\left(\frac{(z+h_e)^2}{2\sigma_z^2}\right)}\right]$$

For C stability 500 m downwind of release location

$$\sigma_y = \frac{\sigma_\theta x}{1 + 0.031(x)^{0.46}} \qquad \sigma_z = 0.06x(1 + 0.0002x)^{-0.5}$$

$$\sigma_y = \frac{0.305 * 500 \text{ m}}{1 + 0.031(500)^{0.46}} \qquad \sigma_z = 0.08 * 500 \text{ m}(1 + 0.0002 * 500)^{-0.5}$$

$$\sigma_y = 99.13 \text{ m} \qquad \sigma_z = 38.13 \text{ m}$$

$$\frac{\chi}{Q} = \frac{e^{-0.5((117.09)/38.13)^2} + e^{-0.5((117.09)/38.13)^2}}{2 * 3.14 * 99.13 \text{ m} * 38.13 \text{ m} * 4 \text{ m/s}} = 1.88\text{E-07 s/m}^3$$