POWER AUTHORITY OF THE STATE OF NEW YORK
JAMES A. FITZPATRICK NUCLEAR POWER PLANT
DOCKET #50-333

DISPERSION MODEL DESCRIPTION
FOR THE
JAMES A. FITZPATRICK/NINE MILE POINT NUCLEAR STATIONS

INTRODUCTION

Appendix E to 10 CFR Part 50 requires licensees to maintain the capability for determining the magnitude of and assessing the impact of the release of radioactivity. Provided herein is a description of the major attributes of the atmospheric transport and diffusion assessment software which will be used at the Nine Mile Point/James A. Fitzpatrick Nuclear Power Plants.

The atmospheric dispersion model will be capable of providing dosage estimates and plume characterization (plume dimensions and location, magnitude of and arrival time of peak relative concentrations) within the Emergency Preparedness Zone (50 miles) or for travel periods of three hours. The model will perform validation of meteorological data and alert operators to possible meteorological tower malfunctions. The model will also alert the operator if certain predetermined criteria are exceeded (e.g. EPA protective action guidelines).

Calculations are performed by using a puff advection model for atmospheric dispersion. Site specific aspects of the model include:

- a lake breeze algorithm utilizing onsite data
- a wind field alogrithm utilizing onsite and offsite data
- incorporating the split sigma approach
- applying an approach for using σ_θ (standard deviation of wind direction fluctuation) under stable conditions and light winds
- site specific power laws to estimate missing wind speeds
- building wake effects
- source locations

The model will continuously sample and process meteorological and release data. Meteorological data will be averaged over a 15 minute time span. Additionally, σ_θ is computed on a running three minute average based upon wind direction data. Meteorological data will be stored in a working file for three hours and updated once every 15 minutes. The model will be capable of accepting either manual or automatic input of release data. Although the model uses real time, meteorological and release data, provisions have been made for inputting projected release or meteorological data. This gives personnel the capability of predicting dispersion of radionuclides due to controlled or uncontrolled release with actual or predicted meteorology.

The model will calculate values for X/Q for the sector of interest for 15 minute, 1 hour, 3 hour and 6 hour time periods. Using these X/Q values, dosages for the isotopes listed in Table 1 will be calculated. Whole body, skin, and inhalation doses due to immersion in a cloud will be calculated. Additionally, ground deposition concentration of iodine and particulates and whole body doses due to deposited activity will be computed.

TABLE 1

LISTING OF RADIONUCLIDES CONSIDERED IN DISPERSION MODELING

FOR THE NINE MILE POINT

AND THE

J.A. FITZPATRICK NUCLEAR STATIONS

Type	Radionuclide	Whole Body	Skin Immersion	Inhalation	Ground Deposition
Noble gases	Kr-83M	X	X		
	Kr-85M	X	X		
	Kr-87	X	X		
	Kr-88	X	X		
	Xe-133	X	X		
	Xe-135m	X	X		
	Xe-135	X	X		
	Xe-138	X	X		
Iodines	I-131	X	X	X	X
	I-132	X	X	X	
	I-133	X	X	X	
	I-134	X	X	X	
	I-135	X	X	X	
Tritium	H-3			X	X
Particulates	Mn-54				X
	Co-58				X
	Co-60				X
	Fictional	X	X		
	Fe-59				X
	Zn-65				X
	Sr-89				X
	Sr-90				X
	Sb-125				X
	Te-132	X	X	X	
	Cs-134				X
	Cs-136				X
	Cs-137				X
	Ba-140				X
	La-140				X

The model will also be capable of providing the following displays:

- graphical map output of the area showing Emergency Response Planning Area (ERPA'S) and contours of whole body dose
- graphical display of the wind field
- graphical display of isotopic source distribution
- tabular displays depicting plume travel time, the arrival time of the concentrations and their values, dose rates, and whole body, skin and thyroid organ integrated doses for 2, 5, 10 and 50 mile radius areas.
- graphical map output showing ERPAs and plume for real time and predicted 1, 3 and 6 hours on 2, 5, 10 and 50 mile radius display.

SECTION 2.0

PUFF ADVECTION MODEL

The puff advection concept assumes that a continuous plume can be broken into an infinite number of individual puffs of infinitesimal source strength which have been serially released. The advection of the continuous plume is defined by the movement of each component puff. This movement is in turn controlled by a wind field which can vary in both time and space. Diffusion of the continuous plume is defined by the growth of each component puff. The concentration at a specific receptor point is obtained through the integration of the contribution of all puffs in the vicinity of the point. Additional details of the model formulation are given below.

2.1 PLUME ADVECTION

Plume advection will be calculated using 15-minute averages of wind speed and wind direction taken from the towers in the site meteorological system and from meteorological data taken at other appropriate stations. This allows the use of data taken from Albany and Buffalo or other stations on a case-by-case basis if required. This will be accomplished by inputting all of the available meteorological data into a site-specific algorithm which estimates the wind flow at the center of each puff. This algorithm is discussed below. For missing parameters, the following replacement procedures will be used.

For missing wind speed in order of preference:

1. the backup system wind speed will be used to replace missing lower level wind speed, or

2. a site-specific wind power law will be used in conjunction with data from operable instruments to estimate the missing wind speed.

If wind direction is missing then in order of preference either:

1. the backup system wind direction will be used to replace missing lower level wind, or direction.

2. a site-specific vertical wind shear value will be used in conjunction with data from operable instruments to estimate the missing wind direction.

The power law and shear estimate will incorporate an index of stability class and will be based upon a statistical analysis of at least one year of on-site data. Following U.S. Nuclear Regulatory Guide 1.111, a wind speed of half the anemometer starting speed will be assigned to calm conditions. Calm wind speeds will not be included in the statistical analysis. Wind speed power law coefficients and vertical wind shear coefficients will be developed for each stability class.

Puffs will be released at 15-minute intervals and tracked to calculate plume advection. Horizontal puff coordinates will be referenced to a cartesian system centered on the plant (0,0) and oriented with north-south (y) and east-west (x) axes. Vertical puff coordinates (z) will be referenced to mean sea level (MSL).

Puff coordinates are updated using the following equations:

$$x_N = x_O + U \Delta t \quad (1)$$

$$y_N = y_O + V \Delta t \quad (2)$$

$$z_N = z_O + W \Delta t \quad (3)$$

where x is the easterly coordinate, y is the northerly coordinate, z is the vertical coordinate, the subscripts N and O represent new and old, respectively, U is the easterly wind speed component, V is the northerly wind speed component, W is the vertical velocity of the plume as determined from the wind field and plume dynamics, and Δt is the length of the advection step (15 minutes in this case). Note that the wind speed components will be estimated by the site-specific algorithm for the end points of the plume segments in a wind field which varies in time and space.

2.2 PLUME DIFFUSION

The diffusion of the continuous plume will be calculated in terms of the growth of puffs which are released every 15 minutes. The growth of each puff will be calculated using the following equation:

$$\sigma_N = \sigma_S (x_v + \Delta x, i) \quad (4)$$

where σ represents either σ_y or σ_z, x_v represents the virtual plume dispersion distance, i represents the current stability class, Δx represents the distance the puff has traveled during the advection step (e.g., $(U^2 + V^2)^{1/2} \Delta t$). The subscripts N and S represent new and standard, respectively; σ_S represents the equations for the standard NRC Pasquill-Gifford dispersion curves (Eimutis, 1972). The virtual distance used in equation (4) is defined by:

$$x_v = F(\sigma_O, i) \quad (5)$$

where F is the functional inverse of σ_S and σ_O is plume dispersion parameter at the end of the prior advection step.

For ground level and mixed mode releases (as per RG 1.111) the vertical dispersion parameter, σ_z, will be modified for the building wake effect prior to the calculation of relative concentration using the following equation:

$$\Sigma_z = \min((\sigma_z^2 + 0.5 A^2/\pi)^{1/2}, \sqrt{3}\,\sigma_z) \quad (6)$$

where σ_z is the modified value and H is the maximum adjacent building height in the vicinity of release. This formulation will also be used when the plume is entrained into the wake of the cooling water currently under construction for Nine Mile Point Unit 2.

The split sigma approach to the calculation of stability class is used. Standard criteria as outlined in proposed revision 1 to Regulatory Guide 1.23 for $\Delta T/\Delta Z$ will be used to determine the stability class for calculation of σ_z. The calculation of σ_y will be based upon the stability class determined from σ_θ. Criteria will be incorporated which will allow the use of the σ_θ stability class in the calculation of σ_y during very stable low wind speed conditions. This will be accomplished by using a smaller averaging time in the calculation of σ_θ.

2.3 CALCULATION OF RELATIVE CONCENTRATION

The locus of the centers of all puffs released at 15-minute intervals defines the plume centerline. The portion of the plume centerline between one puff and the next puff is referred to as a plume segment. The relative concentration at a particular receptor point (x_g, y_g) is calculated as the sum of the contributions of each plume segment to the receptor point.

In this application the contribution of a plume segment to the receptor point (x_g, y_g) will be calculated using the following equation.

$$\frac{\chi}{Q} = \frac{1}{\sqrt{2\pi}\,\sigma_y} \exp\left(-0.5 \left(\frac{y_g'}{\sigma_y}\right)^2\right) G \phi \qquad (7)$$

where G is an edge effect term given by:

$$G = 0.5 \left(\operatorname{erf} \frac{x_g'}{\sqrt{2}\,\sigma_y} + \operatorname{erf} \frac{D - x_g'}{\sqrt{2}\,\sigma_y} \right) \qquad (8)$$

and ϕ is a vertical dispersion term defined by:

$$\phi = \frac{2}{\sqrt{2\pi}\,\sigma_z} \exp\left(-0.5 \left(\frac{H + Z_p - Z_t}{\sigma_z}\right)^2\right) \qquad (8a)$$

where H is the plume height, Z_p is the elevation of the plant (MSL). This particular form for the vertical dispersion term assumes total plume reflection in conjunction with variations in topography. This particular form for the vertical term is used for non lake breeze conditions. The specific formulation of ϕ for use during lake breezes is discussed later. H will be calculated using the formulation of Briggs plume as presented in Regulatory Guide 1.111.

The point (x_g', y_g') represents the coordinates of the receptor point in a new coordinate system which has been translated to the coordinates of the puff which define the start of the plume segment and has been rotated in a manner which orients the x' axis with the plume centerline in the downwind direction. D represents the length of the plume segment, σ_y and σ_z are the horizontal and vertical dispersion parameters, and V* is given by:

$$V^* = D/\Delta t$$

In this application it should be noted that D, the length of a plume segment, is a function of time because the net effect of horizontal wind shear is to cause a stretching of the plume (e.g. end point puffs move relative to one another). The variation of the dispersion parameters along the plume segment centerline will be calculated using the values of the dispersion parameters of the puffs which bound the plume segment. This calculation will be made using a power law interpolation.

Plume depletion estimates and deposition rate estimates will be calculated by multiplying the results obtained using equation (7) by the factors contained in U.S. NRC Regulatory Guide 1.111. Relative concentration, decayed relative concentration and depleted relative concentration and deposition rate will be output as appropriate for use in dosage calculations.

The model will be structured to accept input of wind speed and direction from several wind sensors which are located within 50 miles of the site. The model will use an interpolation algorithm to estimate wind fields from sensor data. The specifics of the algorithm are given below.

Let (x,y) represent the point at which the horizontal wind is required and r_m represent the distance between this point and the meteorological station. The interpolation algorithm utilized in this model consists of two distinct steps. The first step is defined by the following relationship:

$$\vec{V} = \sum_m w_m \vec{V}_m$$

where $\vec{V}$ is the estimated horizontal wind vector at point (x,y,z), $\vec{V}_m$ is the horizontal wind vector at the m[th] station, the summation runs over meteorological stations which satisfy the following constraint:

$$r_m < r_c$$

where r_c is the site-specific cutoff distance.

Vertical variation of $\vec{V}_m$ will be modeled using site-specific power laws.

The weight, w_m is selected in a fashion which makes the interpolation a weighted average, thus

$$\sum_m w_m = 1, \quad (0 < w_m < 1)$$

and w_m is taken to be inversely proportional to r_m

$$w_m = c\, r_m^{-1}$$

where c is defined by

$$c = \left(\sum_m r_m^{-1}\right)^{-1}$$

This step of the interpolation algorithm has the following advantages:

- The algorithm returns the wind vector at the sensor when the position of the point is conincident with sensor (i.e. when $r_m = 0$).
- The algorithm gives a higher weight to sensors which are closer to the point where the wind vector is required. This is consistent with observations of spacial correlation coefficients which show a decline with distance.

The second step of the interpolation procedure is to adjust the wind field $\bar{V}$ to render it both nondivergent and mass consistant. This is accomplished by calculating the vertical component of $\bar{V}$ using the continuity equation and then by the application of a relaxation procedure which modifies the horizontal components of $\bar{V}$ to insure that

$$|\nabla \cdot \bar{V}| \leq c_d$$

where c_d is on the order 10^{-5} and represents the maximum error in divergence acceptable in the nondivergence flow.

2.4 CALCULATION OF RELATIVE CONCENTRATIONS IN SHORELINE ENVIRONMENTS

The incorporation of a formulation of a lake breeze fumigation algorithm is based upon the work of Lyons, et al (1981), Schuh (1975), Wiese [illegible] Hirt (1975) and others. The approach is two-tier in that meteorological conditions are first checked for the existence of a lake breeze and the Thermal Internal Boundary Layer (TIBL). A modified version of equation (7) is then used to calculate relative concentrations and associated doses if the conditions of lake breeze fumigatin exist.

Figure 1 illustrates the checks which will be made prior to the use of the modified lake breeze formulation. These checks involve the time of day, wind speed, wind direction and the land-lake temperature differential.

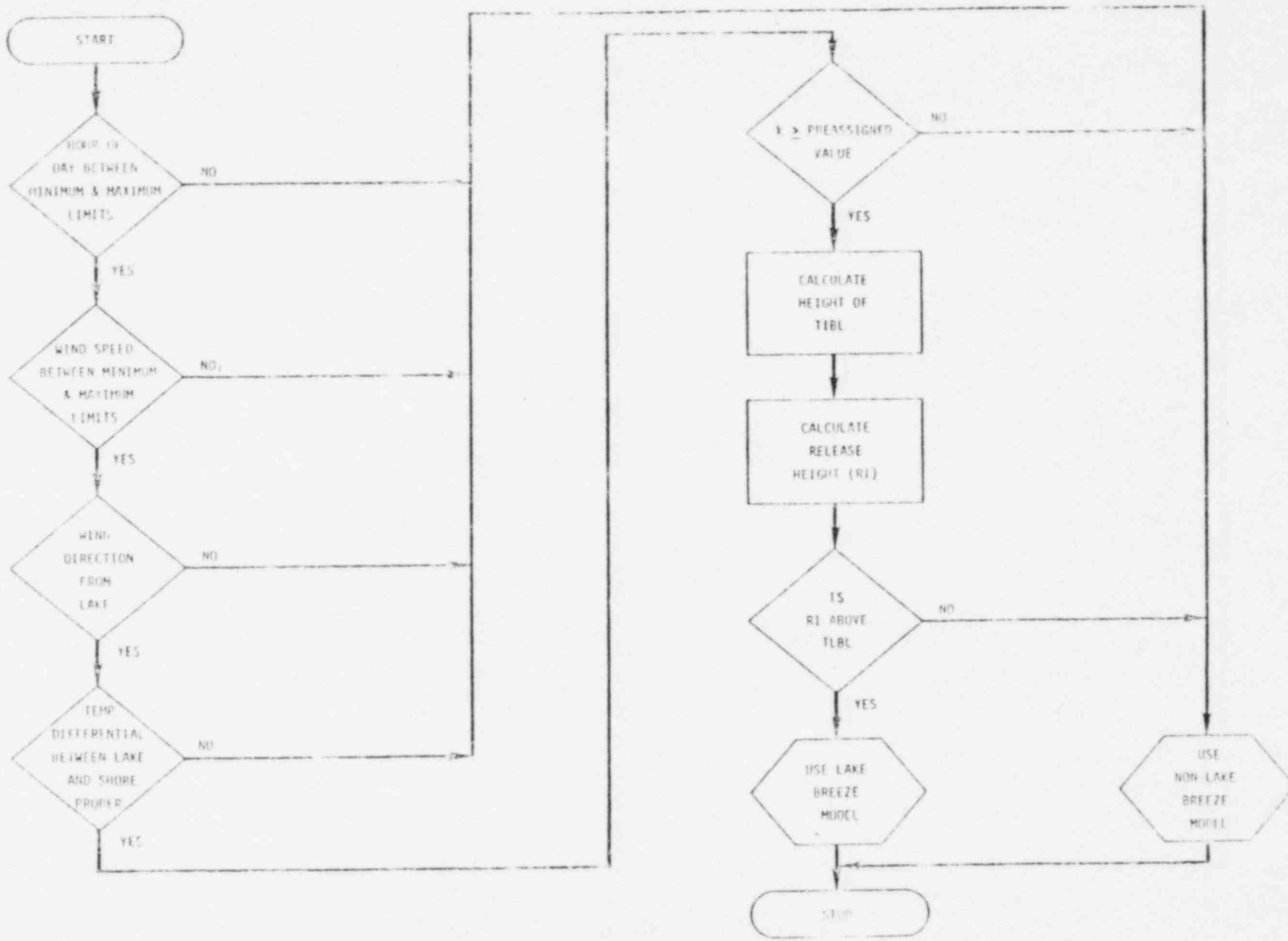


Figure 1. Lake Breeze Criteria

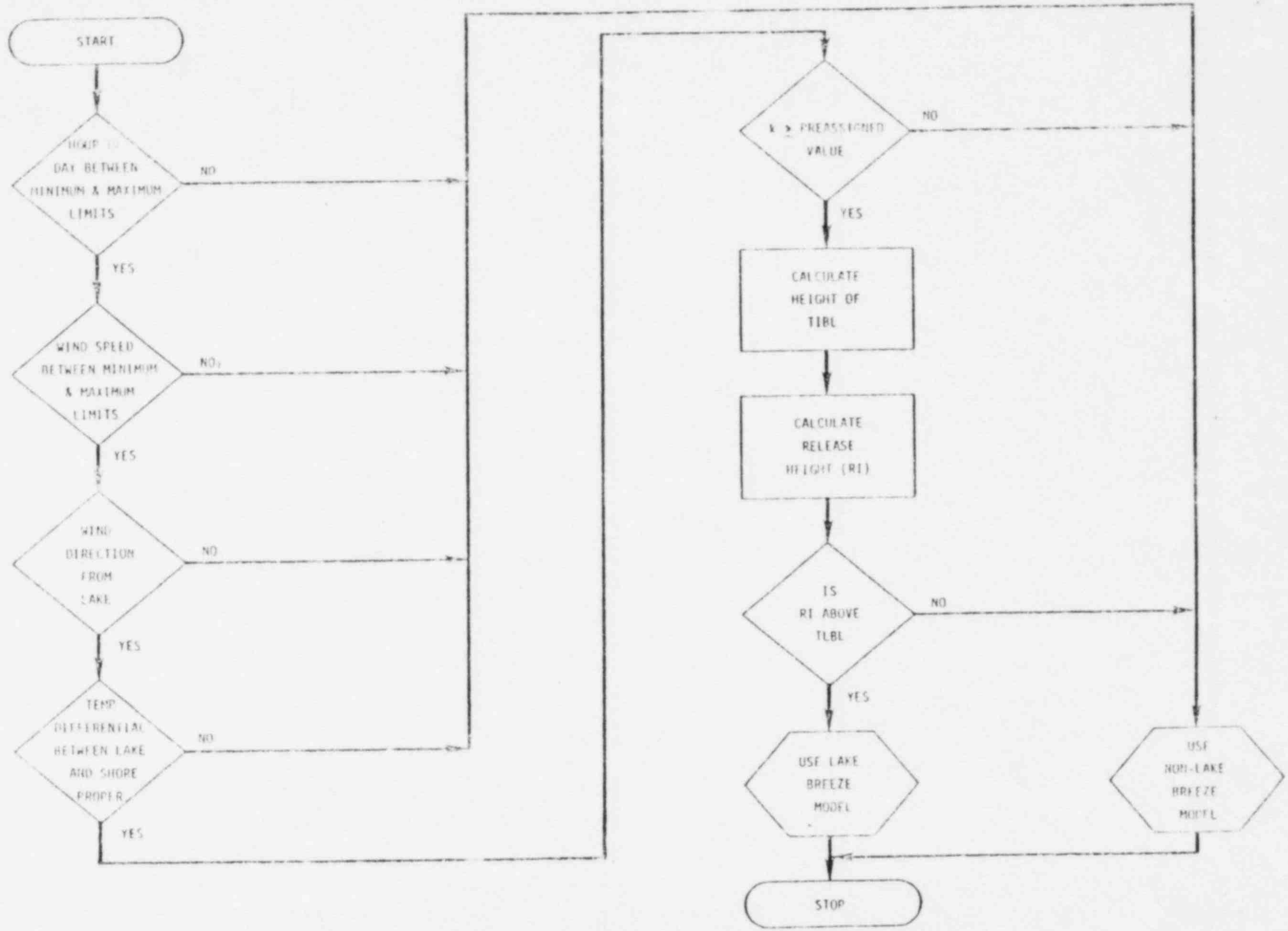


Figure 1. Lake Breeze Criteria

The three components of the lake breeze dispersion algorithm are (1) a model for the prediction of TIBL height and shape as a function of meteorological and downwind distance, (2) a modified dispersion equation and (3) an algorithm which determines where the plume is relative to the TIBL and how the dispersion equations should be applied.

Weisman and Hirt (1975) and Lyons have developed equations for determining the height of the TIBL. Weisman and Hirt's equation is acceptable for TIBL application since it is based on average wind speed and the lake-land temperature difference. The Lyons equation is a simple adaptation of the fundamental theory describing the growth of the convection layer.

The Weisman and Hirt TIBL equation is:

$$L(x) = f(U, \Delta T)x^{n} \qquad (9)$$

where,

$L(x)$ = the height of the TIBL as a function of downwind distance.

$f(U, \Delta T)$ = a function of mean wind speed U and the difference in lake surface temperature from daily maximum, ΔT.

x = downwind distance.

$n = 0.5$

The function f is related to the parameter $\bar{U}^2/C_p$ T empirically.

The modification of the dispersion equation for the lake breeze fumigation condition is essentially a simple change to the vertical term in equation (8):

$$\text{[illegible]}_1 = \frac{1}{\sqrt{2\pi}\, L} \int_{-\infty}^{q} \exp\left(- \left(\frac{p^2}{2}\right)\right) dP \qquad (10)$$

where,

$$q = \frac{L-H}{\sigma_z} \qquad (11)$$

and H is the equilibrium plume height. This approach is based upon Lyons (1981).

Figures 2 and 3 (Schuh 1975, and Lyons 1981) present the geometry of the plume in a lake breeze situation. Two basic cases must be considered:

1. plume equilibrium height is below the TIBL, and
2. plume equilibrium height is above the TIBL.

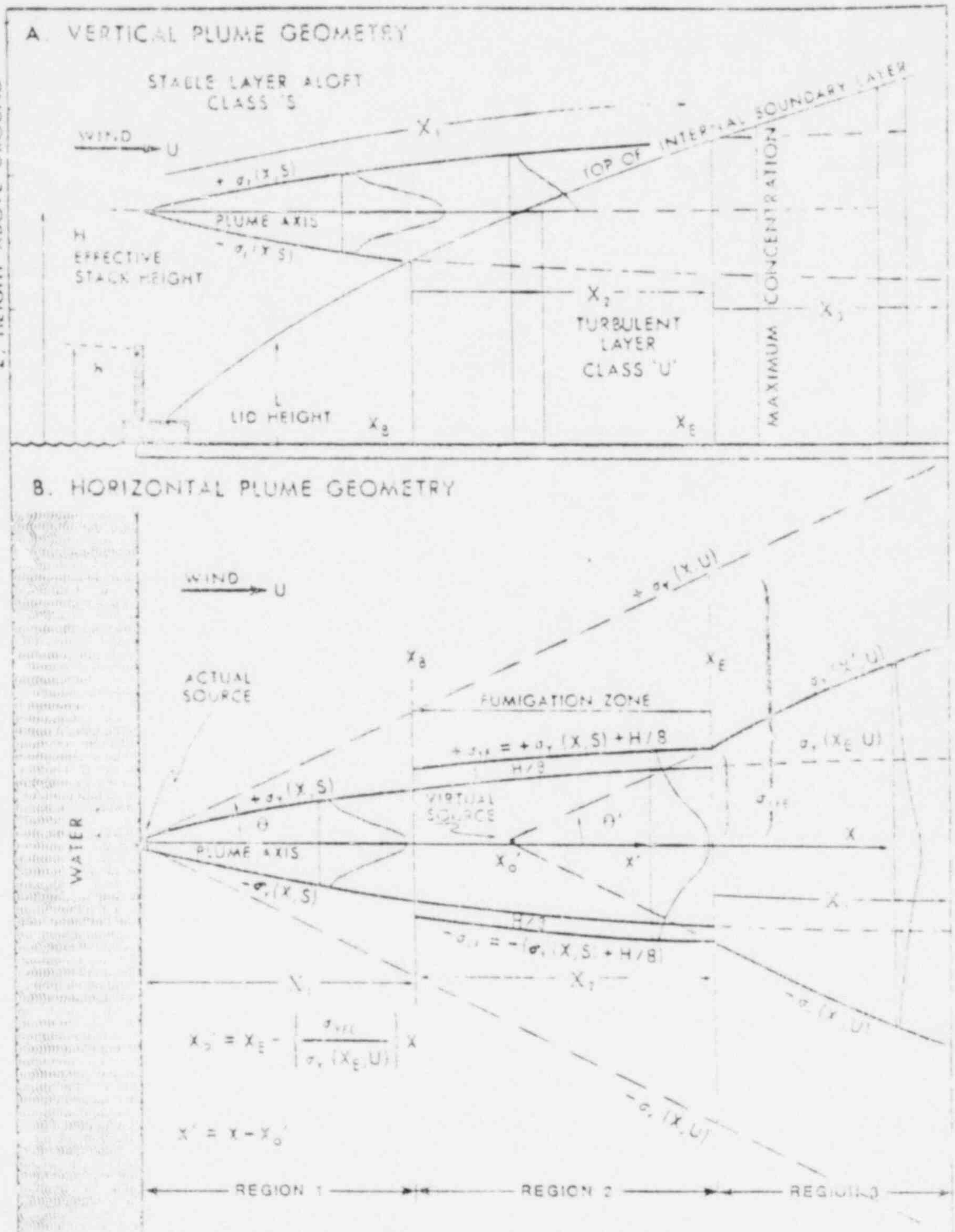
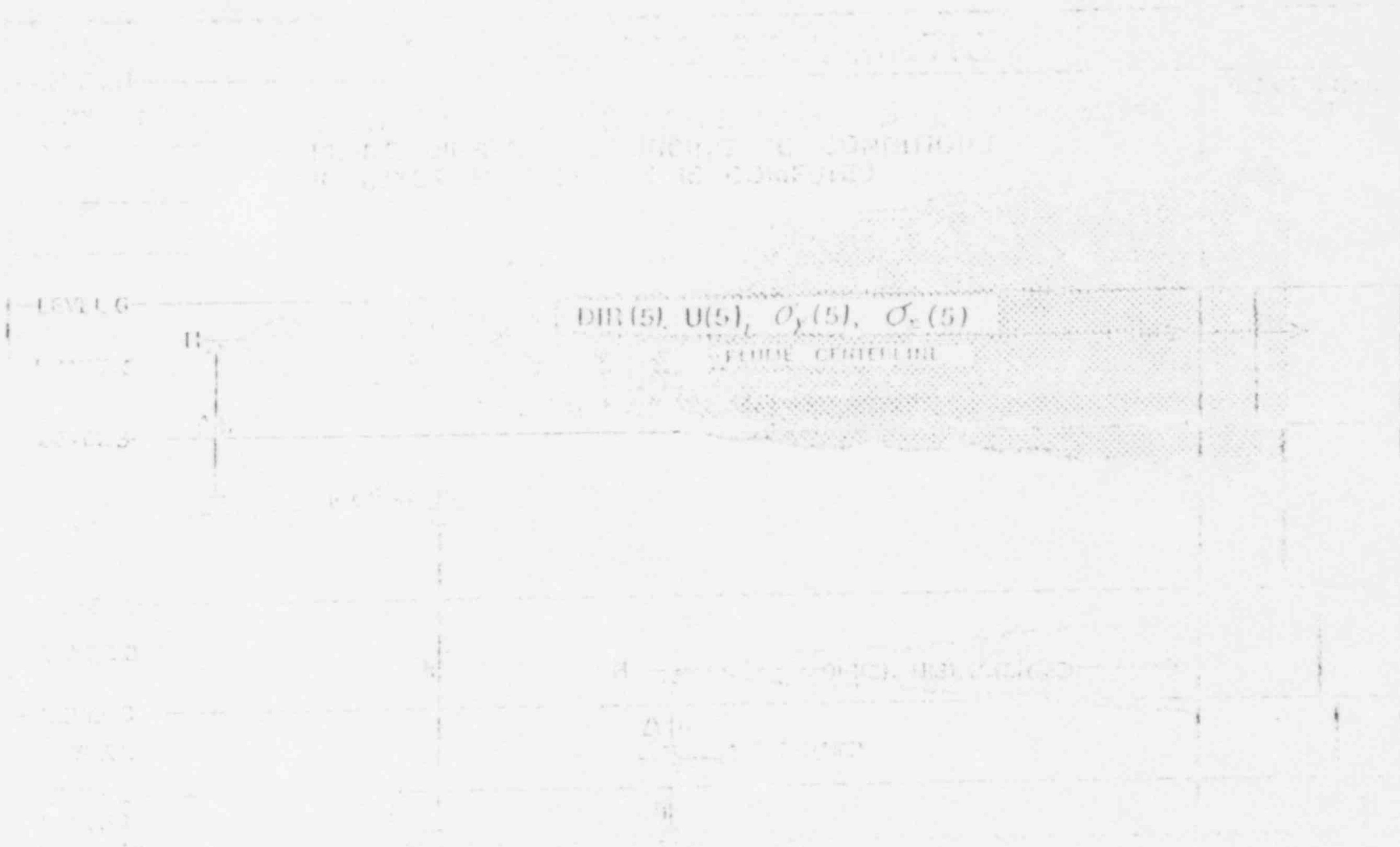


Figure 2. Plume Geometry in Lake Breeze Fumigation Situation (Figure 13 from Lyons and Cole 1973)



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