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May 9, 1984
LIC-84-053

Mr. James R. Miller, Chief
U. S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Division of Licensing
Operating Reactors Branch No. 3
Washington, D. C. 20555

Reference: Docket No. 50-285

Dear Mr. Miller:

Class A/B Site-Specific
Atmospheric Diffusion Model

Please find attached a description of Omaha Public Power District's site-specific Class A/B atmospheric diffusion model. This description is being submitted pursuant to Appendix 2 - Annex 1(7) - of NUREG-0654. This model is a combination of Class A (to be used out to the plume exposure EPZ) and Class B (to be used out to the plume ingestion EPZ) models. Please note the District's Class A/B model is currently in operation and was utilized for dose assessment functions during the 1983 annual exercise.

Sincerely,

W. C. Jones
Division Manager
Production Operations

WCJ/JJF/nh

Attachments

cc: LeBoeuf, Lamb, Leiby & MacRae
Mr. E. G. Tourigny, NRC Project Manager
Mr. L. A. Yandell, NRC Resident Inspector

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Description of Atmospheric Diffusion Model

The site-specific atmospheric diffusion model is designed to provide diffusion estimates for gaseous effluent releases from the Fort Calhoun Station using actual 15-minute average, on-site meteorological data. This base model is a Gaussian "segment-plume" model. This model is a combination of Class A (to be used out to the plume exposure EPZ) and Class B (to be used out to the ingestion EPZ) models as outlined in Appendix 2 (page 2-3) of NUREG-0654.

The "segment-plume" model is a variable trajectory model based on the statistical approach to diffusion. The model allows the deformation of a continuous plume by dividing the plume into a number of contiguous segments. Each plume segment describes a portion of plume behavior between successive time intervals with advection by the local wind field and diffusion in a Gaussian fashion. Ground-level concentrations and depositions are calculated by determining the contribution each plume segment makes to the grid of receptors over which it passes.

The "segment plume" model is one class of the plume element models identified in Regulatory Guide 1.111. The basic model has the capability to account for both ground and elevated modes of effluent releases, buoyancy and momentum plume rise, building wake influence, terrain interaction, and dry deposition. Detailed descriptions of the "segment-plume" concept and modeling algorithms for the Fort Calhoun Station emergency preparedness accident assessment are presented below.

A. BASIS OF THE SEGMENT-PLUME MODEL

The fundamental basis for the "segment-plume" model is an integral mass balance over a finite plume segment. Mathematically, the conservation of mass over a plume segment of length can be expressed by the following mass balance equation:

$$\Delta Q = \int_{0}^{\infty}\int_{-\infty}^{\infty} \{G(s,r,z)drdz\}ds$$

$$+ \int_{0}^{\infty}\int_{-\infty}^{\infty} u\chi drdz\Big|_{s+\Delta s} - \int_{0}^{\infty}\int_{-\infty}^{\infty} u\chi drdz\Big|_{s} \qquad (1)$$

Where s, r, and z are the longitudinal, lateral, and vertical plume coordinates, G(s,r,z) is the rate of change (gain-loss) of effluent concentration $\chi(s,r,z)$ by decay and removal processes, ΔQ is the resultant rate of change of effluent mass, and u is the wind speed. Assuming a quasi-steady state, G(s,r,z) and u are considered to be constant from s to $s+\Delta s$, where s is the current distance of a plume segment endpoint from the release point, measured along the plume axis.

Two possible vertical concentration distribution functions can be chosen in the model for diffusion estimates: Case 1; a vertical Gaussian profile, ignoring any effects of the mixing depth; or Case 2; a uniform vertical distribution below the mixing lid.

For Case 1, the ground-level concentration (s,r) of a plume segment is calculated by:

$$\chi(s,r) = \frac{Q(s)}{\pi u \sigma_z(s)\sigma_y(s)} \exp\left[\frac{-r^2}{2\sigma_y^2}\right] \exp\left[\frac{-h_e^2}{2\sigma_z^2}\right] \qquad (2)$$

Where $Q(s)$ is the effluent mass flux, h_e is the effective plume height, and $\sigma_y(s)$ and $\sigma_z(s)$ are, respectively, the lateral and vertical dispersion coefficients at downwind distance s. Full reflection from the ground is assumed.

For Case 2, if the effective plume height lies below the mixed lid H_m, the ground-level concentration of the plume segment is calculated by the expression for uniform vertical mixing:

$$\chi(s,r) = \frac{Q(s)}{2\pi u H_m \sigma_y(s)} \exp\left[\frac{-r^2}{2\sigma_y^2}\right] \qquad (3)$$

Where H_m is the mixing depth encountered by the plume segment. If the plume centerline lies above the mixing lid, no ground-level concentrations are calculated.

The computational scheme of the "segment-plume" model has three distinct functional elements: (1) a Lagrangian plume trajectory function, (2) a plume dispersion function, and (3) a plume sampling function.

The Lagrangian plume trajectory function is used to advect the endpoints of each plume segment during a basic time step; the resultant distance between consecutive endpoints defines the length of each plume segment. In a temporally-varying but spatially-homogeneous wind field, the position of the endpoint from the source can be expressed mathematically by the following equation:

$$s(t+\Delta t) = s(t) + u(t+\Delta t)\Delta t \qquad (4)$$

The plume dispersion function determines the horizontal spread of a plume along its trajectory by the following equation:

$$\sigma y(s+\Delta s) = \sigma y(s) + \Delta s\left[\frac{d\sigma y}{ds}\right]_{s+\Delta s/2} \quad (5)$$

$$\sigma z(s+\Delta s) = \sigma z(s) + \Delta s\left[\frac{d\sigma z}{ds}\right]_{s+\Delta s/2} \quad (6)$$

These terms allow for spatial and temporal changes in atmospheric stability to be included, without violating the entropy principle (centerline concentrations cannot increase with downwind distance).

The set of equations (1) through (6) provides the theoretical framework of the "segment-plume" model under a temporally-varying but spatially-homogeneous meteorological field. Under steady-state conditions, the model should yield the same results as the straight-line Gaussian dispersion model.

B. MAJOR FEATURES OF THE MODEL

The site-specific atmospheric diffusion model is based on the Gaussian "segment-plume" concept. The model combines and enhances various dispersion modeling algorithms into the computer program that can be used to provide near real-time diffusion estimates during a radiological emergency condition and to determine the dimension and location of the plume trajectory, and the location and magnitude of maximum concentrations and depositions for each 15-minute time interval. The model

uses a time-dependent, homogeneous wind field as meteorological input. Major features of the model are described below.

B.1 Release Mode

Two types of source release modes are considered: elevated release and ground-level release. The elevated release consists of any release in which the effective release height is higher than twice the height of an adjacent solid structure. The ground-level release includes all releases with a release height of less than twice the height of the tallest adjacent structure. In practice, the release height for the ground-level release is assumed to be at the 10-meter level above the ground.

B.2 Atmospheric Dispersion Coefficients

The atmospheric dispersion coefficients used in the model calculations are based on the Pasquill-Gifford's curves presented on Figures 1 and 2 of Regulatory Guide 1.145. As indicated in these two figures, the horizontal and vertical dispersion coefficients, σy and σz, without building wake effects are restricted to no greater than 10,000 and 3,000 meters, respectively. The following approximations are used to estimate the atmospheric dispersion coefficients under extremely stable atmospheric conditions (Pasquill stability class G):

$$\sigma y(G) = 2/3\ \sigma y(F) \tag{7}$$

$$\sigma z(G) = 3/5\ \sigma z(F) \tag{8}$$

The atmospheric dispersion coefficients are calculated for each plume segment in a given time period using Equations (5) and (6), based on the values they had for that plume segment in the previous time period. Since the atmospheric stability may change during real-time dispersion, the derivative terms in these two equations account for the growth of a plume as a function of travel distance along the plume trajectory for each specified time interval.

B.3 Building Wake Adjustment

The building wake adjustment is applied to ground-level releases only and follows the formulation stipulated in Regulatory Guide 1.111. This formulation is expressed by:

$$\sigma y' = (y + CA/\pi)^{1/2} \quad (9)$$

$$\sigma z' = (z + CA/\pi)^{1/2} \quad (10)$$

Where:

$\sigma y'$, $\sigma z'$ are modified horizontal and vertical dispersion coefficients accounting for building-induced turbulence, respectively;

σy, σz are Pasquill-Gifford horizontal and vertical dispersion coefficients without building influence, respectively;

C is building shape factor (C = 0.5); and

A is minimum vertical-plane cross-sectional area of the reactor building.

B.4 Effective Plume Height

For elevated releases, the effective plume height is calculated from:

$$h_e = h_s + \Delta h - h_t - c \qquad (11)$$

Where:

h_e is the effective plume height;

Δh is the final rise of the plume above the release point;

h_s is the physical stack/vent height;

h_t is the terrain height between the release point and the point for which the calculation is made (h_t must be greater than or equal to zero); and

c is the correction term for stack downwash

When the vertical exit velocity is less than 1.5 times the horizontal wind speed, a correction for stack downwash is subtracted from Equation (11) by the following equation:

$$c = 3(1.5 - W/u)d \tag{12}$$

Where:

- d is the inside diameter of the stack/vent release point;
- u is the mean wind speed at the height of release; and
- W is the vertical exit velocity of the plume.

Both the momentum and buoyancy aspects of the plume rise is incorporated into the model using Brigg's formulae. The higher final plume rise due to either its momentum or buoyancy effect is used in the atmospheric diffusion calculations.

For neutral or unstable conditions, the final momentum plume rise is calculated from:

$$\Delta h_m = \Delta h_1 = 3.0(W/u)d \tag{13}$$

For stable conditions, the final momentum plume rise is calculated from:

$$\Delta h_m = \min(\Delta h_1, \Delta h_2, \Delta h_3) \tag{14}$$

With

$$\Delta h_2 = 4(F_m/s)^{1/4}$$

$$\Delta h_3 = 1.5(F_m/u)^{1/3} \quad s^{-1/6}$$

$$F_m = 0.25(Wd)^2$$

$$s = g/T \; \sigma\theta/\sigma z$$

Where

Δh_m is the final plume rise due to the momentum of the plume;

F_m is the momentum flux parameter;

s is the stability parameter;

T is the ambient temperature;

g is the acceleration of gravity; and

θ is the ambient potential temperature.

For unstable or neutral conditions, the buoyant plume rise, Δh_b, is calculated from:

$$\Delta h_b = 1.6 \; F^{1/3} \; (5\overline{x})^{2/3} \; u^{-1} \qquad (15)$$

With $F = 4.3 \times 10^{-3} Q_h$

and $\overline{x} = 0.52 F^{0.4} h_s^{0.6}$

Where

Δh_b is the final plume rise due to buoyancy of the plume;

h_s is the stack or vent height;

Q_h is the effluent heat flux; and

F is the buoyancy flux parameter.

Under stable conditions, Δh_b is defined by:

$$\Delta h_b = 2.9(F/us)^{1/3} \qquad (16)$$

B.5 Vertical Variation of Wind Speed

The vertical variation of wind speed with height is calculated by the following power-law relationship:

$$u = u_m (z/z_m)^p \qquad (17)$$

Where

u is the wind speed at height z;

u_m is the wind speed at the sensor height z_m; and

P is the power law exponent which is stability dependent.

Values of P as a function of atmospheric stability are taken from: DeMarrais, G.A., 1959; "Wind Speed Profiles at Brookhaven National Laboratory", Journal of Applied Meteorology, Vol. 16, pp. 181-189.

B.6 Plume Depletion

Radioactive material may be removed when the plume touches vegetation or other surfaces. These physical removal processes are included in the plume dispersion calculation by means of a correction factor for plume depletion. This correction factor is expressed as the fraction of material released which remains in the plume.

The plume depletion correction factors shown in Figures 2 through 5 of Regulatory Guide 1.111 are used to assess plume depletion effects for all distances from the source and atmospheric stability classes for both ground and elevated release modes. The relative concentration calculated at a given receptor using Equations (2) or (3) is multiplied by the fraction remaining in the plume, as determined from these figures, to arrive at the corresponding depleted relative concentration.

B.7 Dry Deposition

Dry deposition of elemental radioiodines and other particulates is calculated for both ground and elevated releases. The relative deposition rate as a function of release height and atmospheric stability, shown in Figures 6 through 9 of Regulatory Guide 1.111 is used in the model. The relative deposition rate is deposition rate per unit downwind distance divided by the source strength. To obtain the relative deposition per unit area at a given receptor in a given sector, the relative deposition rate is divided by the arc length of the sector. It is noted that the figures in Regulatory Guide 1.111 are based on the assumption that the effluent concentration in a given sector is uniform across the sector at a given distance. For the "segment-plume" model where concentration at a given distance is not uniform across the sector, the relative dry deposition at a specific receptor is calculated by the following procedure:

1. Determine the relative deposition per unit area at the receptor as a function of release height and atmospheric stability;

2. Multiply the undepleted relative concentration at the receptor by the relative deposition per unit area; and

3. Divide the resulting value by the undepleted sector-average relative concentration across the sector.