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SOFTWARE DESIGN REPORT FOR THE CLASS A MODEL, AND THE METEOROLOGICAL, RADIOLOGICAL EFFLUENT AND DOSE REPORTS FOR POINT BEACH NUCLEAR PLANT

Wisconsin Electric Power Company
Milwaukee, Wisconsin

JANUARY 1984
FINAL

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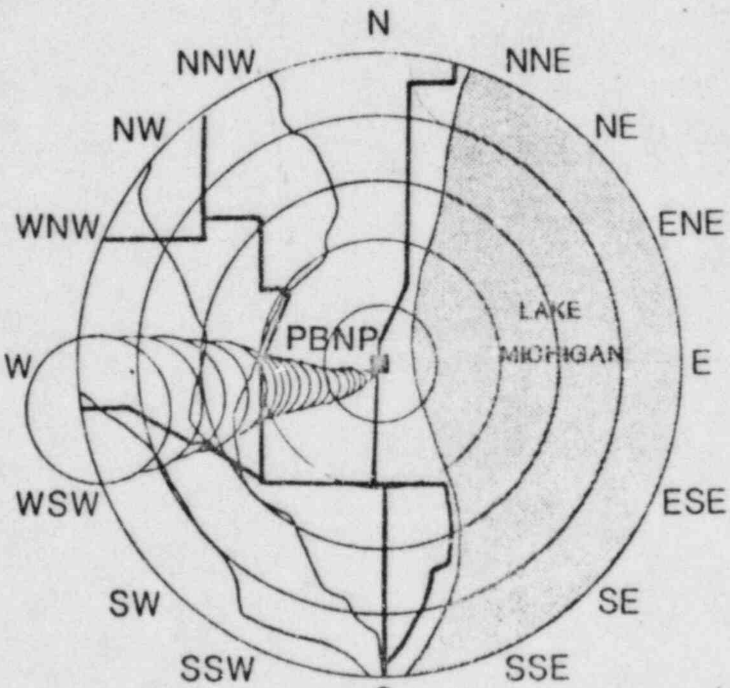

ENERGY IMPACT Associates
Pittsburgh, Pennsylvania

SOFTWARE DESIGN REPORT
FOR THE
CLASS A MODEL, AND THE METEOROLOGICAL, RADIOLOGICAL EFFLUENT AND DOSE REPORTS
FOR
POINT BEACH NUCLEAR PLANT

Prepared for

WISCONSIN ELECTRIC POWER COMPANY
Milwaukee Wisconsin

January 1984

FINAL

Prepared by

ENERGY IMPACT ASSOCIATES
P. O. Box 1899
Pittsburgh, Pennsylvania 15230

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LIST OF ABBREVIATIONS

EIA	Energy Impact Associates, Inc.
MAD	Meteorological and Dose Program
SDR	Software Design Report
SVR	Software Verification Report
SVP	Software Verification Plan
WE	Wisconsin Electric Power Company

INTRODUCTION

This document is intended to provide the methodology used to develop the working equations used in the Class A model, and the meteorological, radiological effluent and dose reports software. It is the framework upon which all software development and coding is based. Variances to the model design structure, specified in this document, during development will be documented in the Software Verification Report (SVR).

This document is consistent with Energy Impact Associates' (EIA's) Software Verification Plan (SVP) Revision 0 and contains the following:

- o Section 1 Purpose of Software Development
- o Section 2 Technical Basis and Rationale for Model Operations
- o Section 3 Model Specifications and Flowcharts.

SECTION 1.0
PURPOSE OF SOFTWARE DEVELOPMENT

1.1 CLASS A SOFTWARE PACKAGE

Energy Impact Associates (EIA) is designing and developing a Class A model for the Point Beach Nuclear Plant (PBNP) to aid Wisconsin Electric Power Company (WE) in satisfying the Nuclear Regulatory Commission (NRC) requirements for a real-time Class A model (Revision 1 to NUREG-0654).[(1)] The software for the Class A model is designed to interface the EIA puff-advection model and the dose model included in the WE Meteorological and Dose (MAD) program. This software allows access to the WE meteorological data base once every 15 minutes to perform χ/Q calculations based on a puff-advection model and dose calculations based on the MAD formulation. No changes are to be made to the dose assessment portion of the MAD program.

EIA's real-time puff-advection model calculates the χ/Q values at the receptor grid included in the dose model and consists of the following:

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The following assumptions are made regarding the release locations and the meteorological parameters:

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1.2 SOFTWARE FOR METEOROLOGICAL, RADIOLOGICAL EFFLUENT RELEASES AND DOSE REPORTS

In addition to a Class A package, EIA is supplying Meteorological, Radiological Effluent Releases and Dose Reports (MREDR) system to satisfy Regulatory Guides 1.21,[2] 1.23[3] and Appendix I of 10 CFR Part 50[4] requirements, respectively. This program allows quarterly, semi-annual and annual reports to be generated for direct submittal to the NRC.

This package runs separate from the model and includes:

- Gaseous and Liquid Effluent Release Reports in accordance with Regulatory Guide 1.21;[2]
- Meteorological Reports in accordance with Regulatory Guide 1.23;[3]
- Radiological Dose Assessment Reports in accordance with Regulatory Guide 1.21[2] and Appendix I of 10 CFR Part 50.[4]

The software will be developed in accordance with Task I.A.7, Task I.A.13, and Task V.C of the WE Scope of Services (April 7, 1983).

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SECTION 2.0

TECHNICAL BASIS AND RATIONALE FOR MODEL OPERATIONS

This section describes the technical basis and rationale used to develop EIA's puff-advection model. Because dose assessment methodology was developed by WE, its description is not included in this document. It is anticipated that WE will provide EIA with the detailed description for later inclusion in the Class A model documentation.

Also discussed in this section is the technical basis for the radiological dose assessment report designed to meet NRC Regulatory Guide 1.21 and Appendix I of 10 CFR Part 50 requirements as a part of the meteorological, radiological effluent and dose reports.

2.1 THE 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 individual puff. The concentration at a specific receptor point is obtained by integrating the contribution of all puffs in the vicinity of that receptor.

2.1.1 PUFF-ADVECTION CONCEPT

The puff-advection concept is typically implemented in models which make the following sequence of calculations:

- puff release
- puff advection
- puff diffusion
- calculation of concentration.

In the past, the following two techniques have been used to implement the puff-advection concept in nuclear applications:

- o the simulated release of individual puffs, and
- o the simulated release of plume segments.

In both techniques the release, advection and diffusion processes are calculated by tracking individual puffs which are sequentially released. The basic difference between the two techniques lies in the calculation of the concentration field. A numerical integration (a sum of individual puff contributions) is used to calculate concentration in the first technique, while an analytical integration is used in the second technique. The use of the analytical technique ensures effective use of the host system's core storage.

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TABLE 2-1

CLASSIFICATION OF ATMOSPHERIC STABILITY BY THE VERTICAL TEMPERATURE DIFFERENCE AND BY THE STANDARD DEVIATION OF THE HORIZONTAL WIND DIRECTION TYPING SCHEMES[3]

Stability Classification	Pasquill Categories	Temperature Change With Height, °C/100 m	σ_θ, degrees	σ_θ, degrees Median Value
Extremely unstable	A	$\Delta T/\Delta Z \leq -1.9$	$\sigma_\theta \geq 22.5$	25.0
Moderately unstable	B	$-1.9 < \Delta T/\Delta Z \leq -1.7$	$22.5 > \sigma_\theta \geq 17.5$	20.0
Slightly unstable	C	$-1.7 < \Delta T/\Delta Z \leq -1.5$	$17.5 > \sigma_\theta \geq 12.5$	15.0
Neutral	D	$-1.5 < \Delta T/\Delta Z \leq -0.5$	$12.5 > \sigma_\theta \geq 7.5$	10.0
Slightly stable	E	$-0.5 < \Delta T/\Delta Z \leq 1.5$	$7.5 > \sigma_\theta \geq 3.8$	5.0
Moderately stable	F	$1.5 < \Delta T/\Delta Z \leq 4.0$	$3.8 > \sigma_\theta \geq 2.1$	2.5
Extremely stable	G	$4.0 < \Delta T/\Delta Z$	$2.1 > \sigma_\theta$	1.7

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TABLE 2-3

FORMULATION AND COEFFICIENTS USED TO CALCULATE σ_y AND σ_z IN THE PUFF-ADVECTION MODEL FOR PBNP[5,6]

I. σ_y Formulation and Coefficients

$$\sigma_y = (k_1 \sigma_\theta^2 + k_2 \sigma_\theta + k_3)\, x^{0.9031}$$

where,

$k_1 = 2.46 \times 10^{-4}$

$k_2 = 5.76 \times 10\text{-}3$

$k_3 = 0.066$

and σ_y and x are expressed in meters.

Values of the coefficients $A = k_1 \sigma_\theta^2 + k_2 \sigma_\theta + k_3$ and σ_θ used in formulating σ_y as a function of atmospheric stability and downwind distance x are:

Stability Class	σ_θ	A
A	25°	0.3658
B	20°	0.2751
C	15°	0.2089
D	10°	0.1471
E	5°	0.1046
F	1.5°	0.0722
G	1°	0.0481*

* Assumes that σ_y (atmospheric stability G) = 0.667 σ_y (atmospheric stability F).

II. σ_z Formulation and Coefficients

$$\sigma_z = \begin{cases} A_1 x^{B_1} + C_1 & \text{if } 1000\text{ m} \le x \\ A_2 x^{B_2} + C_2 & \text{if } 100\text{ m} \le x < 1000\text{m} \\ A_3^{B_3} & \text{if } x < 100\text{m} \end{cases}$$

(Continued)

TABLE 2-3 (Continued)

Values of A_i, B_i, and C_i used in formulating σ_z as a function of atmospheric stability and downwind distance x are:

	Stability Class	A_i	B_i	C_i	Usable Range
i=1	A	0.00024	2.094	- 9.6	>1000m
	B	0.055	1.098	2.0	
	C	0.113	0.911	0.0	
	D	1.26	0.516	-13	
	E	6.73	0.305	-34	
	F	18.05	0.18	-48.6	
	G	12.04*	0.18*	-32.4*	
i=2	A	0.0015	1.941	9.27	100-1000m
	B	0.028	1.149	3.3	
	C	0.113	0.911	0.0	
	D	0.222	0.725	- 1.7	
	E	0.211	0.678	- 1.3	
	F	0.086	0.74	- 0.35	
	G	0.057*	0.74*	- 0.23*	
i=3	A	0.192	0.936	N/A	<100m
	B	0.156	0.922	N/A	
	C	0.116	0.905	N/A	
	D	0.079	0.881	N/A	
	E	0.063	0.871	N/A	
	F	0.053	0.814	N/A	
	G	0.035*	0.814*	N/A	

* Assumes that σ_z (Atmospheric Stability G) = 0.667 σ_z (Atmospheric Stability F).

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2.1.4 BUILDING WAKE EFFECTS

The EIA approach to handling building wake effects is identical to that recommended by NRC in their Regulatory Guide 1.111[6] and in NUREG/CR-2919.[10] Accordingly, the vertical dispersion parameter, σ_z, is modified to account for building wake effect any time the release is from a building or the release

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point is close to a large building or structure. The wake effect causes the plume to disperse much faster than a plume dispersed above flat topography in the absence of surface obstruction. The enhanced dispersion is due to the mechanical turbulence produced by the building structure. Beyond about 10 to 15 obstruction heights the plume's dispersion approaches the normal dispersion conditions that exist in the absence of the obstruction.

The modified dispersion parameter that accounts for the building wake effect is:

$$\Sigma_z = \min\left[(\sigma_z^2 + 0.5\, D_z^2/\pi)^{1/2},\ \sqrt{3}\,\sigma_z\right] \qquad (16)$$

where,

Σ_z = modified vertical dispersion parameters used under building wake conditions, m

D_z = height of the building, m.

Equation (16) requires the calculation of two modified dispersion parameters and the smallest of the two is used.

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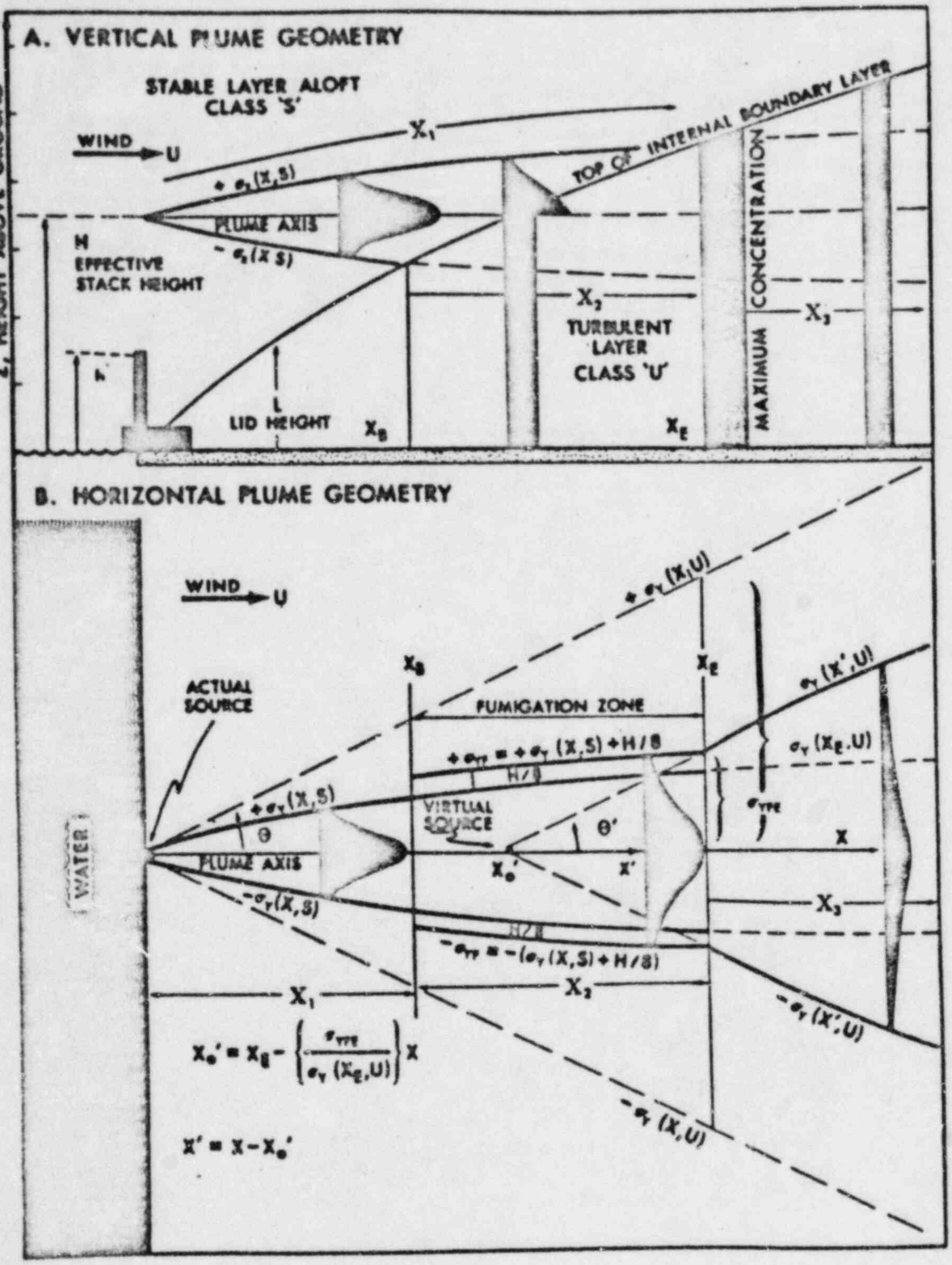

Figure 2-2. Plume Geometry in Lake Induced Fumigation Situation (Lyons and Cole 1973[13])

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- gaseous effluent dose to total body of an individual: 5 mrem/year per unit
- gaseous effluent dose to skin of an individual: 5 mrem/year per unit
- radioiodines and particulates dose to any organ from all pathways: 15 mrem/year per unit

o average individual that represents the average habits, physiological and metabolic characteristics of the population and is used to estimate the exposure to the population within 50 miles of the site.

The population is considered to be made up of infants (0 to 1 year), children (1 to 11 years), teenagers (11 to 17 years) and adults (17 years and older). The dose for the maximum individual is calculated for each age group. In the case of a population dose, the exposure of each age group is calculated and weighted by the actual population age distribution and summed to yield the population dose within a 50-mile radius around the plant site. Population distribution is one of the required inputs to the radiological dose model.

The potential radioactive exposure pathways considered in the dose model include:

o Gamma and beta air dose from noble gas releases
o Total body dose from noble gas releases
o Skin dose from noble gas releases
o Organ dose from deposited activity on the ground
o Inhalation organ dose
o Organ dose from ingested activity considering food pathways
o Tritium dose.

Dose calculations are made for the various exposure pathways at selected receptor locations as follows:

1. Gamma and beta air dose from noble gas releases are calculated at the center of each of the 16 wind direction sectors for 10 down-

wind distances (0.5, 1.5, 2.5, 3.5, 4.5,7.5, 15, 25, 35, 45 miles) and for the critical sector at site boundary.

2. Total body dose from noble gas releases, skin dose and dose due to ground deposition from radionuclides releases to maximum individual are calculated at the same receptors included in (1).

3. Population integrated total body dose for each of the 16 wind direction sectors for the 11 downwind distances under (1).

4. Organ dose due to inhalation to maximum individual for the four age groups at the same receptors as included in (1) and population integrated doses.

5. Organ dose due to ingestion to maximum individual
   - at the critical dairy farm from the milk pathway
   - at the critical cattle farm from the meat pathway
   - at the critical vegetable farm from the produce pathway
   - at the critical vegetable farm from the leafy vegetable pathway
   - Tritium dose.

   Critical is defined as the point of calculated maximum concentration of radioactive materials in milk, meat, produce, and leafy vegetable pathways. It is the nearest distance to these pathways in the case of PBNP.

Appendix A includes examples of output dose tables.

2.2.2 RELATIVE CONCENTRATIONS IN MIXED MODE RELEASE

This section provides a discussion of the methodology used to calculate the χ/Q values used in the radiological dose model software including the mixed mode release consideration.

2.2.2.1 RELATIVE CONCENTRATIONS

Relative concentrations used in the radiological model are calculated using the formulation of the puff-advection model discussed in Section 2.1 with the provisions for average hourly calculations and the use of the mixed mode release approach. Included here are tables for the plume depletion factor (DF), due to dry deposition, for elevated releases used in deposition calculations. Tables 2-7 and 2-8 contain the DF values for 30 m and 60 m release heights. The 60 m DF values are used for release heights exceeding 45 m (structure height plus plume rise) and the 30 m DF values are used for release heights less than 45 m (building downwash).

Appendix A includes examples of χ/Q tables and meteorological data tables.

2.2.2.2 MIXED MODE RELEASE

The mixed mode release approach is utilized under normal release situations. This mode allows considering vent releases as elevated if a certain wind condition is met, as elevated release for part of the time and as ground-level release for the remainder of the time under another wind condition, and as a ground-level release under a third wind condition. The methodology employed here is based upon the one outlined in the NRC Regulatory Guide 1.111.(6)

Plume rise is calculated for elevated releases using the Briggs plume rise formulation as presented in Regulatory Guide 1.111.(6)

2.2.2.2.1 CRITERIA FOR DETERMINING THE RELEASE TO BE GROUND LEVEL OR ELEVATED

The relative concentration equation for a mixed mode release is:

$$(\chi/Q)_m = (\chi/Q)_e (1-E_t) + (\chi/Q)_g E_t \quad (29)$$

where,

$(\chi/Q)_m$ = relative concentration under mixed mode release, sec/m^3
$(\chi/Q)_e$ = relative concentration due to elevated release, sec/m^3
$(\chi/Q)_g$ = relative concentration due to ground-level release, sec/m^3
E_t = an entrainment factor, dimensionless.

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The entrainment factor varies between 0 to 1 according to the W_o/U ratio,

where,

W_o = vent exit velocity, m/sec

U = mean wind speed, m/sec.

That is:

$$E_t = \begin{cases} 1 & (W_o/U) \leq 1 & (30) \\ 2.58-1.58(W_o/U) & 1<(W_o/U) \leq 1.5 & (31) \\ 0.3-0.06(W_o/U) & 1.5<(W_o/U) \leq 5 & (32) \\ 0 & (W_o/U)>5 & (33) \end{cases}$$

Equation (29) represents ground release if condition (30) is met; mixed mode (part-time ground level and the remainder of the time elevated) release if condition (31) or (32) is met and elevated release if condition (33) is met.*

Once the puff is released, its release is treated either as elevated or ground level and the status of the released puff is unchanged until it is dropped from the calculations.

2.2.2.2.2 PLUME RISE

Plume rise and final plume heights are calculated for elevated releases using the NRC-recommended methodology outlined by Sagendorf et al.[10] Basicially the rise of the plume is calculated from the Briggs plume rise equations.[15] Nuclear power stations generally have ambient or near ambient temperature plumes, so that the heat release is zero or near zero; the plume rise is calculated from the momentum equations (non-buoyant plumes). In the event heat is released from the stack, the plume rise is calculated accounting for both momentum and buoyancy considerations and the final plume rise equals the one-third power of the sum of the cubes of the momentum and buoyant plume rises.

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* Additional criteria for determining release mode are presented in Reg. Guide 1.111 (pages 1.111-10 and 1.111-11). Also see page 2-2 of the document "Class A Model for PBNP, Volume I, User's Information."

The effective plume height is:

$$H = h_s + h_p \tag{34}$$

where,

H = effective plume height, m

h_s = physical stack height, m

h_p = plume rise, m.

Momentum Plume Rise Equations for Neutral and Unstable Conditions

For neutral and unstable atmospheric conditions, plume rise is calculated from:

$$h_{p1} = 1.44\left(\frac{W_o}{U}\right)^{2/3} \cdot \left(\frac{x}{D}\right)^{1/3} \cdot D \tag{35}$$

where,

W_o = stack or vent exit velocity, m/sec

x = downwind distance, m

U = wind speed at release height, m/sec

D = internal stack diameter, m.

When the exit velocity is less than 1.5 times the wind speed, a correction[16] for plume downwash (C) is subtracted from h_{p1} [Equation (35)]:

$$C = 3\left(1.5 - \frac{W_o}{U}\right) D \tag{36}$$

The result from Equation (35) corrected by Equation (36), if necessary, is compared with:

$$h_{p3} = 3\left(\frac{W_o}{U}\right) D \tag{37}$$

and the smaller value is used as the plume rise in the dispersion calculations.

Momentum Plume Rise Equations for Stable Conditions

For stable conditions, plume rise equations for the unstable conditions [Equations (35) and (37)] are compared with results from the following two equations:

$$h_{p4} = 4\ (F_m/S)^{1/4} \qquad (38)$$

and

$$h_{p5} = 1.5\ (F_m/U)^{1/3}\ .\ S^{-1/6} \qquad (39)$$

where,

$$F_m = (W_o D/2)^2$$

and

$$S = \frac{g}{T}\frac{\partial\theta}{\partial z}$$

and,

F_m = the momentum flux parameter, m^4/sec^2

S = stability parameter, sec^{-2}

g = gravitational acceleration, m/sec^2

T = ambient air temperature, °K

$\partial\theta/\partial z$ = vertical potential temperature gradient, °K/m.

Values of the stability parameters used in the model calculations are:

Atmospheric Stability	S, sec^{-2}
E	8.7×10^{-4}
F	1.75×10^{-3}
G	2.4×10^{-3}

The smallest of the plume rise calculations from Equations (35), (37), (38) and (39) is used in calculations for stable conditions.

Buoyant Plume Rise for Neutral and Unstable Conditions

For a buoyant (heated) plume in neutral or unstable stability conditions, plume rise is calculated according to the following equations:

$$h_p = \begin{cases} f(x) & x < x^* \\ f(x^*)\ g(x) & x^* \leq x \leq 5x^* \\ f(x^*)\ g(5x^*) & 5x^* < x \end{cases} \qquad (40)$$

where the following notation is used

$$f(x) = 1.6\ F^{1/3}\ x^{2/3}/U$$
$$g(x) = (0.4 + \Psi\ (0.64 + 2.2\ \Psi))/(1 + 0.8\ \Psi)^2$$
$$\Psi = x/x^*$$
$$x^* = 2.16\ F^{2/5}\ h_s^{3/5}$$

The length x^* is a measure of the downwind distance at which atmospheric turbulence begins to dominate plume entrainment and is valid for stacks less than 305 meters in height. The buoyancy flux parameter, F, is given by:

$$F = 9.807\ (D/2)^2\ W_o(T_s - T)/T_s \qquad (41)$$

where,

D = stack exit diameter, m
T_s = stack exit temperature, °K

Buoyant Plume Rise for Stable Conditions

Under stable conditions the buoyant plume rise is calculated according to:

$$h_p = \begin{cases} f(x) & x < x^* \\ 2.4\ (F/(US))^{1/3} & x \geq x^* \end{cases} \qquad (42)$$

where,

$$x^* = 2.4\ US^{-0.5} \qquad (43)$$

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2.2.3.2 GAMMA AIR DOSE FROM GROUND LEVEL RELEASE OF NOBLE GASES

The hourly γ dose from ground level releases [Equations (7) and (B-5)] in Regulatory Guide 1.109] is given by:

$$D^{\gamma}(r,\theta) = 10^{12} \sum_{i} Q_{Di} \left(\chi/Q \right) DF_i^{\gamma} \tag{47}$$

where,

$D^{\gamma}(r,\theta)$ = the hourly air gamma dose at a distance r in sector at the angle θ from the release point, mrad/hr

Q_{Di} = the depleted release rate, Ci/hr

r = the radial distance to receptor, m

θ = the angular component of the receptor polar coordinates, degrees

(χ/Q) = the hourly average dispersion factor at a distance r (meters) in sector θ, sec/m^3

DF_i^{γ} = the gamma air dose factor for semi-infinite cloud of radionuclide 'i', (Table B-1 of Regulatory Guide 1.109), mrad-m^3/pCi-sec

10^{12} = the number of pCi per Ci, pCi/Ci.

2.2.3.3 BETA AIR DOSE FROM GROUND LEVEL RELEASE OF NOBLE GASES

The hourly β dose from ground level releases [Equations (7) and (B-5) in Regulatory Guide 1.109] is given by:

$$D^{\beta}(r,\theta) = 10^{12} \sum_{i} Q_{Di} \left(\chi/Q \right) DF_i^{\beta} \tag{48}$$

where,

$D^{\beta}(r,\theta)$ = the hourly beta air dose at a distance r in a sector at the angle θ from the release point, mrad/hr

DF_i^{β} = the beta air dose factor for a semi-infinite cloud of radionuclide 'i' (Table B-1 of Regulatory Guide 1.109), mrad-m^3/pCi-sec.

2.2.3.4 TOTAL BODY DOSE FROM ELEVATED RELEASE OF NOBLE GASES

The hourly total body γ dose from elevated release [Equations (8) and (B-6) in Regulatory Guide 1.109] is given by:

$$D^T(r,\theta) = 1.11\ S_F \sum_i D_i^\gamma(r,\theta)\ \exp\left(-\mu_a^T t_d\right) \tag{49}$$

where,

$D^T(r,\theta)$ = the hourly total body dose at a distance r in sector θ, mRem/hr

S_F = the attenuation factor that accounts for the dose reduction due to shielding provided by residential structures, (equals 0.7 for maximum individual; equals 0.5 for general population, Table E-15 Regulatory Guide 1.109), dimensionless

D_i^γ = the hourly gamma air dose from nuclide 'i' [Equation (44)], mrad/hr

μ_a^T = the tissue energy absorption coefficient, for nuclide 'i', cm^2/g

t_d = the product of tissue density and depth used to determine total body dose, g/cm^2

1.11 = average ratio of tissue to air energy absorption coefficient, mRem/mrad

2.2.3.5 SKIN DOSE FROM ELEVATED RELEASE OF NOBLE GASES

The hourly γ and β skin dose from elevated release [Equations (9) and (B-7) in Regulatory Guide 1.109] is given by:

$$D^S(r,\theta) = 1.11\ S_F\ D^\gamma(r,\theta) + 10^{12} \sum_i Q_{Di} \left(\chi/Q\right) DFS_i \tag{50}$$

where,

$D^S(r,\theta)$ = the hourly skin dose at a distance r in sector θ, mRem/hr

DFS_i = the beta skin dose factor for a semi-infinite cloud of radionuclide 'i' (Table B-1 of Regulatory Guide 1.109), $mRem\text{-}m^3/pCi\text{-}sec$.

It should be noted that the first term on the right hand side of Equation (50) contains the γ air dose calculated from Equation (44).

2.2.3.6 TOTAL BODY DOSE FROM GROUND LEVEL RELEASE OF NOBLE GASES

The hourly total body γ dose from a ground level release [Equations (10) and (B-8) in Regulatory Guide 1.109] is given by:

$$D_{\infty}^{T}(r,\theta) = S_F \times 10^{12} \sum_i Q_{Di} \left(\chi/Q \right) DFB_i \tag{51}$$

where,

$D_{\infty}^{T}(r,\theta)$ = the hourly total body dose due to immersion in a semi-infinite cloud at a distance r in sector θ, mRem/hr

DFB_i = the total body dose factor for a semi-infinite cloud of the radionuclide 'i', which includes the attenuation of 5 g/cm^2 of tissue (Table B-1 in Regulatory Guide 1.109), mRem-m^3/pCi-sec.

This equation is also used under stable onshore flow conditions for elevated releases.

2.2.3.7 SKIN DOSE FROM GROUND LEVEL RELEASE OF NOBLE GASES

The hourly γ and β skin dose from a ground level release [Equations (11) and (B-9) in Regulatory Guide 1.109] is given by:

$$D_{\infty}^{S}(r,\theta) = 1.11 \times S_F \times 10^{12} \sum_i Q_{Di} \left(\chi/Q \right) DF_i^{\gamma} +$$

$$10^{12} \sum_i Q_{Di} \left(\chi/Q \right) DFS_i \tag{52}$$

where,

$D_{\infty}^{S}(r,\theta)$ = hourly skin dose due to immersion in a semi-infinite cloud at a distance r in sector θ, mRem/hr.

All other parameters are defined in previous sections.

2.2.3.8 DOSE FROM EXTERNAL RADIATION DUE TO RADIOACTIVITY DEPOSITED ONTO THE GROUND SURFACE

The hourly organ dose due to deposited activity of radioiodines and particulates radionuclides on the ground [Equations (12), (C-1) and C-2) in Regulatory Guide 1.109] is given by:

$$D_j^G\,(r,\theta) = S_F \sum_i C_i^G\,(r,\theta)\; DFG_{ij} \tag{53}$$

where,

$D_j^G(r,\theta)$ = the hourly ground deposition dose to organ 'j' at location (r,θ), mRem/hr

$C_i^G(r,\theta)$ = the ground plane concentration of radionuclide 'i' at location (r,θ), pCi/m^2

DFG_{ij} = the field ground plane dose conversion factor for organ 'j' from radionuclide 'i' (Table E-6 of Regulatory Guide 1.109), $mRem\text{-}m^2/pCi\text{-}hr$.

Values for the DFG_{ij} factors for the skin and total body are given in Table E-6 of Regulatory Guide 1.109. The annual dose to all other organs is taken to be equivalent to the total body dose. The factor S_F is assumed to have the value of 0.7.

The ground plane concentration of radionuclide 'i' at the location (r,θ) relative to the release point is given by:

$$C_i^G(r,\theta) = \frac{1.0 \times 1.0^{12}\, D_{ti}}{\lambda_i} \left[1\text{-}\exp\left(-\lambda_i t_b\right)\right] \tag{54}$$

where,

D_{ti} = the hourly total deposition rate of radionuclide 'i' at (r,θ) considering plume depletion due to dry and wet deposition, $Ci/m^2\text{-}hr$

λ_i = the radioactive decay constant of radionuclide 'i', hr^{-1}

t_b = the time period over which the accumulation is evaluated which is 15 years or 1.314×10^5 hrs.

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2.2.3.9 DOSE DUE TO INHALATION OF RADIONUCLIDES IN AIR

The hourly organ dose due to inhalation of radioiodines and particulates radionuclides [Equations (13) and (C-4) in Regulatory Guide 1.109] is given by:

$$D_{ja}^{A}(r,\theta) = R_a \times 10^{12} \sum_i Q_{Di}\left(\chi/Q\right) DFA_{ija} \tag{58}$$

where,

$D_{ja}^{A}(r,\theta)$ = the hourly inhalation dose to organ 'j' of an individual in age group 'a', mRem/hr

R_a = the hourly air intake rate for individuals in the age group 'a', m^3/sec (equals 4.4394×10^{-5} m^3/sec for infant; 1.1733×10^{-4} m^3/sec for child; 2.5368×10^{-4} m^3/sec for teenager and adult)

DFA_{ija} = the inhalation dose factor for radionuclide 'i', organ 'j' and age group 'a', (Tables E-7 through E-10 of Regulatory Guide 1.109), mRem/pCi.

2.2.3.10 DOSE FROM INGESTION OF ATMOSPHERICALLY RELEASED RADIONUCLIDES IN FOOD

The organ dose due to ingestion of food containing radioactivity from radionuclides released into the atmosphere [Equations (14) and (C-13) in Regulatory Guide 1.109] is given by:

$$D_{ja}^{D}(r,\theta) = 1.1416 \times 10^{4} \sum_i DFI_{ija}\Big(U_a^V f_g C_i^V(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_\ell C_i^L(r,\theta)\Big) \tag{59}$$

where,

$D_{ja}^{D}(r,\theta)$ = the hourly dose to organ 'j' of an individual in age group 'a' from ingestion of produce, milk, leafy vegetables and meat at location (r,θ), mRem/hr

DFI_{ija} = the ingestion dose factor for nuclide 'i', organ 'j' and age group 'a', mRem/pCi (Tables E-11 through E-14 of Regulatory Guide 1.109)

$C_i^v(r,\theta)$, $C_i^m(r,\theta)$,

$C_i^L(r,\theta)$, $C_i^F(r,\theta)$ = concentrations of radionuclide 'i' in produce (non-leafy-vegetables, fruits, and grains), milk, leafy vegetables, and meat, respectively, at location (r,θ), pCi/kg or pCi/ℓ

f_g, f_ℓ = respective fractions of the ingestion rates of produce and leafy vegetables that are produced in the garden of interest; ($f_g = 0.76$, $f_\ell = 1.0$)

U_a^v, U_a^m, U_a^F, U_a^L = annual intake (usage) of produce, milk, meat, and leafy vegetables, respectively, for individuals in the age group 'a', in kg/yr or ℓ/yr (equivalent to U_{ap}).

1.1416×10^{-4} = conversion factor from year to hour (1/8760).

Values of the annual intake rate for food are given in Table 2-9. They are multiplied by the conversion factor 1.1416×10^{-4} to provide hourly intake values.

<u>Concentration of Radionuclides in Produce and Leafy Vegetable</u>

The concentration of nuclide 'i' in produce at location (r,θ) is given by [Equation (C-5) in Regulatory Guide 1.109]:

$$C_i^v(r,\theta) = d_i(r,\theta)\left\{\frac{r\left[1 - \exp\left(-\lambda_{Ei}t_e\right)\right]}{Y_v\lambda_{Ei}} + \frac{B_{iv}\left[1 - \exp\left(-\lambda_i t_b\right)\right]}{P\lambda_i}\right\}\exp(-\lambda_i t_h) \quad (60)$$

where,

$C_i^v(r,\theta)$ = concentration of radionuclide 'i' in produce at location (r,θ), pCi/kg

$d_i(r,\theta)$ = deposition rate of radionuclide 'i' onto ground at location (r,θ), pCi/m^2-hr

r = the fraction of deposited activity retained on the produce (equals 1.0 for iodines, and 0.2 for other particulates), dimensionless

λ_{Ei} = the effective removal rate constant for radionuclide 'i' from produce, which is the sum of the radioactive decay constant (λ_i) and the removal rate constant for physical loss by weathering (equals 0.0021 hr^{-1}), λ_i +0.0021, hr^{-1}

TABLE 2-9

AVERAGE AND MAXIMUM ANNUAL INTAKE RATE (USAGE) FOR FOOD FOR INDIVIDUALS IN THE AGE GROUP A

Pathway	Usage of Food							
	Infant		Child		Teenager		Adult	
	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
Produce (U_a^V), kg/yr	0	0	520	200	630	240	520	190
Milk (U_a^m), ℓ/yr	330	0	330	170	400	240	310	190
Meat (U_a^F), kg/yr	0	0	41	37	65	59	110	95
Leafy Vegetable (U_a^L), kg/yr	0	--	26	--	59	42	64	--

t_e = period of produce exposure during growing season, equals 1440 hr

Y_v = agricultural productivity by unit area (yield), equals 2.0 kg/m^2

B_{iv} = concentration factor for uptake of radionuclide 'i' from soil by edible parts of the produce (Table E-1 of Regulatory Guide 1.109), pCi/kg produce per pCi/kg soil

t_b = period of long-term buildup for activity in sediment or soil, nominally 15 yr = 1.31×10^5 hr

P = effective surface density of soil, equals 240 kg/m^2

t_h = time delay between harvest of produce and ingestion, equals 1440 hr for produce and maximum individual and 24 hr for leafy vegetable and maximum individual.

Equation (60) is used to estimate concentration of radionuclides in produce and leafy vegetable. The proper parameters must be used in each case. The deposition rate, d_i, from the plume [Equation (C-7) in Regulatory Guide 1.109] is given by:

$$d_i(r,\theta) = \begin{cases} 10^{12}\, D_{ti} & \text{for particulates} \\ 5 \times 10^{11}\, D_{ti} & \text{for radioiodines} \end{cases} \qquad (61)$$

where,

D_{ti} = the total deposition rate for radionuclide 'i', Ci/m^2-hr.

<u>Concentration of Radionuclides in Milk</u>

The radionuclide concentration in milk [Equation (C-10) in Regulatory Guide 1.109] is given by:

$$C_i^m(r,\theta) = F_m C_i^v(r,\theta) Q_F \exp(-\lambda_i t_f) \qquad (62)$$

where,

$C_i^m(r,\theta)$ = the concentration in milk of nuclide 'i', pCi/liter

$C_i^v(r,\theta)$ = the concentration of radionuclide 'i' in the animal's feed, pCi/kg

F_m = the average fraction of the animal's daily intake of radionuclide 'i' which appears in each liter of milk, days/liter (Tables E-1 and E-2 of Regulatory Guide 1.109 for cow and goat data, respectively; for nuclides not listed in Table E-2, the values in Table E-1 are used)

Q_F = consumption rate of contaminated feed and forage by an animal equals 50 kg/day for cattle and 6 kg/day for goats (Table E-3 of Regulatory Guide 1.109)

t_f = the average transport time of the activity from the feed into the milk and to the receptor equals 48 hr

λ_i = the radiological decay constant of nuclide 'i', hr^{-1}.

The concentrations of radionuclide in the animal's feed is calculated as [Equation (C-11) in Regulatory Guide 1.109]:

$$C_i^V(r,\theta) = f_p f_s \; C_i^P(r,\theta) + (1-f_p) \; C_i^S(r,\theta) + f_p(1-f_s)C_i^S(r,\theta) \qquad (63)$$

where,

$C_i^V(r,\theta)$ = the concentration of radionuclide 'i' in the animal's feed, pCi/kg

$C_i^P(r,\theta)$ = the concentration of radionuclide 'i' on pasture grass (calculated using Equation (60) with t_h=0, t_e=720 hr, Y_v=0.7 kg/m^2), pCi/kg

$C_i^S(r,\theta)$ = the concentration of radionuclide 'i' in stored feeds (calculated using Equation (60) with t_h=90 days, t_e=720 hr, Y_v=0.7 kg/m^2, pCi/kg

f_p = fraction of year that animals graze on pasture, equals 0.75

f_s = fraction of daily feed that is pasture grass when the animal grazes on pasture, equals 1.0.

Concentration of Radionuclides in Meat

The concentration of radionuclide 'i' in meat [Equation (C-12) in Regulatory Guide 1.109] is given by:

$$C_i^F(r,\theta) = F_f C_i^V(r,\theta) Q_f \; \exp(-\lambda_i t_s) \qquad (64)$$

where,

$C_i^F(r,\theta)$ = the concentration of nuclide 'i' in animal flesh, pCi/kg

F_f = the fraction of the animal's daily intake of nuclide 'i' which appears in each kilogram of flesh, (Table E-1 of Regulatory Guide 1.109), days/kg

t_s = the average time from slaughter to consumption, equals 20 days

Q_F = consumption rate of feed by animal, equals 50 kg/day

C_i^v = calculated concentration of radionuclide 'i' in animal feed Equation (63), pCi/kg.

2.2.3.11 POPULATION INTEGRATED DOSE

The equation for calculating hourly population-integrated dose [Equation (D-1) in Regulatory Guide 1.109] is:

$$D_j^P = 0.001 \sum_d P_d \sum_a D_{jda} f_{da} \qquad (65)$$

where,

D_{jda} = the hourly dose to organ 'j' (total body or thyroid) of an average individual of age group 'a' in subregion 'd', mRem/hr

D_j^P = the hourly population-integrated dose to organ 'j' (total body or thyroid), man-Rems or thyroid man-Rems

f_{da} = the fraction of the population in subregion 'd' that is in age group 'a'

P_d = the population associated with subregion 'd'

0.001 = the conversion factor from mRem to Rem, mRem/Rem.

The hourly dose to organ 'j', D_{jda} used to calculate the hourly population integrated dose includes:

- o total body dose from elevated [Equation (49)] or ground [Equation (51)] releases
- o inhalation dose to total body or thyroid [Equation (58)].

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2.3 REFERENCES

1. U.S. Nuclear Regulatory Commission and Federal Emergency Management Agency, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants," NUREG-0654, FEMAREP-1, Revision 1, October 1980.

2. U.S. Nuclear Regulatory Commission, "Regulatory Guide 1.21, Measuring, Evaluating and Reporting Radioactivity in Solid Wastes and Releases of Radioactive Materials in Liquid and Gaseous Effluents from Light-Water-Cooled Nuclear Power Plants," June 1974.

3. U.S. Nuclear Regulatory Commission, "Regulatory Guide 1.23 (Revision 1) Meteorological Programs in Support of Nuclear Power Plants," October 1981.

4. 10 CFR Part 50, Appendix I, Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion, "As Low as is Reasonably Achievable for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," April 18, 1977.

5. Eimutis, E. C. and Konicek, M. G., 1972: "Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients," Atmospheric Environment, Pergamon Press, 1972, Vol. 6, pp. 859-863. Printed in Great Britain.

6. U.S. Nuclear Regulatory Commission, "Regulatory Guide 1.111 (Revision 1) Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," July 1977.

7. Slade, D. H., Editor, "Meteorology and Atomic Energy," TID-24190, 1968.

8. Sutton, O. G., Micrometeorlogy, McGraw-Hill Book Company, 1953.

9. Mitchell, A. E., Jr. and Timbre, K. O., Atmospheric Stability Class from Horizontal Wind Fluctuations, 72nd Annual Meeting APCA, Cincinnati, Ohio, June 24, 1979.

10. Sagendorf, J. F., Goll, J. T. and Sandusky, W. F., "XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations," NUREG/CR-2919 (PNL-4380), September 1982.

11. Lyons, W. A., 1976: "Turbulent Diffusion and Pollutant Transport in Shoreline Environments," Lectures on Air Pollution and Environmental Impact Analysis, Duane A. Haugen (ed), AMS, Boston.

12. Lyons, W. A., et al, "An Updated Expanded Coastal Fumigation Model," The 74th Annual Meeting of the Air Pollution Control Association, Paper 81-31.4, June 21-26, 1981.

(Continued)

13. Lyons, W. A. and Cole, H. S., "Fumigation and Plume Trapping on the Shores of Lake Michigan During Stable Onshore Flow," Journal of Applied Meteorology, Vol. 12, pp. 494-510, 1973.

14. U.S. Nuclear Regulatory Commission, "Regulatory Guide 1.109, Calculations of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50 Appendix I, October 1977.

15. Briggs, G. C., "Plume Rise," TID-25075, 1969.

16. Gifford, F. A., "Atmospheric Transport and Diffusion Over Cities," Nuclear Safety, Vol. 13, pp. 391-402, 1972.

17. Brenk, H. D. and Vogt, K. J., "The Calculation of Wet Deposition from Radioactive Plumes," Nuclear Safety, Vol. 22, No. 3, pp. 362-371, May-June 1981.

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