ATMOSPHERIC DISPERSION MODELING OF

AIR ENTRAINABLE RADIOACTIVE EFFLUENT

A Thesis

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ABSTRACT

Atmospheric dispersion calculations are per-
formed by a computer model, PTDOSE, that was developed
using the bivariant Gaussian diffusion equation with
the following restrictions:

1)   There are no spatial or time changes in
turbulence for the sample time period being considered;

2)   There is no gravity fallout or precipitation
washout of the air entrainable effluent;

3)   There is no ground absorption of the
effluent;

4)   Wind speed is assumed to be non-zero so
that diffusion in the x-direction can be neglected in
comparison with forward transport and stretching by the
wind; and

5)   There is a continuous effluent release from
a point source.
Using the Gaussian equation, PTDOSE calculates ground-
level atmospheric concentrations at specified downwind
locations resulting from an air entrainable radioactive
effluent. Using these concentrations, PTDOSE calculates
dose equivalent rates for the radioactive effluent.

Chapter I

INTRODUCTION

An organization wishing to construct or operate
an industrial facility has the responsibility to ensure
that the area surrounding the facility will not be
adversely affected by any of the proposed activities for
the chosen facility site. The Environmental Protection
Agency (EPA) has been charged with the duty of overseeing
efforts in preventing degradation of the atmospheric
quality that could result from effluent releases to the
atmosphere. To this end, the nuclear industry must
analyze not only potential hazards due to chemical
toxicity of such releases but also hazards associated
with the release of radioactive material.

The objective of this thesis is to develop a
computer program for analyzing atmospheric environmental
hazards due to releases of an air entrainable radioactive
effluent. Utilizing a continuously emitting point
effluent source, the computer program PTDOSE was
developed to:

1) Determine maximum downwind atmospheric
concentration for several meteorological conditions;

2) Select the worst case from the above;

3) Utilizing the worst case data, calculate atmospheric concentration at various downwind locations along the centerline of the spreading airborne effluent stream;

4) Calculate dose rates occurring at the same downwind locations as above; and

5) Generate a set of quadrant grid locations at which airborne concentrations and dose rates are calculated to show effects of an airborne effluent stream as it spreads out downwind from the source. The program is unique in that no other performs all of the above tasks utilizing one data set. By performing all of these tasks, PTDOSE saves time and effort on the part of the user.

The program analyzes the spreading or dispersion of an effluent plume (the atmospheric volume containing the effluent) by using an equation developed from the Fickian diffusion equation. For simplicity the basic Fickian equation in three-dimensions is

$$\frac{d\bar{q}}{dt} = \frac{\delta}{\delta x} \left(K_x \frac{\delta \bar{q}}{\delta x}\right) + \frac{\delta}{\delta y} \left(K_y \frac{\delta \bar{q}}{\delta y}\right) + \frac{\delta}{\delta z} \left(K_z \frac{\delta \bar{q}}{\delta z}\right) \qquad (1-1)$$

where K is an eddy-diffusivity coefficient, $\bar{q}$ refers to the mean value of some conservative air property per unit mass, x, y, and z are the spatial coordinates, and t is

time.[1] The fundamental solution to equation (1-1) is a Gaussian function of the form:

$$\frac{\overline{q}(x,y,z,t)}{Q} = (4\pi t)^{-3/2} (K_x K_y K_z)^{-1/2}$$

$$* \exp \left[- \frac{1}{4t} \left(\frac{x^2}{K_x} + \frac{y^2}{K_y} + \frac{z^2}{K_z}\right)\right]. \qquad (1-2)$$

where Q is the effluent emission rate.

The restrictions of the Fickian equation and PTDOSE are:

1) No time or spatial changes in turbulence or mean wind direction and velocity over the time period of interest;

2) No reduction in effluent content by gravity-induced fallout or washout by precipitation. This implies that PTDOSE would provide best results with chemically inert effluents such as xenon and krypton;

3) No ground absorption of the gaseous effluent;

4) Non-zero wind speed so that diffusion in the x-direction can be neglected in comparison with forward transport and stretching by the wind;[2] and

5) Since PTDOSE treats continuous point source effluent releases, the effluent travel time to a point of interest must be less than or equal to the time of effluent release.[3]

The Gaussian solution to the Fickian diffusion equation in two spatial dimensions (x and y) results in an

equation that is known as the bivariant Gaussian diffusion equation. It is used in dispersion concentration calculations because it yields conservative answers, is not as complicated as statistical models in finding suitable dispersions coefficients and is readily solvable given the above restraints. In addition, the bivariant Gaussian diffusion equation has proved itself to be fairly successful in correlating with observed concentrations.[1]

Chapter II

ATMOSPHERIC STABILITY

Before one can attempt to predict downwind effects resulting from a radioactive effluent release to the atmosphere, he should have a basic understanding of how the atmosphere will disperse the effluent. Atmospheric dispersion of an airborne effluent is dependent on the stability of the atmosphere into which the effluent is released. Atmospheric stability is defined in terms of the amount of atmospheric turbulence existing at the time of effluent release.

Turbulence can be thought of as continuous fluctuations in wind speed and direction largely dependent on the temperature gradient change in the atmosphere as altitude increases. Assume that a small volume of air exists in the atmosphere and if moved vertically no exchange of heat between the volume and its surrounding environment occurs. If the volume of air is moved upward, it will encounter lower pressure, expand and cool without heat exchange to its surroundings. The change of atmospheric temperature with increasing altitude necessary to insure the above process has a value of -1°C per 100 meters of increased altitude and

is known as the Dry Adiabatic Lapse Rate (DALR). In general, a lapse rate is the rate of change of an elemental value, in this case temperature, with respect to altitude. Seldom will the dry adiabatic lapse rate be encountered for other than the briefest periods of time due to the changing atmospheric temperature gradient. Using the dry adiabatic lapse rate as a reference, there are five basic atmospheric temperature gradients (Figure 2-1).[4]

A super adiabatic lapse rate occurs when the temperature lapse rate decreases at a rate faster than the dry adiabatic lapse rate. It can be found during times of strong solar heating or when a cold air mass is transported over a warmer surface layer. Super adiabatic lapse rates favor strong atmospheric turbulence. When the temperature lapse rate closely approximates that of the dry adiabatic lapse rate, the term neutral lapse rate is applied. A small volume of air tends neither to gain or lose its bouyancy while existing in a neutral lapse rate environment. Neutral lapse rates are associated with overcast skies and moderate to strong winds. A temperature lapse rate that is less than that associated with the DALR is termed subadiabatic. This is a very stable condition because a volume of air moved upward will become more dense than the surrounding air and moves downward to its original position. Conversely, a

volume of air moved downward becomes less dense that its surroundings and moves upward to its original position.

Isothermal lapse rates occur when the ambient temperature is constant with increasing altitude. There is a slight tendency for a volume of air to resist vertical movement. An inversion lapse rate occurs when the temperature increases with increasing altitude. Surface inversions usually occur at night with light winds and clear skies. These are caused by the ground cooling faster than the adjacent air layers. If a cooler layer moves under a warmer layer, then an inversion will exist. An airborne effluent encountering an inverted layer tends not to exhibit any vertical motion in the inverted layer and is essentially trapped below the inverted layer. If an inversion aloft exists under which the air is turbulent and above which the air is relatively clean then the atmosphere beneath the inversion is known as a mixing layer and is where effluent dispersion will occur. Dispersion is the dilution of airborne effluent by effects of atmospheric turbulence. Mixing layers are usually 300 to 2000 meters thick. The layer above the mixing layer is known as a capping layer. An effluent rising through the mixing layer will encounter the capping layer and not penetrate it. This causes all dispersion to take place closer to

Isothermal   Inversion
Superadiabatic — Dry Adiabatic Lapse Rate   Neutral   Subadiabatic
Height (m)   Temperature °C

Figure 2-1

Typical Lapse Rates in Relation to the Dry Adiabatic Lapse Rate.

Note: In each diagram, the dashed line represents the relative position of the Dry Adiabatic Lapse Rate.

volume of air moved downward becomes less dense that its surroundings and moves upward to its original position.

Isothermal lapse rates occur when the ambient temperature is constant with increasing altitude. There is a slight tendency for a volume of air to resist vertical movement. An inversion lapse rate occurs when the temperature increases with increasing altitude. Surface inversions usually occur at night with light winds and clear skies. They are caused by the ground cooling faster than the adjacent air layers. If a cooler layer moves under a warmer layer, then an inversion will exist. An airborne effluent encountering an inverted layer tends not to exhibit any vertical motion into the inverted layer and is essentially trapped below the inverted layer. If an inversion aloft exists under which the air is turbulent and above which the air is relatively clean, then the atmosphere beneath the inversion is known as a mixing layer and is where all effluent dispersion will occur. Dispersion is the dilution of an airborne effluent by effects of atmospheric turbulence. Mixing layers are usually 300 to 3000 meters deep.[1] The layer above the mixing layer is known as a lid or capping layer. An effluent rising through the mixing layer will encounter the capping layer and not penetrate it. This causes all dispersion to take place closer to
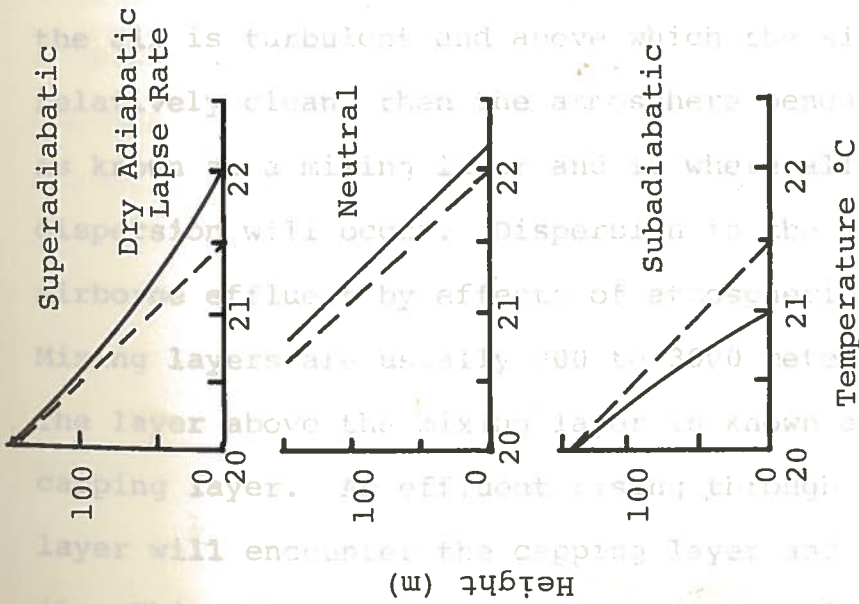
the ground that would normally occur if the capping
layer were not present. If the mixing layer is shallow,
then severe pollution of this atmospheric volume can
occur. An example of the adverse effects of a capping
layer is the pollution problem in Los Angeles.

The stability of the atmosphere at any point in
time and place is dependent on the amount of turbulence
in the atmosphere. The more turbulence occurring, the
more unstable the atmosphere. Since turbulence can be
thought of as wind fluctuations, there should exist some
relationship between these fluctuations and atmospheric
stability. Pasquill derived an empirical relationship
between the standard deviation of the horizontal wind
direction and atmospheric stability.[1] The standard
deviation of the wind direction is determined for a
sampling time period that can range between 10 and 60
minutes in length. The mean sample value for wind
direction during the sample time period is found to be:[5]

$$\bar{\theta} = \frac{\sum\limits_{i=1}^{n} \theta_i}{n} \qquad (2\text{-}1)$$

where

   $\bar{\theta} \equiv$ mean wind direction measured in degrees
        from grid north;

   $i \equiv$ summation index;

$n \equiv$ total number of samples taken;

$\theta_i \equiv$ wind direction in degrees of the ith sample.

The standard deviation of the wind direction is

$$\sigma_\theta = (\frac{\sum\limits_{i=1}^{n} (\theta_i - \bar{\theta})^2}{n})^{1/2} \qquad (2-2)$$

where σ_θ is defined as the standard deviation of the wind direction in units of degrees.[5]

Pasquill's categories of atmospheric stability and associated wind direction standard deviation values are shown in Table 2-1.[6] The categories are designated "A" for extremely unstable to "F" for moderately stable. Category "D" represents the neutral condition where a small volume of air demonstrate no tendency for vertical motion. There is a stability category "G" that is even more stable than "F", but occurs so infrequently that it is not considered here. It should be mentioned that the term "stability category" can be used interchangeably with the term "stability class".

Table 2-1

Atmospheric Stability Classification

Atmospheric Classification	Pasquill Stability Class	Wind Standard Deviation in Degrees
Extremely unstable	A	over 23
Moderately unstable	B	18 to 23
Slightly unstable	C	13 to 18
Neutral	D	8 to 13
Slightly stable	E	4 to 8
Moderately stable	F	less than 4

Chapter III

ATMOSPHERIC CONCENTRATION EQUATIONS

The bivariant Gaussian diffusion equation was developed from the Fickian diffusion equation as outlined in Chapter Two. To discuss the Gaussian equation and its use in calculating atmospheric effluent concentration one must identify a reference coordinate system (Figure 3-1). The source is placed at the origin of the coordinate system. The x-axis is set to correspond to the mean wind direction of the sample time period of time being analyzed. The y-axis is in the crosswind direction while the z-axis is the vertical. The actual height of the effluent release point is represented by h. The altitude at which the effluent plume centerline becomes essentially horizontally is H. The importance of this last parameter will be discussed later. After the Fickian equation is solved using a divariant Gaussian solution, one finds the downwind, plume centerline concentration as[3]

$$X(x,y,z; H) = \frac{Q}{2\pi \, \sigma_y \, \sigma_z u} \exp \left[-\frac{1}{2}(\frac{y}{\sigma_y})^2 \right] \left[\exp \left[-\frac{1}{2}(\frac{Z+H}{\sigma_z})^2 \right] \right.$$

$$\left. + \exp \left[-\frac{1}{2}(\frac{Z-H}{\sigma_z})^2 \right] \right] \tag{3-1}$$

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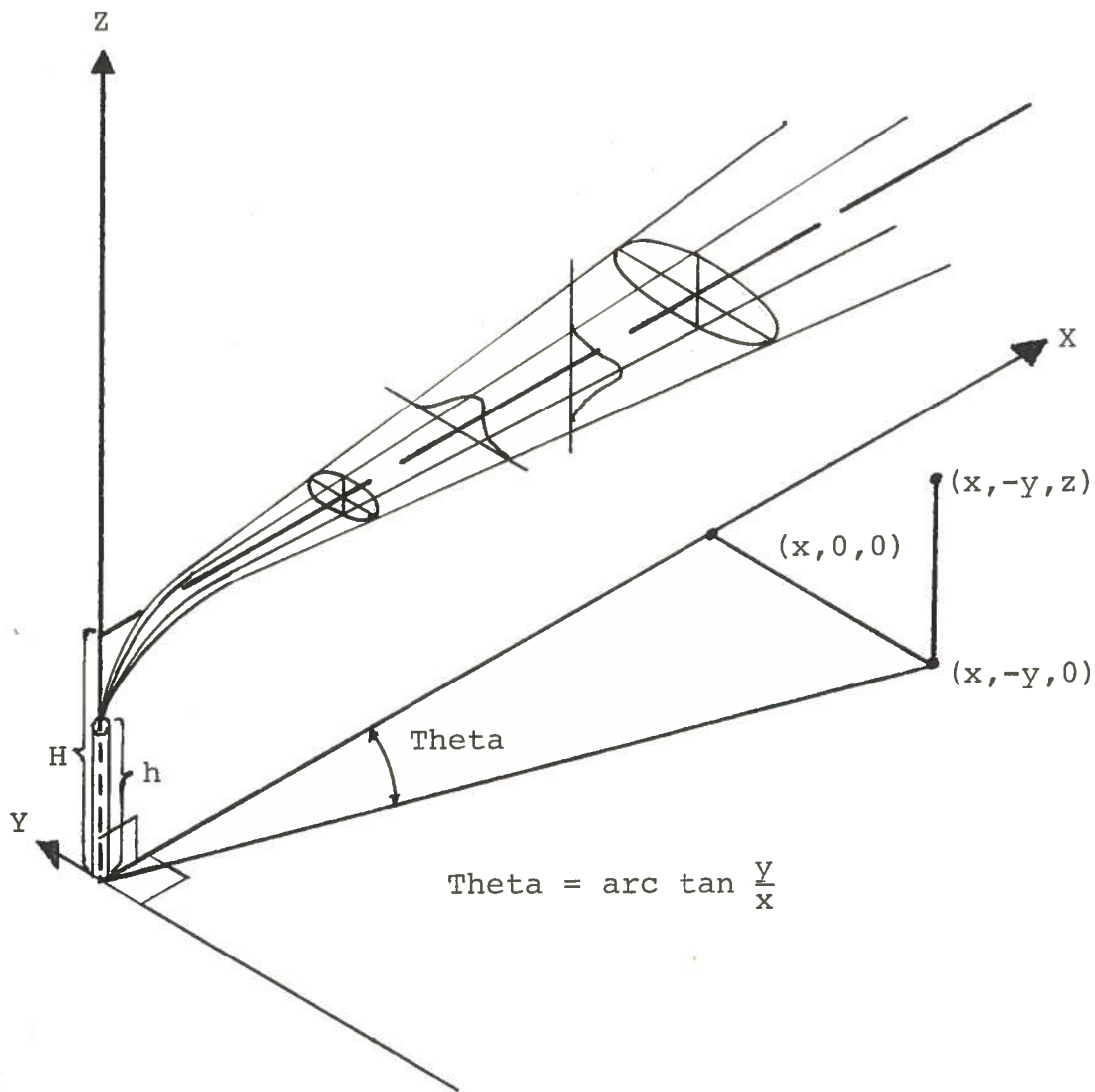
Figure 3-1

Coordinate System Showing Horizontal and
Vertical Gaussian Distributions

where

$\chi \equiv$ concentration of effluent in curies per cubic meter at a point specified by the cartesian coordinates x, y, and z;

x, y, z $\equiv$ cartesian coordinates in meters;

Q $\equiv$ effluent emission rate in curies per second;

and

$\sigma_y, \sigma_z \equiv$ standard deviation of the plume in cross wind and vertical directions respectively in meters.

The variables σ_y and σ_z are the standard deviations of the plume in their respective directions and are known as the horizonal and vertical dispersion coefficents. Both dispersion coefficients are functions of atmospheric stability and downwind distance. The coefficients are determined by[7]

$$\sigma_y = Cx^D \qquad (3-2)$$

and

$$\sigma_z = Ax^B \qquad (3-3)$$

where

x $\equiv$ downwind distance in meters.

The values of A, B, C and D are constants dependent on the downwind distance and are determined by a curve fitting routine applied to a set of curves that plot standard deviations versus downwind distances for each stability class. Tables 3-1 and 3-2 show tabulated values of the constants A, B, C and D.[7] In both tables, stability class D has been broken down into two values. Stability class D is a little more turbulent during the daylight hours then at hours of darkness and is represented by DD while DN represents the hours of darkness.

The height of the plume centerline at the point at which it becomes essentially horizontal, represented by H, is known as the effective release height and is important to controlling the airborne effluent concentration. The dispersion coefficient, σ_y and σ_z, are measured from the plumes centerline and define the plume's boundaries in the crosswind and vertical directions. The greater the dispersion coefficients' values, the greater the volume of atmosphere enclosed by the plume encompasses for a given effluent release rate the greater the effluent dilution. Since one is usually interested in atmospheric concentrations near the earth's surface, the longer the effluent stays dispersing above the earth's surface then the lower the atmospheric

Table 3-1

Coefficients for Sigma Generation

$$\sigma_z = Ax^B$$

Stability Class	A			B		
	$x < 500$ m	$500 \le x < 5000$	$x \ge 5000$	$x < 500$	$500 \le x < 5000$	$x \ge 5000$
A	.0383	.000254	.000254	1.281	2.089	2.089
B	.1393	.0494	.0494	.9467	1.114	1.114
C	.112	.101	.115	.910	.926	.911
DD	.0856	.259	.737	.865	.687	.564
DN	.0818	.253	1.297	.8155	.634	.442
E	.0545	.265	.9177	.8124	.636	.481
F	.0545	.305	1.095	.8124	.556	.403

Table 3-2

Coefficients for Sigma Generation

$$\sigma_Y = Cx^D$$

Stability Class	C		D	
	x < 10000	x ≥ 10000	x < 10000	x ≥ 10000
A	.495	.606	.873	.85
B	.310	.523	.897	.84
C	.197	.285	.908	.86
DD	.122	.193	.916	.86
DN	.122	.193	.916	.86
E	.0934	.141	.912	.86
F	.0625	.0800	.911	.86

concentration near the earth's surface. By having a
large value of the effective stack height, the plume
disperses for a longer period of time before the lower
boundary comes near the earth's surface thus decreasing
the atmospheric concentrations. Effective stack height
is determined by the actual release height and the plume
rise due to effluent emission conditions. Effective
stack height is calculated from:

$$H = h + \Delta H \qquad (3-4)$$

where h is the actual effluent release point height in
meters and ΔH is the plume rise due to emission con-
ditions. Plume rise is produced by both bouyant and
momentum forces as a result of emission temperature and
emission stream velocity respectively. Bouyancy and
momentum plume rise equations are divided into two
types.[7]   The first is for atmospheric stability
classes E and F while the second type is for stability
classes A, B, C and D. For stability class E and F the
bouyant plume rise equation is

$$\Delta H(x) = 1.6 \; F^{1/3} \; x^{2/3} \; U^{-1}. \qquad (3-5)$$

The momentum plume rise equation is

$$\Delta H_{max} = 1.5 \; (VR)^{2/3} \; U^{-1/3} \; S^{-1/b} \qquad (3-6)$$

where

$$S = 0.02 \ g/T_A \ \text{for E stability} \qquad (3-7)$$

or $\quad S = 0.035 \ g/T_A \ \text{for F stability.} \qquad (3-8)$

Equations (3-5) and (3-6) share the following variable names and definitions:

$$F = g \ VR^2 \ (T - T_A)/T \qquad (3-9)$$

where

T = source temperature in degrees kelvin;

T_A = ambient temperature in degrees kelvin;

V = effluent velocity in meters per second;

R = radius of release point in meters;

x = downwind distance in meters;

U = wind speed in meters per second;

g = acceleration due to gravity, 9.8 meters per second per second.

The same variable names and definitions are used in the bouyant and momentum plume equations for stability classes A, B, C and D. The bouyant plume rise equation is

$$\Delta H(x) = 1.6 \ F^{1/3} \ x^{2/3} \ U^{-1} \qquad (3-10)$$

for x less than 3.5 x´. The value of x´ is dependent on the value of 'F' as given in Equation (3-9) or

$$x' = 14 \ F^{5/8} \tag{3-11}$$

for 'F' less than 55. If F is greater than 55 then

$$x' = 34 \ F^{2/5}. \tag{3-12}$$

The value of 'F' must be determined so that x' can be calculated and then compared to the downwind distance x. If x' is less than 3.5 x' then Equation (3-10) is used to determine the bouyant plume rise. If x' is greater than 3.5 x' then the bouyant plume rise is determined as:

$$\Delta H_{max} = 1.6 \ F^{1/3} \ (3.5 \ x')^{2/3} \ U^{-1}. \tag{3-13}$$

Notice that Equation (3-13) gives a maximum value for bouyant plume rise for the stated condition on x'. This indicates that once the downwind distance has reached a value greater than 3.5 x', the plume centerline has become horizontal and the maximum effective plume height has been reached. The momentum plume rise equation is

$$\Delta H(x) = 3.78 \ (\frac{V}{U \ (V + 3U)})^{2/3} \ (\frac{xR^2}{2}). \tag{3-14}$$

Only one value of plume rise can be used by PTDOSE in any given set of calculations. Therefore, for a given set of effluent release conditions, the plume due to both bouyant and momentum forces must be calculated. The

lowest value for plume rise is used by PTDOSE. This is done in order to obtain the highest concentrations possible near the ground which in turn will yield the worst conditions for a given effluent release.

In Chapter Two, the capping layer phenomenon was introduced. Recall that an effluent does not penetrate this layer and is effectively reflected back into the mixing layer below the capping layer. Recall from Chapter 1 that the third restriction on PTDOSE was that there occurred no ground absorption of the effluent. If a plume is trapped between a capping layer and a non-absorbing ground, then Equation (3-1) must be modified to show the effect on airborne concentration of a plume that is reflected back and forth between the capping layer and the non-absorbing ground. Now, the airborne concentration is:[3]

$$X(x,y,z:H) = \frac{Q}{2\pi \sigma_z \sigma_y u} \exp \left[-\frac{1}{2} \left(\frac{Y}{\sigma_y}\right)^2\right] \left[\exp \left(-\frac{1}{2} \left(\frac{Z-H}{\sigma_z}\right)^2\right)\right.$$

$$+ \exp \left(-\frac{1}{2} \left(\frac{Z+H}{\sigma_z}\right)^2\right) + \sum_{N=1}^{N=4} \left[\exp \left(-\frac{1}{2} \left(\frac{Z-H-2NL}{\sigma_z}\right)^2\right)\right.$$

$$+ \exp \left(-\frac{1}{2} \left(\frac{Z+H-2NL}{\sigma_z}\right)^2\right) + \exp \left(-\frac{1}{2} \left(\frac{Z-H+2NL}{\sigma_z}\right)^2\right)$$

$$\left.\left.+ \exp \left(-\frac{1}{2} \left(\frac{Z+H+2NL}{\sigma_z}\right)^2\right)\right]\right]. \qquad (3-15)$$

The mixing layer height in meters is specified by L. The summation index N has an upper limit set equal to four to account for the significant reflections.

It would become very cumbersome to use Equation (3-15) each time one wished to calculate the concentrations for various effluent release rates and wind speeds while atmospheric stability is held constant. Dividing both sides of Equation (3-15) by the effluent release rate Q and multiplying both sides by wind speed will result in an equation dependent only on the atmospheric stability. This equation could be used with any pair of effluent release rate wind speed values to determine a corresponding concentration. Performing the operations as indicated, one has:

$$\frac{\chi u}{Q} (x,y,z:H) = \frac{1}{2\pi \ \sigma_y \ \sigma_z} \ E. \tag{3-16}$$

The symbol E represents the exponential and summation terms of Equation (3-15) which have been omitted for the sake of clarity. The left side of Equation (3-16) is known as the relative dispersion concentration and is calculated once for each stability class and may be used with different sets of effluent release rates and wind speeds to yield the concentration χ. The relative dispersion coefficient has units of inverse meter squared ($1/m^2$).

A factor independent of the effluent release rate can be determined by dividing Equation (3-15) through by the effluent release rate, Q, or

$$\frac{\chi}{Q}(x,y,z:H) = \frac{1}{2\pi \, \sigma_y \, \sigma_z u} E \tag{3-17}$$

The left hand side of Equation (3-17) is known as the relative concentration and has units of second per cubic meter. The relative concentration allows one to make a wind speed dependent calculation once and use the result with many different effluent rates to calculate atmospheric concentrations. As with Equation (3-15), Equations (3-16) and (3-17) are for a specified stability class, for a particular plume centerline height and a point specified by the coordinates x, y, z.

The largest concentrations will occur along the effluent plume centerline at any downwind distance and can be found by setting y equal to zero in Equations (3-15) through (3-17). One is usually interested in determining the ground level concentration which is found by setting z equal to zero in Equation (3-15) through (3-17). Performing these two operations on Equation (3-15) yields the maximum ground level concentration for a given downwind distance or

$$\chi(x:H) = \frac{Q}{2\pi\ \sigma_z\ \sigma_y u}\ \exp\left(-\frac{1}{2}\left(\frac{-H}{\sigma_z}\right)^2\right)\ [\ \exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)$$

$$+ \sum_{N=1}^{N=4}\ [\exp\left(-\frac{1}{2}\left(\frac{-H-2NL}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{H-2NL}{\sigma_z}\right)^2\right)$$

$$+ \exp\left(-\frac{1}{2}\left(\frac{-H+2NL}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{H+2NL}{\sigma_z}\right)^2\right)]]\ .$$

$$(3-18)$$

Notice that $\chi(x:H)$ is no longer dependent on y or z but only on the downwind distance x and effective release height H. Equation (3-18) is utilized by PTDOSE to determine ground level concentrations along the plume centerline.

The program also calculates ground level concentration at points perpendicular to the plume centerline from:

$$\chi(x,y:H) = \frac{Q}{2\pi\,\sigma_y\,\sigma_z u}\,\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left[\exp\left(-\frac{1}{2}\left(\frac{-H}{\sigma_z}\right)^2\right)\right.$$

$$+ \exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right) + \sum_{N=1}^{N=4}\left[\exp\left(-\frac{1}{2}\left(\frac{-H-2NL}{\sigma_z}\right)^2\right)\right.$$

$$+ \exp\left(-\frac{1}{2}\left(\frac{H-2NL}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{-H+2NL}{\sigma_z}\right)^2\right)$$

$$\left.\left.+ \exp\left(-\frac{1}{2}\left(\frac{H+2NL}{\sigma_z}\right)^2\right)\right]\right] \quad . \tag{3-19}$$

All concentrations discussed from this point on will be
at ground level utilizing equations where z equals zero.

Chapter IV

DOSE RATE CALCULATIONS

PTDOSE evaluates an air entrainable effluent's release to the atmosphere from a continuously emitting point source. There are two basic methods to provide a continuous source for radioactive effluents. Under normal operating conditions, a nuclear facility will release radioactive effluents at a constant rate through the stack of an exhaust system. Another continuous source occurs when, under accident conditions, fission products are released into the containment structure and then leaked to the atmosphere.[8] Release under steady state operating conditions allow small amounts of radioactive effluents to be discharged to the atmosphere under controlled conditions in order to minimize the effluent's effect on the environment. However, when fission products are released into the containment structure and the leak to the environment, a much greater amount of radioactive effluent may be released to the environment than that occurring under normal operations.

Noble gases and iodines make up the major portion of the radioactivity due to fission product release under accident conditions.[1, 9] Immediately after release,

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fission products will tend to cool with the chemically active elements tending to agglomerate. Chemically reactive fission products will be subject to deposition on surfaces which will cause much of the iodine inventory to deposit out. Noble gas fission products will not deposit on surfaces and will be available for release from a containment structure by leakage. Once leaked, noble gases will mix well with the atmosphere and be eliminated only by radioactive decay. Since PTDOSE does not treat chemically reactive or readily depositable effluents, the noble fission products lend themselves quite well to dispersion analysis by PTDOSE.

Once airborne, a radioactive effluent will serve as an external source to the body as the effluent passes over a person. After the effluent passes, a person could be subjected to radiation from any part of the effluent plume that may have been deposited on exposed surfaces or inhaled or ingested. The program treats only the external dose resulting from the effluent plume's passage. External whole body doses are calculated using an infinite uniform cloud model.[8, 10] An infinite cloud is one in which the dimensions are much larger than the distance traveled by the effluent's gamma rays and beta particles. Since a receptor point is usually placed at ground level and along the plume's centerline to obtain

the dose rate, a submerged body at that receptor point would be exposed to radiation from a hemispherical shell of the cloud. Therefore, any dose rates calculated from an infinite cloud model would be reduced by a factor of two.

Once a body is submerged in a radioactive effluent plume, it receives energy from all incident radiations. In order to measure the amount of energy absorbed by a body, the unit of radiation absorbed dose (rad) is defined as 100 ergs of energy absorbed per gram of material.[8] The biological damage associated with a particular type of radiation is dependent on its linear energy transfer, L_{∞}, which can be defined as the energy loss per path length along the radiation's path. Linear energy transfer increases with the mass and charge of the radiation particle. Therefore, if the absorbed doses are equal, an alpha particle will cause more biological damage than a gamma ray.

In order to discuss and equate biological effects of different radiations with the same absorbed dose, the quality factor of radiation, represented by QF, has been introduced by the International Commission on Radiation Units.[8] The quality factor is a function of linear energy transfer. The product of absorbed dose and a suitable quality factor is known as the dose equivalent.

The unit of measure for dose equivalent is known as a rem. For beta particles with energies above 0.03 MeV and for photons, the quality factor is equal to one.[8] This means that for an absorbed dose of one rad, the dose equivalent is one rem for both photons and betas.

For a plume having an effluent concentration of χ curies per cubic meter, the skin surface dose equivalent rate for a beta particles with average energy of $\bar{E}_\beta$ MeV per disintegration is given by:

$$\dot{H}_\beta = 0.23 \times \bar{E}_\beta \ QF_\beta \qquad (4-1)$$

where QF_β is the beta quality factor which is equal to unity and $\dot{H}_\beta$ is the dose equivalent rate in rem per second.[8]

For a plume having an effluent concentration of χ curies per cubic meter, the skin surface equivalent dose for gamma rays with average energy of $\bar{E}_\gamma$ MeV per disintegration is given by

$$\dot{H}_\gamma = 0.26 \times \bar{E}_\gamma \ QF_\gamma \qquad (4-2)$$

where QF_γ is the gamma quality factor which is equal to one and $\dot{H}_\gamma$ is the dose equivalent rate in rem per second.[8]

The program calculates the skin surface dose
equivalent rates at a point due to beta and gamma
radiations from all effluent plume constituents and sums
them to yield the total dose equivalent rate,

$$T \text{ DOSE} = \sum_{i=1}^{J} (\dot{H}_\beta + \dot{H}_\gamma)_i . \qquad (4-3)$$

The index i is limited to six which is the maximum
number of isotopes that PTDOSE can evaluate in any
single run.

Chapter V

PROGRAM DESCRIPTION

The program calculates dispersion concentrations
and dose equivalent rates at downwind locations due to
radioactive effluent release to the atmosphere. No
compensation is made for depletion of the effluent
concentration due to decay, rain washout, chemical
action or absorption due to contact with the ground.
Reduction of the plume concentration is by diffusion only.
The effluent release time is assumed to be greater than
or equal to travel time from the release point to sampling
receptor point. The program makes calculations for up to
six air entrainable radioisotopes.

The program has three major computational sections.
The first section contains calculations of maximum
concentrations for each stability class and set of
corresponding wind speeds. Section two calculates
dispersion concentrations and dose equivalent rates at
various downwind distances from the source using a
specified pair of wind speed and stability class values.
Section three calculates dispersion concentrations and
dose equivalent rates for points on a grid map generated
by utilizing a user specified grid distance increment.

A group of wind speeds that are common for a particular stability class is used to derive a set of maximum dispersion concentrations, one for each wind speed. After all six stability classes and their associated wind speeds have been analyzed, PTDOSE chooses the maximum dispersion concentration from a group that has been narrowed due to plume height and downwind distance restrictions. Any distance greater than 100 Km is rejected along with its maximum because the same atmospheric conditions around the source may not exist 100 Km downwind. Also, the experimentally derived charts from which the vertical and crosswind standard deviations were derived were valid only out to a distance of 100 Km from the source.[2] Any maximum associated with a plume height greater than 200 meters is rejected because the wind profile existing below 200 meters may not be the same as above 200 meters. In addition, superadiabatic lapse rates seldom exist above 200 meters.[4] The selected maximum along with its associated wind speed and stability class is output to a printer and retained for future possible use.

Input parameters for section one are found in Table A-1 of Appendix A. The actual stack height, HP, usually has a value equal to or greater than the containment building height. In most cases, the value of HP is

much greater than the building height so that the turbulent wake generated by the wind blowing over the structure does not affect the effluent plume dispersion. In the sample problem, HP is given a value greater than the structure's height. Stack temperature, TS, refers to the effluent temperature in degrees kelvin at the release point. The effluent volumetric flow rate, VF, at the point of release is in cubic meters per second. If VF is not specified then the release point diameter, D, in meters and the effluent release point velocity, VS, in meters per second must be specified. If VF is specified, then D and VS can be omitted. Mixing layer depth, HMIX, is specified in meters. Although the mixing layer depth will change during the day due to temperature differences, a value of 1050 meters is used in PTDOSE as being representative of the mixing layer depth in which all effluent diffusion should take place.* All para-meters discussed so far specified on the first data card. Table A-1 describes the input format for these variables. All parameters are right adjusted and care must be taken to assure each datum is in its allotted space on the card.

* This is a commonly used value in dispersion calculations made by Kemron Environmental Services of Baton Rouge, LA.

Input parameters of the second data card are
also found in Table A-1. To compute downwind dispersion
concentrations, the source location must be specified
in the conventional x-y coordinate system. The ordinate
value, RQ, and coordinate value, SQ, have units of
kilometers. The use of the parameter KNTRL will be
explained later. Ambient temperature in degrees kelvin
and ambient pressure in millibars are represented by T
and P respectively.

Section two of PTDOSE computes relative
dispersion concentrations (CUDQ) for a given set of
distances that are downwind from the source. The para-
meter KNTRL is evaluated by PTDOSE to determine if an
internally generated pair of stability class and wind
speed values are to be used or if a user specified pair
are to be used. If KNTRL is set equal to one, then an
internally generated pair of values from section one will
be used. If KNTRL is set equal to two then the pair of
values specified by the user are utilized.

Table A-2 of Appendix A contains the input
variables of section two. Downwind distances in this
section are divided into two groups. The first group is
generated by a distance increment internal to the model
that has a value of 1.0 Km. The second group is generated
from a user specified distance increment, DELINC, in

kilometers. PTDOSE generates one-hundred distances per increment for a total of two-hundred downwind distances.

The next two parameters are input only if the parameter KNTRL has a value of two. If this is the case then KST is set to the desired stability class. The wind speed, U, in meters per second is used with KST to obtain the desired results. If KNTRL is set equal to one, KST and U are left blank.

The number of isotopes to be evaluated is NI. This parameter is an integer between one and six. For each isotope to be evaluated, an alphanumeric title identifier, ALP, is used to identify printed data by isotope. The next parameter, BETA, specifies the average beta energy in MeV per disintegration for the isotope evaluated. GAMMA is the average energy in MeV per disintegration for the isotope evaluated. The release rate, QR, in curies per second is specified for each isotope. Each isotope evaluated must have a Card Type 6 followed by a Card Type 7 which is followed by a Card Type 8. If there are NI isotopes to be evaluated, then there must be NI sets of Card Types 6, 7, and 8, in that order, stacked behind Card Type 5. The stack arrangement of the sets is not important as long as each set is arranged as stated above and the sets are placed behind Card Type 5.

The results of the previous sections yield concentrations along the effluent plume centerline. However, effluent plumes do not disperse in a manner that allows the only significant information to occur along the plume's centerline. In actuality a plume as shown in Figure 3-1 will disperse in directions that are horizontally and vertically normal to the plume centerline. This produces concentrations at points downwind from the source that are not along the plume centerline. The purpose of section three of PTDOSE is to produce from given data the effluent concentrations and dose equivalent rates that can be expected to occur not only along the plume centerline but also at points normal to the centerline. The end result of section three is a grid map that can be used in determining locations of concentrations or dose equivalent rates.

As with the other two sections there are several input parameters used by section three in generating its results (Table A-3 of Appendix A). The grid increment, DEL, in kilometers is used to scale distances in both the ordinate and coordinate directions of the grid map. The parameters, QRGX and ORGY, are the locations of the map's origin and for the sample problem are set equal to 1.0 Km each. This was done so that the source would be upwind of the map origin. For an effluent released from a stack height much greater than the containment

structures height, the effluent plume will be on its
ascent with very little dispersion for distances close
to the source. Significant dispersion over the grid map
does not start until the plume centerline height
approaches that of the effective plume centerline height.
If there were factors that would force the plume to
disperse close to the source, then the grid map origin
would be set at the same location as the source. A low
release height would be one such factor. The values, NX
and NY, are used to specify the number of ordinate and
coordinate points of the grid map with a maximum of
fifteen for each.

Theta is the time averaged wind direction measured
in degrees from magnetic north occurring during a one hour
time period. The mixing layer depth measured in meters
is represented by HL. Ambient temperature, T, in degrees
kelvin and ambient pressure, P, in millibars are the last
two input parameters.

Data generation, printing and storage are
facilitated in PTDOSE by use of intermediate variables
in each section. The variable names and descriptions are
shown in Tables B-1, B-2, and B-3 of Appendix B. The
intermediate variables are mentioned here in case one
wishes to modify PTDOSE. The program makes use of several
subroutines that are briefly described in Appendix C.

The subroutines are discussed only for the purpose of providing the potential user with a more complete outline of how PTDOSE accomplishes its objective.

Chapter VI

SAMPLE PROBLEM

In the sample problem, a single nuclide,
Xenon 133, was chosen to test the abilities of the
program because it emits both betas and gamma rays.
The sample problem follows the major assumptions of no
effluent depletion other than that allowed for by
dispersion and plume travel time is less than effluent
release time. The actual stack height was assumed to be
high enough to escape any significant effect of the
containment structure's trubulent wake on the effluent
plume. Sample problem input parameters used can be
expected to occur in a common facility.

Table 6-1 shows data values for the first two
input cards. The actual stack height was set at 50
meters. Volumetric flowrate was specified as were stack
velocity and exit point diameter to show that all could
be used. Volumetric flowrate could have been left blank
as long as stack velocity and diameter are specified.
Mixing layer height was set at 1050 meters. Source
location was set so that it would be outside the
grid map thus allowing analysis of an area outside the
facility boundary (see Figure 6-2 for orientation). The
selection parameter was set equal to an integer value of

Table 6-1

Effluent Source Data

Description	Variable Name	Value
Actual stack height	HP	50 meters
Stack temperature	TS	398 °K
Volumetric flow rate	VF	159 m^3/sec
Effluent velocity	VS	50 m/sec
Stack diameter	D	2 meters
Mixing layer depth	HMIX	1050 meters
Source ordinate location	RQ	0.0 Km
Source coordinate location	SQ	0.0 Km
Selection parameter	KNTRL	2
Ambient temperature	T	293 °K
Ambient pressure	P	1000 mbar

'2' which allows a user specified stability class and wind speed to be utilized in downwind concentration calculations. Ambient temperature and pressure were set at 293 degrees kelvin and 1000 millibars respectively. Temperature and pressure are used to generate centerline downwind relative concentrations and may vary from temperature and pressure values used to generate grid map relative concentrations.

Table 6-2 contains the data values for input cards three through nine. A distance increment of 0.25 Km was chosen to calculate relative concentration close to the source. User specified stability class 'C' and wind speed of 7 meters per second were chosen to provide good effluent mixing without being overly turbulent. Xenon-133 was the only nuclide evaluated. It has an average beta energy of 0.146 MeV per disintegration and an average gamma energy of 0.03 MeV per disintegration. A release rate of 10 Ci per second was used. A grid increment of 0.25 kilometers was used to generate relative concentrations close to the facility. Ordinate and coordinate origins were set at 1.0 kilometers each so that the facility would lie upwind of the grid origin. The ordinate and coordinate increments were set to a maximum value of fifteen to yield a complete grid.

Table 6-3 contains data for input card ten. This card is repeated for each hour of meterology

Table 6-2

User Specified Input Data

Description	Variable Name	Value (units)
Distance increment	DELINC	0.25 Km
User specified stability class	KST	3
User specified wind speed	U	7 m/sec
Number of isotopes	NI	1
Isotope title	ALP	Xe-133
Average beta energy	BETA	0.146 MeV per disintegration
Average gamma energy	GAMMA	0.03 MeV per disintegration
Release rate	QR	10 Ci/sec
Grid increment	DEL	0.25 Km
Grid ordinate origin	ORGX	1.0 Km
Grid coordinate origin	ORGY	1.0 Km
Number of ordinate increments	NX	15
Number of coordinate increments	NY	15

Table 6-3

Grid Map Meteorology Data

Time Period	Description	Variable Name	Value
Hour 1	Wind direction	THETA	215 degrees
	Mixing layer depth	HL	1050 meters
	Ambient temperature	T	298°K
	Ambient pressure	P	1000 mbar
Hour 2	Wind direction	THETA	220 degrees
	Mixing layer depth	HL	1050 meters
	Ambient temperature	T	298 °K
	Ambient pressure	P	1000 mbar
Hour 3	Wind direction	THETA	225 degrees
	Mixing layer depth	HL	1050 meters
	Ambient temperature	T	298 °K
	Ambient pressure	P	1000 mbar

recorded up to a maximum of twenty-four. Multiple cards
are stacked one behind the other in the order in which
the user wants the parameter values to change. If (as
in the sample problem) three hours of meteorology data
is to be used, then three cards of the number ten type
are prepared following the format shown in Table A-3.
The change in the direction from which the wind is blowing
can be any value and was varied by ten degrees for each
hour of meteorological data in the sample problem. The
three hour time averaged direction from which the wind
was blowing was out of the southwest. Temperature and
pressure are time averaged values for each hour sampled
and for each hour were set at 298 degrees Kelvin and
1000 millibars respectively. Mixing layer depth may
change during each hour for which data is collected.
However, the mixing layer depth was held constant at
1050 meters.

　　　　As can be expected, PTDOSE generates a great
amount of data which are tabulated into rather lengthy
tables of output. In order to facilitate understanding
PTDOSE and its use, the most significant output data
are summarized in Tables 6-4 through 6-13.

　　　　Table 6-4 contains maximum values of the relative
concentration for various combinations of stability close
and wind speed. Other information given are distance

Table 6-4

Maximum Relative Concentrations

Stability Class	Wind Speed (m/sec)	χ/Q (sec/m^3)	Distance to Max χ/Q (Km)	Plume Height (m)	
A	0.5	8.25 E-07	1.59	1441.	(2)
A	1.0	1.05 E-06	1.16	745.	(2)
A	1.5	1.19 E-06	0.98	514.	(2)
A	3.0	1.39 E-06	0.74	282.	(2)
B	3.0	7.84 E-07	1.81	282	(2)
B	5.0	9.69 E-07	1.26	189	(2)
C	2.0	4.47 E-07	5.34	398	(2)
C	4.0	6.99 E-07	2.84	224	(2)
C	5.0	7.82 E-07	2.36	189	
C	7.0	8.93 E-07	1.82	149	
C	10.0	9.74 E-07	1.43	119	
C	12.0	9.95 E-07	1.28	107	
C	15.0	9.98 E-07	1.13	96	
D	4.0	2.73 E-07	11.0	224	(2)
D	5.0	3.35 E-07	8.83	189	
D	7.0	4.30 E-07	5.66	149	
D	15.0	5.94 E-07	2.79	96	
D	20.0	6.06 E-07	2.28	85	
E	2.0	7.01 E-07	13.3	159	
E	5.0	4.96 E-07	9.32	130	

Table 6-4 (continued)

Stability Class	Wind Speed (m/sec)	χ/Q (sec/m^3)	Distance to Max χ/Q (Km)	Plume Height (m)
F	2.0	3.55 E-07	35.1	140
F	3.0	3.35 E-07	28.4	129
F	5.0	3.08 E-07	22.0	117

Note: 8.25 E-07 is read as 8.25×10^{-7}.

from the source to the maximum and the plume centerline
height at that maximum. The numbers in parenthesis
indicate those data lines rejected by the program for
any of the following reasons:

1) The distance to point of maximum is so
great (over 100 Km) that the same stability class is
not likely to persist long enough for the plume to travel
this far;

2) The plume is of sufficient height that the
indicated stability class and wind speed may not exist
at that height; and

3) No computation attempted for this height as
point of maximum is greater than 100 Km from source.

Once exclusions have been made, the maximum relative
concentration can be found to correspond to stability
class 'C' and wind speed of 15 meters per second. This
data line is saved for possible use by PTDOSE depending
on the value of KNTRL. If KNTRL is set equal to an
integer value of 2 as in the sample problem, then a
user specified stability class and wind speed combination
are used for future calculation instead of the program
selected pair. A stability class and wind speed other
than those associated with the maximum relative
concentration from Table 6-4 were used to demonstrate
the ability of PTDOSE to utilize a user specified

combination. Ordinarily, one is interested in the worst case conditions and would allow the program to select the worst case data line from Table 6-4 for future use. Examining Table 6-4, one finds that for each stability class, the plume height and distance to the maximum relative concentration both decrease as the maximum relative concentration and wind speed increase in value. As the wind speed increases it causes the plume centerline to become horizontal faster. Therefore, the centerline height is closer to the ground which means the plume's downward dispersion from the centerline contacts the ground sooner than it would for a larger value of centerline height. Since no deposition or chemical reaction with the ground is allowed, the concentration builds up to a maximum at a point closer to the source than would occur for a lower wind speed.

Table 6-5 contains the meteorological conditions used in the downwind relative concentration calculations which are summarized in Tables 6-6 through 6-9.

Tables 6-6 and 6-7 summarize downwind relative concentrations for distance increments of 0.25 Km and 1.0 Km respectively. There are six columns in each table. The first one is distance downwind from the source at which the calculation is made. The next column is the plume centerline height at the distance specified in column one. The third and fourth columns contain the

Table 6-5

Meteorological Conditions Used in
Downwind Concentration Calculations

Description	Value
Ambient pressure	1000 mbar
Ambient temperature	293 °K
Stability class	C
Wind speed	7.0 m/sec
Mixing layer depth	1050 meters
Final effective plume height	152 meters
Distance to final effective height	0.832 Km

Table 6-6

Values of Relative Dispersion Concentration
and Relative Concentration Using a
Distance Increment of 0.25 Km

Distance (Km)	Plume Height (m)	SIGY (m)	SIGZ (m)	$\chi u/Q$ $(1/m^3)$	χ/Q (s/m^3)
0.25	95.9	29.0	17.2	1.15 E-10	1.65 E-11
0.50	123.	54.8	32.4	1.88 E-07	1.97 E-08
0.75	145.	79.3	47.0	7.11 E-07	1.02 E-07
1.00	152.	103.	61.1	2.27 E-06	3.24 E-07
1.25	152.	126.	75.0	4.27 E-06	6.10 E-07
1.50	152.	149.	88.6	5.51 E-06	7.86 E-07
1.75	152.	171.	102.	5.97 E-06	8.53 E-07
2.00	152.	193.	116.	5.96 E-06	8.52 E-07
2.25	152.	215.	128.	5.70 E-06	8.14 E-07
2.50	152.	237.	141.	5.33 E-06	7.61 E-07
2.75	152.	258.	154.	4.91 E-06	7.02 E-07
3.00	152.	279.	167.	4.51 E-06	6.44 E-07
3.25	152.	300.	180.	4.13 E-06	5.89 E-07
3.50	152.	321.	192.	3.77 E-06	5.39 E-07
3.75	152.	341.	204.	3.46 E-06	4.94 E-07
4.00	152.	361.	217.	3.17 E-06	4.53 E-07

Table 6-7

Values of Relative Dispersion Concentrations
and Relative Concentrations for
Distance Increment of 1.0 Km

Distance (Km)	Plume Height (m)	SIGY (m)	SIGZ (m)	$\chi u/Q$ $(1/m^2)$	χ/Q (s/m^3)
1.0	152.	103.	61.	2.27 E-06	3.24 E-07
2.0	152.	193.	115.	5.96 E-06	8.52 E-07
3.0	152.	279.	167.	4.51 E-06	6.44 E-07
4.0	152.	361.	217.	3.17 E-06	4.53 E-07
5.0	152.	442.	266.	2.30 E-06	3.28 E-07
6.0	152.	520.	315.	1.73 E-06	2.47 E-07
7.0	152.	597.	362.	1.35 E-06	1.92 E-07

plume dispersion standard deviations in the crosswind and vertical directions respectively. Column five contains values of the relative dispersion concentration while column six contains values of the relative concentration. The maximum values for the relative dispersion concentration and relative concentration occur at 1.75 Km (Table 6-6) and at 2.0 Km in Table 6-7. One may think that maximum values would occur at a point where the plume comes into contact with the ground. This would be true if not for the influence of plume dispersion diluting the concentration as the plume travels downwind. For the specified stability class and windspeed (Table 6-5), the plume rises to a centerline height of 152 meters where it becomes essentially horizontal. Tables 6-6 and 6-7 show that although the centerline height remains constant with distance, the plume continues to spread as shown by increases in SIGY and SIGZ.

Tables 6-8 and 6-9 contain the beta, gamma and total dose equivalent rates for each downwind distance shown in Tables 6-6 and 6-7. Figure 6-1 shows how the dose equivalent rates increase to a maximum and then fall off with increasing distance. The maximum dose equivalent rates in Tables 6-8 and 6-9 occur at 1.75 Km and 2.0 Km respectively since the maximum relative dispersion concentrations occur at those distances.

Table 6-8

Dose Equivalent Rates for Xe-133 Using
a Distance Increment of 0.25 Km
(Release rate is 10 Curies per second)

Distance (Km)	Beta (rem/hr)	Gamma (rem/hr)	Total (rem/hr)
0.25	1.98 E-08	4.81 E-09	2.46 E-08
0.50	2.37 E-05	5.55 E-06	2.93 E-05
0.75	1.23 E-04	2.89 E-05	1.62 E-04
1.00	3.91 E-04	9.25 E-05	4.84 E-04
1.25	7.35 E-04	1.72 E-04	7.52 E-04
1.50	9.46 E-04	2.22 E-04	9.68 E-04
1.75	1.03 E-03	2.41 E-04	1.27 E-03
2.00	1.02 E-03	2.40 E-04	1.26 E-03
2.25	9.89 E-04	2.30 E-04	1.21 E-03
2.50	9.03 E-04	2.15 E-04	1.12 E-03
2.75	8.60 E-04	1.98 E-04	1.06 E-03
3.00	7.74 E-04	1.82 E-04	9.56 E-04
3.25	7.31 E-04	1.66 E-04	8.97 E-04
3.50	6.45 E-04	1.52 E-04	7.97 E-04
3.75	6.02 E-04	1.39 E-04	7.41 E-04
4.00	5.59 E-04	1.28 E-04	6.87 E-04

Table 6-9

Dose Equivalent Rates from Xe-133 With
a Distance Increment of 1 Km
(Release rate is 10 Curies per second)

Distance (Km)	Beta (rem/hr)	Gamma (rem/hr)	Total (rem/hr)
1.0	3.91 E-04	9.25 E-05	4.84 E-04
2.0	1.02 E-03	2.40 E-04	1.26 E-03
3.0	7.74 E-04	1.82 E-04	9.56 E-04
4.0	5.59 E-04	1.28 E-04	6.87 E-04
5.0	4.27 E-04	9.29 E-05	5.19 E-04
6.0	2.98 E-04	6.99 E-05	3.68 E-04
7.0	2.32 E-04	5.44 E-05	2.86 E-04

Figure 6-1

Dose Equivalent Rate vs Downwind Distance
for a Stack Height of 50 Meters
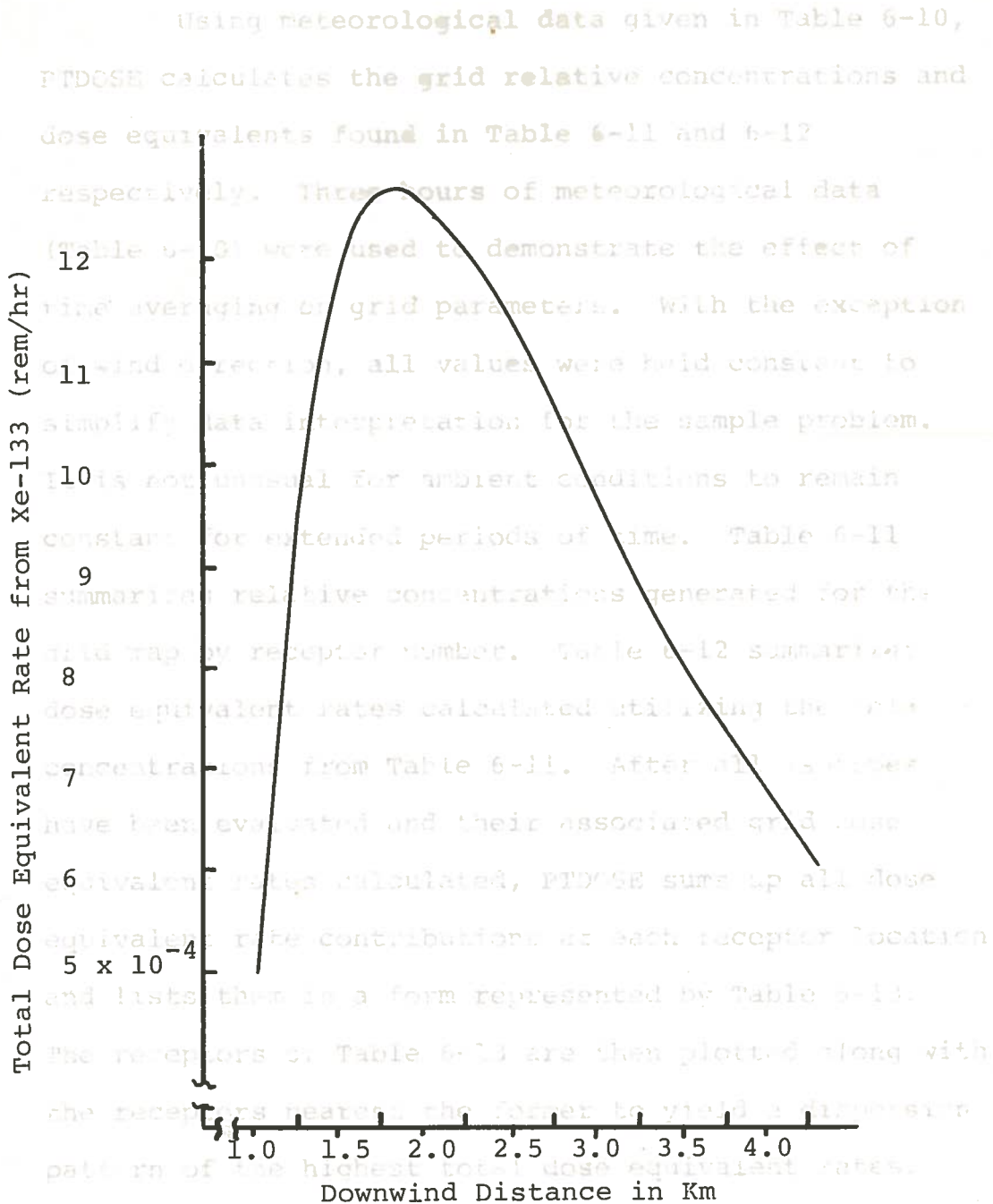(Release rate is 10 Curies per second)

55

Figure 6-1

Dose Equivalent Rate vs Downwind Distance
for a Stack Height of 50 Meters
(Release rate is 10 Curies per second)

Using meteorological data given in Table 6-10, PTDOSE calculates the grid relative concentrations and dose equivalents found in Table 6-11 and 6-12 respectively. Three hours of meteorological data (Table 6-10) were used to demonstrate the effect of time averaging on grid parameters. With the exception of wind direction, all values were held constant to simplify data interpretation for the sample problem. It is not unusual for ambient conditions to remain constant for extended periods of time. Table 6-11 summarizes relative concentrations generated for the grid map by receptor number. Table 6-12 summarizes dose equivalent rates calculated utilizing the relative concentrations from Table 6-11. After all isotopes have been evaluated and their associated grid dose equivalent rates calculated, PTDOSE sums up all dose equivalent rate contributions at each receptor location and lists them in a form represented by Table 6-13. The receptors of Table 6-13 are then plotted along with the receptors nearest the former to yield a dispersion pattern of the highest total dose equivalent rates.

Figure 6-2 has a translated coordinate system depicted by solid-lined axes and a primary coordinate system represented by dash-lined axes. The translated system corresponds to the receptor locations contained

Table 6-10

Meteorology Used for Time Averaging

Hour	Wind Direction (degrees)	Pasquill Stability Class	Wind Speed (m/sec)	Mixing Layer Depth (m)	Ambient Temp. (°K)	Ambient Pressure (mbar)
1	215	C	7.0	1050.	298	1000.
2	225	C	7.0	1050.	298	1000.
3	235	C	7.0	1050.	298	1000.

Note: The wind direction given is the direction from which the wind is blowing. The 3 hour averaged value would be from the southwest.

Table 6-11

Receptor Location Relative Concentration

Receptor Number	Receptor Ordinate (Km)	Receptor Coordinate (Km)	χ/Q (s/m^3)
2	1.00	1.25	3.91 E-07
17	1.25	1.25	3.15 E-07
32	1.50	1.25	4.00 E-07
48	1.75	1.50	3.69 E-07
64	2.00	1.75	3.28 E-07
79	2.25	1.75	2.96 E-07
95	2.50	2.00	2.61 E-07
110	2.75	2.00	2.29 E-07
126	3.00	2.25	2.06 E-07
142	3.25	2.50	1.83 E-07
158	3.50	2.75	1.63 E-07
173	3.75	2.75	1.47 E-07
189	4.00	3.00	1.23 E-07
205	4.25	3.25	1.20 E-07
220	4.50	3.25	1.10 E-07

Table 6-12

Dose Equivalent Rate from Xe-133
at Selected Receptor Locations
(Release rate is 10 Curies per second)

Receptor Number	Beta (rem/hr)	Gamma (rem/hr)	Total (rem/hr)
2	4.47 E-04	1.05 E-04	5.52 E-04
17	4.99 E-04	1.17 E-04	6.16 E-04
32	4.82 E-04	1.13 E-04	5.94 E-04
48	4.56 E-04	1.04 E-04	5.60 E-04
64	3.95 E-04	9.29 E-04	4.88 E-04
79	3.56 E-04	8.36 E-05	4.40 E-04
95	3.14 E-04	7.36 E-05	3.87 E-04
110	2.76 E-04	6.48 E-05	3.41 E-04
126	2.48 E-04	5.81 E-05	3.06 E-04
142	2.21 E-04	5.14 E-05	2.72 E-04
158	1.96 E-04	4.59 E-05	2.42 E-04
173	1.78 E-04	4.18 E-05	2.19 E-04
189	1.61 E-04	3.77 E-05	1.98 E-04
205	1.45 E-04	3.40 E-05	1.79 E-04
220	1.32 E-04	3.11 E-05	1.64 E-04

Table 6-13

Total Dose Equivalent Rate for All Effluent
Isotopes at Selected Receptor Locations
(Release rate is 10 Curies per second)

Receptor Number	Total for all Isotopes (rem/hr)
2	5.52 E-04
17	6.16 E-04
32	5.94 E-04
48	5.60 E-04
64	4.88 E-04
79	4.40 E-04
95	3.87 E-04
110	3.41 E-04
126	3.06 E-04
142	2.72 E-04
158	2.42 E-04
173	2.19 E-04
189	1.98 E-04
205	1.79 E-04
220	1.64 E-04

Wind blowing
from SW

Plume
Centerline

4.0

3.0

Km

2.0

1.0

Grid Origin

0   1.0   2.0   3.0   4.0
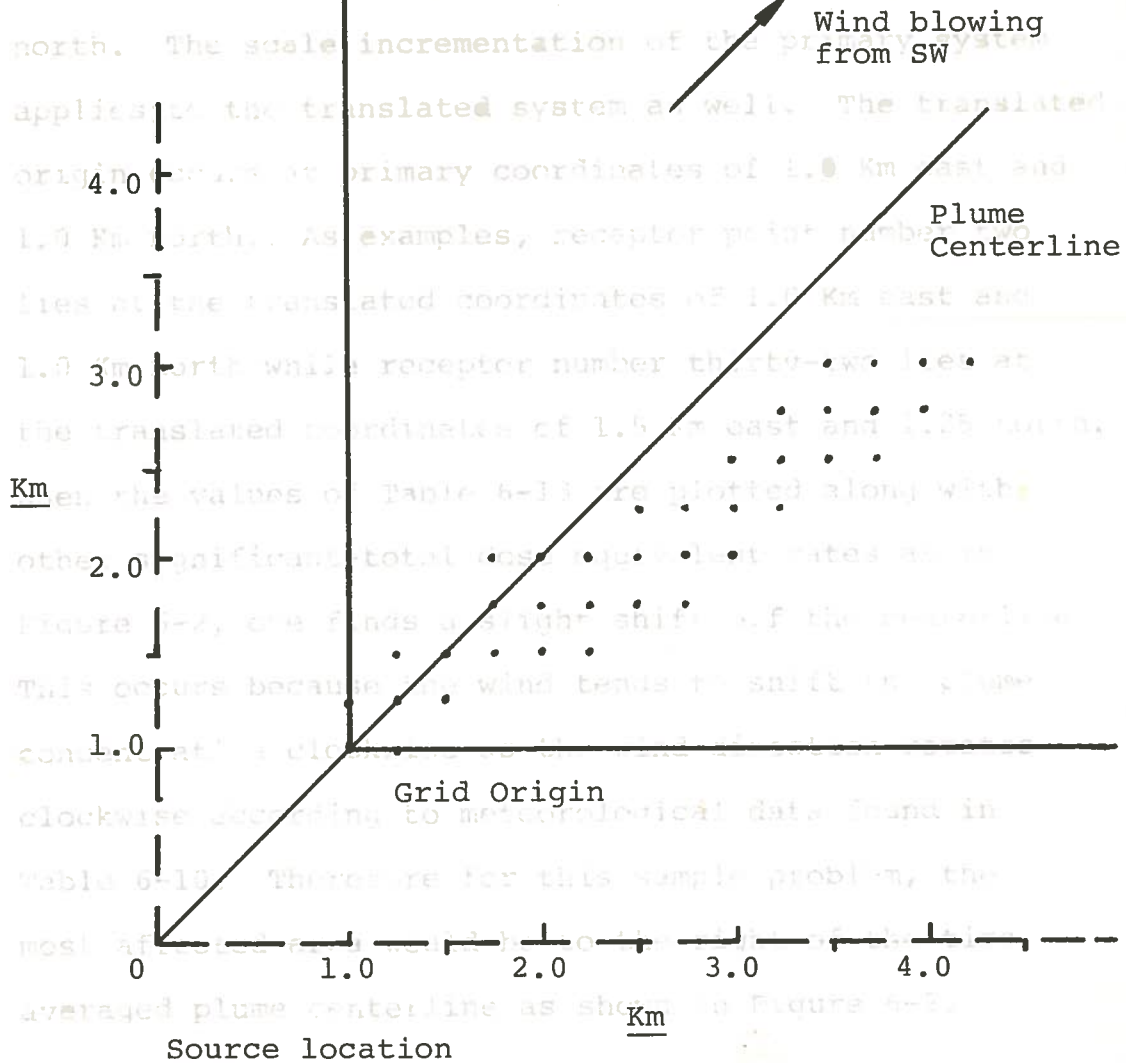
Km

Source location

Figure 6-2

Receptor Grid Map Showing Location of Significant
Concentrations Time Averaged Over a 3 hour Period
(Release rate is 10 Curies per second)

in Tables 6-12 and 6-13 while the primary system depicts the reference origin and source location. Both are located at coordinate point 0.0 Km east and 0.0 Km north. The scale incrementation of the primary system applies to the translated system as well. The translated origin occurs at primary coordinates of 1.0 Km east and 1.0 Km north. As examples, receptor point number two lies at the translated coordinates of 1.0 Km east and 1.0 Km north while receptor number thirty-two lies at the translated coordinates of 1.5 Km east and 1.25 north. When the values of Table 6-13 are plotted along with other significant total dose equivalent rates as in Figure 6-2, one finds a slight shift off the centerline. This occurs because the wind tends to shift the plume concentration clockwise as the wind direction rotates clockwise according to meteorological data found in Table 6-10. Therefore for this sample problem, the most affected area would be to the right of the time averaged plume centerline as shown in Figure 6-2.

Chapter VII

RESULTS AND SUMMARY

The sample problem has shown PTDOSE capable of
handling an isotope that emits both beta and gamma
radiation. For the meteorological conditions of
stability class C and windspeed of seven meters per
second and for a release rate of ten Curies per second,
one found the worst effluent concentrations would occur
about 1.75 Km downwind from the source and that for the
specified wind direction, the worst effluent concentr-
ations lie in a pattern to the right of the time averaged
plume centerline (Figure 6-2). In this case, the
direction from which the wind came was allowed to vary
from 215° to 235° over a three hour period. As shown
in Figure 6-2, the wind moved already airborne effluent
in a clockwise manner as the wind direction changed in
a clockwise fashion. The net effect was a slight build
up of the airborne effluent in the right lower half of
the grid map. The largest dose equivalent rate occurs
at receptor seventeen.

The program, PTDOSE, was prepared with the
intent of providing students and faculty of the Nuclear
Science Center at Louisiana State University with a
program that calculates downwind concentrations and
dose equivalent rates for an air entrainable radioactive

effluent. PTDOSE provides the user with a program that combines several steps and functions used in atmospheric effluent analysis into one operational unit. Assembled in PTDOSE are the abilities

      1) To calculate the maximum relative concentration for a given stability class and wind speed;

      2) To internally select or allow the user to specify a pair of stability class and wind speed values used in calculating relative concentrations for specified distances downwind from the source;

      3) To calculate dose equivalent rates for up to six effluent isotopes using the relative concentrations previously calculated; and

      4) To calculate relative concentrations and dose equivalent rates for specified receptor locations of a downwind grid map.

PTDOSE allows the user to centralize data input. Other programs require a data set be made so that concentrations can be calculated. These concentrations are then used as part of a second data set used by still another program to calculate dose equivalent rates.

      The program was created with the intent of yielding conservative concentrations and dose equivalent rates. The processes of accounting for plume depletion to causes other than due to diffusion are numerous and

complicated. The calculations to account for decay of the effluent constituents would become rather involved due to the potentially large number of daughter products that could be encountered. Depletion mechanisms such as washout, chemical reactions and surface depositions occur at different rates and are dependent on prevailing atmospheric conditions. By not accounting for these processes, PTDOSE provides an adequate means for treating the most likely effluent from nuclear facilities, the noble gases.

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Appendix A

PTDOSE Input Instructions

Table A-1

Input Instructions for Section One of PTDOSE

Card Type	Format	Variable	Parameter	Unit
1	F 8.2	HP	Actual stack height	meters
1	F 8.2	TS	Stack temperature	°K
1	F 8.2	VF	Volumetric flow rate	m^3/sec
1	F 8.2	VS	Effluent velocity	m/sec
1	F 8.2	D	Stack diameter	meters
1	F 8.2	HMIX	Mixing layer depth	meters
2	F10.2	RQ	Ordinate of source	Km
2	F10.2	SQ	Coordinate of source	Km
2	I5	KNTRL	Selection parameter	(unitless)
2	F10.4	T	Ambient temperature	°K
2	F10.4	P	Ambient pressure	mbar

Table A-2

Input Instructions for Section Two of PTDOSE

Card Type	Format	Variable	Description
3	F10.5	DELINC	User specified distance increment in Km
4	I5	KST	Pasquill stability class. For class A, use KST = 1 For class B, use KST = 2 For class C, use KST = 3 For class D, use KST = 4 For class E, use KST = 5 For class F, use KST = 6
4	F 5.1	U	Wind speed, m/sec
5	I5	NI	Number of isotopes to be evaluated
6	20A4	ALP	Alphanumeric title identifying isotope being evaluated
7	F10.3	BETA	Average beta energy of isotope, MeV per disintegration
7	F10.5	GAMMA	Average gamma energy of isotope, MeV per disintegration
8	F10.5	QR	Effluent release rate, Ci/sec

Table A-3

Input Instructions for Section Three of PTDOSE

Card Type	Format	Variable	Description
9	F 5.0	DEL	Grid increment, Km
9	F10.0	ORGX	Ordinate of origin, Km
9	F10.0	ORGY	Coordinate of origin, Km
9	I5	NX	Number of ordinate increments
9	I5	NY	Number of coordinate increments
10	F10.0	THETA	Wind direction, degrees measured from magnetic north
10	F10.0	HL	Mixing layer depth, meters
10	F10.0	T	Ambient temperature, °K
10	F10.0	P	Ambient pressure, mbar

Appendix B

PTDOSE Intermediate Parameters by Section

Table B-1

Intermediate Parameters for Section One of PTDOSE

Variable Name	Description
KST	Pasquill stability class
UA	Wind speed in meters/second
CM	Relative concentration, $\frac{sec}{m^3}$
XM	Distance to CM in Km
AD	Alphanumeric limiter used in exclusion process
HE	Plume height in meters
AH	Alphanumeric limiter used in exclusion process

Table B-2

Intermediate Parameters for Section Two of PTDOSE

Variable Name	Description
HMIX	Mixing layer depth in meters
HFIN	Final effective plume height in meters
DFIN	Distance to HFIN in meters
X	Downwind distance in Km
H	Plume height at X, meters
SY	Standard deviation of plume in cross wind direction, meters
SZ	Standard deviation of plume in vertical direction, meters
CUDQ	Relative dispersion concentration $1/m^2$
RC	Relative concentration, sec/m
HPI	Stack height, meters
TPI	Stack temperature, °K
VSI	Effluent release velocity, m/sec
DI	Stack exit diameter, meters
VFI	Effluent volumetric flow rate
RQI	Source ordinate location, Km
SQI	Source coordinate location, Km

Table B-2 (continued)

Variable Name	Description
XN	Downwind distance from source,
DRBA	Beta dose equivalent rate, rem/hr
DRGA	Gamma dose equivalent rate, rem/hr
TDOSE	Total dose equivalent rate for a particular isotope, rem/hr

Table B-3

Intermediate Parameters of Section
Three for PTDOSE

Variable Name	Description
K	Number of hours of meteorology
ANJ	Receptor number
RRECJ	Receptor ordinate value, Km
SRECJ	Receptor coordinate value, Km
SPCON	Relative concentration, $\frac{sec}{m^3}$

Appendix C

Brief Description of Subroutines

Subroutine BEHQ 72

This calculates an effective plume centerline height for a given downwind distance. It also calculates the maximum effective plume centerline height and its corresponding distance.

Subroutine DBTRCX

It calculates a relative concentration for a given downwind distance, effective plume centerline height and downwind distance.

Subroutine DBTSIG

It calculates the plume dispersion standard deviation for a given stability class and downwind distance.

Subroutine DBTMCX

It calculates a maximum relative concentration for a given pair of stability class and wind speed values. The distance at which this maximum occurs is also determined.

VITA

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