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NASA/MSFC MULTILAYER DIFFUSION MODELS AND COMPUTER PROGRAM FOR OPERATIONAL PREDICTION OF TOXIC FUEL HAZARDS

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This report describes the NASA/MSFC Multilayer Diffusion Models used in applying meteorological information to the estimation of toxic fuel hazards resulting from the launch of rocket vehicle and from accidental cold spills and leaks of toxic fuels.

The main body of the report contains five sections. Section 1 includes background information, the purpose of the report, and a definition of terms used in the report. Section 2 contains a description of the generalized concentration and dosage models which form the basis of the multilayer concept. Formulas for determining the buoyant rise of hot exhaust clouds or plumes from conflagrations, necessary for specifying model input parameters, are given in Section 3. Section 4 contains a description of the multilayer diffusion models and lists the mathematical formulas forming the basis of the computer program. A brief description of the computer program is given in Section 5. Finally, Section 6 contains some sample problems and their solutions obtained using the computer program.

There are five appendices to the report. Appendix A contains derivations of the cloud rise formulas described in Section 3. Appendix B contains users instructions for the computer program; and Appendix D contains example computer program output listings. Meteorological and source inputs used in the examples described in Section 6 of the report are contained in tables presented in Appendix E.
FOREWORD

This report is submitted to the Aerospace Environment Division, Aero-Astrodynamics Laboratory, NASA-Marshall Space Flight Center, Alabama in partial fulfillment of requirements under Contract No. NAS8-29033. The purpose of this report is to document revisions to the NASA Handbook for Estimating Toxic Fuel Hazards (Dumbauld, et al., 1970) and, in particular, the computer program associated with the Handbook. As experience has been gained in the application of the NASA/MSFC Multilayer Diffusion Model Program, it has become apparent that the program input requirements should be simplified for more efficient use of the multilayer concept. This report consists of:

- A description of the mathematical specifications for the NASA/MSFC Multilayer Diffusion Models
- Procedures for obtaining and calculating meteorological and source inputs to the revised diffusion model computer program
- A description of the revised NASA/MSFC Multilayer Diffusion Model Program
- A usage manual for implementing the revised NASA/MSFC Multilayer Diffusion Model Program
- Worked example problems illustrating the use of the diffusion models and computer program

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

The use of mathematical prediction models in applying meteorological information to the estimation of toxic fuel hazards is mandatory because of the inherent scarcity and fragmentary nature of measurements of the behavior of toxic clouds resulting from NASA operations. The concept of developing generalized dosage and concentration models for use in hazard estimation for a variety of environmental situations and for a variety of source configurations was originally developed and implemented for the U. S. Army (Cramer, et al., 1964; 1967; Cramer and Dumbauld, 1968). The concept was adapted to the prediction of environmental hazards from NASA operations by Record, et al. (1970) and Dumbauld, et al. (1970). This work under two concurrent NASA contracts (Contract Nos. NAS8-21453 and NAS8-30503) resulted in the publication of the NASA Handbook for Estimating Toxic Fuel Hazards and included a computer program specifically designed for research-oriented projects and for use in hazard estimation. The program was designed to permit hazard calculations downwind from normal and abnormal launches of rocket vehicles and from accidental cold spills and leaks of toxic fuels. The hazard estimation procedures and computer program developed under the above contracts have subsequently found wide use in estimation of hazards associated with vehicle launches and launch aborts (Cramer, et al., 1970; Dumbauld and Bjorklund, 1971; Cramer, et al., 1971; Cramer, et al., 1972a; 1972b; Dumbauld and Bjorklund, 1972).

1.2 PURPOSE

As experience has been gained in the application of the NASA/MSFC Multi-layer Diffusion Model Program, it has become apparent that some revisions to the
original program design could be made to simplify the use of the program while
retaining its overall flexibility in application to a variety of hazard problems. The
purpose of this report is to document the simplifications made in the computer
program.

The majority of the revisions entailed a streamlining of data input require-
ments and procedures used to enter data into the program. In the new version of
the program, all source and meteorological data inputs required by the dispersion-
transport models are entered into the program using a FORTRAN NAMELIST
format. The ISKIP options used to control program options in the original prograr}._
have been considerably simplified. In addition, requirements for duplicate entries
of some meteorological inputs in the original version of the program have been
eliminated and some parameters need not be entered unless changes in preset
values are required.

The original program contained seven versions of the basic diffusion
models, labeled Model 1 to Model 7. Each version was applicable to a specific
type of problem. Some of the original seven model versions have been eliminated
because experience has shown them to be of limited use in hazard estimation.
Others have been revised. A complete description of the revised versions of the
basic diffusion models is included in this report.

1.3 DEFINITION OF TERMS USED IN THE REPORT

The terminology used in this report conforms, in general, with the standard
nomenclature of diffusion meteorology. Concentration refers to the mass of a pollutant
per unit volume at a point, but it may be referenced to the ambient atmosphere, as in
parts per million. Dosage is the time-integrated concentration at a point and has the
units of concentration multiplied by unit time (for example, milligram-seconds per
cubic meter or parts per million-seconds). This definition of dosage, which conforms
to the terminology of the U. S. Army, does not include physiological factors such as
the respiration rate of a receptor. Some agencies, notably the U. S. Air Force, use
the term exposure to refer to the time-integrated concentration. The concentration and dosage terms used in this report are defined as follows:

- The maximum concentration $\chi\{x, y, z\}$ at a point $(x, y, z)$ is the maximum concentration in time that occurs at the point.

- The dosage $D\{x, y, z\}$ is the time-integrated concentration at the point $(x, y, z)$.

- The maximum centerline concentration $\chi_c\{x, y=0, z\}$ is the maximum concentration in time in the plane of the horizon at the downwind distance $x$ and the height above the ground $z$.

- The average alongwind concentration $\overline{\chi}\{x, y, z\}$ is the time-integrated concentration (dosage) at the point $(x, y, z)$ averaged over the cloud passage time.

- The time-mean alongwind concentration $\chi\{x, y, z; T_A\}$ is the partial dosage from time $t_a - T_A/2$ to time $t_a + T_A/2$ averaged over the time $T_A$, where $t_a$ is the arrival time of the cloud centroid at downwind distance $x$; for cloud passage times of less than $T_A$, $\chi\{x, y, z; T_A\}$ is then the total dosage averaged over $T_A$.

- The centerline dosage $D_c\{x, y=0, z\}$ is the maximum dosage in the plane of the horizon at the downwind distance $x$ and the height $z$.

1.4 ORGANIZATION OF THE REPORT

The main body of the report contains five sections. Section 2 contains a description of the generalized concentration and dosage models which form the
basis of the multilayer concept. Formulas for determining the buoyant rise of hot exhaust clouds or plumes from conflagrations, necessary for specifying model input parameters, are given in Section 3. Section 4 contains a description of the multilayer diffusion models and lists the mathematical formulas forming the basis of the computer program. A brief description of the computer program is given in Section 5. Finally, Section 6 contains some sample problems and their solutions obtained using the computer program.

There are five appendices to the report. Appendix A contains derivations of the cloud rise formulas described in Section 3. Appendix B contains users instructions for the computer program; Appendix C contains a complete listing of the computer program; and Appendix D contains example computer program output listings. Meteorological and source inputs used in the examples described in Section 6 of the report are contained in tables presented in Appendix E.
SECTION 2
GENERALIZED CONCENTRATION AND DOSAGE MODELS

The generalized models developed under the previous Government contracts described in Section 1 are presented here because they form the basis of the computerized NASA/MSFC multilayer diffusion models and computer program described in Sections 4 and 5 below. Generalized models are given for nearly-instantaneous releases in which the cloud of toxic material is detached from the source after a few seconds or, at the most, a few minutes. This condition is typical of normal and abnormal launches. Adaptation of the generalized models to continuous source emissions resulting from cold fuel spills and fuel leaks is outlined at the end of this section.

2.1 GENERALIZED CONCENTRATION MODEL

The generalized concentration model is expressed as the product of five modular terms:

\[
\text{Concentration} = \{\text{Peak Concentration Term}\} \times \{\text{Alongwind Term}\} \times \{\text{Lateral Term}\} \times \{\text{Vertical Term}\} \times \{\text{Depletion Term}\}
\]

The mathematical formulas given below for the various terms are written according to conventional usage. Specifically, the concentration model is referred to a Cartesian coordinate system with the origin at \(x = 0, y = 0\) and \(z = 0\) with the source located at an effective height \(H\) above the origin. The direction of \(x\) is along the mean azimuth wind direction, \(y\) is normal to the mean wind direction in the plane of the horizon, and \(z\) is directed vertically with \(z = 0\) at ground level. The distribution of concentration along each of the three coordinate axes is assumed to be Gaussian. None of the above assumptions is required. The model equations are easily transformed to a polar coordinate system or other systems, and other distribution functions may be substituted for the Gaussian function.
The Peak Concentration Term refers to the concentration at the point $x, y = 0, z = H$ and is defined by the expression

$$\frac{Q}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z}$$

where

- $Q =$ source strength
- $\sigma_x =$ standard deviation of the alongwind concentration distribution
- $\sigma_y =$ standard deviation of the crosswind concentration distribution
- $\sigma_z =$ standard deviation of the vertical concentration distribution

The Alongwind Term is defined by the expression

$$\exp \left[ - \frac{1}{2} \left( \frac{x - \bar{u}t}{\sigma_x} \right)^2 \right]$$

where

- $\bar{u} =$ mean wind speed
- $t =$ time of cloud travel

The Lateral Term is defined by the expression

$$\exp \left[ - \frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right]$$

The Vertical Term is given by the expression
\[
\exp \left[ - \frac{1}{2} \left( \frac{H-z}{\sigma_z} \right)^2 \right] + \exp \left[ - \frac{1}{2} \left( \frac{H+z}{\sigma_z} \right)^2 \right] + \sum_{i=1}^{\infty} \exp \left[ - \frac{1}{2} \left( \frac{2iH_m - H - z}{\sigma_z} \right)^2 \right] + \exp \left[ - \frac{1}{2} \left( \frac{2iH_m + H - z}{\sigma_z} \right)^2 \right]
\]

(2-4)

\[
+ \exp \left[ - \frac{1}{2} \left( \frac{2iH_m - H + z}{\sigma_z} \right)^2 \right] + \exp \left[ - \frac{1}{2} \left( \frac{2iH_m + H + z}{\sigma_z} \right)^2 \right] + \exp \left[ - \frac{1}{2} \left( \frac{2iH_m + H - z}{\sigma_z} \right)^2 \right]
\]

where

\[ H = \text{effective source height} \]
\[ H_m = \text{height of the top of the mixing layer} \]

The multiple reflection terms following the summation sign stop the vertical cloud growth at the top of the mixing layer and eventually change the form of the vertical concentration distribution from Gaussian to rectangular.

The **Depletion Term** refers to the loss of material by simple decay processes, precipitation scavenging, or gravitational settling. The form of the Depletion Term for each of these processes is:

(Decay) \[
\exp \left[ - kt \right]
\]

(2-5)

(Precipitation Scavenging) \[
\exp \left[ - \Lambda t \right]
\]

(2-6)

(Gravitational Settling)

\[
\exp \left[ - \frac{1}{2} \left( \frac{H - (V_s x/\bar{u}) - z}{\sigma_z} \right)^2 \right] + \exp \left[ - \frac{1}{2} \left( \frac{2H_m - H + (V_s x/\bar{u}) - z}{\sigma_z} \right)^2 \right]
\]

(2-7)

where

\[ k = \text{decay coefficient or fraction of material lost per unit time} \]
\[ t = \text{time} \]
A = washout coefficient or fraction of material removed by scavenging per unit time

\[ V_S = \text{settling velocity} \]

When Equation (2-7) is used for the Depletion Term, the Vertical Term given by Equation (2-4) is set equal to unity. This causes the cloud axis to be inclined downward at the angle \( \tan^{-1}(V_S/\bar{u}) \) with respect to the horizon, following W. Schmidt's sedimentation hypothesis (see Pasquill, 1962, p. 226); material that deposits on the ground surface is retained and not reflected. The vertical growth of the cloud is stopped at the top of the mixing layer and reflected toward the ground by the second exponential term in Equation (2-7). The depletion by gravitational settling of material containing a size distribution is calculated by partitioning the distribution into various settling-velocity categories, solving Equation (2-7) for each settling velocity, and superposing the solutions.

2.2 GENERALIZED DOSAGE MODEL

The generalized dosage model is similar in form to the generalized concentration model and is defined by the product of four modular terms:

\[ \text{Dosage} = \{\text{Peak Dosage Term}\} \times \{\text{Lateral Term}\} \times \{\text{Vertical Term}\} \times \{\text{Depletion Term}\} \]

The \textbf{Peak Dosage Term} is given by the expression

\[ \frac{Q}{2\pi \bar{u} \sigma_y \sigma_z} \]  

(2-8)

where

\[ Q = \text{source strength} \]

\[ \bar{u} = \text{mean wind speed} \]
\[ \sigma_y = \text{standard deviation of the crosswind dosage distribution} \]
\[ \sigma_z = \text{standard deviation of the vertical dosage distribution} \]

The remaining terms in the generalized dosage model are defined in the same manner as the corresponding terms for the generalized concentration model which are given by Equations (2-3), (2-4), (2-5), (2-6) and (2-7).

2.3 SUBSET OF EQUATIONS FOR \( \sigma_y, \sigma_z \) AND \( \sigma_x \)

The following subset of equations is used to define the distance dependence of the standard deviations of the crosswind, vertical and alongwind distributions in the generalized concentration and dosage models described above:

\[ \sigma_y(x) = \left\{ \left[ \sigma'_A(\tau) \frac{x_{ry}}{t} \left( \frac{x_{ry} - x_{ry}(1-\alpha)}{\alpha x_{ry}} \right) \right]^2 + \left[ \frac{\Delta \theta x}{4,3} \right]^2 \right\}^{1/2} \]  
\[ (2-9) \]

where

\[ \sigma'_A(\tau) = \text{standard deviation of the azimuth wind angle in radians for the cloud stabilization time } \tau \]
\[ x_{ry} = \text{distance over which rectilinear crosswind expansion occurs downwind from an ideal point source} \]
\[ x_y = \text{virtual distance} \]

\[ \sigma_x = \left\{ \left[ \frac{\sigma_y}{\sigma'_A(\tau)} - \frac{x_{ry}}{t} \right]^{1/\alpha} + \left[ \frac{\sigma_y}{\sigma'_A(\tau)} \right]^{1/\alpha} - \frac{x_{ry}}{t} \right\} \]

\[ \sigma_y = \text{standard deviation of the crosswind distribution at } x_{ry} \]
\[ x_{Ry} = \text{distance from the source at which } \sigma_{yo} \text{ is measured} \]

\[ \alpha = \text{lateral diffusion coefficient of the order of unity} \]

\[ \Delta\theta' = \text{azimuth wind direction shear in radians within the layer containing the cloud} \]

\[ \sigma_z(x) = \sigma_z^1 \frac{(x + x_{rz} - x_{rz} \beta (1 - \beta))}{\beta x_{rz}} \]  \hspace{1cm} \text{(2-10)}

where

\[ \sigma_z^1 = \text{standard deviation of the wind elevation angle in radians at height } H \]

\[ x_{rz} = \text{distance over which rectilinear vertical expansion occurs} \]

\[ x_z = \text{virtual distance} \]

\[ \left\{ \begin{array}{c}
\frac{\sigma_{zO}}{\sigma_z^1} - x_{rz} ; \sigma_{zO} \leq \sigma_z^1 \frac{x_{rz}}{x_z} \\
\beta x_{rz} \left( \frac{\sigma_{zO}}{\sigma_z^1 \frac{x_{rz}}{x_z}} \right)^{1/\beta} - x_{rz} + x_{rz} (1 - \beta) ; \sigma_{zO} > \sigma_z^1 \frac{x_{rz}}{x_z} 
\end{array} \right\} \]

\[ \sigma_{zO} = \text{standard deviation of the vertical distribution at } x_{Rz} \]

\[ x_{Rz} = \text{distance from the source at which } \sigma_{zO} \text{ is measured} \]

\[ \beta = \text{vertical diffusion coefficient of the order of unity} \]

\[ \sigma_x(x) = \left[ \left(\frac{L(x)}{4.3} \right)^2 + \sigma_{xo}^2 \right]^{1/2} \]  \hspace{1cm} \text{(2-11)}

where

\[ L(x) = \text{alongwind cloud length of a point source when the center of the cloud is a distance } x \text{ from the source} \]

\[ = \frac{0.28 (\Delta u)(x)}{\bar{u}} \]

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\[ \Delta u = \text{wind speed shear within the layer containing the cloud} \]
\[ \sigma_{xo} = \text{standard deviation of the alongwind distribution at the source} \]

In Equation (2-9) above, \( \sigma_A^t \) is expressed as a function of time \( \tau \) where \( \tau \) is the time after release required for the cloud to reach equilibrium with ambient atmospheric conditions. Values of \( \sigma_A^t \) for nearly-instantaneous releases are difficult to measure directly, but can be calculated from the following semi-empirical relationship (Cramer, et al., 1964):

\[ \sigma_A^t(\tau) = \sigma_A^t(\tau_0) \left( \frac{\tau}{\tau_0} \right)^{1/5} \]  

(2-12)

where \( \tau_0 \) is \( \leq \) 10 minutes. The standard deviation of the wind elevation angle \( \sigma_E^t \) is assumed independent of the release time \( \tau \) because of the relatively narrow frequency range in the power spectrum of the vertical wind velocity component that contains significant amounts of turbulent energy. This assumption is generally valid at heights \( \leq \) 100 meters above the ground surface. In the presence of large convective cells and at heights of the order of 1 kilometer, the assumption that \( \sigma_E^t \) is independent of \( \tau \) likely does not hold. However, the effect on the accuracy of ground-level concentration and dosage estimates is thought to be slight.

The source dimensions \( \sigma_{xo} \), \( \sigma_y \), \( \sigma_z \), in the above subset refer to a stabilized cloud at time \( \tau \). These source dimensions are best estimated from direct measurements or observations. The virtual distances \( x_y \), \( x_z \) are used to adjust the lateral and vertical terms of the generalized models for the initial source dimensions \( \sigma_y \) and \( \sigma_z \). Two virtual distances are employed to facilitate the treatment of asymmetrical sources where \( \sigma_y \neq \sigma_z \). In applications, \( x_y \) and \( x_z \) are constrained to be positive. The height of the stabilized cloud above ground level, when the emission mode is accompanied by the release of significant amounts of thermal energy, must be estimated from observations or by means of a mathematical formula for buoyant plume rise such as those given in Section 3 below.
2.4 MODEL FORMULAS FOR GROUND DEPOSITION CAUSED BY PRECIPITATION SCAVENGING AND GRAVITATIONAL SETTLING

The total amount of material deposited on the ground surface by precipitation scavenging, at some distance \(x\), is given by the expression

\[
\frac{\Lambda Q}{\sqrt{2\pi} \sigma_y u} \left\{ \exp \left[ - \frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right] \right\} \left\{ \exp \left[ - \Lambda \left( \frac{x}{u} - t_1 \right) \right] \right\} \tag{2-13}
\]

where \(t_1\) is the time at which the precipitation begins. The principal assumptions made in deriving the above expression are:

- The rate of precipitation is steady over an area that is large compared to the horizontal dimension of the cloud of toxic material.
- The precipitation originates at a level above the top of the toxic cloud so that hydrometeors pass vertically through the entire cloud.
- The time duration of the precipitation is sufficiently long so that the entire alongwind length of the toxic cloud passes over the point \(x\).

Engelmann (see Slade, 1968, pp. 208-221) discusses the general problems of calculating the amount of material removed by precipitation scavenging and recommends values of the coefficient \(\Lambda\) that may be combined with precipitation rates to obtain estimates of total surface deposition. Other useful information may be obtained from the proceedings of the 1970 Symposium on Precipitation Scavenging (Engelmann and Slinn, 1970).
The total deposition due to the gravitational settling of heavy particles or droplets with settling velocity $V_s$, at a downwind distance $x$ from the source and on the projection of the alongwind cloud axis on the ground plane, is given by the expression

$$\frac{Q}{\sqrt{2\pi} \sigma_y} \frac{d}{dx} \left\{ \frac{1}{\sqrt{2\pi}} \right\} \int_{-\infty}^{0} \exp \left[ -\frac{1}{2} \left( \frac{H-(V_s x/\bar{u})-z}{\sigma_z} \right)^2 \right] dz$$

After the integration and differentiation are performed, the above expression becomes

$$\frac{Q}{2\pi \sigma_y} \left[ \frac{\beta H^+ \left( 1 - \left( \frac{\beta x}{z - rz(1-\beta)} \right) \right) V_s \left( x + x - rz(1-\beta) \right) / \bar{u}}{ \sigma_z \left( z^2 - rz(1-\beta) \right) } \right] \exp \left[ -\frac{1}{2} \left( \frac{H-(V_s x/\bar{u})}{\sigma_z} \right)^2 \right]$$

$$+ \left[ \frac{\beta (2H_m - H)^+ \left( 1 - \left( \frac{\beta x}{z - rz(1-\beta)} \right) \right) V_s \left( x - x - rz(1-\beta) \right) / \bar{u}}{ \sigma_z \left( z^2 - rz(1-\beta) \right) } \right] \exp \left[ -\frac{1}{2} \left( \frac{2H_m (V_s x/\bar{u})}{\sigma_z} \right)^2 \right]$$

2.5 ADAPTATION OF THE GENERALIZED MODELS TO CONTINUOUS SOURCE EMISSIONS

The generalized concentration and dosage models discussed in Sections 2.1 and 2.2 above are applicable to cases in which the source is nearly-instantaneous.
Treatment of cold spills and fuel leaks that occur near ground level requires that these models be adapted for use in predicting concentrations downwind from continuous sources.

The generalized concentration model for continuous source emission is given by the product of four terms

\[ \text{Concentration} = \{ \text{Peak Concentration} \} \times \{ \text{Lateral Term} \} \]
\[ \times \{ \text{Vertical Term} \} \times \{ \text{Depletion Term} \} \]

The Peak Concentration Term is given by the expression

\[
\frac{Q}{2\pi \bar{u} \sigma_y \sigma_z}
\]

(2-16)

where

- \( Q \) = source strength in units of total mass released per unit time
- \( \bar{u} \) = mean wind speed at the effective source height
- \( \sigma_y \) = standard deviation of the crosswind concentration distribution
- \( \sigma_z \) = standard deviation of the vertical concentration distribution

The Lateral Term, Vertical Term and the subset of equations defining \( \sigma_y \) and \( \sigma_z \) are respectively given by Equations (2-3), (2-4), (2-9) and (2-10). The Depletion Term is given by Equations (2-5), (2-6) and (2-7), depending on the depletion mechanism. The expression for the Peak Concentration Term given by Equation (2-16) is very similar to the Peak Dosage Term in Equation (2-8) except for the definition of source strength and the mean wind speed.
SECTION 3
CLOUD RISE FORMULAS

The burning of rocket engines during normal launches and on-pad aborts results in the formation of a cloud of hot exhaust products which subsequently rises and entrains ambient air until an equilibrium with ambient conditions is reached. For normal launches, this cloud is formed principally by the forced ascent of hot turbulent exhaust products that have been deflected laterally and vertically by the launch pad hardware and the ground surface. The height at which this ground cloud stabilizes (i.e., reaches equilibrium with the environment) is determined by the vehicle type and atmospheric stability. The residence time of the vehicle on the pad appears to determine which type of cloud-rise formula is appropriate for predicting the stabilization height. Experience to date indicates that the buoyant rise of exhaust clouds from normal launches of solid-fueled and small liquid-fueled vehicles is best predicted by using a cloud rise model for instantaneous sources; the cloud rise for large liquid-fueled vehicles is best predicted by the use of a cloud rise model for continuous sources. While no cloud rise data are available for on-pad aborts, cloud rise data from static tests of liquid-fueled rockets indicate that the use of a cloud rise model for continuous sources is appropriate in this case.

3.1 CLOUD RISE FORMULAS FOR INSTANTANEOUS SOURCES

The following formulas for the maximum buoyant rise of clouds from instantaneous sources are based on procedures similar to those contained in a preprint of a paper presented by G. A. Briggs (1970) at the Second International Clean Air Congress. Derivations of these plume rise formulas are contained in Appendix A.
3.1.1 Adiabatic Atmosphere

The maximum cloud rise \( z_{ml} \) downwind from an instantaneous source in an adiabatic atmosphere (potential temperature constant with height) is given by

\[
z_{ml} = \left[ \frac{2F_I t_{SI}^2}{\gamma_I^3} + \left( \frac{r_R}{\gamma_I} \right)^4 \right]^{1/4} - \frac{r_R}{\gamma_I}
\]

(3-1)

where

\( F_I = \) the buoyancy parameter

\[
F_I = \frac{3g Q_I}{4\pi \rho c_p T}
\]

(3-2)

\( g = \) acceleration due to gravity (m sec\(^{-2}\))
\( Q_I = \) the effective heat released (cal)
\( c_p = \) specific height of air at constant pressure (cal gm\(^{-1}\) °K\(^{-1}\))
\( T = \) ambient air temperature (°K)
\( \rho = \) density of ambient air (gm m\(^{-3}\))
\( \gamma_I = \) the entrainment coefficient for an instantaneous source
\( r_R = \) the initial cloud radius at the surface (m)
\( t_{SI} = \) the time required for the cloud to reach stabilization (sec)

3.1.2 Stable Atmosphere

The maximum cloud rise \( z_{ml} \) downwind from an instantaneous source in a stable atmosphere is given by

\[
z_{ml} = \left[ \frac{8F_I}{\gamma_I^3 t} + \left( \frac{r_R}{\gamma_I} \right)^4 \right]^{1/4} - \frac{r_R}{\gamma_I}
\]

(3-3)
where

\[ s = \frac{g}{T} \frac{\partial \phi}{\partial z} \approx \frac{g}{T} \frac{\Delta \phi}{\Delta z} \]

\[ \frac{\Delta \phi}{\Delta z} = \text{the vertical gradient of ambient potential temperature} \]

Equations (3-1) and (3-3) assume that the initial upward momentum imparted to the exhaust gases by reflection from the ground surface and launch pad hardware is insignificant in comparison with the effect of thermal buoyancy. Based on limited experience in predicting cloud rise from launches at Vandenberg Air Force Base, this assumption appears to be justified.

3.2 CLOUD RISE FORMULAS FOR CONTINUOUS SOURCES

The following formulas for the maximum buoyant rise of clouds from continuous sources are also based on procedures similar to those given by Briggs (1970). The derivations of these formulas are given in Appendix A.

3.2.1 Adiabatic Atmosphere

The maximum cloud rise \( z_{mc} \) downwind from a continuous source in an adiabatic atmosphere is given by

\[ z_{mc} = \left[ \frac{3 F_c x_{sc}^2}{2 \gamma_c^2 u^3} + \left( \frac{r_R}{\gamma_c} \right)^3 \right]^{1/3} - \frac{r_R}{\gamma_c} \]  

(3-4)

where

\[ F_c = \text{the buoyancy flux parameter} \]

\[ = \frac{g Q_c}{\pi \rho_c T} \]  

(3-5)
\( Q_c \) = the effective rate of heat release (cal sec\(^{-1}\))
\( \gamma_c \) = the entrainment coefficient for a continuous source
\( \bar{u} \) = the mean wind speed (m sec\(^{-1}\))
\( x_{sc} \) = the downwind distance at which the cloud reaches its stabilization height (m)

3.2.2 Stable Atmosphere

The maximum cloud rise \( z_{mc} \) downwind from a continuous source in a stable atmosphere is given by

\[
z_{mc} = \left[ \frac{6 F_c}{\bar{u} \gamma_c^2 \gamma_s} + \left( \frac{r_R}{\gamma_c} \right)^3 \right]^{1/3} - \frac{r_R}{\gamma_c}
\]

Equations (3-4) and (3-6) assume that the initial momentum flux imparted to the cloud by dynamic forces is negligible in comparison with the buoyancy flux. Again, experience in calculating cloud rise for normal launches of large liquid fueled rockets and for static firings has shown that this assumption is reasonable.
SECTION 4
THE NASA/MSFC MULTILAYER DIFFUSION MODEL

4.1 THE MULTILAYER CONCEPT

The meteorological structure in the low-level reference air volume (from the surface to a height of about 5 kilometers) is usually comprised of several layers with distinctive wind, temperature and humidity fields. Large horizontal spatial variations in wind regimes may also occur in the surface layer, usually as a consequence of changes in terrain or land-water interfaces. The generalized diffusion models described in Section 2 have been adapted to these variations in meteorological structure. The vertical stratification problem in the reference volume is handled by applying the models to individual layers in which the meteorological structure is reasonably homogenous. Layer boundaries are placed at the points of major discontinuities in the vertical profiles of wind, temperature, and humidity.

For simplicity, it is assumed that there is no flux of material across layer boundaries due to turbulent mixing. Provision is made, however, for the flux of material across layer boundaries as a result of gravitational settling or precipitation scavenging.

Step changes in the meteorological structure of layers, at some arbitrary time or downwind distance from the point of release, are accommodated by stopping the transport and diffusion processes in the layers affected by the change in structure, calculating new sets of initial source and meteorological model input parameters, and re-starting the transport and diffusion process with the new inputs. The model provisions for step changes in meteorological structure can also be used to account for the vertical distribution of material within the stabilized cloud. The use of this feature of the program is further explained in Section 4.5 below.
Two geometries are involved in the multilayer concepts outlined above. The first is the layer geometry used with the Cartesian coordinate system of the generalized models in which the x-axis is along the mean wind direction in the layer. The second geometry refers to a basic reference polar coordinate grid system used in the computer program for the calculation of concentration and dosage fields.

The above concepts have been used to develop a multilayer construct, based on the generalized diffusion models, for application to the toxic fuel hazard problem at NASA installations. Mathematical specifications for the various layer models used in the NASA/MSFC multilayer construct are given below. These specifications provide the foundation for the computer programs that constitute the principal methods for estimating toxic fuel hazards. The six layer models first described refer principally to the transport, dispersal and depletion of toxic material formed as the result of normal and abnormal launches. The use of the multilayer diffusion program for estimating concentration fields downwind from cold fuel spills and surface fuel leaks is described at the end of the section.

4.2 MODEL 1

In this layer model, the source extends vertically through the entire layer and turbulent mixing is occurring. It is assumed that the vertical distribution of toxic material is uniform with height and that the distributions of toxic material along the x- and y-layer coordinates are Gaussian.

4.2.1 Dosage Equation for Model 1

The dosage equation for Model 1 in the $K^{th}$ layer is
In the above expression

\[ Q_K = \text{the source strength in units of mass per unit layer depth} \]

The quantity \( \bar{u}_K \) in Equation (4-1) is the mean cloud transport speed in meters per second in the \( K \)th layer. In the surface layer (\( K = 1 \)), the wind speed-height profile is defined according to the power-law expression

\[ \bar{u}_K \{ z, K = 1 \} = \bar{u}_R \left( \frac{z_K \{ K = 1 \}}{z_R} \right)^p \quad (4-2) \]

where

\[ \bar{u}_R = \text{mean wind speed measured at the reference height } z_R \]

\[ p = \text{power-law exponent for the wind speed profile in the surface layer} \]

\[ = \log \left( \frac{\bar{u}_{TK} \{ K = 1 \}}{\bar{u}_R} \right) / \log \left( \frac{z_{TK} \{ K = 1 \}}{z_R} \right) \]

\[ \bar{u}_{TK} \{ K = 1 \} = \text{mean wind speed at the top of the surface layer } z_{TK} \{ K = 1 \} \]

\[ z_K \{ K = 1 \} = \text{height in the surface layer} \]

Thus, in the surface layer, the mean cloud transport speed is defined by the expression

\[ \bar{u}_K \{ K = 1 \} = \frac{\bar{u}_R}{\left( z_{TK} \{ K = 1 \} - z_R \right)^{1+p} \int_{z_R}^{z_{TK} \{ K = 1 \}} \left( z_K \{ K = 1 \} \right)^p \, dz} \]

\[ = \frac{\bar{u}_R \left[ \left( z_{TK} \{ K = 1 \} \right)^{1+p} - (z_R)^{1+p} \right]}{\left( z_{TK} \{ K = 1 \} - z_R \right) \left( z_R \right)^p \left( 1+p \right)} \]
In layers above the surface layer \((K > 1)\), the wind speed-height profile is assumed linear and defined by the expression

\[
\bar{u}\{z_{K}, K \geq 1\} = \bar{u}_{BK} + \left(\frac{\bar{u}_{TK} - \bar{u}_{BK}}{z_{TK} - z_{BK}}\right) (z_{K} - z_{BK})
\]  

(4-3)

where

\[
\bar{u}_{TK} = \text{mean wind speed at the top of the layer } z_{TK}
\]

\[
\bar{u}_{BK} = \text{mean wind speed at the base of the layer } z_{BK}
\]

In the \(K^{th}\) layer \((K > 1)\), the mean cloud transport speed is given by the expression

\[
\bar{u}_{K}(K > 1) = \left(\bar{u}_{TK} + \bar{u}_{BK}\right)/2
\]

The standard deviation of the crosswind dosage distribution \(\sigma_{yK}\) is defined by the expression

\[
\sigma_{yK} = \left\{ \left[ \sigma_{AK}^{t}(\tau_{K}) x_{ryK} \left( \frac{x_{K} + x_{yK} - x_{ryK} (1 - \alpha_{K})}{\alpha_{K} x_{ryK}} \right)^{\alpha_{K}} \right]^{2} + \left[ \frac{\Delta \theta_{K} x_{yK}}{4.3} \right]^{2} \right\}^{1/2}
\]  

(4-4)

where

\[
\sigma_{AK}^{t}(\tau_{K}) = \text{mean layer standard deviation of the wind azimuth angle in radians for the cloud stabilization time } \tau_{K}
\]

In the surface layer \((K = 1)\),
\[
\sigma'_{\text{ATK}}(\tau_K, K=1) = \frac{\sigma'_{\text{AR}}(\tau_K) \left[ \left( z_{\text{TK}}(K=1) \right)^{m+1} - \left( z_R \right)^{m+1} \right]}{(m+1) \left( z_{\text{TK}}(K=1) - z_R \right) \left( z_R \right)^m} 
\]

(4-5)

where

\[
\sigma'_{\text{AR}}(\tau_K) = \text{standard deviation of the wind azimuth angle in radians at height } z_R \text{ and for the cloud stabilization time } \tau_K 
\]

\[
= \sigma'_{\text{AR}}(\tau_{oK}) \left( \frac{\tau_K}{\tau_{oK}} \right)^{1/5} \left( \frac{\pi}{180} \right) 
\]

\[
\sigma'_{\text{AR}}(\tau_{oK}) = \text{standard deviation of the wind azimuth angle in degrees at height } z_R \text{ and for the reference time period } \tau_{oK} 
\]

\[
m = \text{power-law exponent for the vertical profile of the standard deviation of the wind azimuth angle in the surface layer} 
\]

\[
= \log \left( \frac{\sigma'_{\text{ATK}}(\tau_K, K=1)}{\sigma'_{\text{AR}}(\tau_K)} \right) / \log \left( \frac{z_{\text{TK}}(K=1)}{z_R} \right) 
\]

\[
\sigma'_{\text{ATK}}(\tau_K, K=1) = \sigma'_{\text{ATK}}(\tau_{oK}, K=1) \left( \frac{\tau_K}{\tau_{oK}} \right)^{1/5} \left( \frac{\pi}{180} \right) 
\]

\[
\sigma'_{\text{ATK}}(\tau_{oK}, K=1) = \text{standard deviation of the wind azimuth angle in degrees at the top of the surface layer } z_{\text{TK}} \text{ for the reference time period } \tau_{oK} 
\]

For layers above the surface (K > 1),

\[
\sigma'_{\text{ATK}}(\tau_K, K>1) = \left( \sigma'_{\text{ATK}}(\tau_K) + \sigma'_{\text{ABK}}(\tau_K) \right) / 2 
\]

(4-6)
where
\[
\sigma'_{\text{ATK}}(r_K) = \sigma_{\text{ATK}}(r_{0K}) \left( \frac{r_K}{r_{0K}} \right)^{1/5} \left( \frac{\pi}{180} \right)
\]

\[
\sigma_{\text{ATK}}(r_{0K}) = \text{standard deviation of the wind azimuth angle in degrees at the top of the layer for the reference time period } r_{0K}
\]

\[
\sigma'_{\text{ABK}}(r_K) = \sigma_{\text{ABK}}(r_{0K}) \left( \frac{r_K}{r_{0K}} \right)^{1/5} \left( \frac{\pi}{180} \right)
\]

\[
\sigma_{\text{ABK}}(r_{0K}) = \text{standard deviation of the wind azimuth angle in degrees at the base of the layer for the reference time period } r_{0K}
\]

\[x_K = \text{downwind distance from the source}\]
\[y_K = \text{crosswind distance from the axis of the cloud}\]
\[x_{yK} = \text{crosswind virtual distance}\]

\[
\frac{\sigma_{yo}(K)}{\sigma'_{\text{ABK}}(r_K)} = x_{ RyK}
\]

when \( \sigma_{yo}(K) \leq \sigma'_{\text{ATK}}(r_K) x_{ ryK} \)

\[
= \alpha_K x_{ ryK} \left( \frac{\sigma_{yo}(K)}{\sigma'_{\text{ATK}}(r_K) x_{ ryK}} \right)^{1/\alpha_K} - x_{ RyK} + x_{ ryK}(1-\alpha_K)
\]

when \( \sigma_{yo}(K) \geq \sigma'_{\text{ATK}}(r_K) x_{ ryK} \)

\[
\sigma_{yo}(K) = \text{standard deviation of the lateral source dimension in the layer at downwind distance } x_{ RyK}
\]
\( x_{RyK} \) = distance from the source at which \( \sigma_{y_0}(K) \) is measured in the \( K^{th} \) layer

\( x_{ryK} \) = distance over which rectilinear crosswind expansion occurs downwind from an ideal point source in the \( K^{th} \) layer

\( \alpha_K \) = lateral diffusion coefficient in the layer

\( \Delta \theta'_K \) = vertical wind direction shear in the layer

\[ \Delta \theta'_K = \left( \theta_{TK} - \theta_{BK} \right) \left( \frac{\pi}{180} \right) \]

\( \theta_{TK} \) = mean wind direction in degrees at the top of the layer

\( \theta_{BK} \) = mean wind direction in degrees at the base of the layer

4.2.2 Concentration Equation for Model 1

The maximum concentration for Model 1 in the \( K^{th} \) layer is given by the expression

\[ x_K\{x_K, y_K, z_K\} = \frac{D_K \bar{u}_K}{\sqrt{2\pi} \sigma_xK} \] (4-7)

where

\( \sigma_xK \) = standard deviation of the alongwind concentration distribution in the layer

\[ = \left[ \left( \frac{L(x_K)}{4.3} \right)^2 + \sigma_{x_0}(K) \right]^{1/2} \] (4-8)

\( L(x_K) \) = alongwind cloud length for a point source in the layer at the distance \( x_K \) from the source

\[ = \begin{cases} \frac{0.28 (\Delta \bar{u}_K) (x_K)}{\bar{u}_K} ; & \Delta \bar{u}_K \geq 0 \\ 0 ; & \Delta \bar{u}_K \leq 0 \end{cases} \] (4-9)
\[ \Delta u_K = \text{vertical wind speed shear in the layer} \]

\[ \Delta u_K(K=1) = \bar{u}_{TK}(K=1) - \bar{u}_R \]

\[ \Delta u_K(K \approx 1) = \bar{u}_{TK} - \bar{u}_{BK} \]

\[ \sigma_{\chi_0}(K) = \text{standard deviation of the alongwind source dimension in the layer at the point of cloud stabilization} \]

The above equation for \( L(x_K) \) is based on the theoretical and empirical results reported by Tyldesley and Wallington (1965) who analyzed ground-level concentration measurements made at distances of 5 to 120 kilometers downwind from instantaneous line-source releases.

The maximum centerline concentration for Model 1 in the \( K^{th} \) layer is given by the expression

\[ \chi_{CK}(x_K, y_K, z_K) = \chi_K / \{ \text{LATERAL TERM} \} \quad (4-10) \]

The average alongwind concentration is defined as

\[ \bar{\chi}_K = D_K / t_{PK} \quad (4-11) \]

where

\[ t_{PK} = \text{cloud passage time in seconds in the } K^{th} \text{ layer} \]

\[ \approx 4.3 \sigma_{\chi_K} / \bar{u}_K \]

The time mean alongwind concentration in the \( K^{th} \) layer is defined by the expression

\[ \chi_K(x_K', y_K', z_K'; T_A) = \frac{D_K}{T_A} \left\{ \text{erf} \left( \frac{\bar{u}_K T_A}{2 \sqrt{2} \sigma_{\chi_K}} \right) \right\} \quad (4-12) \]
where

\[ T_A = \text{time in seconds over which concentration is to be averaged} \]

The time mean alongwind concentration is equivalent to the average alongwind concentration when \( t_p^K \) equals \( T_A \).

4.3 MODEL 2

Layer Model 2 refers to the same source configuration as Model 1 in which the source extends vertically through the entire depth of the layer and the distribution of toxic material is uniform with height. In Model 2, however, it is assumed that no turbulent mixing is occurring. Consequently, there is no dilution of the cloud due to turbulent expansion. The dosage and concentration equations for Model 2 are given by Equations (4-1) and (4-7), respectively, with the following substitutions:

\[ \sigma_y^K = \sigma_{yo} \tag{4-13} \]

\[ \sigma_{x^K} = \sigma_{xo} \tag{4-14} \]

4.4 MODEL 3

This layer model differs from Models 1 and 2 in that the vertical extent of the source is less than the depth of the layer. The model equation thus contains vertical expansion terms.

4.4.1 Dosage Equation for Model 3

The dosage equation for Model 3 in the \( K^{th} \) layer is given by the expression
\[ D_K \{x_K, y_K, z_{BK} < z_K < z_{TK}\} = \frac{Q_K}{2\pi \sigma y_K \sigma z_K \tilde{u}_K} \left\{ \exp \left[ \frac{-y_K^2}{2\sigma^2 y_K^2} \right] \right\} \]

\[ + \sum_{i=1}^{\infty} \left\{ \exp \left[ -\frac{(2i(z_{TK}-z_{BK})-(H_K-2z_{BK}+z_K))^2}{2\sigma^2 z_K^2} \right] \right\} \]

\[ \text{exp} \left[ -\frac{(2i(z_{TK}-z_{BK})+(H_K-z_K))^2}{2\sigma^2 z_K^2} \right] + \exp \left[ -\frac{(2i(z_{TK}-z_{BK})-(H_K-z_K))^2}{2\sigma^2 z_K^2} \right] \]

\[ + \exp \left[ -\frac{(2i(z_{TK}-z_{BK})+(H_K-2z_{BK}+z_K))^2}{2\sigma^2 z_K^2} \right] \]

where

- \( Q_K \) = source strength or total mass of material in the layer
- \( H_K \) = effective source height or height of the centroid of the stabilized cloud
- \( \sigma_{zK} \) = standard deviation of the vertical dosage distribution in the layer

The remaining terms are the same as those in Equation (4-1) for Model 1.

The standard deviation of the vertical dosage distribution is defined by the expression

\[ \sigma_{zK} = \sigma_{EK_z} x_{rzK} \left( \frac{x_K + x_{zK} - x_{rzK}(1-\beta_K)/\beta_K}{\beta_K x_{rzK}} \right)^{\beta_K} \]
where

\[ \sigma_{EK}^{1} = \text{mean standard deviation of the wind elevation angle in radians for the layer} \]

\[ x_{zK} = \text{vertical virtual distance in the layer} \]

\[ \beta_{K} = \text{vertical diffusion coefficient in the layer} \]

\[ x_{rzK} = \text{distance over which rectilinear vertical expansion occurs downwind from an ideal point source in the } K^{th} \text{ layer} \]

In the surface layer \((K = 1)\),

\[ \sigma_{EK}^{1} = \frac{\sigma_{ER} \left[ \left( z_{TK}^{1} \right)^{q+1} - \left( z_{R} \right)^{q+1} \right]}{(q+1) \left( z_{TK}^{1} - z_{R} \right) \left( z_{R} \right)^{q}} \left( \frac{\pi}{180} \right) \]  \(\text{(4-17)}\)

where

\[ \sigma_{ER} = \text{standard deviation of the wind elevation angle in degrees at the height } z_{R} \]

\[ q = \text{power-law exponent for the vertical profile of the standard deviation of the wind elevation angle in the surface layer} \]

\[ = \log \left( \frac{\sigma_{ETK}^{1}}{\sigma_{ER}} \right) \left/ \log \left( \frac{z_{TK}^{1}}{z_{R}} \right) \right. \]

\[ \sigma_{ETK}^{1} = \text{standard deviation of the wind elevation angle in degrees at the top of the surface layer} \]

Above the surface layer \((K > 1)\),

\[ \sigma_{EK}^{1} = \left( \sigma_{ETK} + \sigma_{EBK} \right) \left( \frac{\pi}{360} \right) \]

where

\[ \sigma_{ETK} = \text{standard deviation of the wind elevation angle in degrees at the top of the layer} \]

\[ \sigma_{EBK} = \text{standard deviation of the wind elevation angle in degrees at the base of the layer} \]
The vertical virtual distance $x_{zK}$ is given by the expression

\[
\left\{ \begin{array}{l}
\frac{\sigma_{z_0}^{(K)}}{\sigma_{E}^{(K)}} - x_{RzK} \\
\beta_{K} x_{r_{zK}} \left( \frac{\sigma_{z_0}^{(K)}}{\sigma_{E}^{(K)}} \right)^{1/\beta_{K}} - x_{RzK} + x_{r_{zK}}(1-\beta_{K}) ; \; \sigma_{z_0}^{(K)} \geq \sigma_{E}^{(K)} x_{r_{zK}}
\end{array} \right.
\]

where

\[\sigma_{z_0}^{(K)} = \text{standard deviation of the vertical dosage distribution at } x_{RzK}\]

\[x_{RzK} = \text{distance from the source at which } \sigma_{z_0}^{(K)} \text{ is measured in the } K^{th} \text{ layer}\]

4.4.2 Concentration Equation for Model 3

The concentration equation for Model 3 is the same as that for Model 1 which is given by Equation (4-7) in Section 4.2.2 with $D_{K}$ from Equation (4-15). Equation (4-10) in Section 4.2.2 also gives the maximum centerline concentration for Model 3. Similarly, average and time mean alongwind concentrations for Model 3 are given by Equations (4-11) and (4-12) with $D_{K}$ from Equation (4-15).

4.5 MODEL 4

Model 4, the layer-breakdown model, may be used to calculate concentration and dosage fields resulting from changes in the meteorological layer structure. Model 4 may also be used to determine concentration and dosage fields in the surface mixing layer downwind from a source in which the source strength varies with height in the layer. The application of Model 4 requires the following assumptions:
• The boundary between adjacent layers or sublayers is eliminated and the layers are replaced by a single layer L.

• Turbulent mixing is occurring in Layer L.

• The material in each of the layers or sublayers is initially uniformly distributed in the vertical.

• Reflection occurs at the upper and lower boundaries of Layer L.

The selection of Model 4 for layer breakdown calculations or to accommodate vertical source strength variations in the surface mixing layer is controlled in the computer program by selection of certain options (see Appendix B) available in the input configuration. If no special provision is made and Model 4 is specified for use, the program assumes that the function of the model is to accommodate to vertical source strength variations. For example, the surface mixing layer can be divided into several sublayers where the source strength, although assumed to be vertically uniform in the \( K^{th} \) sublayer, increases with height in subsequent layers (see example problems in Section 6). In this case, Model 4 calculates the contribution from each sublayer to the composite concentration and dosage fields in the surface mixing layer by permitting turbulent mixing across the initial sublayer boundaries.

If Model 4 is to be used to predict the concentration and dosage fields downwind from a change in meteorological structure, the program option ISKIP(2) must be properly set, the input parameter NBK must be initialized, and the meteorological parameters for the new \( L^{th} \) layer and the time \( t^* \) at which layer breakdown occurs must be specified (see Appendix B).
4.5.1 Dosage Equation for Model 4

The dosage equation for Model 4 for the contribution from the portion of the cloud in the \( k \)th layer to the receptor position in the layer \( L \) is given by the expression

\[
D_{LK} = \frac{Q_K}{2\sqrt{2\pi}} \frac{u_L}{\sigma_{yLK}} \left\{ \exp \left[ - \left( \frac{y_L^2}{2\sigma_{yLK}^2} \right) \right] \right\}
\]

\[
\sum_{i=0}^{\infty} \left[ \text{erf} \left( \frac{2i(z_{TL} - z_{BL}) - z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right) + \text{erf} \left( \frac{2i(z_{TL} - z_{BL}) + z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right) \right]
\]

\[
+ \text{erf} \left( \frac{2i(z_{TL} - z_{BL}) + 2z_{BL} - z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right) + \text{erf} \left( \frac{2i(z_{TL} - z_{BL}) - 2z_{BL} + z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right)
\]

\[
\sum_{i=1}^{\infty} \left[ \text{erf} \left( \frac{-2i(z_{TL} - z_{BL}) - z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right) + \text{erf} \left( \frac{-2i(z_{TL} - z_{BL}) + z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right) \right]
\]

\[
+ \text{erf} \left( \frac{-2i(z_{TL} - z_{BL}) + 2z_{BL} - z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right) + \text{erf} \left( \frac{-2i(z_{TL} - z_{BL}) - 2z_{BL} + z_{BK} + z_L}{\sqrt{2} \sigma_{zLK}} \right) \right) \right\}
\]

The total contribution to a receptor position in Layer \( L \) is calculated by summing the contributions from all \( K \) layers. In the above expression

\[
Q_K = \text{source strength in units of mass per unit layer depth (g m}^{-1}) \text{for the source in the layer \( K \)}
\]
In Model 4, the quantity $\bar{u}_L$ is the mean cloud transport in the $L^{th}$ layer. If the layer $L$ is the surface mixing layer ($L = 1$), the wind speed-height profile is defined according to the expression

$$\bar{u}\{z_L, L=1\} = \bar{u}_{RL} \left( \frac{z_L\{L=1\}}{z_R} \right)^{p_L}$$

where

- $\bar{u}_{RL}$ = mean wind speed at the reference height $z_R$ in the new surface layer $L$
- $p_L$ = power-law exponent for the wind speed profile in the surface layer ($L = 1$)

$$= \log \left( \frac{\bar{u}_{TL}\{L=1\}}{\bar{u}_{RL}} \right) \log \left( \frac{z_{TL}\{L=1\}}{z_R} \right)$$

$$\bar{u}_{TL}\{L=1\} = \text{mean wind speed at the top of the surface layer } z_{TL}\{L=1\}$$

$$z_L\{L=1\} = \text{height in the surface layer}$$

The mean cloud transport speed in the surface layer is given by

$$\bar{u}_L\{L=1\} = \frac{\bar{u}_{RL} \left[ (z_{TL}\{L=1\})^{1+p_L} - (z_R)^{1+p_L} \right]}{(z_{TL}\{L=1\} - z_R)(z_R)^{p_L} (1+p_L)} \quad (4-19)$$

For layers above the surface layer ($L > 1$), the wind speed-height profile is assumed to be defined by the expression

$$\bar{u}\{z_{LK}, L>1\} = \bar{u}_{BL} + \left( \frac{\bar{u}_{TL} - \bar{u}_{BL}}{z_{TL} - z_{BL}} \right) \left( z_L - z_{BL} \right)$$
where

\[ \bar{u}_{\text{TL}} = \text{mean wind speed at the top of the layer } z_{\text{TL}} \]
\[ \bar{u}_{\text{BL}} = \text{mean wind speed at the base of the layer } z_{\text{BL}}. \]

The mean cloud transport speed is thus,

\[ \bar{u}_L \{ l, t \} = \left( \bar{u}_{\text{TL}} + \bar{u}_{\text{BL}} \right) / 2 \] \hspace{1cm} (4-20)

The crosswind distance from the axis of the cloud to a receptor \( y_L \) (defined positive to the right looking downwind) is given by the expression

\[ y_L = \left( y_j - y_{SK} \right) \sin \theta_L + \left( x_j - x_{SK} \right) \cos \theta_L \] \hspace{1cm} (4-21)

where

- \( x_j, y_j \) = position of the receptor with respect to the origin of the reference coordinate system with the y axis positive northward and the x axis positive eastward
- \( x_{SK}, y_{SK} \) = coordinates of the cloud centroid in the \( K^{th} \) layer at time \( t^* \) with respect to the origin of the reference coordinate system
- \( x_i, y_i \) = coordinates of the real source in the \( K^{th} \) layer with respect to the origin of the reference coordinate system
- \( \theta_L = \left( \theta_{\text{TL}} + \theta_{\text{BL}} \right) \left( \frac{\pi}{360} \right) \)
- \( \theta_{\text{TL}} = \text{mean wind direction in degrees at the top of the layer } z_{\text{TL}} \)
- \( \theta_{\text{BL}} = \text{mean wind direction in degrees at the base of the layer } z_{\text{BL}} \)
- \( \theta_K = \left( \theta_{\text{TK}} + \theta_{\text{BK}} \right) \left( \frac{\pi}{360} \right) \)
The standard deviation of the crosswind dosage distribution \( \sigma_{yL} \) in the \( L^{th} \) layer is defined by the expression

\[
\sigma_{yL} = \left\{ \left[ \sigma_{AL}^{(\tau_L)} x_{ryL} \left( \frac{x_L + x_{yKL} - x_{ryL} (1 - \alpha_L)}{\alpha_L x_{ryL}} \right) \right]^{\frac{1}{2}} + \left[ \frac{\Delta \theta_L x_L}{4.3} \right] \right\}^{1/2}
\]

where

\( \sigma_{AL}^{(\tau_L)} = \text{mean layer standard deviation of the wind azimuth angle in radians for the effective cloud stabilization time } \tau_L \)

In the surface layer (\( L = 1 \)),

\[
\sigma_{AL}^{(\tau_L, L=1)} = \frac{\sigma_{ARL}^{(\tau_L)} \left[ (z_{TL,L=1})^{m_L+1} - (z_R)^{m_L+1} \right]}{(m_L+1) (z_{TL,L=1} - z_R) (z_R)^{m_L}}
\]

where

\( \sigma_{ARL}^{(\tau_L)} = \text{standard deviation of the wind azimuth angle in radians at height } z_R \text{ and for time } \tau_L \)

\[
= \sigma_{ARL}^{(\tau_{OL})} \left( \frac{\tau_L}{\tau_{OL}} \right)^{1/5} \left( \frac{\pi}{180} \right)
\]

\( \sigma_{ARL}^{(\tau_{OL})} = \text{standard deviation of the wind azimuth angle in degrees at height } z_R \text{ and for the reference time period } \tau_{OL} \)

\( m_L = \text{power-law exponent for the vertical profile of the standard deviation of the wind azimuth angle in the surface layer } L = 1 \)
\[ m_L = \log \left( \frac{\sigma'_{\text{ATL}}(\tau_{L,L=1})}{\sigma'_{\text{ABL}}(\tau_L)} \right) / \log \left( \frac{z_{\text{TL}}(L=1)}{z_R} \right) \]

\[ \sigma'_{\text{ATL}}(\tau_{L,L=1}) = \sigma'_{\text{ATL}}(\tau_{oL,L=1}) \left( \frac{\tau_L}{\tau_{oL}} \right)^{1/5} \left( \frac{\pi}{180} \right) \]

\[ \sigma_{\text{ATL}}(\tau_{oL,L=1}) = \text{standard deviation of the wind azimuth angle in degrees at the top of the surface layer } z_{\text{TL}} \text{ for the reference time period } \tau_{oL} \]

For layers above the surface layer \((L > 1)\),

\[ \sigma'_{\text{AL}}(\tau_{L,L>1}) = \left( \sigma'_{\text{ATL}}(\tau_L) + \sigma'_{\text{ABL}}(\tau_L) \right) / 2 \quad (4-24) \]

where

\[ \sigma'_{\text{ATL}}(\tau_L) = \sigma_{\text{ATL}}(\tau_{oL}) \left( \frac{\tau_L}{\tau_{oL}} \right)^{1/5} \left( \frac{\pi}{180} \right) \]

\[ \sigma_{\text{ATL}}(\tau_{oL}) = \text{standard deviation of the wind azimuth angle in degrees at the top of the layer for the reference time period } \tau_{oL} \]

\[ \sigma'_{\text{ABL}}(\tau_L) = \sigma_{\text{ABL}}(\tau_{oL}) \left( \frac{\tau_L}{\tau_{oL}} \right)^{1/5} \left( \frac{\pi}{180} \right) \]

\[ \sigma_{\text{ABL}}(\tau_{oL}) = \text{standard deviation of the wind azimuth angle in degrees at the base of the layer for the reference time } \tau_{oL} \]

The wind direction shear in radians in the layer is given by the expression

\[ \Delta \theta'_{L} = \left( \theta_{\text{TL}} - \theta_{\text{BL}} \right) \left( \frac{\pi}{180} \right) \]
The crosswind virtual distance in the \( L \)\textsuperscript{th} layer due to source (cloud) originating in the \( K \)\textsuperscript{th} layer is given by the expression

\[
x_{yKL}^* = \frac{1}{\alpha_L} \left( \frac{\sigma_{yKL}}{\sigma_{AL}^* \tau_L} \right)^{1/\alpha_L} + x_{ryL} (1 - \alpha_L)
\]

where

- \( \sigma_{yKL}^* \) = crosswind source dimension in Layer \( L \) due to source (cloud) originating in the \( K \)\textsuperscript{th} layer

\[
= \left\{ \left[ (\sigma_{yK})^2 \sin^2 \left( \theta_K - \theta_L \right) \right] + \left[ (\sigma_{yK})^2 \cos^2 \left( \theta_K - \theta_L \right) \right] \right\}^{1/2}
\]

- \( \sigma_{xK}^* \) = alongwind standard deviation of the dosage distribution in the \( K \)\textsuperscript{th} layer at time \( t^* \)

- \( \sigma_{yK}^* \) = crosswind standard deviation of the dosage distribution in the \( K \)\textsuperscript{th} layer at time \( t^* \)

- \( \alpha_L \) = lateral diffusion coefficient in the layer

- \( x_{ryL} \) = distance over which rectilinear crosswind expansion occurs downwind from an ideal point source in the \( L \)\textsuperscript{th} layer

The downwind distance from the point where the change in layer structure occurs for the source (cloud) in the \( K \)\textsuperscript{th} layer to the point where the dosage is to be calculated \( x_L \) is given by the expression

\[
x_L = - \left( x_j - x_{SK} \right) \sin \theta_L - \left( y_j - y_{SK} \right) \cos \theta_L \quad (4-25)
\]

The standard deviation of the vertical dosage distribution \( \sigma_{zLK} \) in the \( L \)\textsuperscript{th} layer is defined by the expression

\[
\sigma_{zLK} = \sigma_{EL}^1 x_{rzL} \left( \frac{x_L}{x_{rzL}} \right)^{\beta_L} \quad (4-26)
\]
where

\[ \sigma_{EL} = \text{mean standard deviation of the wind elevation angle in radians for the layer} \]

\[ \beta_L = \text{vertical diffusion coefficient in the layer} \]

\[ x_{rzL} = \text{distance over which rectilinear vertical expansion occurs downwind of an ideal point source in the } L\text{th layer} \]

In the surface layer \((L = 1)\),

\[
\sigma_{EL}^{(L=1)} = \frac{\sigma_{ERL}\left[(z_{TL}^{(L=1)})^{q_L+1} - (z_R)^{q_L+1}\right]}{(q_L+1)(z_{TL}^{(L=1)} - z_R)(z_R)^{q_L}} \left(\frac{\pi}{180}\right) \tag{4-27}
\]

where

\[ \sigma_{ERL} = \text{standard deviation of the wind elevation angle in degrees at the reference height } z_R \]

\[ q_L = \text{power-law exponent for the vertical profile of the standard deviation of the wind elevation angle in the surface layer} \]

\[ = \log\left(\frac{\sigma_{ETL}^{(L=1)}}{\sigma_{ERL}}\right) \cdot \log\left(\frac{z_{TL}^{(L=1)}}{z_R}\right) \]

\[ \sigma_{ETL}^{(L=1)} = \text{standard deviation of the wind elevation angle in degrees at the top of the layer } z_{TL} \]

Above the surface layer \((L > 1)\),

\[
\sigma_{EL}^{(L>1)} = \left(\sigma_{ETL} + \sigma_{EBL}\right) \left(\frac{\pi}{360}\right) \tag{4-28}
\]

where

\[ \sigma_{ETL} = \text{standard deviation of the wind elevation angle in degrees at the top of the layer } z_{TL} \]

\[ \sigma_{EBL} = \text{standard deviation of the wind elevation angle in degrees at the base of the layer } z_{BL} \]
4.5.2 Concentration Equation for Model 4

The maximum concentration equation for Model 4 is given by

\[ \chi_{LK} (x_L, y_L, z_L) = \frac{D_{LK}}{\sqrt{2\pi} \sigma_{xLK}} \]  

(4-29)

where

\[ \sigma_{xLK} = \text{standard deviation of the cloud alongwind concentration distribution in the layer} \]

\[ = \left[ \left( \frac{L(x_{LK})}{4.3} \right)^2 + \left( \sigma^*_{xKL} \right)^2 \right]^{1/2} \]

\[ L(x_{LK}) = \text{alongwind cloud length of a point source at distance } x_L \]

\[
\begin{aligned}
\Delta \bar{u}_L &= \text{vertical wind speed shear in the layer} \\
\Delta \bar{u}_L \{L=1\} &= \bar{u}_{TL} \{L=1\} - \bar{u}_{RL} \\
\Delta \bar{u}_L \{L>1\} &= \bar{u}_{TL} - \bar{u}_{BL} \\
\sigma^*_{xKL} &= \text{alongwind source dimension in Layer } L \text{ due to source (cloud) originating in the } K^{th} \text{ layer} \\
&= \left\{ \left[ \left( \sigma_{xK} \right)^2 \cos^2 (\theta_K - \theta_L^*) \right] + \left[ (\sigma_{yK}^*)^2 \sin^2 (\theta_K^* - \theta_L^*) \right] \right\}^{1/2}
\end{aligned}
\]
The maximum centerline concentration for Model 4 in the $L^{th}$ layer is given by the expression

$$\chi_{CLK}^{(xL_K, yL_K, zL_K)} = \chi_{LK}^{\{\text{LATERAL TERM}\}}$$

$$\chi_{LK} \left\{ \exp \left[ - \left( \frac{\bar{y}_L^2}{2\sigma^2_{yL_K}} \right) \right] \right\}^{-1}$$

(4-31)

The average alongwind concentration at the cloud centerline is defined as

$$\bar{x}_{LK} = \frac{D_{LK}}{t_{pL}}$$

(4-32)

where

$$t_{pL} = \text{cloud passage time in seconds in the } L^{th} \text{ layer}$$

$$= 4.3 \sigma_{xL_K} / \bar{u}_L$$

The time mean alongwind concentration in the $L^{th}$ layer is defined by the expression

$$\bar{x}_K^{(xL_K, yL_K, zL_K; T_A)} = \frac{D_{LK}}{T_A} \left\{ \text{erf} \left( \frac{\bar{u}_L T_A}{2 \sqrt{2} \sigma_{xL_K}} \right) \right\}$$

(4-33)

4.6 MODEL 5

This model is used to calculate the amount of material deposited on the surface by precipitation scavenging in the $K^{th}$ layer. The assumptions made in deriving the model are stated in Section 2.4. The ground-level deposition $W_{D_K}$ due to precipitation scavenging, for the case in which the vertical distribution of toxic material in the layer is uniform with height is given by the expression
\[ WD_K(x_K, y_K, z=0) = \frac{\Lambda Q_K(z_{TK} - z_{BK})}{\sqrt{2\pi} \frac{\sigma}{y_K} \bar{u}_K} \left\{ \exp \left[ - \frac{1}{2} \left( \frac{y_K}{\sigma y_K} \right)^2 \right] \right\} \]

\[ \left\{ \exp \left[ - \Lambda \left( \frac{x_K}{\bar{u}_K} - t_1 \right) \right] \right\} \]

(4-34)

where

\[ Q_K = \text{source strength in units of mass per unit layer depth (g m}^{-1}) \]

for the source in Layer K

\[ t_1 = \text{time precipitation begins} \]

\[ \Lambda = \text{percent of material removed per unit time} \]

For the case in which the vertical extent of the source is less than the depth of the layer (Model 3), the term \( z_{TK} - z_{BK} \) in Equation (4-34) is set equal to unity.

When changes in layer structure occur at time \( t^* \), the contribution to ground deposition \( WD_{LK} \) due to precipitation scavenging in the \( K^{th} \) layer is given by the expression

\[ WD_{LK}(x_L, y_L, z=0) = \frac{\Lambda Q_K(z_{TK} - z_{BK})}{\sqrt{2\pi} \frac{\sigma}{y_L} \bar{u}_L} \left\{ \exp \left[ - \frac{1}{2} \left( \frac{y_L}{\sigma y_L} \right)^2 \right] \right\} \]

\[ \left\{ \exp \left[ - \Lambda \left( \frac{x_L}{\bar{u}_L} + t^* - t_1 \right) \right] \right\} \]

(4-35)

Maximum ground-level deposition at a point \((x_L, y_L, z=0)\), assuming no previous cloud depletion due to scavenging, can be obtained by setting the second
exponential term in Equation (4-35) to unity. Total ground deposition is obtained by summing the contributions from all layers through which precipitation is falling at points on the reference grid coordinate system. The height of the top of the uppermost layer through which precipitation is falling \( z_{\text{lim}} \) must be supplied as an input to the computer program.

The dosage or concentration at a point in space, assuming precipitation scavenging occurs, is obtained by multiplying the appropriate dosage or concentration equation by the exponential term in Equation (4-34) or (4-35) containing the coefficient \( A \).

4.7 MODEL 6

This model is used to calculate the ground deposition due to gravitational settling. The basic source configuration is an area source of finite lateral extent and unit vertical extent. Other source configurations are treated by summing the deposition at the ground resulting from a number of basic sources arranged to simulate the desired configuration. The model is essentially a tilted plume model in which the effects of wind shear are taken into account. The axis of a particle or droplet cloud of a given settling velocity intersects the ground plane at a distance from the source and at an angle from the mean surface wind direction that are proportional to the total angular wind shear and the residence time of the settling material in the layers between the source and the ground surface. In any layer, the inclination of the cloud axis from the horizontal is given by \( \tan^{-1} \frac{V_s}{\bar{u}} \), where \( V_s \) is the particle or droplet settling velocity and \( \bar{u} \) is the mean transport wind speed in the layer. In all cases, material released in the \( K \)th layer and dispersed upwards by turbulence is assumed to be reflected downwards at the interface of the \( K \)th and \( (K + 1) \)th layers. The basic model is used to calculate the ground-level deposition pattern for a single value of the settling velocity. The total deposition
pattern is obtained by summing the results for all settling velocities representative of the particle or droplet-size distribution of the released material on a reference coordinate grid system.

In the computer program, provision is made for calculating deposition from a source which fills the layer in the vertical and for a source in which the vertical extent is less than the depth of the layer. These models are described below.

4.7.1 Gravitational Deposition Model for a Source that Extends Vertically Through the Entire Layer

Ground-level deposition by gravitational settling for a source that extends vertically through the entire layer and in which the material is uniformly distributed in the vertical is calculated by summing contributions from a number of elementary sources in the \( K \)th layer. Deposition at the surface for a single elementary source at height \( H_{nK} \) in the layer is given by the expression

\[
DEP_{nK} = \frac{f_i Q_K T_K}{2\pi \sigma y_{nK} \zeta_K} \left\{ M_{nK} + N_{nK} \right\} \left\{ \exp \left[ - \frac{1}{2} \left( \frac{y_s}{\sigma y_{nK}} \right)^2 \right] \right\}
\]

where

- \( f_i \) = fraction of particles or droplets with settling velocity \( V_s \)
- \( Q_K \) = source emission rate in layer \( K \) (g sec\(^{-1}\))
- \( T_K \) = source emission time in layer \( K \)
- \( \zeta_K \) = number of elementary sources in layer \( K \) for simulating a uniform vertical distribution
- \( y_s \) = lateral distance from the deposition axis of particles or droplets with settling velocity \( V_s \)
  
  \[ y_s = R_s \sin \phi_s \]
- \( R_s \) = radial distance in the horizontal plane from the source to a receptor
\( \phi_s \) = angle between the axis of the ground-level deposition pattern and the radial connecting source and receptor for settling velocity \( V_s \).

The terms \( M_{nK} \) and \( N_{nK} \) are vertical terms that include provision for reflection from the boundary between the \( K^{th} \) and \((K+1)^{th}\) layers. These terms are defined by the expressions

\[
M_{nK} = \left\{ \frac{\beta_K (1-\beta_K) V_s x_s / \bar{u}_{nK}}{\sigma_{EnK}(x_s) 1+\beta_K} \right\} \left\{ \exp \left[ -\frac{1}{2} \left( \frac{H_{nK} - (V_s x_s / \bar{u}_{nK})^2}{\sigma_{EnK}(x_s) + \beta_K} \right) \right] \right\} (4-37)
\]

\[
N_{nK} = \left\{ \frac{\beta_K (2z_{TK} - H_{nK}) (1-\beta_K) V_s x_s / \bar{u}_{nK}}{\sigma_{EnK}(x_s) 1+\beta_K} \right\} \left\{ \exp \left[ -\frac{1}{2} \left( \frac{2z_{TK} - H_{nK} + (V_s x_s / \bar{u}_{nK})^2}{\sigma_{EnK}(x_s) + \beta_K} \right) \right] \right\} (4-38)
\]

where

\( x_s = R_s \cos \phi_s \)

\( \bar{u}_{nK} \) = mean wind transport speed in the layer between \( H_{nK} \) and the ground

\[
= \left( \frac{x_{nK}^2 + y_{nK}^2}{H_{nK}} \right)^{1/2} V_s
\]

\[
x_{nK} = \frac{\bar{u}_{HK}}{V_s b_K} \left\{ \sin \left[ b_K (H_{nK} - z_{BK}) + S\theta'_{K-1} \right] - \sin(S\theta'_{K-1}) \right\}
\]

\[
+ \sum_{i=1}^{K-1} \left\{ \frac{\bar{u}_i}{V_s b_i} \left[ \sin(S\theta'_{i}) - \sin(S\theta'_{i-1}) \right] \right\}
\]
\[ Y_{nK} = \frac{\bar{u}_{HK}}{V_s b_K} \left\{ \cos \left[ b_K (H_{nK} - z_{BL}) + S\theta'_{K-1} \right] - \cos (S\theta'_{K-1}) \right\} \]

\[ + \sum_{i=1}^{K-1} \left\{ \frac{-\bar{u}_i}{V_s b_i} \left[ \cos (S\theta'_{i}) - \cos (S\theta'_{i-1}) \right] \right\} \]

\[ S\theta'_{K-1} = \sum_{i=1}^{K-1} \Delta \theta'_{i} \]

\[ S\theta'_{K} = \sum_{i=1}^{K} \Delta \theta'_{i} \]

\[ b_K = \frac{S\theta'_{K} - S\theta'_{K-1}}{z_{TK} - z_{BK}} \]

The quantity \( \bar{u}_{HK} \) is the mean layer wind speed between the height \( H_{nK} \) and the base of the \( K \)th layer. The following expressions define the mean layer wind speeds in the surface layer (\( K = 1 \)) and the layers above the surface layer (\( K > 1 \)):

\[ \bar{u}_{HK}^{(K=1)} = \frac{\bar{u}_R \left[ (H_{nK}^{(K=1)})^{1+p} - (z_R)^{1+p} \right]}{(1+p) \left[ (H_{nK}^{(K=1)} - z_R) (z_R)^p \right]} \quad (4-39) \]

\[ \bar{u}_{HK}^{(K>1)} = \left[ \left( \frac{\bar{u}_{TK} - \bar{u}_{BK}}{z_{TK} - z_{BK}} \right) \left( \frac{H_{nK} - z_{BK}}{2} \right) \right] + \left[ \frac{\bar{u}_{BK}}{2} \right] \quad (4-40) \]
The mean standard deviation of the wind elevation angle in radians in the layer between \( H_{nK} \) and the base of the \( K^{th} \) layer is given by the expressions

\[
\sigma'_{EnK\{K=1\}} = \frac{\sigma_{ER} \left[ \left( H_{nK\{K=1\}} \right)^{1+q} - \left( z_R \right)^{1+p} \right]}{(1+q) \left( H_{nK\{K=1\}} - z_R \right) \left( z_R \right)^q} \left( \frac{\pi}{180} \right) \tag{4-41}
\]

\[
\sigma'_{EnK\{K>1\}} = \frac{1}{H_{nK}} \left\{ \left[ \sigma'_{EnK\{K=1\}} \right] + \left( \sum_{i=2}^{K-1} \sigma'_{Ei} \left( z_{Ti} - z_{Bi} \right) \right) \right\} + \frac{\pi}{360} \left( \frac{H_{nK} - z_{BK}}{z_{TK} - z_{BK}} \right) \left[ \left( \frac{\sigma_{ETK} - \sigma_{EBK}}{z_{ETK} - z_{EBK}} \right) \left( H_{nK} - z_{BK} \right) \right] \tag{4-42}
\]

The vertical diffusion coefficient in the layer between \( H_{nK} \) and the base of the \( K^{th} \) layer is given by the terms

\[
\bar{\beta}_K\{K=1\} = \beta_K \tag{4-43}
\]

\[
\bar{\beta}_K\{K>1\} = \frac{1}{H_{nK}} \left\{ \left( \sum_{i=1}^{K-1} \beta_i \left( z_{Ti} - z_{Bi} \right) \right) + \left[ \beta_K \left( H_{nK} - z_{BK} \right) \right] \right\} \tag{4-44}
\]

The standard deviation of the crosswind distribution of material downwind from the source \( \sigma_{ynK} \) is given by the expression

\[
\sigma_{ynK} = \left\{ \left[ \sigma'_{AnK} \left( \frac{x_s + x_K}{y_K} \right) \bar{\sigma}_K \right]^2 + \left[ \Delta Y_K \right]^2 \right\}^{1/2} \tag{4-45}
\]

where

\( \sigma'_{AnK} = \) mean standard deviation of the wind azimuth angle in radians in the layer between \( H_{nK} \) and the ground
The mean lateral diffusion coefficient in the layer between $H_{nK}$ and the surface is given by the terms

\[
\begin{align*}
\sigma_{AnK}^{'}(K=1) &= \frac{\sigma_{AR}[(H_{nK}(K=1))^{1+m} - (z_R)^{1+m}]}{(1+m)(H_{nK}(K=1) - z_R)(z_R)^m} \\
\sigma_{AnK}^{'}(K>1) &= \frac{1}{H_{nK}} \left\{ \left[ \sigma_{AnK}^{'}(K=1) \right] + \left[ \sum_{i=2}^{K-1} \sigma_{AnK}^{'}(z_{Ti} - z_{Bi}) \right] \right. \\
&\quad \quad + \frac{\pi (H_{nK} - z_{BK})}{360} \left[ \left( \frac{\sigma_{ATK} - \sigma_{BTK}}{z_{TK} - z_{BK}} \right) (H_{nK} - z_{BK}) + \sigma_{ABK} \right] \right\} (4-46)
\end{align*}
\]

\[\Delta Y_K = \frac{\sigma_{EnK}(x_s)^{\beta_K} y_{nK}}{H_{nK}}\]

The number of elementary sources $\xi_K$ required to simulate a uniformly distributed source in the vertical is given by the expression

\[\xi_K = (z_{TK} - z_{BK})/\Delta h_K \] (4-48)
where

\[ \Delta h_K = \text{vertical separation of elementary sources in the } K^{th} \text{ layer} \]

\[ = R \sigma^\prime_{EH} \left( X_{HK}^2 + Y_{HK}^2 \right)^{1/2} \left( 1 + \frac{V_s}{\bar{u}_{HK}} \right)^{1/2} \]

\[ R = \text{a constant value depending on the accuracy desired in simulating a vertical line source configuration. A value of } R = 0.45 \text{ yields deposition estimates that are within 10 percent of the true value} \]

\[ \sigma^\prime_{EH} = \sigma^\prime_{EnK} \text{ with } H_{nK} = \frac{1}{3} \left( z_{TK} - z_{BK} \right) + z_{BK} \]

\[ X_{HK} = X_{nK} \text{ with } H_{nK} = \frac{1}{3} \left( z_{TK} - z_{BK} \right) + z_{BK} \]

\[ Y_{HK} = Y_{nK} \text{ with } H_{nK} = \frac{1}{3} \left( z_{TK} - z_{BK} \right) + z_{BK} \]

\[ \bar{u}_{HK} = \bar{u}_{nK} \text{ with } H_{nK} = \frac{1}{3} \left( z_{TK} - z_{BK} \right) + z_{BK} \]

The computer program for calculating gravitational deposition automatically distributes \( \xi_K \) sources in the \( K^{th} \) layer with uniform vertical spacing. The height \( H_{nK} \) in the above equations is the height above the ground of each elementary source.

The angle between the axis of the ground-level deposition pattern and the radial connecting source and receptor for settling velocity \( V_s \) is defined by the expression

\[ \phi_s = \left| \theta_1 - 180 + \phi_s - \theta_R \right| \quad \left( 0 < \theta_1 < 180 \right) \]

\[ \phi_s = \left| \theta_1 + 180 + \phi_s - \theta_R \right| \quad \left( 180 < \theta_1 < 360 \right) \]

where

\[ \theta_1 = \text{mean wind direction at the reference height } z_R \]

\[ \theta_R = \text{angle between north and a line connecting source and receptor} \]

\[ \phi_s = \tan^{-1} \left( \frac{Y_{nK}}{X_{nK}} \right) \]
4.7.2 Gravitational Deposition Model for a Volume Source in the Kth Layer

For a volume source at height \( H_{SK} \) in the \( K \)th layer, the ground-level deposition from gravitational settling is given by the expression

\[
DEP_{SK} = \frac{1}{2\pi} \frac{Q_{SK}}{y_{SK}} \left\{ \frac{M_{SK} + N_{SK}}{2} \right\} \exp \left[ -\frac{1}{2} \left( \frac{y_{SK}}{\sigma_{y_{SK}}} \right)^2 \right]
\]

(4-50)

where the subscript \( SK \) indicates that the parameters refer to a single source in the \( K \)th layer. The subset of equations which define the \( SK \) subscripted parameters is the same as the subset defining the terms in Equation (4-36), except the following substitution is made for the term \( x \) appearing in Equations (4-37) and (4-38):

\[
x_s = R_{SK} \cos \phi_{SK} + x_{zSK}
\]

(4-51)

where

\[
x_{zSK} = \text{the vertical virtual distance for the volume source}
\]

\[
x_{zSK} = \left( \frac{\sigma_{zo}{SK}}{\sigma_{ESK}} \right)^{1/2}
\]

\[\sigma_{ESK} = \text{mean standard deviation of the wind elevation angle in the layer between } H_{SK} \text{ and the ground}\]

\[\sigma_{zo}{SK} = \text{vertical source dimension of the volume source}\]

In using Equation (4-50), deposition patterns from all values of \( V_{SK} \) representative of the particle or droplet size distribution of the volume source are summed on a reference coordinate system to obtain the total deposition pattern.
4.8 USE OF THE MULTILAYER CONSTRUCT FOR COLD SPILLS AND FUEL LEAKS IN THE SURFACE LAYER

The NASA/MSFC Multilayer Diffusion Model Program can be used, through adaptation of model inputs, to estimate concentration fields downwind from cold spills at the surface and fuel leaks near ground level. As mentioned in Section 2.5, the concentration model for continuous source emission is similar in form to the dosage model for instantaneous sources. In the computer program, Model 3 (described in Section 4) can be used as a concentration model for surface spills and leaks if proper adjustments are made in the values of the model input parameters. The adjustments include the requirement that the turbulence parameters \( \sigma_A \) and \( \sigma_E \) be specified at source height. Also, \( \sigma_A \) must be adjusted for emission times exceeding 10 minutes and the source strength \( Q_K \) must be specified in units of mass emitted per unit time.

As indicated above, for correct application of Model 3 to cold spills and fuel leaks, \( \sigma_A \) must be adjusted for source emission times. According to Hino (1968) and others, time-mean concentrations downwind from continuous sources are inversely proportional to the square root of the time \( \tau \) for values of \( \tau \) ranging from about 10 to 60 minutes. For \( \tau \leq 10 \) minutes, a one-fifth power law is applicable (see Equation (2-12)). The computer program adjusts \( \sigma_A(\tau) \) for source emission times less than 10 minutes, but has no provision for adjusting \( \sigma_A(\tau) \) for source emission times exceeding 10 minutes. Thus, when source emission times exceed 10 minutes, the following substitute value of \( \tau \) must be used in the program:

\[
\tau \text{ (input value)} = \left( \frac{\tau_0}{\tau} \right)^{-3/2} \left( \frac{\tau}{\tau_0} \right)^{5/2}
\]  

(4-52)

where

\( \tau_0 = \) reference time period (between 10 and 60 minutes) over which \( \sigma_A(\tau_0) \) is measured

\( \tau = \) source emission time \( \geq 10 \) minutes for cold spills and leaks
Appropriate values of $\sigma_{A,\{\tau_o\}}$ and $\sigma_E$ at the source height $H$ can be obtained from the expression

$$\sigma_{A,\{\tau_o, H\}} = \begin{cases} 
\sigma_{AR,\{\tau_oK\}} \left( \frac{H}{z_R} \right)^m & ; \ H \geq z_R \\
\sigma_{AR,\{\tau_oK\}} & ; \ H < z_R
\end{cases}$$

(4-53)

$$\sigma_{E,\{H\}} = \begin{cases} 
\sigma_{ER} \left( \frac{H}{z_R^q} \right) & ; \ H \geq z_R \\
\sigma_{ER} & ; \ H < z_R
\end{cases}$$

(4-54)

where the power-law exponents $m$ and $q$ are defined in the text following Equations (4-5) and (4-17), respectively. These values must then be substituted for the inputs ordinarily used by the program from the following expressions

$$\sigma_{AR,\{\tau_oK\}} \text{ (input value)} = \sigma_{ATK,\{\tau_oK\}} \text{ (input value)} = \sigma_{A,\{\tau_o, H\}}$$

(4-55)

$$\sigma_{ER} \text{ (input value)} = \sigma_{ETK} \text{ (input value)} = \sigma_{E,\{H\}}$$

(4-56)
SECTION 5
DESCRIPTION OF THE NASA/MSFC MULTILAYER DIFFUSION MODEL COMPUTER PROGRAM

The NASA/MSFC Multilayer Diffusion Model Program combines the dosage, concentration and deposition models of Section 4 into a generalized computer program. This section describes the organization of the computer program.

5.1 ORGANIZATION OF THE COMPUTER PROGRAM

The computer program for the NASA/MSFC Multilayer Model is written in FORTRAN V and is designed for execution on a UNIVAC 1108 computer. The program consists of sixteen subroutines, including the main program and requires 2942110 words of core storage on the UNIVAC 1108 including systems and Fortran library programs.

Figure 5-1 shows in block diagram form the six diffusion models and the five major logic sections of the computer program. Logic section 1 provides for calculations of dosage, concentration, time mean alongwind concentration, time of passage, and average alongwind concentration patterns. Calculations are performed at selected points on a three-dimensional reference grid system where the horizontal plane is in polar coordinates and the vertical axis is provided by the atmospheric layer structure. The polar grid system in the horizontal plane fixes north at 0 degrees and east at 90 degrees with a maximum of 10,000 grid points. The vertical axis is limited to 20 layers and 100 possible calculation heights between the bottom and the top of the layer structure. As shown in Figure 5-1, logic section 1 uses Models 1 through 5 to calculate layer concentration and dosage patterns, with the option to include dosage and concentration with depletion due to precipitation scavenging or simple time dependent decay.
CONCENTRATION, DOSAGE, AND DEPOSITION MODELS

1. SOURCE EXTENDS VERTICALLY THROUGH ENTIRE DEPTH OF LAYER AND TURBULENT MIXING IS OCCURRING
2. SOURCE EXTENDS VERTICALLY THROUGH ENTIRE DEPTH OF LAYER AND TURBULENT MIXING IS NOT OCCURRING
3. SOURCE DOES NOT EXTEND VERTICALLY THROUGH ENTIRE DEPTH OF LAYER
4. FULL TRANSITION MODEL FOR STEP-CHANGE IN LAYER STRUCTURE
5. DEPOSITION DUE TO PRECIPITATION SCAVENGING
6. DEPOSITION DUE TO GRAVITATIONAL SETTLING

LOGIC SECTION 1
CALCULATES DOSAGE AND CONCENTRATION PATTERNS AND SURFACE DEPOSITION DUE TO PRECIPITATION SCAVENGING: MODELS 1, 2, 3, 4, 5

LOGIC SECTION 2
CALCULATES PEAK DOSAGE AND PEAK CONCENTRATION: MODELS 1, 2, 3

LOGIC SECTION 3
CALCULATES ISOPLETHS OF DOSAGE AND CONCENTRATION IN THE x-y PLANE: MODELS 1, 2, 3

LOGIC SECTION 4
CALCULATES ISOPLETHS OF DOSAGE AND CONCENTRATION IN THE y-z PLANE: MODELS 1, 2, 3

LOGIC SECTION 5
CALCULATES DEPOSITION DUE TO GRAVITATIONAL SETTLING: MODEL 6

OUTPUT LISTING

FIGURE 5-1. Block diagram of the computer program for the NASA/MSFC Multilayer Diffusion Model.
Logic sections 2 through 4 of the computer program provide for special calculations relative to the cloud alongwind axis in each layer. Section 2 produces maximum centerline concentration and centerline dosage on the alongwind cloud axis. Section 3 produces dosage and concentration isopleths in the horizontal plane about the alongwind cloud axis. Section 4 produces dosage and concentration isopleths in the vertical plane at selected distances, about the alongwind cloud axis. Sections 2 through 4 are applicable only to Models 1, 2 and 3 and provide the option of calculations with depletion due to precipitation scavenging or simple time-dependent decay.

Logic section 5 of the computer program calculates gravitational surface deposition patterns using Model 6. This section of the program uses the same grid system as explained for section 1. Provision is made in this section for an optional vehicle destruct in the uppermost layer.

A detailed explanation of the computer program is given in Appendix B and a complete listing of the program is given in Appendix C. Sample problems are described in detail in Section 6 with example program input data sheets shown in Appendix B and computer program output shown in Appendix D.

Assembly time for the computer program is approximately 26 seconds and the average run time is 0.01 seconds per calculation grid point.
SECTION 6
EXAMPLE CALCULATIONS

Example calculations have been made for both normal and abnormal launches of a rocket vehicle to illustrate the use of the computer program described in Section 5 in the estimation of downwind hazards. For this purpose, it has been assumed that the vehicle is a Titan III C and the launch and launch abort occur at Kennedy Space Center. Fuel properties and vehicle rise data for the Titan III C vehicle are described in Section 6.1 and the calculations for normal and abnormal launches are given in Sections 6.2 and 6.3, respectively.

6.1 FUEL PROPERTIES AND VEHICLE RISE DATA

Characteristic fuel properties used in the example calculations are given in Table 6-1. The fuel expenditure rate given in the table for a normal launch is an average rate for the first 40 seconds following ignition. The expenditure rate for an abnormal launch is based on the premise that the Titan III C vehicle is restrained on the pad because one solid-fueled engine of the Titan III C failed to ignite. In this case, one engine burns for a period of 112 seconds. The fuel heat content shown in the table for the solid-fueled engines does not include heat that may be generated by a recombination of chemical radicals as the exhaust cloud cools to ambient air temperature or the heat due to the release of kinetic energy. We have used this heat content because the cloud-rise values calculated using it are in good agreement with the limited measurements of cloud rise which are available.

The altitude-time curve of the Titan III C is also required to calculate the rise of the ground cloud of exhaust products during a normal launch. A logarithmic least-squares regression curve fitted to the data results in the approximate relationship
<table>
<thead>
<tr>
<th>Table 6-1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FUEL PROPERTIES OF THE TITAN III C ZERO-STAGE ENGINES</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fuel Expenditure Rate ( \text{g sec}^{-1} )</strong></td>
</tr>
<tr>
<td>Normal Launch</td>
</tr>
<tr>
<td>Abnormal Launch (On-Pad Abort)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fuel Heat Content ( \text{cal g}^{-1} )</strong></td>
</tr>
<tr>
<td>Normal and Abnormal Launch</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fuel Composition (Percent by Weight)</strong></td>
</tr>
<tr>
<td>HCl</td>
</tr>
<tr>
<td>(\text{Al}_2\text{O}_3)</td>
</tr>
</tbody>
</table>

\[ t_R = 0.63463 z^{0.4837} \]  \hspace{1cm} (6-1)

where
\[ t_R = \text{time after ignition in seconds} \]
\[ z = \text{altitude above the pad in meters} \]

Figure 6-1 shows a plot of the vehicle altitude versus time calculated from Equation (6-1).

6.2 NORMAL LAUNCH

The HCl concentration and dosage downwind from a normal launch of a Titan III C vehicle have been calculated to illustrate the use of Models 1, 3 and 4 described in Section 4. Washout deposition of HCl on the surface has been calculated using Model 5 and the gravitational deposition of \( \text{Al}_2\text{O}_3 \) has been calculated using Model 6.

6.2.1 Concentration and Dosage

Meteorological Inputs

Ground-level concentrations and dosages were calculated for the launch of a Titan vehicle during an afternoon sea-breeze regime, a meteorological regime typical of all seasons at Kennedy Space Center. Meteorological profiles of temperature, wind speed and wind direction obtained from rawinsonde data and from the NASA 150-Meter Ground Wind Tower at KSC are shown in Figure 6-2. Inspection of the vertical profile of temperature shows that the surface mixing layer extends to a height of 800 meters. The wind speed in the mixing layer increases from 6 meters per second at the surface to about 11 meters per second at the top of the layer. The wind direction veers from 150 degrees at the surface to 180 degrees
FIGURE 6-1. Height of the Titan III C vehicle as a function of time $t_R$ after ignition.
FIGURE 6-2. Vertical profiles of temperature, wind speed and wind direction for a sea-breeze meteorological regime at Kennedy Space Center.
at the top of the layer, then veers more rapidly to the southwest in the capping-inversion above the mixing layer. The temperature, wind speed and wind direction data are inputs used directly in either the calculation of cloud rise or the concentration and dosage models. The turbulence parameters, the standard deviations of the wind azimuth $\sigma_A$ and elevation $\sigma_E$ angle fluctuations, can be obtained from direct measurements or, in the absence of direct measurements, deduced from the profile measurements such as those presented in Figure 6-2. The procedures used in these example problems to obtain the turbulence parameters are described in Appendix E. Meteorological inputs used in this sample calculation of concentration and dosage and in the cloud rise calculation are given in Table E-1 of Appendix E.

Source Inputs

It follows from the discussion of cloud-rise formulas in Section 3 and the diffusion models in Section 4 that source inputs required for the diffusion model calculations include the stabilization height of the exhaust cloud and initial cloud dimensions, as well as the vertical distribution of exhaust products in the stabilized cloud.

Equation (3-3) was used in the cloud-rise calculation for the normal launch of a Titan III C vehicle because of the stable temperature profile shown in Figure 6-2 and because experience has shown that the nearly-instantaneous cloud-rise formulas are appropriate for use with vehicles with relatively short residence times in the vicinity of the surface. Limited experience has also shown that the entrainment parameter $\gamma_I$ for Titan III C vehicles is about 0.64. The effective heat available for buoyant cloud rise was calculated from the expression

$$Q_I = (Q_F - Q') t_R \frac{z}{m_I} \] (6-2)
where

\[ Q_F = \text{rate of heat released by burning fuel} \]
\[ = H \cdot W \]

\[ H = \text{heat content of fuel (Table 6-1)} \]
\[ W = \text{fuel expenditure rate (Table 6-1)} \]

\[ Q' = \text{rate heat is used to heat and vaporize deluge water used in cooling the launch complex} \]
\[ t_{R/\text{mI}} = \text{time required for the rocket to reach the cloud stabilization height} \]

In the cloud-rise calculations for this example, \( Q' \) was assigned a value of \( 1.25 \times 10^9 \) calories per second, \( \rho \) was equal to 1236.2 grams per cubic meter, and \( c_p \) was set equal to 0.24 calories per gram per degree Celsius. The vertical gradient of potential temperature was calculated from the expression

\[
\frac{\Delta \Phi}{\Delta z} = \frac{\Phi\{z_{\text{mI}}\} - \Phi_R}{z_{\text{mI}} - z_R} \quad (6-3)
\]

where

\[ \Phi\{z_{\text{mI}}\} = \text{potential temperature at the cloud stabilization height} \]
\[ = T\{z_{\text{mI}}\} \left( \frac{1000}{P\{z_{\text{mI}}\}} \right)^{0.286} \]

\[ T\{z_{\text{mI}}\} = \text{ambient air temperature in degrees Kelvin at the cloud stabilization height} \]
\[ P\{z_{\text{mI}}\} = \text{atmospheric pressure in millibars at the cloud stabilization height} \]

\[ \Phi_R = \text{potential temperature at the reference height} \]
\[ = T\{z_R\} \left( \frac{1000}{P\{z_R\}} \right)^{0.286} \]
As noted in Section 3, the interdependence between the calculated stabilization height, the potential temperature gradient, and the value of $\frac{1}{T} \frac{\partial z}{R}$ requires that the stabilization height be obtained through iteration of Equation (3-3). In this example, the calculated stabilization height was found equal to 832 meters with stabilization occurring at about 461 seconds.

Models 3 and 4 were used to calculate the concentration and dosage fields in the surface mixing layer. The calculated concentration and dosage fields near the source are dependent upon which model and source input procedures are selected.

The procedure for calculating the source dimension for application of Model 4 in the surface mixing layer assumes that the cloud radius at any height $z$ is given by the expression

$$r(z) = \begin{cases} r_R + \gamma z & ; z \leq z_{mI} \\ r_R + \gamma (2 z_{mI} - z) \geq 200 \text{ meters} & ; z > z_{mI} \end{cases}$$

(6-4)

In the example calculation, the radius of the cloud at ground level $r_R$ was set equal to zero. For $z > z_{mI}$, the minimum radius of the exhaust plume at stabilization was set equal to 200 meters. These cloud dimensions as a function of height are shown in Figure 6-3.

As indicated by Figure 6-3, the atmosphere was divided into 11 layers for Model 4 calculation—eight layers in the surface mixing layer $z \leq H_m$ and 3 layers in the inversion above the mixing layer. The cloud was assumed
FIGURE 6-3. Dimensions of the stabilized cloud of exhaust products for use with Model 4 calculated for the sea-breeze meteorological regime at Kennedy Space Center. Height of cloud centroid is 832 meters and the surface mixing layer depth is 800 meters.
symmetrical about a vertical axis through the cloud centroid. The alongwind and crosswind source dimensions in each layer were calculated under the following assumptions:

- The distribution of exhaust products within the cloud is Gaussian in the plane of the horizon.
- The concentration of exhaust products at a lateral distance of one radius from the cloud vertical axis is 10 percent of the concentration at the vertical axis.

Thus, the alongwind and crosswind dimensions are defined in each layer by

$$\sigma_{xo}^{(K)} = \sigma_{yo}^{(K)} = \begin{cases} 
\frac{r_R + \gamma z'}{2.15} & ; z' \leq z_{mI} \\
\frac{r_R + \gamma (2z_{mI} - z')}{2.15} & ; z' > z_{mI}
\end{cases}$$  \quad (6-5)

where

$$z' = \text{midpoint of the } K^{th} \text{ layer}$$

$$= \frac{(z_{BK} + z_{TK})}{2}$$

The corresponding vertical source dimension for each layer was calculated from the expression

$$\sigma_{zo}^{(K)} = \frac{(z_{TK} - z_{BK})}{\sqrt{12}}$$  \quad (6-6)

Equation (6-6) assumes that the vertical distribution of material in the $K^{th}$ layer is rectangular.

The distribution of material by weight for the case in which Model 4 was used was determined from the expression for the fraction of material in each of the $K$ layers.
\[ \begin{align*}
\mathcal{F}(K) &= \begin{cases} 
Q \mathcal{P}(z_{TK}) &; K = 1 \\
Q \left( \mathcal{P}(z_{TK}) - \mathcal{P}(z_{BK}) \right) &; K > 1
\end{cases} 
\end{align*} \quad (6-7) \]

where

\[ \mathcal{F}(K) = \text{fraction of the pollutant in the } K^{th} \text{ layer} \]

\[ Q = \text{total weight of exhaust products in the stabilized ground cloud} \]

\[ = \left( \frac{Q_R}{t_{mI}} \right) \left( \frac{z_{mI}}{Z_{mI}} \right) (\text{FM}) \quad (6-8) \]

\[ Q_R = \text{fuel expenditure rate from Table 6-1} \]

\[ \text{FM} = \text{percentage by weight of pollutant material in the fuel from Table 6-1} \]

\[ \mathcal{P}(z_{TK}) = \frac{1}{\sqrt{2\pi} \sigma} \int_{-\infty}^{Z_{TK}} \exp \left[ -\frac{1}{2} \left( \frac{z - z_{mI}}{\sigma} \right)^2 \right] dz \quad (6-9) \]

\[ = \Phi \left( \frac{Z_{TK} - z_{mI}}{\sigma} \right) \]

\[ \sigma = r \left( z = z_{mI} \right) / 2.15 \]

\[ \mathcal{P}(z_{BK}) = \frac{1}{\sqrt{2\pi} \sigma} \int_{-\infty}^{Z_{BK}} \exp \left[ -\frac{1}{2} \left( \frac{z - z_{mI}}{\sigma} \right)^2 \right] dz \quad (6-10) \]

\[ = \Phi \left( \frac{Z_{BK} - z_{mI}}{\sigma} \right) \]

\[ \Phi(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} \exp \left( -\frac{t^2}{2} \right) dt \]
Inspection of Equations (6-9) and (6-10) shows that a Gaussian vertical distribution of material is assumed about the height $z_{ml}$. Model 4 requires that source strength in each of the $K$ layers be specified per unit height. Since the desired units for concentration are parts per million of HCl and for dosage are parts per million-seconds, the complete expression for the source strength model input for the $K^{th}$ layer is 

$$Q_K = \left(\frac{F\{K\}}{(z_{TK} - z_{BK})}\right) \left(\frac{10^3}{g}\right) \left(\frac{22.4}{M}\right) \left(\frac{T\{z_R\}}{273.16}\right) \left(\frac{10^{13.2}}{P\{z_R\}}\right)$$  \hspace{1cm} (6-11) 

where $M$ is the molecular weight of the pollutant.

The source model inputs for the Model 4 concentration and dosage calculations are given in Table E-1 of Appendix E.

Model 3, as noted earlier, was also used to calculate concentration and dosage in the surface mixing layer. The procedures for calculating the source dimensions and vertical distribution of material are much simplified when Model 3 is employed in predicting the dosage and concentration fields in the surface mixing layer. In this case, the alongwind, crosswind and vertical source dimensions are given by the expressions

$$\sigma_{xo}\{K\} = \sigma_{yo}\{K\} = \frac{r\{z_{ml}\}}{2.15}$$ \hspace{1cm} (6-12) 

$$\sigma_{zo}\{K\} = \begin{cases} 
\frac{H_m - z_{ml} + r\{z_{ml}\}}{4.3} ; & H_m \leq z_{ml} + r\{z_{ml}\} \\
\frac{r\{z_{ml}\}}{2.15} ; & H_m > z_{ml} + r\{z_{ml}\}
\end{cases}$$ \hspace{1cm} (6-13)
where the surface mixing layer is considered as a single layer \((K = 1)\). To use Model 3 in the general case, an effective source height \(H_{\text{eff}}\) in the surface mixing layer is defined by

\[
H_{\text{eff}} = \begin{cases} 
\frac{H_m + Z_{ml} - r\{Z_{ml}\}}{2} & ; \quad H_m \leq Z_{ml} + r\{Z_{ml}\} \\
Z_{ml} & ; \quad H_m > Z_{ml} + r\{Z_{ml}\}
\end{cases}
\]

(6-14)

where \(H_m\) is the depth of the surface mixing layer. For the sea-breeze meteorological regime, \(H_{\text{eff}}\) is approximately 550 meters. Figure 6-4 shows the source configuration for this case.

Since Model 3 requires that source strength in the layer be expressed as the total amount of material, the source strength in the mixing layer was calculated from the expression

\[
F_{K\{K=1\}} = \frac{V'}{V_T} \cdot Q
\]

(6-15)

where

\[
V' = \text{volume of the cloud in the surface mixing layer}
\]

\[
= \begin{cases} 
\frac{\pi}{3} \left( H_m + r\{Z_{ml}\} - Z_{ml} \right)^2 \left( 2r\{Z_{ml}\} - H_m + Z_{ml} \right) ; \quad H_m \leq Z_{ml} + r\{Z_{ml}\} \\
\frac{4}{3} \pi r^3\{Z_{ml}\} & ; \quad H_m > Z_{ml} + r\{Z_{ml}\}
\end{cases}
\]

and \(Q\) is defined by Equation (6-8). Because the desired units are parts per million for concentration and parts per million-seconds for dosage, the source strength for Model 3 is given by
FIGURE 6-4. Dimensions of the stabilized cloud of exhaust products for use with Model 3 calculated for the sea-breeze meteorological regime at Kennedy Space Center. The effective height of the cloud in the surface layer is 550 meters.
The source and meteorological inputs for Model 3 calculations, derived by the procedures outlined above, are given in Table E-2 of Appendix E.

**Results of the Calculations**

The results of the concentration and dosage calculations for the normal launch of a Titan III C vehicle during a sea-breeze regime at Kennedy Space Center are presented in Figures 6-5 through 6-11.

Figure 6-5 shows maximum centerline concentrations downwind from the point of cloud stabilization. In the figure, the results obtained by applying Model 4 in the surface mixing layer are given by the solid curve and those obtained by applying Model 3 are shown by the dashed curve. Inspection of the curves shown in Figure 6-5 indicates that the initial source configuration assumed in the mixing layer affects the concentrations in only the first few kilometers downwind from the source. It is important to recognize that the detailed knowledge of the vertical distribution of material in the stabilized ground cloud required to accurately apply the multilayer techniques of Model 4 is not available from measurements. Until accurate measurements are made, model calculations of concentration and dosage at distances close to the source are subject to uncertainty. The agreement in the two procedures at distances beyond several kilometers from the source occurs because, at these distances, the cloud is becoming uniformly mixed in the surface layer. A partial computer output listing for this example is given in Section D.1 of Appendix D.

Figure 6-6 shows the average alongwind concentration calculated at ground-level using Models 3 (dashed curve) and 4 (solid curve) and Figure 6-7

\[ Q_{K\{K-1\}} = F_{K\{K=1\}} \left( \frac{10^3 \text{ mg}}{\text{g}} \right) \left( \frac{22.4}{\text{M}} \right) \left( \frac{T(z_R)}{273.16} \right) \left( \frac{1013.2}{P(z_R)} \right) \]  

(6-16)
FIGURE 6-5. Maximum centerline concentrations at ground level downwind from the point of cloud stabilization for a normal launch during a sea-breeze meteorological regime at Kennedy Space Center. The dashed profile was calculated using Model 3 and the solid profile was calculated using Model 4.
FIGURE 6-6. Average alongwind concentration at ground level downwind from the point of cloud stabilization for a normal launch during a sea-breeze meteorological regime at Kennedy Space Center. The dashed profile was calculated using Model 3 and the solid profile was calculated using Model 4.
shows the time mean alongwind concentration for both Models. An averaging time of 10 minutes was used for the time mean concentrations shown in Figure 6-7. In both figures, the concentrations calculated from Models 3 and 4 are equivalent beyond about 7 kilometers downwind from the point of cloud stabilization.

The centerline concentrations, average alongwind concentrations, and time-mean alongwind concentrations at ground level calculated using Model 4 are shown for comparison in Figure 6-8. Inspection of Figure 6-8 shows that, as expected, the 10-minute time-mean concentration is less than the average concentration until the cloud passage time exceeds 10 minutes, which in this case occurs nearly 40 kilometers from the source. A partial computer output listing for this example problem is given in Section D.2 of Appendix D.

Figure 6-9 shows the ground-level maximum concentration field calculated using Model 4 (Equation (4-29)). As expected from inspection of Figure 6-5, the concentration isopleths in Figure 6-9 indicate that HCl concentrations downwind from the source exceed 1 part per million to a distance of about 12 kilometers from the point of cloud stabilization. A partial computer output listing for this example problem is given in Section D.3 of Appendix D.

The computer program was also used to calculate HCl concentrations in the inversion layer above the surface mixing layer. Figure 6-10 shows the results of the calculations using Model 1 at a height of 1300 meters above the surface. In the inversion layer, the 10-minute time-mean concentration exceeds the average alongwind cloud concentration at about 10 kilometers from the source, indicating that cloud passage time beyond 12 kilometers from the source exceeds 10 minutes. Inspection of Figure 6-10 shows that the maximum centerline HCl concentration at 1300 meters above the surface falls to levels below 1 part per million near 10 kilometers from the source.
FIGURE 6-7. Ten-minute time mean alongwind concentration at ground level downwind from the point of cloud stabilization for a normal launch during a sea-breeze meteorological regime at Kennedy Space Center. The dashed profile was calculated using Model 3 and the solid profile was calculated using Model 4.
FIGURE 6-8. Maximum centerline, average alongwind, and ten-minute time mean alongwind concentrations at ground level for a normal launch during a sea-breeze meteorological regime at KSC. All profiles were calculated using Model 4.
FIGURE 6-10. Maximum centerline, average alongwind, and ten-minute time mean alongwind concentrations at a height of 1300 meters for a normal launch during a sea-breeze meteorological regime at KSC. All profiles were calculated using Model 1.
FIGURE 6-9. Isopleths of ground-level maximum HCl concentration downwind from a normal launch during a sea-breeze meteorological regime at Kennedy Space Center. The calculations were made using Model 4. (Units are parts per million.)
Finally, Figure 6-11 shows the centerline ground-level dosage calculated using Models 3 (Equation (4-15)) and 4 (Equation (4-18)).

6.2.2 Deposition by Precipitation Scavenging and Concentration
With Cloud Depletion by Scavenging

**Meteorological Inputs**

The ground-level deposition pattern resulting from precipitation scavenging and the concentration downwind from the launch of a Titan III C vehicle during the time of a cold-front passage at Kennedy Space Center were calculated to illustrate the use of Equation (4-34). Meteorological profiles of temperature, wind speed, and wind direction obtained during the cold-front passage are shown in Figure 6-12. The temperature profile in Figure 6-12 indicates a vertical lapse rate of temperature which results in a positive potential temperature gradient. Wind speed increases throughout the lowest 2 kilometers of the atmosphere and wind direction veers at a nearly constant rate.

The removal of aerosols and gases from the atmosphere by scavenging has long been understood in a qualitative sense, but quantitative knowledge is still limited. The value of $\Lambda$, the washout coefficient appearing in Equation (4-34), is dependent on factors such as the rainfall rate, the drop-size distribution of the rain, and the physical and chemical nature of the aerosol or gas being removed.

The washout coefficient for particles of diameter $p$ is given by

$$\Lambda = \int_0^\infty N(a) U(a) E(a,p) A(a) \, da$$

(6-17)

$$= \int_0^\infty F(a) E(a,p) A(a) \, da$$
FIGURE 6-11. Centerline dosage at ground level downwind from the point of cloud stabilization for a normal launch during a sea-breeze meteorological regime at KSC. The dashed profile was calculated using Model 3 and the solid profile was calculated using Model 4.
FIGURE 6-12. Vertical profiles of temperature, wind speed and wind direction during the passage of a cold front at Kennedy Space Center.
where

\[ \begin{align*}
N(a) &= \text{number of drops with diameters in the range from } a \text{ to } a + da \\
U(a) &= \text{fall velocity of droplets with diameter } a \\
E(a, p) &= \text{the collection efficiency of drops with diameter } a \text{ for particles of diameter } p \\
A(a) &= \pi/4 \, a^2, \text{ the areal cross-section of the drop} \\
F(a) &= \text{the flux of drops with diameters in the range from } a \text{ to } a + da
\end{align*} \]

The collection efficiency \( E \) is the quantity which is the most difficult to specify. It is usually calculated from inertial capture theory, leading to the result that collection is proportional to the ratio of the target diameter to the drop diameter. Unfortunately, this theory leads to the erroneous conclusion that the collection efficiency is near zero for gases. In reality, factors such as electrical attraction and solubility lead to high collection efficiencies for some gases, and particles of one micron diameter have been experimentally observed to have washout coefficients an order of magnitude larger than predicted by inertial capture theory (Dana, 1970).

Equation (6-17) may be rewritten in the form

\[ \Lambda = \bar{E} \left[ \frac{\pi}{4} \int_{0}^{\infty} F(a) \, a^2 \, da \right] = \bar{E} \alpha \quad (6-18) \]

where \( \bar{E} \) is the mean collection efficiency for the given raindrop size spectrum and the specific aerosol or gas. In field tests, Dana (1970) found the ratio of \( \alpha \) to the rainfall rate \( R \) to be nearly constant. Dana determined the average value of \( \alpha/R \) to be 1.6 \( (\text{mm}^{-1}) \), with observed values ranging from 1.4 to 1.8. Thus, the most difficult problem in determining washout rates is to specify the mean collection efficiency for a given aerosol or gas and raindrop size spectrum. These mean collection efficiencies will probably have to be determined empirically for gases and submicron particulates.
Experimental studies of washout coefficients for gases have largely been confined to major atmospheric pollutants such as SO$_2$, and there are little or no data regarding HCl washout. However, because of the well-known affinity of HCl for water, a mean collection efficiency of unity would seem to be reasonable. Washout coefficients for HCl may then be estimated on the basis of rainfall rates using Dana's average $\alpha/R$ value of 1.6. For example, a typical rainfall rate for Florida summer showers is 15 millimeters per hour (Miller and Eden, 1972), leading to a washout coefficient $\Lambda$ of $6.667 \times 10^{-3}$ $\text{sec}^{-1}$ for HCl. This value of $\Lambda$ was used in the example calculations. The remaining meteorological input parameters used in the calculations are given in Table E-3 of Appendix E.

**Source inputs**

The same procedures used in deriving the source inputs for Model 4 calculations for the sea-breeze regime were used to calculate the inputs for the precipitation scavenging example. In this case, the height $z_{mi}$, also calculated using Equation (3-3), was found to be about 675 meters and the time of cloud stabilization was equal to about 317 seconds. The cloud dimensions for this calculation are shown in Figure 6-13. The source strength for the calculation of deposition by scavenging was expressed in units of milligrams per meter of height in the layer to yield deposition in units of milligrams per square meter. That is, source strength in the $K^{th}$ layer was obtained from the expression

$$Q_K = \frac{F\{K\}}{z_{TK} - z_{BK}}$$

(6-19)

where $F\{K\}$ is defined by Equation (6-7). For the calculation of concentration with cloud depletion, Equation (6-11) was used to define $Q_K$ so that concentration units would be parts per million HCl. The source input parameters for this example are given in Table E-3 of Appendix E.
FIGURE 6-13. Dimensions of the stabilized ground cloud of exhaust products from a normal launch calculated for the prediction of ground-level deposition due to precipitation scavenging and gravitational deposition during the passage of a cold front at KSC.
Results of the Calculations

The results of the calculation of ground-level deposition of HCl due to precipitation scavenging are shown in Figure 6-14. Figure 6-15 shows the corresponding ground-level concentrations with precipitation occurring.

As indicated by Figure 6-14, deposition due to scavenging was calculated for precipitation beginning at times \( t_1 \) ranging from 394 to 6297 seconds after cloud stabilization, corresponding to cloud travel distances of 5 to 80 kilometers downwind from the source. The solid line connecting the peaks of the deposition curves represents the maximum deposition of HCl due to precipitation scavenging that would be expected to occur downwind from the launch site under the specified meteorological conditions.

Figure 6-15 shows the air concentration at ground level with precipitation beginning at the same times \( t_1 \) used to obtain the deposition curves in Figure 6-14. Inspection of the concentration profiles shows that the rather high rainfall rate assumed in the calculation is extremely effective in reducing the air concentration of HCl.

6.2.3 Gravitational Deposition

Meteorological Inputs

The ground-level deposition pattern resulting from the gravitational deposition of \( \text{Al}_2\text{O}_3 \) downwind from the launch of a Titan III C vehicle during the time of a cold-front passage at KSC was calculated to illustrate the use of Equation (4-36). The meteorological profiles for this example are the same as those used in the example discussed in Section 6.2.2 above and illustrated in Figure 6-12.
FIGURE 6-14. Maximum ground-level deposition of HCl due to precipitation scavenging downwind from the point of cloud stabilization for a normal launch during the passage of a cold front at KSC and for various times $t_1$, when precipitation begins.
FIGURE 6-15. Maximum centerline concentration of HCl at ground level downwind from the point of cloud stabilization for a normal launch during the passage of a cold front at KSC. Profiles show the reduction in air concentration of HCl due to precipitation scavenging for precipitation beginning at times $t_1$. 

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Source Inputs

The initial vertical distribution of material in the stabilized ground cloud and the initial cloud dimensions for this example problem are the same as those for the precipitation scavenging example in Section 6.2.2. In this case, the source strength must be expressed in units of milligrams per meter of height in the layer to yield deposition units of milligrams per square meter.

The terminal fall velocity $V_s$ and fraction of material $f_i$, having fall velocities $V_s$ must be specified for use of Equation (4-36). The size distribution of $\text{Al}_2\text{O}_3$ particles in the exhaust of solid rocket motors was not known, so the logarithmic distribution shown in Figure 6-16 was assumed to represent the distribution. As indicated by Figure 6-16, 98 percent of the mass of $\text{Al}_2\text{O}_3$ is assumed to have particle diameters less than 150 micrometers, and the mean mass diameter of the distribution is about 12.3 micrometers. The ten class frequency intervals and the geometric mean particle diameters in each interval are indicated in the figure. Terminal fall velocities for these mean diameters were calculated using procedures outlined by McDonald (1960) for spherical particles. The fall velocities $V_s$ and fraction of material in each frequency interval $f_i$ are given in Table 6-2. The meteorological and source model inputs for this example are given in Table E-4 of Appendix E.

Results of the Calculations

The results of the calculations of gravitational deposition are shown in Figure 6-17, which shows isopleths of $\text{Al}_2\text{O}_3$ deposition in units of milligrams per square meter. The fan-shaped deposition pattern is caused by the wind direction shear between the surface and 2000 meters which acts to spread the particles as they fall.
FIGURE 6-16. Cumulative mass distribution versus particle diameters used in the calculation of gravitational deposition downwind from a normal launch. Vertical lines indicate the class frequency intervals used in the calculation and the numbers refer to the mean mass diameter in the interval.
TABLE 6-2
CLASS INTERVAL OF PARTICLE DIAMETERS, MASS FRACTION \( f_1 \) IN THE INTERVAL, AND TERMINAL FALL VELOCITY \( V_s \)

<table>
<thead>
<tr>
<th>Diameter Class Interval (micrometers)</th>
<th>Mass Mean Radius (micrometers)</th>
<th>Mass Fraction (percent)</th>
<th>Terminal Fall Velocity (meters second(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 2.6</td>
<td>0.805</td>
<td>10</td>
<td>( 3 \times 10^{-4} )</td>
</tr>
<tr>
<td>2.7 - 4.5</td>
<td>1.71</td>
<td>10</td>
<td>( 1.4 \times 10^{-3} )</td>
</tr>
<tr>
<td>4.6 - 6.6</td>
<td>2.73</td>
<td>10</td>
<td>( 3.5 \times 10^{-3} )</td>
</tr>
<tr>
<td>6.7 - 9.2</td>
<td>3.90</td>
<td>10</td>
<td>( 7.2 \times 10^{-3} )</td>
</tr>
<tr>
<td>9.3 - 12.5</td>
<td>5.36</td>
<td>10</td>
<td>( 1.4 \times 10^{-2} )</td>
</tr>
<tr>
<td>12.6 - 17.0</td>
<td>7.29</td>
<td>10</td>
<td>( 2.5 \times 10^{-2} )</td>
</tr>
<tr>
<td>17.1 - 24.0</td>
<td>10.05</td>
<td>10</td>
<td>( 4.8 \times 10^{-2} )</td>
</tr>
<tr>
<td>24.1 - 35.0</td>
<td>14.49</td>
<td>10</td>
<td>( 1.0 \times 10^{-1} )</td>
</tr>
<tr>
<td>35.1 - 59.0</td>
<td>22.72</td>
<td>10</td>
<td>( 2.5 \times 10^{-1} )</td>
</tr>
<tr>
<td>59.1 - 150</td>
<td>47.04</td>
<td>10</td>
<td>( 7.0 \times 10^{-1} )</td>
</tr>
</tbody>
</table>
FIGURE 6-17. Isopleths of ground-level deposition of Al₂O₃ in units of micrograms per square meter downwind from a normal launch during the passage of a cold front at KSC.
6.3 ABNORMAL LAUNCH

Only one type of abnormal launch was considered in the example problems of this report. Concentration and dosage were calculated, using both Models 3 and 4, for an on-pad abort in which one solid engine of a Titan III C zero stage fails to ignite and the other engine burns over a normal firing period of 112 seconds. The vehicle was assumed to be restrained on the pad with the other stages of the vehicle unaffected by the abort and not contributing to the combustion products or heat released to the atmosphere during the abort.

**Meteorological Inputs**

The meteorological inputs for the on-pad abort example were selected from rawinsonde and tower data taken about one day after a cold front passage at KSC. The vertical profiles of temperature, wind speed and wind direction for this meteorological regime are shown in Figure 6-18. As indicated by inspection of the temperature profile, the mixing layer extends to about 1400 meters above the surface. The wind speed increases from 6 meters per second near the surface to 11 meters per second at 800 meters above the surface, then remains nearly constant to a height of 1400 meters. The wind speed decreases in the inversion above the surface mixing layer. The wind direction backs with height from about 80 degrees at the surface to 55 degrees at the base of the inversion. The meteorological parameters selected from these profiles and used in the concentration and dosage calculations, as well as the cloud rise calculation, are given in Table E-5 of Appendix E for application of Model 4 and in Table E-6 for application of Model 3.

**Source Inputs**

Equation (3-6) was used in the calculation of the cloud rise from this assumed on-pad abort situation because of the longer time required for the complete burn of the single engine. We have no measurements to verify calculations of cloud
FIGURE 6-18. Vertical profiles of temperature, wind speed and wind direction after the passage of a cold front at Kennedy Space Center.
rise from on-pad aborts of this type. A value of the entrainment parameter \( \gamma_c \) equal 0.5 was selected for use in Equation (3-6) because experience has shown this value to be appropriate for longer vehicle emission times in the vicinity of the surface. The effective heat rate available for buoyant cloud rise was calculated from the expression

\[
Q_c = (W \cdot H) - Q'
\]  

(6-20)

where \( W \) is the fuel expenditure rate for the abnormal launch and \( H \) is the heat content (see Table 6-1). In this case, \( Q' \), the heat loss due to the heating and vaporization of the deluge water, was set equal to \( 4.63 \times 10^8 \) calories per second.

In the plume rise calculation \( \rho \) was equal to 1197.1 grams per cubic meter, \( c_p \) was set equal to 0.24 calories per gram per degree Celsius, and \( u \) was assumed equal to 9.3 meters per second. The initial cloud radius at the surface \( r_R \) was set equal to zero. The iteration of Equation (3-6) using these values and the potential temperature gradient yielded an effective cloud rise \( z_{mc} \) of 1132 meters with stabilization occurring at about 450 seconds. The total weight of pollutant in the cloud formed by the abnormal launch was calculated from the expression

\[
Q = (W \cdot FM) \text{(112 seconds)}
\]  

(6-21)

where \( W \) is the fuel expenditure rate for an abnormal launch and \( FM \) is the percentage by weight of pollutant material in the fuel. The fraction of pollutant material in the \( K \)th layer \( F(K) \) is then obtained using Equation (6-7) above.

As noted above, both Model 3 and Model 4 were used in this example calculation. Dimensions of the stabilized cloud for applications of Model 4 in the surface mixing layer, calculated according to the procedures outlined in Section 6.2.1, are illustrated in Figure 6-19. The effective source height calculated from Equation (6-14) with \( z_{mc} \) substituted for \( z_{mI} \) yielded \( H_{eff} \) equal 983 meters. The
FIGURE 6-19. Dimensions of the stabilized cloud of exhaust products for use with Model 4 calculated for the post-cold front meteorological regime at KSC and the on-pad abort of a Titan III C vehicle. Height of the cloud centroid is 1132 meters and the surface mixing layer depth is 1400 meters.
stabilized cloud dimensions for use in Model 3, calculated from Equations (6-12) and (6-13), are shown in Figure 6-20. The source model inputs, including the vertical distribution of material calculated according to the procedures outlined in Section 6.2.1, are given in Table E-5 of Appendix E for Model 4 and in Table E-6 for application of Model 3.

Results of the Calculations

Results of the concentration and dosage calculations for the on-pad abort of a Titan III C vehicle during a post-cold front meteorological regime at KSC are presented in Figures 6-21 and 6-22. In both figures, the results obtained by applying Model 3 are given by the dashed curve and those obtained by applying Model 4 by the solid curves. Figure 6-21 shows maximum centerline concentrations $x_c$ at ground level, calculated using both models, at distances beyond 10 kilometers downwind from the point of cloud stabilization. At these distances, there is essentially no difference in the results obtained by using either Model 3 or Model 4. Average alongwind centerline concentration and 10-minute time mean centerline concentrations calculated using Model 4 are also shown in Figure 6-21. Dosages downwind from the on-pad abort calculated using Models 3 and 4 are shown in Figure 6-22.
FIGURE 6-20. Dimensions of the stabilized cloud of exhaust products for use with Model 3 calculated for the post-cold front meteorological regime at Kennedy Space Center and the on-pad abort of a Titan III C vehicle. The effective height of the cloud in the surface layer is 983 meters.
FIGURE 6-21. Maximum centerline, average alongwind and ten-minute time mean alongwind concentrations at ground level for an on-pad abort during a post-cold front meteorological regime at KSC. The dashed profile for maximum centerline concentration was calculated using Model 3 and the remaining profiles were calculated using Model 4.
FIGURE 6-22. Maximum centerline dosage at ground level downwind from the point of cloud stabilization for an on-pad abort during a post-cold front meteorological regime at KSC. The dashed profile was calculated using Model 3 and the solid profile was calculated using Model 4.
REFERENCES


REFERENCES (Continued)


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APPENDIX A

DERIVATION OF MAXIMUM CLOUD RISE FORMULAS FOR
INSTANTANEOUS AND CONTINUOUS SOURCES

Derivations are presented below of the formulas given in Section 3 for the maximum buoyant cloud rise from instantaneous and continuous sources. These derivations are based principally on material contained in a preprint of a paper by G. A. Briggs (1970) presented at the Second International Clean Air Congress.

A.1 INSTANTANEOUS CLOUD RISE FORMULAS

The derivations of the cloud rise formulas for instantaneous sources assume that the cloud has a horizontal component of motion nearly equal to the mean wind speed $\bar{u}$ and nearly the same density $\rho$ as the ambient air. For a cloud of radius $r$, the mass is then approximately \( \frac{4}{3} \pi r^3 \rho \). The vertical momentum is $w(\frac{4}{3} \pi r^3 \rho)$, where $w$ is the vertical velocity of the cloud center moving downwind at a speed $\bar{u}$ so that

\[
    w = \bar{u} \frac{dz}{dx} = \frac{dz}{dt} \tag{A-1}
\]

where $x$ is the downwind distance from the point of release. The initial momentum divided by $\frac{4}{3} \pi \rho$ is defined by

\[
    F_m = w_o r_o^3 = \text{constant} \tag{A-2}
\]

where $w_o$ is the initial vertical velocity imparted to the cloud over an effective radius $r_o$. Setting the time rate of change of vertical momentum equal to the buoyancy, we obtain the expression

\[
    \frac{d(w r^3)}{dt} = \bar{u} \frac{d(w r^3)}{dx} = b r^3 \tag{A-3}
\]

A-1
where

\[ b = \text{the buoyant acceleration of the cloud} \quad g(\rho - \rho_c)/\rho \]
\[ g = \text{the acceleration due to gravity} \]
\[ \rho_c = \text{the density of the cloud} \]
\[ \rho = \text{the density of the ambient air} \]

The initial value of \( b r^3 \) is defined by the expression

\[ F_I = b r^3 \approx \frac{3g Q_I}{4 c_p \pi \rho T} = \text{constant} \tag{A-4} \]

where

\[ Q_I = \text{heat released (cal)} \]
\[ c_p = \text{specific heat of air at constant pressure (cal g}^{-1} \text{O}^{\circ} \text{K}^{-1}) \]
\[ T = \text{ambient air temperature (}^{\circ}\text{K)} \]

A.1.1 Instantaneous Cloud Rise Formula for an Adiabatic Atmosphere

For an adiabatic atmosphere (potential temperature constant with height), the total buoyancy of the cloud is conserved and Equation (A-3) becomes

\[ \frac{d(w r^3)}{dt} = \tilde{u} \frac{d(w r^3)}{dx} = b r^3 = F_I \tag{A-5} \]

Integration of Equation (A-5) with respect to \( x \) yields

\[ w r^3 = F_I x/\tilde{u} + F_m \tag{A-6} \]

where the constant \( F_m \) results from Equation (A-2) and the boundary condition \( x = 0 \) at \( t = 0 \). Experimental evidence (Briggs, 1970) indicates a linear dependence of \( r \) with height which may be generalized to the form.
\[ r = \gamma_I z + r_R \] (A-7)

where

- \( \gamma_I \) = the entrainment coefficient for an instantaneous source
- \( r_R \) = the reference cloud radius at the source when the initial cloud dimension is large
- \( z \) = the height above the source

Substitution of Equations (A-1) and (A-7) into Equation (A-6) gives

\[ \bar{u} (\gamma_I z + r_R)^3 dz = F_I \frac{x}{\bar{u}} dx + F_m dx \] (A-8)

which may be integrated to give

\[ \frac{\bar{u}}{4 \gamma_I} (\gamma_I z + r_R)^4 = \frac{F_I}{2 \bar{u}} x^2 + F_m x + C \] (A-9)

The boundary condition that \( x = z = 0 \) at \( t = 0 \) defines \( C \) as \( \bar{u} r_R^{4/\gamma_I} \). Equation (A-9) may then be solved for \( z \) to give the cloud rise as

\[ z = \left[ \frac{2 F_I}{\bar{u}^2 \gamma_I^3} x^2 + \frac{4 F_m}{\bar{u} \gamma_I^3} x + \left( \frac{r_R}{\gamma_I} \right)^4 \right]^{1/4} - \frac{r_R}{\gamma_I} \] (A-10)

In general, the momentum term \( F_m \) is negligible in comparison with the buoyancy term \( F_I \). The maximum buoyant rise of an instantaneous cloud in an adiabatic atmosphere is then given by

\[ z_{mI} = \left[ \frac{2 F_I t s}{3 \gamma_I^3} + \left( \frac{r_R}{\gamma_I} \right)^4 \right]^{1/4} - \frac{r_R}{\gamma_I} \] (A-11)
where \( x = \tilde{u} t \) and \( t_{SI} \) is the time in seconds required for the cloud to achieve stabilization in an adiabatic atmosphere. Limited experimental evidence indicates that \( t_{SI} \) is a constant for each launch vehicle, ranging from about 180 to 380 seconds.

### A.1.2 Instantaneous Cloud Rise Formula for a Stable Atmosphere

If heat is conserved as the cloud rises adiabatically in a stable environment, the rate at which each cloud element loses temperature relative to the ambient air entrained into the cloud as it rises is given by the product of the ambient potential temperature gradient and the rate of rise. The resulting decay of buoyancy is given by the expression

\[
d(b r^3)/dt = \tilde{u} \frac{d(b r^3)}{dx} = -w s r^3
\]

(A-12)

where

\[
s = \frac{\rho}{T} \frac{\partial \Phi}{\partial z} \approx \frac{\rho}{T} \frac{\Delta \Phi}{\Delta z}
\]

(A-13)

\[
\frac{\Delta \Phi}{\Delta z} = \text{vertical gradient of ambient potential temperature}
\]

Differentiating the central term of Equation (A-3) with respect to time, we obtain

\[
d^2(w r^3)/dt^2 = \frac{d}{dt} \left[ \tilde{u} \frac{d(w r^3)}{dx} \right]
\]

\[
= \tilde{u} \frac{d}{dx} \left[ \frac{d(w r^3)}{dt} \right]
\]

and, since \( x = \tilde{u} t \),

\[
d^2(w r^3)/dt^2 = \tilde{u} \frac{d}{dx} \left[ \tilde{u} \frac{d(w r^3)}{dx} \right]
\]

(A-14)

\[
= \tilde{u}^2 \left[ \frac{d^2(w r^3)}{dx^2} \right]
\]

A-4
Also, by differentiating the right-hand term of Equation (A-3) with respect to time, we obtain

\[ \frac{d^2 (w r^3)}{dt^2} = \frac{d(b r^3)}{dt} \]
\[ = \ddot{u} \frac{d(b r^3)}{dx} \]  \hspace{1cm} (A-15)

Thus, equating Equations (A-14) and (A-15), we obtain

\[ \ddot{u}^2 \frac{d^2 (w r^3)}{dx^2} = \ddot{u} \frac{d(b r^3)}{dx} \]  \hspace{1cm} (A-16)

After substituting Equation (A-12) into Equation (A-16), the result is

\[ \ddot{u}^2 \frac{d^2 (w r^3)}{dx^2} = -s(w r^3) \]  \hspace{1cm} (A-17)

If \( s \) is positive and approximately constant with height, the momentum can be expressed as the harmonic function

\[ w r^3 = A \cos \left(s^{1/2} \frac{x}{u}\right) + B \sin \left(s^{1/2} \frac{x}{u}\right) \]  \hspace{1cm} (A-18)

where \( A \) and \( B \) are constants to be determined. Thus,

\[ \frac{d(w r^3)}{dx} = -\frac{A s}{u}^{1/2} \sin \left(s^{1/2} \frac{x}{u}\right) + \frac{B s}{u}^{1/2} \cos \left(s^{1/2} \frac{x}{u}\right) \]  \hspace{1cm} (A-19)

and from Equation (A-3)

\[ \frac{d(w r^3)}{dx} = \frac{b r^3}{u} \]  \hspace{1cm} (A-20)

Also,

\[ \frac{d^2 (w r^3)}{dx^2} = -\frac{A s}{u^2} \cos \left(s^{1/2} \frac{x}{u}\right) + \frac{B s}{u^2} \sin \left(s^{1/2} \frac{x}{u}\right) \]  \hspace{1cm} (A-21)
and, from Equation (A-17),

\[ \frac{d^2 (w \cdot r^3)}{dx^2} = - \frac{s}{\bar{u}^2} (w \cdot r^3) \]  \hspace{1cm} (A-22)

From Equations (A-2), (A-21) and (A-22), at time \( t = 0 \) and distance \( x = 0 \), the value of \( A \) is

\[ A = (w \cdot r^3) \bigg|_{t=0} = w_o \cdot r_o^3 = F_m \]

Similarly, the value of \( B \) from Equations (A-3), (A-4), (A-19) and (A-20) is

\[ B = \frac{b r_o^3}{s^{1/2}} = \frac{F_l}{s^{1/2}} \]

Equation (A-18) can then be rewritten in the form

\[ w \cdot r^3 = F_m \cos \left( s^{1/2} \frac{x}{\bar{u}} \right) + \frac{F_l}{s^{1/2}} \sin \left( s^{1/2} \frac{x}{\bar{u}} \right) \]  \hspace{1cm} (A-23)

If we assume the cloud radius to be defined by Equation (A-7) and substitute this relationship in Equation (A-23), the result is

\[ w \left( r_R + \gamma I^2 \right)^3 = F_m \cos \left( s^{1/2} \frac{x}{\bar{u}} \right) + \frac{F_l}{s^{1/2}} \sin \left( s^{1/2} \frac{x}{\bar{u}} \right) \]  \hspace{1cm} (A-24)

Substituting \( w = \bar{u} \frac{dz}{dx} \),

A-6
Integrating Equation (A-25), we obtain

\[
\tilde{u} \left( r_R + \gamma_I z \right)^3 \frac{dz}{dz} = F_m \cos \left( s^{1/2} \frac{x}{\tilde{u}} \right) dx + \frac{F_I}{s^{1/2}} \sin \left( s^{1/2} \frac{x}{\tilde{u}} \right) \quad (A-25)
\]

or

\[
\frac{\tilde{u} \left( r_R + \gamma_I z \right)^4}{4 \gamma_I} = \frac{F_m}{s^{1/2}} \sin \left( s^{1/2} \frac{x}{\tilde{u}} \right) - \frac{F_I \tilde{u}}{s} \cos \left( s^{1/2} \frac{x}{\tilde{u}} \right) + C \quad (A-26)
\]

Evaluating \( C' \) at \( t = 0 \) gives

\[
C' = \frac{4F_I}{3 \gamma_I s} \left( \frac{r_R}{\gamma_I} \right)^4 \quad (A-28)
\]

Rewriting Equation (A-27) with \( C' \) given by Equation (A-28) and \( x = \tilde{u} t \) gives

\[
z = \left[ \frac{4F_m}{3 \gamma_I s} \sin \left( s^{1/2} \frac{x}{\tilde{u}} \right) + \frac{4F_I}{3 \gamma_I s} \left( 1 - \cos \left( s^{1/2} \frac{x}{\tilde{u}} \right) \right) + \left( \frac{r_R}{\gamma_I} \right)^4 \right]^{1/4} - \frac{r_R}{\gamma_I} \quad (A-29)
\]

The maximum buoyant cloud rise in a stable atmosphere \( z_{ml'} \) where \( F_m \) is negligible when compared with \( F_I \), occurs at \( t = \pi/s^{1/2} \). The resulting expression is

\[
z_{ml} = \left[ \frac{8F_I}{3 \gamma_I s} + \left( \frac{r_R}{\gamma_I} \right)^4 \right]^{1/4} - \frac{r_R}{\gamma_I} \quad (A-30)
\]
A. 2  CONTINUOUS CLOUD RISE FORMULAS

The derivations of the buoyant cloud rise formulas for continuous sources also assume that the cloud density $\rho$ is nearly the same as the density of the ambient air and that the horizontal component of cloud motion is approximately equal to the mean wind speed $\bar{u}$. The buoyancy flux (divided by $\pi \rho$) is given by the time derivative of the vertical momentum flux (divided by $\pi \rho$)

$$
\frac{d(w \bar{u} r^2)}{dt} = \bar{u} \frac{d(w \bar{u} r^2)}{dx} = b \bar{u} r^2
$$

The terms and form of Equation (A-31) are analogous to Equation (A-3), except that we are now considering a flux of both buoyancy and momentum. The initial momentum flux divided by $\pi \rho$ is defined by

$$
F_m = (w \bar{u} r^2)_{t=0} = w_o \bar{u} r_o^2
$$

where $w_o$ is the initial vertical velocity imparted to the cloud over an effective radius $r_o$. The initial value of the buoyancy flux (divided by $\pi \rho$) $b \bar{u} r^2$ is approximately defined by the expression

$$
F_c = (b \bar{u} r^2)_{t=0} = b w_o r_o^2 \approx \frac{g Q_c}{\pi \rho c_p T}
$$

where $Q_c$ is the effective rate of heat release in calories per second, and the other terms are defined in the same manner as those of Equation (A-4).

A. 2.1  Continuous Cloud Rise Formula for an Adiabatic Atmosphere

For an adiabatic atmosphere, the buoyancy flux is conserved, and Equation (A-31) becomes
\[
\frac{d(w \bar{u} r^2)}{dt} = \bar{u} \frac{d(w \bar{u} r^2)}{dx} = b w_o r_o^2 = F_c \tag{A-34}
\]

Integration of Equation (A-34) with respect to \(x\) yields

\[
w \bar{u} r^2 = F_c x + F_m w_o \tag{A-35}
\]

where the constant \(F_m w_o\) is determined by Equation (A-32) and the boundary condition that \(x = 0\) at \(t = 0\). Substitution of Equations (A-1) and (A-7) into Equation (A-35) gives

\[
\bar{u}^3 (\gamma_c z + r^2) \, dz = F_c x \, dx + F_m w_o \, dx \tag{A-36}
\]

where \(\gamma_c\) is the entrainment coefficient for a continuous source. Equation (A-36) may be integrated to find that

\[
\frac{\bar{u}^3}{3 \gamma_c} (\gamma_c z + r^2)^3 = \frac{F_c}{2} x^2 + F_m w_o x + C \tag{A-37}
\]

Since \(x\) and \(z\) are zero at \(t = 0\), the constant \(C\) is equal to \((\bar{u} r^2)^3 / 3 \gamma_c\). Equation (A-37) may then be solved for \(z\) to give the cloud rise

\[
z = \left[ \frac{3 F_c}{2 \gamma_c \bar{u}^3} x^2 + \frac{2 F_m w_o}{\gamma_c^2 \bar{u}^3} x + \left( \frac{r^2}{\gamma_c} \right)^3 \right]^{1/3} - \frac{r R}{\gamma_c} \tag{A-38}
\]

For buoyancy-dominated rise, the momentum term may be neglected, and the maximum buoyant rise for a continuous source is given by
where \( x_{sc} \) is the downwind distance in meters required for the cloud to reach stabilization. The value of \( x_{sc} \) is dependent on vehicle type, atmospheric stability, and the wind speed. For large vehicles, \( x_{sc} \) is 1 to 2 kilometers.

### A.2.2 Continuous Cloud Rise Formula for a Stable Atmosphere

In analogy to Equation (A-12), the decay of the buoyancy flux (divided by \( \pi \rho \)) with time in a stable atmosphere is given by

\[
d(b \bar{u} r^2)/dt = \bar{u} d(b \bar{u} r^2)/dx = -w s \bar{u} r^2
\]

where the terms are defined in the same manner as those of Equation (A-12).

Differentiating Equation (A-31) with respect to time, assuming \( x = \bar{u} t \), and substituting Equation (A-40) leads to the expression

\[
\bar{u}^2 \frac{d^2(w \bar{u} r^2)}{dx^2} = -s(w \bar{u} r^2)
\]

If the quantity \( s \) is approximately constant with height, Equation (A-41) indicates that the vertical momentum flux (divided by \( \pi \rho \)) can be expressed by the harmonic function

\[
(w \bar{u} r^2) = F_m \cos \left( s^{1/2} \frac{x}{\bar{u}} \right) + \frac{F_c}{s^{1/2}} \sin \left( s^{1/2} \frac{x}{\bar{u}} \right)
\]

where the constants \( F_m \) and \( F_c \) are determined from Equations (A-32) and (A-33) and the boundary condition that \( x = 0 \) at \( t = 0 \).
Substitution of Equations (A-1) and (A-7) into Equation (A-42) yields

\[ \bar{u}^2 (\gamma_c z + r_R)^2 \, dz = F_m \cos\left(\frac{s^{1/2} x}{\bar{u}}\right) \, dx + \frac{F_c}{s^{1/2}} \sin\left(\frac{s^{1/2} x}{\bar{u}}\right) \, dx \]  (A-43)

where \( \gamma_c \) is the entrainment coefficient for a continuous source. Integrating Equation (A-43) and solving for \( z \) with the boundary condition that \( z = 0 \) when \( x = t = 0 \) gives

\[
z = \left[ \frac{3 F_m}{\bar{u} s^{1/2}} \gamma_c \sin\left(s^{1/2} t\right) + \frac{3 F_c}{\bar{u} s^{1/2}} \gamma_c \left(1 - \cos\left(s^{1/2} t\right)\right) \right]
+ \left(\frac{r_R}{\gamma_c}\right)^3 \right]^{1/3} - \frac{r_R}{\gamma_c}
\]  (A-44)

For buoyancy dominated rise, the buoyant cloud rise is given by

\[
z = \left[ \frac{3 F_c}{\bar{u} s^{1/2}} \gamma_c \left(1 - \cos\left(s^{1/2} t\right)\right) + \left(\frac{r_R}{\gamma_c}\right)^3 \right]^{1/3} - \frac{r_R}{\gamma_c}
\]  (A-45)

The maximum rise of the continuous cloud in a stable atmosphere occurs at \( t = \pi/s^{1/2} \) and is given by

\[ z_{mc} = \left[ \frac{6 F_c}{\bar{u} s^{1/2}} + \left(\frac{r_R}{\gamma_c}\right)^3 \right]^{1/3} - \frac{r_R}{\gamma_c}
\]  (A-46)
APPENDIX B
USER INSTRUCTIONS FOR THE NASA/MSFC MULTILAYER DIFFUSION MODEL COMPUTER PROGRAM

B.1 PROGRAM DESCRIPTION

The NASA/MSFC Multilayer Diffusion Model Program is constructed using 16 subroutines, including the main driver program. The program is written in the FORTRAN V language and is designed for execution on a UNIVAC 1108 computer. The program requires $29436_{10}$ words of executable core storage on the UNIVAC 1108 including necessary Fortran library and system programs. The multilayer program uses $16707_{10}$ locations for program variable storage with the remainder of storage used for machine instructions. The program consists of five main logic sections which provide different types of calculations and program output. A block diagram of these logic sections is given in Figure 5-1 in the main body of the report and a diagram of the program linkage is given in Section B.6. The subroutine linkage of each logic section is shown in Section B.7. Program assembly time is approximately 26 seconds and the average execution time is 0.01 seconds per calculation grid point.

B.1.1 Logic Section 1

Logic Section 1 calculates fields of dosage, concentration, time-mean alongwind concentration, and average alongwind concentration on a three-dimensional reference polar coordinate grid system. The orientation of the grid fixes north at 0 degrees and east at 90 degrees. The vertical coordinates are provided by the layer structure with optional heights within the layers. Options in this section include the calculation of dosage and concentration with cloud depletion by precipitation scavenging, deposition on the ground due to precipitation scavenging and simple time-dependent decay. Models 1 through 5 are used in Logic Section 1. This section uses subroutines READER, WASHT, TESTR, BREAK, ISØ, PEAK, EL, LATER, VERT, SIGMA, COORD, as well as the main driver program.
Subroutine READER reads and converts all of the program input data. All program input instructions reference logical tape 5 (card reader) and all output instructions reference logical tape 6 (printer). Model equations included in this subroutine are (4-2), (4-3), (4-5), (4-6), (4-17), (4-19), (4-20), (4-23), (4-24), (4-27) and (4-28) given in Section 4 of the main body of this report.

Subroutine WASHT calculates ground-level patterns of deposition due to precipitation scavenging using Model 5 (Equations (4-34) and (4-35)).

Subroutine TESTR defines the new layer structure for layer step-change Model 4.

Subroutine BREAK is the main calculation routine for Logic Section 1 and includes Models 1 through 5. Equations used in this subroutine include the peak terms of (4-1), (4-7), (4-15), (4-18), (4-29) and part of the error function of (4-18).

Subroutine ISØ evaluates the error function, Equation (4-18), used in the calculations of Model 4.

Subroutine PEAK calculates the peak terms for dosage and concentration in Models 1, 2 and 3 using Equations (4-1), (4-7) and (4-15).

Subroutine ACH has entry points EL and LATER. EL evaluates the term $L\{x_K\}$ as given by Equation (4-9) and LATER evaluates the crosswind terms in $y$ used in Equations (4-1) and (4-15).

Subroutine VERT calculates the vertical and vertical reflection terms for Model 3 as given by Equation (4-15).

Subroutine SIGMA calculates the various standard deviations for the dosage and concentration distributions as given by Equations (4-4), (4-8), (4-13), (4-14), (4-16) and (4-22).
Subroutine COORD performs all coordinate transformations. The layer models are written with reference to a cloud or plume coordinate system where the x-axis is oriented along the mean wind direction from the source, the y-axis is perpendicular to the x-axis in the crosswind direction, and the z-axis is directed vertically. The subroutine relates the cloud coordinate system which is relative to a source location to the fixed reference coordinate system.

B.1.2 Logic Section 2

Logic Section 2 calculates centerline dosage and maximum centerline concentration along the downwind cloud axis relative to the source location for Models 1, 2 and 3. Options include the calculation of dosage and concentration in the presence of cloud depletion by precipitation scavenging or simple time dependent decay. This section uses subroutines CENTRL, EL, PEAK, VERT and SIGMA, as well as the main driver program.

Subroutine CENTRL performs the main calculations and controls all output. All other subroutines used in this section have the same function as described above.

B.1.3 Logic Section 3

Logic Section 3 calculates isopleths of dosage and/or concentration in the horizontal plane, about the cloud alongwind axis, using Models 1, 2 and 3. Options include the calculation of dosage and concentration isopleths with cloud depletion by precipitation scavenging or simple time-dependent decay. This section uses subroutines ISOXY, EL, PEAK, VERT, and SIGMA, as well as the main driver program.

Subroutine ISOXY performs the main calculations for Logic Section 3 and controls all output.
B.1.4 Logic Section 4

Logic Section 4 calculates isopleths of dosage and concentration in the vertical plane about the alongwind cloud axis at selected downwind distances for Models 1, 2 and/or 3. Options include calculations of dosage and concentration isopleths with cloud depletion by precipitation scavenging and simple time-dependent decay. This section uses subroutines ISØYZ, EL, PEAK, VERT, and SIGMA, as well as the main driver program.

Subroutine ISØYZ performs the main calculations for Logic Section 4 and controls all output. The functions of all other subroutines in this section have been described above.

B.1.5 Logic Section 5

Logic Section 5 of the program calculates deposition on the ground due to gravitational settling using Model Equations (4-36) through (4-51). This section uses subroutines DEPOØ, SGP, COØRD, as well as the main driver program.

Subroutine DEPOØ controls the logic for calculating the deposition and outputs all calculations.

Subroutine SGP consists of the entry points SGP, UBARS, DEPOØ and BETAK, where SGP evaluates Equations (4-41), (4-42) and (4-46); UBARS evaluates Equations (4-39) and (4-40); DEPOØ evaluates Equations (4-37) and (4-38); and BETAK evaluates Equations (4-43), (4-44) and (4-47).

B.2 PROGRAM INPUT PARAMETERS

The data input parameters required for the computer program are listed in Table B-1. The information categories in the table are defined as follows:
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<td></td>
<td>XLRY</td>
<td>$x_{Ry}$</td>
<td>Meters</td>
<td>$\geq 0.0$</td>
<td>0.0</td>
<td>1</td>
<td>1, 2, 3, 4, 5</td>
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<tr>
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<td>XLRZ</td>
<td>$x_{Rz}$</td>
<td>Meters</td>
<td>$\geq 0.0$</td>
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<td>1</td>
<td>1, 2, 3, 4, 5</td>
</tr>
<tr>
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<td>ZZL</td>
<td>$z$</td>
<td>Meters</td>
<td>$\geq 2.0$</td>
<td>$z$</td>
<td>1</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>IZMØD</td>
<td>N/A</td>
<td>N/A</td>
<td>$= 0, 1, 2, 3$</td>
<td>1</td>
<td>20</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>DECAY</td>
<td>$k$</td>
<td>Seconds$^{-1}$</td>
<td>$\geq 0.0$</td>
<td>0.0</td>
<td>1</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>ZLIM</td>
<td>$z_{lim}$</td>
<td>Meters</td>
<td>$= z_{TK}$</td>
<td>5</td>
<td>1</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>TIM1</td>
<td>$t_1$</td>
<td>Seconds</td>
<td>$&gt;0.0$</td>
<td>5</td>
<td>1</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>BLAMDA</td>
<td>$\Lambda$</td>
<td>Seconds$^{-1}$</td>
<td>$&gt;0.0$</td>
<td>5</td>
<td>1</td>
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<td>N/A</td>
<td>$= 0$ or 1</td>
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<td>100</td>
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<tr>
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<td>DI</td>
<td>$D_K{x_K, y_K', t_K}$</td>
<td>Grams</td>
<td>$&gt;0.0$</td>
<td>5</td>
<td>10</td>
<td>3, 4</td>
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<tr>
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<td>CI</td>
<td>$x_K{x_K', y_K', t_K}$</td>
<td>Grams</td>
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<td>5</td>
<td>10</td>
<td>3, 4</td>
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<tr>
<td></td>
<td>TAST</td>
<td>$t^*$</td>
<td>Seconds</td>
<td>$\geq 0.0$</td>
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<td>10</td>
<td>1</td>
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<td>NAMELIST</td>
<td>FORTRAN</td>
<td>Model</td>
<td>Units</td>
<td>Limits</td>
<td>Value</td>
<td>Array Size</td>
<td>Logic Section</td>
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<td>--------</td>
<td>-------</td>
<td>------------</td>
<td>---------------</td>
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<tr>
<td>NAM2</td>
<td>JBΩT</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>10</td>
<td>1</td>
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<tr>
<td></td>
<td>JTΩP</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>VS</td>
<td>V_S</td>
<td>Meters Sec^{-1}</td>
<td>&gt; 0.0</td>
<td>5</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>PERC</td>
<td>f_I</td>
<td>N/A</td>
<td>&gt; 0.0</td>
<td>5</td>
<td>20</td>
<td>5</td>
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<tr>
<td></td>
<td>ACCUR</td>
<td>R</td>
<td>N/A</td>
<td></td>
<td>6</td>
<td>20</td>
<td>5</td>
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<tr>
<td></td>
<td>VB</td>
<td>V_SK</td>
<td>Meters Sec^{-1}</td>
<td>&gt; 0.0</td>
<td>5</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>PERCB</td>
<td>f_I</td>
<td>N/A</td>
<td>&gt; 0.0</td>
<td>5</td>
<td>20</td>
<td>5</td>
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<tr>
<td></td>
<td>HB</td>
<td>H_SK</td>
<td>Meters</td>
<td>≥ 0.0</td>
<td>0.0</td>
<td>1</td>
<td>5</td>
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<tr>
<td></td>
<td>T</td>
<td>T_K</td>
<td>Seconds</td>
<td>&gt; 0.0</td>
<td>5</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>DELPHI</td>
<td>Δφ</td>
<td>Degrees</td>
<td>≥ 0.0</td>
<td>180.0</td>
<td>1</td>
<td>1,5</td>
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<tr>
<td>NAM3</td>
<td>ALPHL</td>
<td>α_L</td>
<td>N/A</td>
<td>≥ 0.0</td>
<td>ALPHA(JBΩT &amp; JTΩP)</td>
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<td>1</td>
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<tr>
<td></td>
<td>BETL</td>
<td>β_L</td>
<td>N/A</td>
<td>≥ 0.0</td>
<td>BETA(JBΩT &amp; JTΩP)</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>TAUL</td>
<td>τ_L</td>
<td>Seconds</td>
<td>&gt; 0.0</td>
<td>TAUUK</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>TAUØL</td>
<td>τ_oL</td>
<td>Seconds</td>
<td>≥ 0.0</td>
<td>TAUØK</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ZRL</td>
<td>z_RL</td>
<td>Meters</td>
<td>≥ 2.0</td>
<td>ZRK</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>UBARL</td>
<td>g_BL &amp; g_TL</td>
<td>Meters Sec^{-1}</td>
<td>≥ 0.0</td>
<td>UBAR(K(JBΩT &amp; JTΩP)</td>
<td>11</td>
<td>1</td>
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### TABLE B-1 (Continued)

<table>
<thead>
<tr>
<th>NAMELIST</th>
<th>FORTRAN</th>
<th>Model</th>
<th>Units</th>
<th>Limits</th>
<th>Value</th>
<th>Array Size</th>
<th>Logic Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAM3&lt;sup&gt;⑨&lt;/sup&gt;</td>
<td>SIGAL</td>
<td>$\sigma_{ABL}$&amp; $\sigma_{ATL}$</td>
<td>Degrees</td>
<td>$\geq 0.0$</td>
<td>SIGAK(JBÔT &amp; JTÔP)</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>SIGEL</td>
<td>$\sigma_{EBL}$&amp; $\sigma_{ETL}$</td>
<td>Degrees</td>
<td>$\geq 0.0$</td>
<td>SIGEK(JBÔT &amp; JTÔP)</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>THETAL</td>
<td>$\theta_{BL}$&amp; $\theta_{TL}$</td>
<td>Degrees</td>
<td>$\geq 0$ &amp; $\leq 360.0$</td>
<td>THETAK(JBÔT &amp; JTÔP)</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>

1. See Section B.4.2 of Appendix B for the range of values of the ISKIP options.
2. Units depend on model; see Section 4 in the main body of the report.
3. The column under Value is used to simplify the program input deck by providing default values should the parameter be intentionally omitted in the first data case or set to zero. All parameters in Table B-1 remain their previous value for all subsequent cases executed in series unless changed in the input list.
4. Units of dosage and concentration isopleth values must be consistent with the equation units whether output is in grams/meter$^3$, parts per million, etc.
5. These parameters must have values other than zero only if they are used by the logic section selected and only in the applicable layers.
6. See Section B.4.2 of Appendix B on the description of ACCUR.
7. Several variables are dimensioned to a larger value in the program, but the extra space is used for other purposes.
8. The namelist NAM3 is read only if ISKIP(2) equals 3 and NBK is greater than zero. Caution must be used when selecting this option.
TABLE B-1  (Continued)

9 The default value of NYS depends on the spread between the minimum THETAK or THETAL and the maximum THETAK or THETAL.  NYS = \((\text{DELPHI}/2 + \text{MAX}) - (\text{MIN} - \text{DELPHI}/2)\)/5.0.

10 The default values of XX and DXR are: 500, 600, 700, 800, 900, 1000, 1250, 1500, 1750, 2000, 2500, 3000, 3500, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 12500, 15000, 17500, 20000, 25000, 30000, 35000, 40000, 50000, 60000, 70000, 80000, 90000, 100000 meters. Default values of XX and/or DXR are used only if NXS and/or NDXR are set to 0 respectively.

11 The default values of the YY are determined from the maximum THETAK or THETAL plus DELPHI/2 degrees and the minimum THETAK or THETAL minus DELPHI/2 degrees and are placed at 5-degree intervals. These values of YY are used only if NYS = 0. If NYS is set to 1, the program attempts to use the mean wind direction in the layer (see NYS in Section B.4.2).
NAMELIST - Name of the Fortran NAMELIST list to which the variables belong.

FORTRAN - Fortran symbolic notation defining the program input.

MODEL - Mathematical notation corresponding to the Fortran notation.

UNITS - Dimensional units of the input parameters.

LIMITS - Numerical limits on input values.

VALUE - Default value should the parameter have a present value of 0.

ARRAY SIZE - Maximum number of core locations for the input parameter.

LOGIC SECTION - Logic section in which the variable is used.

B. 3 DATA INPUT METHOD

This program uses the Fortran NAMELIST method of inputting data. Input data must be in a specific form in order to be read using a NAMELIST list. The first character in each card to be read must be blank. The first card in each NAMELIST list contains the NAMELIST name preceded by the character $ (or & on the IBM 360). The last card in each NAMELIST list contains $END (&END on IBM 360) to terminate the list. The form of the remaining data items in the list may be:

a. Variable Name = Constant - The variable name may be a subscripted array name or a single variable name. Subscripts must be integer constants. The constant may be integer, real or Hollerith (nH alphanumeric characters) data.

b. Array Name = Set of Constants (separated by commas) - The array name is not subscripted. The set of constants consists of constants of the type integer or real. The number of constants must be less than or equal to the array size. Successive occurrences of the same constant can be represented in the form $k^{*}$ constant.
The sequence of the input data parameters within the list is not significant. A more detailed explanation of the Fortran NAMELIST can be found in any Fortran language manual. Section B. 8 shows two example input data coding sheets. All program input parameters are set to zero prior to input of the first case. Parameters that are not used or have default values need not appear in the input deck. When multiple cases are stacked, all parameters retain their values from the last case and are changed only by input.

B. 4 EXPLANATION OF PROGRAM INPUTS

This section contains a complete description of all program input parameters.

B. 4.1 NAMELIST NAM1

DATE - Run date consisting of up to 12 alphanumeric (Hollerith) characters.

NP - Number of cases of input information. The NAMELIST NAM2 (followed by NAM3 if selected) is repeated NP times.

B. 4.2 NAMELIST NAM2

TESTNØ - Case titling information consisting of up to 72 alphanumeric (Hollerith) characters.

ISKIP(1) - This option controls the execution of Logic Section 5 for gravitational deposition, Model 6.

a. If this option is set to 0, Logic Section 5, Model 6 is not executed.
b. If this option is set to 1, gravitational deposition (Model 6) is executed.

c. If this option is set to 2, gravitational deposition (Model 6) is executed and assumes a destruct or explosion occurs in the top layer.

ISKIP(2) - This option controls the execution of Logic Section 1 where dosage, concentration, time mean concentration, time of passage, and average cloud concentration patterns are calculated over a reference grid system using any one of or a combination of Models 1 through 5.

a. If this option is set to 0, Logic Section 1 is not executed unless ISKIP(7) is set to 1, 3 or 4.

b. If set greater than or equal to 1, Logic Section 1 with all selected models is executed.

c. If it is desired to input the layer step change parameters for Model 4 rather than automatically calculate them, ISKIP(2) must be set to 3.

ISKIP(3) - This option controls the execution of Logic Section 2 where centerline dosage, maximum centerline concentration, centerline time-mean concentration, time of passage and centerline average cloud concentration are calculated downwind of the source along the cloud axis. This option is only available for Models 1, 2 and/or 3. For maximum centerline values from Model 4, see NYS below. See the explanation of DXR below when using the ISKIP(3) option.

a. If this option is set to 0, Logic Section 2 is not executed.
b. If set to 1, dosage and concentration are calculated at all specified heights.

ISKIP(4) - This option controls the execution of Logic Section 3 where isopleths of dosage and concentration are calculated in the horizontal plane about the downwind cloud axis. This option is only available for Models 1, 2 and/or 3.

a. If this option is set to 0, Logic Section 3 is not executed.

b. If set to 1, only dosage isopleths at ground level are calculated.

c. If set to 2, only dosage isopleths at the specified layer boundaries are calculated.

d. If set to 3, only dosage isopleths at all specified calculation heights are calculated.

e. If set to 4, only concentration isopleths at ground level are calculated.

f. If set to 5, only concentration isopleths at the specified layer boundaries are calculated.

g. If set to 6, only concentration isopleths at all specified calculation heights are calculated.

h. If set to 7, 8 or 9, dosage and concentration isopleths are calculated at ground level, specified layer boundaries or all specified calculation heights, respectively. (See the explanation of DXR below when using the ISKIP(4) option.)

ISKIP(5) - This option controls the execution of Logic Section 4 where isopleths of dosage and concentration are calculated in the
vertical plane about the downwind cloud axis. This option is available only for Models 1, 2 and/or 3.

a. If this option is set to 0, Logic Section 4 is not executed.

b. If set to 1, only dosage isopleths are calculated.

c. If set to 2, only concentration isopleths are calculated.

d. If set to 3, both dosage and concentration isopleths are calculated.

(See the explanation of DXR and IFLAG below when using the ISKIP(5) option.)

ISKIP(6) - This option controls the model calculations of dosage and concentration with simple decay.

a. If this option is set to 0, the decay term is not included.

b. If set to 1, the decay term is included in all model calculations in Logic Sections 1 through 4.

ISKIP(7) - This option controls the calculation of deposition on the ground (Model 5) due to precipitation scavenging and dosage and concentration with cloud depletion due to precipitation scavenging.

a. If this option is set to 0, precipitation scavenging and deposition are not calculated.

b. If set to 1, the maximum possible deposition on the ground is calculated. (Logic Section 1 only.)

c. If set to 2, dosage and concentration with depletion due to precipitation scavenging is calculated (Logic Sections 1 through 4).
d. If set to 3, deposition due to precipitation scavenging at ground level is calculated (Logic Section 1 only).

e. If set to 4, both (c) and (d) above are calculated (Logic Section 1 only).

The above ISKIP options cannot be combined in certain problem runs. Allowable combinations of these options and possible models are shown in Table B-2.

NXS - Number of radial distances XX on the reference grid system. If NXS is set to 0, the default value of 34 is used for NXS and the XX array is automatically filled (used only in Logic Sections 1 and 5).

NYS - Number of angular coordinates YY on the reference grid system. If NYS is set to 0, NYS is calculated and the YY are determined from the mean layer wind directions. If NYS is set to 1, the program will calculate only the cloud centerline axis. The program will do this only if the source is located at the origin and if Model 4 is selected t* (TAST) must occur at less than 1.2 seconds. (Used only in Logic Sections 1 and 5, and with the NYS = 1 option only in 1.)

NZS - Total number of initial layer boundaries.

NDI - Number of dosage values for which isopleths are to be calculated in the horizontal and/or vertical planes. (Used only in Logic Sections 3 and 4.)

NCI - Number of concentration values for which isopleths are to be calculated in the horizontal and/or vertical planes. (Used only in Logic Sections 3 and 4.)
### TABLE B-2
ALLOWABLE ISKIP AND MODEL COMBINATIONS FOR ANY ONE CASE PROBLEM AT A PARTICULAR LAYER

<table>
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<tr>
<th>ISKIP Selected</th>
<th>Allowable ISKIP and Model Combinations</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ISKIP(1) = 1 or 2</td>
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<tr>
<td>Model</td>
<td>6</td>
</tr>
<tr>
<td>ISKIP(1) = 1 or 2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Y</td>
</tr>
<tr>
<td>ISKIP(2) = 1 or 3</td>
<td></td>
</tr>
<tr>
<td>1 or 2</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>N</td>
</tr>
<tr>
<td>(1 or 2) &amp; 4</td>
<td>N</td>
</tr>
<tr>
<td>3 and 4</td>
<td>N</td>
</tr>
<tr>
<td>ISKIP(3) = 1</td>
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</tr>
<tr>
<td>1 or 2</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>N</td>
</tr>
<tr>
<td>ISKIP(4) = 1 to 9</td>
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</tr>
<tr>
<td>1 or 2</td>
<td>N</td>
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<td>3</td>
<td>N</td>
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N = NO
Y = YES
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<tr>
<th>ISKIP Selected</th>
<th>Allowable ISKIP and Model Combinations</th>
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<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Model 6 1 or 2 3 (1 or 2) &amp; 4 3 and 4 1 or 2 3 1 or 2 3 1 or 2 3 -- -- 5</td>
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</tr>
<tr>
<td>ISKIP(5) = 1, 2 or 3</td>
<td>1 or 2 N Y N Y N Y N Y N Y N Y Y N</td>
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</tr>
<tr>
<td></td>
<td>3 N N Y N Y N Y N Y Y Y Y N</td>
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<tr>
<td>ISKIP(6) = 1</td>
<td>- N Y Y Y Y Y Y Y Y Y Y Y Y N</td>
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<td></td>
</tr>
<tr>
<td>ISKIP(7) = 2</td>
<td>- N Y Y Y Y Y Y Y Y Y Y Y Y N</td>
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</tr>
<tr>
<td>ISKIP(7) = 1, 3 or 4</td>
<td>5 N Y Y Y Y N N N N N N N N Y</td>
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<td></td>
</tr>
</tbody>
</table>

N = NO
Y = YES
NDXR - Number of radial distances input for all calculations in Logic Sections 2, 3 and 4. (Default value is 34 and DXR is automatically filled.)

NBK - Number of distinct new layers in the layer step (structure) change for Model 4. All new layers are formed by combining two or more of the initial layers into one new layer. (Logic Section 1, Model 4 only.)

NPTS - Number of heights at which calculations are to be performed for Logic Sections 1 through 4. (Default value is NZS -1.)

NVS - Number of droplet or particle terminal fall velocities used to calculate ground-level gravitational deposition from all layers except the layer in which a destruct occurs. (Logic Section 5, Model 6 only.)

NVB - Number of droplet or particle terminal fall velocities used to calculate ground-level gravitational deposition from the layer in which a vehicle destruct occurs. (Logic Section 5, Model 6 only.)

XX - Array of radial distances for the coordinates of the reference grid system used in Logic Sections 1 and 5. (Default values are given in Table B-1 of Appendix B and default values are used only if NXS = 0.)

YY - Array of angular distances for the coordinates of the reference grid system used in Logic Sections 1 and 5. (Default values are given in Table B-1 of Appendix B and default values are used only if NYS = 0 or 1.)
Z - Array of layer boundary heights.

DXR - Array of radial distances along the cloud axis used for calculations in Logic Sections 2, 3 and 4.

DELX - Array of the radial distances to the source location in each layer.

DELY - Array of the angular distances to the source location in each layer measured clockwise from zero degrees north.

Q - Source strength for each initial layer.

UBARK - Mean wind speed at ZRK followed by the mean wind speed at the top of each layer.

SIGAK - Standard deviation of the wind azimuth angle for reference time $\tau_{ok}$ at ZRK followed by the standard deviation of the wind azimuth angle at the top of each layer.

SIGEK - Standard deviation of the wind elevation angle at ZRK followed by the standard deviation of the wind elevation angle at the top of each layer.

SIGXØ - Standard deviation of the alongwind concentration distribution of the source in the layer (alongwind source dimension).

SIGYØ - Standard deviation of the crosswind concentration distribution of the source in the layer at a downwind distance $XLRY$ from the true source (crosswind source dimension).

SIGZØ - Standard deviation of the vertical concentration distribution of the source in the layer at a downwind distance $XLRZ$
from the true source (vertical source dimension). (Default value = \( \frac{z(K+1) - z(K)}{\sqrt{12}} \))

**ALPHA** - Lateral diffusion coefficient in the layer. (Default value is 1.0.)

**BETA** - Vertical diffusion coefficient in the layer. (Default value is 1.0.)

**ZRK** - Reference height in the surface layer for meteorological measurements. (Default value is 2.)

**TIMAV** - Time over which time-mean concentration and average cloud concentration are calculated. (Logic Section 1 only; also, default is 600.0.)

**THETAK** - Mean wind direction at ZRK followed by the mean wind direction at the top of each layer.

**TAUK** - Time required for cloud stabilization in the layers (source emission time).

**TAUOK** - Reference time for the standard deviations of the wind azimuth angle SIGAK. (Default value is 600.0.)

**H** - Effective source height in each layer (Model 3 only).

**XRY** - Distance downwind from the virtual point source over which rectilinear expansion in the lateral occurs. (Default value is 100.0.)

**XRZ** - Distance downwind from the virtual point source over which rectilinear expansion in the vertical occurs. (Default value is 100.0.)
<table>
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<th>Description</th>
</tr>
</thead>
<tbody>
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<td>XLRY</td>
<td>Reference distance from the true source at which SIGY is measured. (Default value is 0.0.)</td>
</tr>
<tr>
<td>XLRZ</td>
<td>Reference distance from the true source at which SIGZ is measured. (Default value is 0.0.)</td>
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<tr>
<td>ZZL</td>
<td>Vertical calculation heights. This parameter can include any heights within the initial layer structure. (Used in Logic Sections 1 through 4.)</td>
</tr>
<tr>
<td>IZMØD</td>
<td>Model selection array identifying the model to use in each initial layer. (Used in Logic Sections 1 through 4 with a default value of 1.)</td>
</tr>
<tr>
<td>DECAY</td>
<td>Coefficient of time-dependent decay. (Used in Logic Sections 1 through 4.)</td>
</tr>
<tr>
<td>ZLIM</td>
<td>Maximum height through which precipitation scavenging can occur. This parameter must be set to a value equal to the upper boundary of the uppermost layer in which precipitation occurs. (Used in Logic Sections 1 through 4.)</td>
</tr>
<tr>
<td>TIM1</td>
<td>Time at which precipitation begins. (Used in Logic Sections 1 through 4.)</td>
</tr>
<tr>
<td>BLAMDA</td>
<td>Precipitation scavenging (washout) coefficient. (Logic Sections 1 through 4.)</td>
</tr>
<tr>
<td>IFLAG</td>
<td>Array used to indicate at which radial distances vertical isopleths are to be calculated. (Logic Section 4.)</td>
</tr>
</tbody>
</table>

a. If IFLAG(l) is set to 0, the $l^{th}$ distance DXR(l) is ignored.
b. If the $i^{th}$ value of IFLAG is set to 1, isopleths are calculated at DXR($i$).

DI - Dosage values for which isopleth half-widths measured from the cloud centerline are calculated. (Logic Sections 3 and 4.)

CI - Concentration values for which isopleth half-widths measured from the cloud centerline are calculated. (Logic Sections 3 and 4.)

TAST - Time of layer structure change. (Logic Section 1 only)

JBØT - Bottom layer of each distinct new layer formed by layer structure change. New layers are formed by two or more of the initial layers. (Logic Section 1 only.)

JTØP - Top layer of each distinct new layer formed by layer structure change. (Logic Section 1 only.)

VS - Droplet or particle terminal fall velocity distribution used in all layers except a layer in which a vehicle destruct occurs. (Logic Section 5.)

PERC - Frequency of occurrence of each velocity category VS. (Logic Section 5.)

ACCUR - Accuracy constant for the line source simulation used in Model 6, Logic Section 5. A value of 0.45 ensures that the calculated ground deposition is within 10 percent of the deposition expected from a vertical line source. If set to 0.32, the calculated deposition is within 5 percent of that expected from a vertical line source.
VB - Droplet or particle terminal fall velocity distribution used in the layer in which a vehicle destruct occurs. The layer must be the top layer. (Logic Section 5.)

PERCB - Frequency of occurrence of each velocity category VB. (Logic Section 5.)

HB - Height at which a vehicle destruct occurs. (Logic Section 5.)

T - Residence time of vehicle in the layer. (Logic Section 5.)

DELPHI - Width of calculation sector. (Logic Sections 1 and 5 and the default value is 180.0.)

B.4.3 NAMELIST NAM3

The layer step change parameters in this list are read only if ISKIP(2) is set to 3 and NBK is greater than zero. These parameters are calculated automatically otherwise. (All parameters are applicable to Logic Section 1 only.)

ALPHL - Lateral diffusion coefficient in each new layer. (Default value is 1.)

BETL - Vertical diffusion coefficient in each new layer. (Default value is 1.)

TAUL - Time required for cloud stabilization in the new layers.

TAUØL - Reference time for the standard deviation of the wind azimuth angle SIGAL in the new layers. (Default value is 600.0.)
ZRL  - Reference height in the surface layer for meteorological measurements. This must be set only if the bottom new layer includes the initial surface layer. (Default value is 2.0.)

UBARL  - Mean wind speed at the bottom and top boundaries of each new layer. These values are input in ascending order of new layers with the value at the top boundary preceded by the bottom. If the bottom new layer contains the initial surface layer, UBARL at ZRL should be input as the bottom value of this layer.

SIGAL  - Standard deviation of the wind azimuth angle for reference time $\tau_0$ at the bottom and top boundaries of each new layer. If the bottom new layer contains the initial surface layer, SIGAL at ZRL should be input as the bottom value of this layer.

SIGEL  - Standard deviations of the wind elevation angle at the bottom and top boundaries of each new layer. If the bottom new layer contains the initial surface layer, SIGEL at ZRL should be input as the bottom value of this layer.

THETAL  - Mean wind direction of the bottom and top boundaries of each new layer. If the bottom new layer contains the initial surface layer, THETAL at ZRL should be input as the bottom value of this layer.

B.5 ADDITIONAL COMMENTS

The NASA/MSFC Multilayer Diffusion Model has been designed for use on a UNIVAC 1108 computer, but can be adapted to other computers with few modifications.
Two statements in Subroutine READER which assume six bytes per word must be changed to conform to the computer used. They are marked as machine dependent statements. The program uses quote marks to identify a Hollerith field in some format statements. The computer program uses the standard UNIVAC 1108 Fortran library functions EXP, SQRT, SIN, COS, ALOG, ACOS and ABS. The names of some of these functions are different on other processors (CDC, IBM, etc.) requiring program changes. Subroutines in which these functions are used can be found by examining the External References table of each subroutine in the program listing in Appendix C. Also, in some program areas, division by zero can occur. When this happens, the program assumes that the result in the arithmetic register is zero and the error is ignored.

B.6 LINKAGE FOR SUBROUTINES IN COMPUTER PROGRAM FOR NASA/MSFC MULTILAYER DIFFUSION MODEL

The physical linkage for the computer program subroutines is shown in Figure B-1. Each connector represents a communication link between the subroutines.

B.7 LINKAGE FOR SUBROUTINES IN LOGIC SECTIONS 1 THROUGH 5

The linkage for subroutines used in Logic Sections 1 through 5 of the computer program for the NASA/MSFC Multilayer Diffusion Model is shown in Figure B-2. Each connector represents a communication link between the subroutines.

B.8 EXAMPLE INPUT DATA CODING SHEET

This section shows two example input data coding sheets. Example 1 shown in Figure B-3 is taken from a case problem in Section 6.2.1 of the main
FIGURE B-1. Diagram of linkage between subroutines of computer program for NASA/MSFC Multilayer Diffusion Model.
FIGURE B-2. Diagram of linkage between subroutines used in Logic Sections of computer program for the NASA/MSFC Multilayer Diffusion Model.
FIGURE B-2. (Continued)
$NAM1

DATE=11HMARCH11.73.

NP=1.

$END

$NAM2

TESTNO=55HCONECCTRATI0N, NORMAL LAUNCH, SEA BREEZE CASE 1, H=832 M,

ISKIP (2)=1.

NYS=1, NzS=12, NBK=1, NPTS=8.

Z=2.100,20.0,30.0,40.0,50.0,60.0,70.0,80.0,130.0,180.0,230.0.

Q=1.44E5,3.49E5,9.66E5,2.27E6,4.55E6,7.7E6,1.1E7,1.39E7,9.61E6,5.4E5.

UBARK=6.9.9.6,9.9,10.2,10.4,10.6,10.8,10.9,10.11,9.13.

SIGAK=8.5.41,5.05,4.85,4.71,4.61,4.52,4.45,4.39,2.1,1.

SIGEF=7.5.8.5,13,4,7,9,4,6,6,4,4,7,4,37,4,29,4,23,4,17,1.9,2*95.

SIGX0=14.8.8,44,65,74,42,10,4,19,133,95,16,3,72,193,4,9,2,23,26,182,7,7,7,2*93.

SIGY0=14.8,8,44,65,74,42,10,4,19,133,95,16,3,72,193,4,9,2,23,26,182,7,7,7,2*93.

SIGZ0=8*28.8,87,2*144,34,115,17.

THETA=3*150,152,153,157,160,170,180,228,240,250.

TAUK=461.

ZDL=2.800,1300,1800.

JB0T=1, JTOP=8.

$END

FIGURE B-3. Example 1 input data coding sheet.
body of this report with a sea-breeze meteorological situation and under normal launch conditions. The problem uses Model 4 to calculate dosage and concentration on the alongwind cloud axis. Necessary parameters for which a default value option was taken are not shown in Figure B-3. These parameters are NXS, XX, YY, DELX, DELY, ALPHA, BETÀ, ZRK, TIMAV, TAUØK, XRY, XRZ, XLRY, XLRZ, IZMØD and TAST. An example output listing for this problem is given in Appendix D, Example 1. Also, Example 3 in Appendix D is a duplicate of the above problem except dosage and concentration patterns in a 180-degree sector about the cloud axis were calculated by omitting the parameter NYS from the input (NYS = 0).

Example 2 shown in Figure B-4 is also taken from Section 6.2.1 in the main body of the report with a sea-breeze meteorological regime and for normal launch conditions. This problem uses Model 3 to calculate maximum centerline concentration and centerline dosage in Logic Section 2. A program output listing for these data is given in Appendix D, Example 2. Necessary parameters for which a default value option was taken are NDXR, DXR, DELX, DELY, ALPHA, BETA, ZRK, TIMAV, TAUØK, XRY, XRZ, XLRY and XLRZ.
FIGURE B-4. Example 2 input data coding sheet.
Appendix C contains a complete listing of the present configuration of the computer program for the NASA/MSFC Multilayer Diffusion Model, Version 2. The program is written in FORTRAN V and has been assembled and executed on a UNIVAC 1108 computer under the EXEC 8 Monitor.
### NASA/MSFC MULTILAYER MODEL

**DATE 053073**

**PAGE 30**

**DFORUS MUEL**

FOR 010L-05/30/73-13:16:09 (2,3)

**MAIN PROGRAM**

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### NASA/MSFC Multilayer Model

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### NASA/MSFC Multilayer Diffusion Model, Version 2

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00100  42  C VRFL = REFLECTION TERM OF DOSAGE EQUATION
00100  43  C DXR = RADIAL DISTANCES FOR MAXIMUM PEAK DOSAGE AND CONCENTRATION
00100  44  C AND ISOPLETHS AND CLOUD HALF-WIDTH CALCULATIONS
00100  45  C T = SOURCE EMISSION TIME IN LAYER FOR GRAVITATIONAL DEP. (SEC)
00100  46  C IFLAG = FLAG TO INDICATE WHICH DISTANCES DXR VERTICAL ISOPLETHS
00100  47  C ARE TO BE CALCULATED
00100  48  C ITAU = FLAG TO INDICATE WHICH RECEPTOR COORDINATES ARE OUTSIDE
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00100  52  C CI = CONCENTRATION ISOPLETH VALUES OF INTEREST
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00100  60  C L = LENGTH OF CLOUD IN ALONG WIND DIRECTION
00100  61  C TH = THETA*PI/180
00100  62  C I = INDEX OF X COORDINATES
00100  63  C J = INDEX OF Y COORDINATES
00100  64  C KK = INDEX OF LAYERS
00100  65  C K = INDEX OVER CALCULATION HEIGHTS Z2L
00100  66  C ST01 = TEMP STORAGE
00100  67  C ST02 = TEMP STORAGE
00100  68  C ST03 = TEMP STORAGE
00100  69  C TRU = HALF CALCULATION SECTOR DELPHI
00100  70  C TAST = TIME OF LAYER STRUCTURE CHANGE (SECONDS)
00100  71  C NBK = NO OF DISTINCT GROUPS OF LAYERS THAT FORM INTO ONE AT TIME
00100  72  C TAST, TAST2
00100  73  C ILK = INDEX ON NEW LAYERS AFTER TIME TAST
00100  74  C NS = NO OF X COORDINATES
00100  75  C NTY = NO OF Y COORDINATES
00100  76  C N2S = NO OF LAYER BASES
00100  77  C ND1 = NO OF DOSAGE ISOPLETHS
00100  78  C NCI = NO OF CONCENTRATION ISOPLETHS
00100  79  C ND2 = NO OF RADIAL DISTANCES DXR ALONG CLOUD AXIS
00100  80  C NPT1 = NO OF CALCULATION HEIGHTS Z2L
00100  81  C RAI = PI/100
00100  82  C NNL = N2S-1 NO OF LAYERS
00100  83  C IUP = TOP OF NEW LAYER AFTER TAST IN TERMS OF OLD LAYER STRUCTURE
00100  84  C IBOT = BOTTOM OF NEW LAYER AFTER TAST IN TERMS OF OLD LAYER STRUCTURE
00100  85  C X1P = STRUCTURE (1STP AND 1STP INDEXES)
00100  86  C XAS = CALCULATE DISTANCE TO TAST
00100  87  C SIGANK = SIGMA OF NEW LAYER STRUCTURE
00100  88  C LAMDA = WASHOUT COEFFICIENT
00100  89  C TIM = TIME OF START OF RAIN (SECONDS)
00100  90  C TIME = TIME RAIN STOPS (SECONDS)
00100  91  C ZLIM = MAXIMUM HEIGHT OF WASHOUT
00100  92  C WASHO = CALCULATE WASHOUT AT (GROUP
00100  93  C UBEAR = WIND SPEED AT EACH LAYER BOUNDARY, LOWER BOUNDARY OF LAYER
00100  94  C 1 FOR UBAN IS ASSUMED AT ZRN (METERS/SEC)
00100  95  C SIGA = SIGMA (INITIAL) AT EACH LAYER BOUNDARY, LOWER BOUNDARY OF
00100  96  C LAYER 1 FOR SIGAK IS ASSUMED AT ZRN (DEGREE)
00100  97  C
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0100  97  C  SIGCH = SIGEP (INITIAL) AT EACH LAYER BOUNDARY, LOWER BOUNDARY OF MOL09700
0100  98  C  LAYER 1 FOR SIGCH IS ASSUMED AT ZRH (DEGREES) MOL09700
0100  99  C  ZRH = REFERENCE HEIGHT IN SURFACE LAYER METERS MOL09700
0100 100  C  THEFAK = WIND DIRECTION AT LAYER BOUNDARIES (DEGREES) MOL10000
0100 101  C  TAUK = TIME IN SECONDS REQUIRED FOR LATERSAL CLOUD STABILIZATION MOL10100
0100 102  C  TAUK = SAMPLING PERIOD AT TOP OF THE LAYER MOL10200
0100 103  C  DECAY = DECAY COEFFICIENT IN DOSAGE EQUATION MOL10300
0100 104  C  UBARL = WIND SPEED AT BOTTOM AND TOP OF EACH NEW LAYER AFTER LAYER MOL10400
0100 105  C  CHNORMAL = CHANGE (METERS) MOL10500
0100 106  C  SIGAP = SIGCH AT BOTTOM AND TOP OF EACH LAYER AFTER LAYER MOL10600
0100 107  C  CHANGE (DEGREES) MOL10700
0100 108  C  SIGAP = SIGCH AT BOTTOM AND TOP OF EACH NEW LAYER AFTER LAYER MOL10800
0100 109  C  CHANGE (DEGREES) MOL10900
0100 110  C  ZRL = REFERENCE HEIGHT IN SURFACE LAYER OF NEW STRUCTURE (METERS) MOL11000
0100 111  C  THEITAL = WIND DIRECTION AT BOTTOM AND TOP OF EACH NEW LAYER AFTER MOL11100
0100 112  C  TAUUL = TIME IN SECONDS FOR LATERAL CLOUD STABILIZATION IN NEW MOL11200
0100 113  C  LAYER STRUCTURE MOL11300
0100 114  C  JBOT = INPUT LAYER NUMBER OF BOTTOM OF NEW LAYER STRUCTURE MOL11400
0100 115  C  RELATIVE TO OLD MOL11500
0100 116  C  NJOFL = INPUT LAYER NUMBER OF TOP OF NEW LAYER STRUCTURE MOL11600
0100 117  C  RELATIVE TO OLD MOL11700
0100 118  C  VS = SETTLING VELOCITY IN GRAVITATIONAL DEPOSITION MODEL MOL11800
0100 119  C  PHERC = FREQUENCY OF VS MOL11900
0100 120  C  ACCUR = DESIRED ACCURACY COEFFICIENT (.45) INSURES THAT GROUND MOL12000
0100 121  C  DEPOSITION FROM NXCI POINT SOURCES IN THE LAYER VARIES MOL12100
0100 122  C  LESS THAN TEN PERCENT FROM DEPOSITION EXPECTED FROM A MOL12200
0100 123  C  VS = VERTICAL LIME SOURCE IN THE LAYER, FOR (.12) REDUCED TO MOL12300
0100 124  C  FIVE PERCENT MOL12400
0100 125  C  VB = SETTLING VELOCITIES FROM A BURST OR DESTRUCT IN LAYER NN MOL12500
0100 126  C  PRCB = FREQUENCY OF VB MOL12600
0100 127  C  HBM = HEIGHT OF BURN (METERS) MOL12700
0100 128  C  CT = HEIGHT OF BURN (METERS) MOL12800
0100 129  C  PPAH = CALCULATED WIND SPEED POWER LAW EXPONENT MOL12900
0100 130  C  QPAH = CALCULATED WIND SPEED POWER LAW EXPONENT MOL13000
0100 131  C  MPH = CALCULATED SIGAP POWER LAW EXPONENT MOL13100
0100 132  C  DTHK = WIND ANGLE DEPH MOL13200
0100 133  C  NN = NUMBER OF SETTLING VELOCITIES VS MOL13300
0100 134  C  NBB = NUMBER OF SETTLING VELOCITIES VB MOL13400
0100 135  C  DATE = RUN DATE MOL13500
0100 136  C  ID = INDEX ON VS AND VB MOL13600
0100 137  C  DEEP = TEMP STORAGE MOL13700
0100 138  C  YBAY = CALCULATED COORDINATE OF POINT ON CLOUD AXES OF VS AT MOL13800
0100 139  C  XBAR = CALCULATED COORDINATE OF POINT ON CLOUD AXES OF VS AT MOL13900
0100 140  C  INTERSECTION BETWEEN GROUND (DEPOSITION) MOL14000
0100 141  C  INTERSECTION BETWEEN GROUND (DEPOSITION) MOL14100
0100 142  C  UBAR = CALCULATED WIND SPEED (DEPOSITION) MOL14200
0100 143  C  DELTANK = CALCULATED DEPOSITION MOL14300
0100 144  C  ALPHAN = CALCULATED ALPHA (DEPOSITION) MOL14400
0100 145  C  DEP = TEMP STORAGE MOL14500
0100 146  C  ANG = ANGLE TO POINT XBAR,YBAR (DEPOSITION) MOL14600
0100 147  C  NXCI = NUMBER OF EIGHT SOURCES IN LAYER (DEPOSITION) MOL14700
0100 148  C  DEP = CALCULATED VALUE OF GRAVITATIONAL DEPOSITION MOL14800
0100 149  C  SIGCHF = SIGCH OF NEW LAYER STRUCTURE IN CALCULATION OF DOSAGE AND MOL14900
0100 150  C  CONCENTRATION MOL15000
0100 151  C  SIGCHF = SIGCH OF DEPOSITION MOL15100
0100 152  C  SIGCH = SIGCH OF DEPOSITION MOL15200
0100 153  C  CONCENTRATION AVERAGING TIME (SECONDS) MOL15300
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00114 211* C READ MODEL PARAMETERS
00121  212* CALL READER (2, NEP)
00122  213* IF (ISKIP(1), NE, 1, AND, ISKIP(1), NE, 2) GO TO 5
00122  214* CALL DEPOS (NP)
00124  215* S CONTINUE
00125  216* GO TO 700
00126  217* 5 CONTINUE
00127  218* TR0 = +SDELI+RAD
00130  219* ILK = 1
00131  220* IF (ISKIP(1), NE, 0) GO TO 20
00133  221* GO 10 1=1+4
00136  222* GO 10 1=1+4
00141  223* 10 WASHQ(U1(1)) = 0.0
00144  224* 20 CONTINUE
00145  225* KTK = 1
00146  226* K = 1
00147  227* DO 500 KK = 1, NNZ
00152  228* C TH = RAD+THETA(KK)
00155  229* *** LIST INPUT PARAMETERS ***
00155  230* WRITE (6,903) KK
00156  231* WRITE (6,904)
00160  232* IF (KK, NE, 1) GO TO 92
00162  233* WRITE (6,905) Q(KK), ZR(KK), UBARK(KK), UBARK(KK+1), SIGAK(KK), SIGAK(KK+1)
00162  234* 1), SIGEK(KK), SIGEK(KK+1), TAUK, TAU0, SIG0(KK), SIG0(KK+1), SIG0(KK)
00160  235* 2), TETAK(KK), TETAK(KK+1), ZIK(KK), ALPHAK(KK), BETAK(KK), H(KK), DELK(KK)
00162  236* 3), DELY(KK), DELI+ZMOD(KK), TIM1, ZLIM=LAMBDA, TIM2, YR, XX, XX, XXR, XLR, XLR, XLR
00223  237* GO TO 93
00224  238* 92 CONTINUE
00225  239* WRITE (6,918) Q(KK), UBARK(KK), UBARK(KK+1), SIGAK(KK), SIGAK(KK+1)
00225  240* SIGEK(KK), SIGEK(KK+1), SIG0(KK), SIG0(KK+1), TETAK(KK), TETAK(KK+1)
00225  241* ZIK(KK), ALPHAK(KK), BETAK(KK), H(KK), DELK(KK), DELY(KK)
00225  242* 3), ZMOD(KK)
00252  243* 93 IF (KK, NE, NNZ) GO TO 94
00254  244* WRITE (6,919) ZKK(1+)
00257  245* 94 CONTINUE
00260  246* IF (NBK, EQ, 0, OR, KK, NE, JBOT(ILK)) GO TO 97
00262  247* IF (JBOT(ILK), NE, 1) GO TO 96
00262  248* LSP = ILK+2
00265  249* WRITE (6,920) ZRL, UBARK(LSP), UBARK(LSP+1), SIGAL(LSP), SIGAL(LSP+1)
00265  250* 1), SIGEL(LSP), SIGEL(LSP+1), TETAL(LSP), TETAL(LSP+1), TAUL, Tau0, Tau0
00265  251* ZALPHA(NNZ+1), ALPHAK(ILK), TAST(ILK), JBOT(ILK), JTOP(ILK)
00307  252* GO TO 97
00310  253* 96 CONTINUE
00311  254* LSP = ILK+2
00312  255* WRITE (6,921) UBARK(ILK), UBARK(ILK+1), SIGAL(LSP), SIGAL(LSP+1)
00312  256* 1), SIGEL(LSP), SIGEL(LSP+1), TETAL(LSP), TETAL(LSP+1), ALPHAK(NNZ+ILK)
00312  257* 2), TALUL(TAL), TALUL(TAL+1), JBOT(ILK), JTOP(ILK)
00353  258* 97 CONTINUE
00353  259* WRITE (6,922) UBARK(KK), TETAK(KK), DELTHP(KK), DELK(KK), SIGAP(KK)
00354  260* 1), SIGELP(KK)
00344  261* IF (NBK, EQ, 0, OR, KK, NE, JBOT(ILK)) GO TO 98
00346  262* WRITE (6,923) UBARK(NNZ+ILK), TETAN(NNZ+ILK), DELTHP(NNZ+ILK), DELK(NNZ+ILK)
00346  263* 1), DELU(NNZ+ILK), SIGAP(NNZ+ILK), SIGEP(NNZ+ILK)
00356  264* 98 CONTINUE
00457  265* CALL TESTR(TK)
00360  266* WRITE (6,917)
00362  267* IF (ISKIP(1), EQ, 0) GO TO 500
00364 268*  IF (K .EQ. 1 .AND. KK .EQ. 1) WRITE (6,909)
00367 270*        C       *** GENERAL GRID PATTERN CALCULATIONS ***
00370 271*        IF (K .GT. NPTS) GO TO 500
00372 272*        IF (ZKL(K)-ZK(K+1)) 148,500,500
00375 273*        148 YKL = 900.0
00376 274*        IF (DEX(KK) .EQ. 0.0) GO TO 160
00400 275*        IF (NBK .EQ. 0) GO TO 149
00402 276*        IF (KK .LT. IBOT OR KK .GT. ITO) GO TO 149
00404 277*        IF (TAS(KK)-TAS(K+1)) 1.0, .AND. KK .EQ. IBOT AND KK .EQ. ITO) GO TO 151
00407 279*        149 IF (THETA(KK) .GE. 180.0) GO TO 150
00411 280*        YKK = THETA(KK)+180.0
00412 281*        GO TO 153
00413 282*        150 YKK = THETA(KK)-180.0
00414 283*        GO TO 153
00415 284*        151 IF (THETA(JF) .GE. 180.0) GO TO 152
00417 285*        YKK = THETA(JF)+180.0
00420 286*        GO TO 153
00421 287*        152 YKK = THETA(JF)-180.0
00422 288*        153 CONTINUE
00425 289*        IF (NYS .EQ. 1) YY(J) = YKK
00428 290*        160 DO 434 I=1,NYS
00430 291*              JCHK = 0
00431 292*              ICHK = 0
00432 293*              DO 310 J=1,NYS
00435 294*              IF (JCHK .NE. 0) GO TO 210
00437 295*              IF (YKK .GT. YY(J)) GO TO 210
00441 296*              YCL = YKK
00442 297*              ICHK = 1
00443 298*              GO TO 220
00444 299*              210 YCL = YY(J)
00445 300*              220 N = 1
00446 301*              CALL BREAK(K,N,XX(J),YY(J),YCL)
00447 302*              IF (ICHK .EQ. 0) GO TO 310
00451 303*              DS1 = DSY(J)
00452 304*              DS2 = CON(J)
00453 305*              DS3 = AVCON(J)
00454 306*              DS4 = PASSIM(J)
00455 307*              DS = AVMCN(J)
00456 308*              JCHK = J
00460 309*              JCHK = 0
00460 310*              IF (YKK-YY(J)) 210,240,310
00443 311*              240 JCHK = -1
00463 312*              310 CONTINUE
00464 313*        C       ****OUTPUT SECTION ****
00466 314*        IF (15KIP(T) .EQ. 1.OR.15KIP(T) .EQ. 3) GO TO 434
00470 315*        IF (I .NE. 1) GO TO 405
00472 316*        IF (JCHK .NE. 0) GO TO 400
00474 317*        WRITE (6,906) ZKL(K)
00477 318*        GO TO 405
00500 319*        400 WRITE (6,925) ZKL(K),YKK
00504 320*        405 WRITE (6,927) XX(J)
00507 321*        IF (15KIP(T) .EQ. 2.OR.15KIP(T) .EQ. 4) WRITE (6,915)
00512 322*        IF (15KIP(T) .EQ. 1) WRITE (6,924)
00515 323*        DO 420 J=1,NYS
00520 324*        IF (JCHK .NE. J) GO TO 406
00582 325  WRITE (6,908) YKK,DS1,DS2,DS3,DS4,DS5
00583 326  IF (ITAG(J),EQ,0,ITAG(J),EQ,1) GO TO 410
00584 327  WRITE (6,908) YY(J),XOS(J),CON(J),AVCON(J),PASSMJ(J),AVMVIP(J)
00585 328  CONTINUE
00586 329  CONTINUE
00587 330  ITAG(J) = 0
00588 331  434 CONTINUE
00589 332  436 CONTINUE
00590 333  WRITE (6,917)
00591 334  IF (ISKPI(7),EQ,0,OR,ISKPI(7),EQ,2) GO TO 440
00592 335  IF (YKK,NE,NNZ) GO TO 440
00593 336  WRITE (6,910)
00594 337  C PRINT WASHOUT DEPOSITION ONLY AT TOP
00595 338  WRITE (6,913)
00596 339  DO 438 IE1=1,NYS
00597 340  WRITE (6,916) XX(I),(YY(J),WASHOU(I,J),JRI,NNYS)
00598 341  DO 438 JRI=1,NYS
00599 342  WASHOU(I,J) = 0.0
00600 343  438 CONTINUE
00601 344  440 CONTINUE
00602 345  C
00603 346  K = K+1
00604 347  IF (K,GT,NNYS) GO TO 500
00605 348  IF (Z2LT1),LT,2(KK+1)) GO TO 160
00606 349  500 CONTINUE
00607 350  512 CALCULATE CENTER LINE CONCENTRATION AND OR DOSAGE ****
00608 351  CALL CENTRL
00609 352  540 CONTINUE
00610 353  C **** ISOPELTH SECTION ****
00611 354  C **** CALCULATE ISOPLETHS X Y PLANE ****
00612 355  IF (ISKPI(4),EQ,0) GO TO 560
00613 356  IF (ISKPI(5),EQ,0) GO TO 560
00614 357  CALL ISOXY
00615 358  C **** ISPLTHS Y Z PLANE ****
00616 359  560 CONTINUE
00617 360  C **** LOOP FOR NEXT TEST ****
00618 361  580 CONTINUE
00619 362  580 CONTINUE
00620 363  580 CONTINUE
00621 364  580 CONTINUE
00622 365  C
00623 366  700 CONTINUE
00624 367  700 CONTINUE
00625 368  700 CONTINUE
00626 369  C 904 FORMAT (110,55,11)**** INPUT DATA **
00627 370  805 FORMAT (110,55,11)**** LAYER,12,6,****
00628 371  805 FORMAT (110,55,11)**** LAYER,12,6,****
00629 372  904 FORMAT (110,55,11)**** INPUT DATA **
00630 373  905 FORMAT (110,55,11)**** LAYER,12,6,****
00631 374  905 FORMAT (110,55,11)**** LAYER,12,6,****
00632 375  905 FORMAT (110,55,11)**** LAYER,12,6,****
00633 376  905 FORMAT (110,55,11)**** LAYER,12,6,****
00634 377  905 FORMAT (110,55,11)**** LAYER,12,6,****
00635 378  905 FORMAT (110,55,11)**** LAYER,12,6,****
00636 379  905 FORMAT (110,55,11)**** LAYER,12,6,****
00637 380  905 FORMAT (110,55,11)**** LAYER,12,6,****
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00136 942 = EXP(-LAMBDA*(TMP01-TIM1))
00140 946  DO5(J) = DO5(J)+A5
00141 946  CONTINUE
00142 51*  AN(1) = UBAR(KK)
00143 52*  AN(2) = SIG(2)
00144 53*  COM(J) = COS(J)*UBAR(KK)/(SOM2P*SIG)
00145 54*  130 IF (SG.EQ.1) GO TO 310
00146 55*  135 IF (U.EQ.9) GO TO 120
00147 56*  136 IF (V.EQ.9) GO TO 120
00148 57*  CALL LO2C((H,K),X,Y,XO,T0,ASP,XS,2)
00149 58*  IF (H.EQ.9) GO TO 200
00150 59*  ELX(K)-1
00151 60*  CALL SIGMA(K,AS)
00152 61*  IF (H.EQ.9) SIG(4) = SIGYNK
00153 62*  STOL = 1.4442145518
00154 63*  TMP01 = 1.4442145518
00155 64*  STO2 = 6.0
00156 65*  IF (SICOL) ZL,J=200147
00157 66*  IF (SIGX) <Z0>200148
00158 67*  IC1 = -1
00159 68*  IC3 = 0
00160 69*  SI = -1.0
00161 70*  150 SI = SI+1.0
00162 71*  SI = 2.0*SI+(Z(INT1)+Z(INT2))
00163 72*  ERFX(1) = (S2-Z*(INT2)-Z(M)-ZL(K))-TMP01
00164 73*  74*  IF (SICOL) SI = SI+1*0
00165 75*  SI = (Z2-E*2) TO 160
00166 76*  IF (IC3 = GL2) TO 160
00167 77*  ERFX(2) = (S2-Z*(INT2)-Z(M)-ZL(K))-TMP01
00168 78*  ERFX(3) = (S2-Z*(INT1)-Z(M)-ZL(K))-TMP01
00169 79*  ERFX(4) = (S2-Z*(INT1)-Z(M)+1)+ZL(K))-TMP01
00170 80*  CALL IS0(T14)
00171 81*  IC3 = IC3 + 1
00172 82*  IC3 = IC3 + 1
00173 83*  GO TO 150
00174 84*  155 STO2 = STO2+ERFX(MS)
00175 85*  GO TO 150
00176 86*  SI = SI+1.0
00177 87*  IC2 = 0
00178 88*  160 SI = 1.0
00179 89*  IC3 = 0
00180 90*  SI = SI+1.0
00181 91*  SI = 2.0*SI+(Z(INT1)+Z(INT2))
00182 92*  ERFX(4) = (S2-Z*(INT2)-Z(M)+1)+ZL(K))-TMP01
00183 93*  IF (Z-T,-1,0) ERFX(1) IC3 = IC3+1
00184 94*  IF (IC3 = GL2) SI = SI+1*0
00185 95*  SI = (Z2-E*2) TO 170
00186 96*  ERFX(3) = (S2-Z(E2)+ZL(K))-TMP01
00187 97*  ERFX(K) = (S2-Z*(INT2)-Z(M)-ZL(K))+TMP01
00188 98*  CALL IS0(T14)
00189 99*  IC2 = IC2+1
00190 100*  GO TO 170
00191 101*  STO2 = STO2+ERFX(MS)
00192 102*  GO TO 135
00193 103*  170 STO2 = STO2+ERFX(MS)
00194 104*  GO TO 135
00195 105*  STO3 = 1.0

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<table>
<thead>
<tr>
<th>Line</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>00263</td>
<td>105* IF (IC1.EQ. IC2) GO TO 185</td>
</tr>
<tr>
<td>00265</td>
<td>106* IF (IC1 .GT. IC2) ST02 = ST02+4.0*FLOAT(IC1-IC2)</td>
</tr>
<tr>
<td>00267</td>
<td>107* IF (IC1 .LE. IC2) ST02 = ST02+4.0*FLOAT(IC2-IC1)</td>
</tr>
<tr>
<td>00271</td>
<td>108* CONTINUE</td>
</tr>
<tr>
<td>00272</td>
<td>109* IF (1Z*MOD(4,N) .EQ. 3) ST03 = 1.0/(Z(N+1)-7(M))</td>
</tr>
<tr>
<td>00274</td>
<td>110* XBARX = EXP(-.5*(Y/SIDX))**2</td>
</tr>
<tr>
<td>00275</td>
<td>111* TPG2 = X*UAR(UF)</td>
</tr>
<tr>
<td>00276</td>
<td>112* SL = (G(M)<em>ST03)/(2.0</em>STN2P*UAR(UF)*SIGXK1)<em>XBARX</em>ST02</td>
</tr>
<tr>
<td>00277</td>
<td>113* IF (1SKIP(7) .EQ. 1) SL = SL<em>EXP(-DECAY</em>TPG2)</td>
</tr>
<tr>
<td>00301</td>
<td>114* IF (1SKIP(7).LE.1.0R.1SKIP(7).EQ.0.0R.TIM1.0R.TPQ2*TAST(ILK-1))</td>
</tr>
<tr>
<td>00304</td>
<td>115* 160 TO 175</td>
</tr>
<tr>
<td>00305</td>
<td>116* IF ((Z(N) .GT. ZLM) GO TO 195</td>
</tr>
<tr>
<td>00306</td>
<td>117* S1 = SL<em>EXP(-LAMBDA(TPG2</em>TAST(ILK-1)-TIM1))</td>
</tr>
<tr>
<td>00307</td>
<td>118* CONTINUE</td>
</tr>
<tr>
<td>00308</td>
<td>119* S2 = SL<em>UAR(UF)/(STN2P</em>SIGXK1)</td>
</tr>
<tr>
<td>00310</td>
<td>120* DOS(J) = D*SL(J)+S1</td>
</tr>
<tr>
<td>00311</td>
<td>121* CON(J) = CUN(J)+S2</td>
</tr>
<tr>
<td>00312</td>
<td>122* CONTINUE</td>
</tr>
<tr>
<td>00314</td>
<td>123* ANG(1) = UAR(UF)</td>
</tr>
<tr>
<td>00315</td>
<td>124* ANG(2) = SIGXK1</td>
</tr>
<tr>
<td>00316</td>
<td>125* CONTINUE</td>
</tr>
<tr>
<td>00317</td>
<td>126* ERFX(1) = ANG(1)<em>TIMAY/(2.8284271</em>ANG(2))</td>
</tr>
<tr>
<td>00320</td>
<td>127* CALL IS0(1,1)</td>
</tr>
<tr>
<td>00323</td>
<td>128* AVLON(J) = (DOS(J)/TIMAY)*ERFX(1)</td>
</tr>
<tr>
<td>00332</td>
<td>129* PAST(K,J) = 0.3*ANG(2)/ANG(1)</td>
</tr>
<tr>
<td>00333</td>
<td>130* AVMK(J) = DOS(J)/PASTM(W)</td>
</tr>
<tr>
<td>00334</td>
<td>131* IF (DOS(J) .GT. 0.0) GO TO 311</td>
</tr>
<tr>
<td>00336</td>
<td>132* PAST(J) = 0.0</td>
</tr>
<tr>
<td>00337</td>
<td>133* CONTINUE</td>
</tr>
<tr>
<td>00342</td>
<td>134* C ** CALCULAT F WASHOUT **</td>
</tr>
<tr>
<td>00343</td>
<td>135* IF (1SKIP(7).EQ.0.0R.1SKIP(7).EQ.2) GO TO 340</td>
</tr>
<tr>
<td>00344</td>
<td>136* IF (ZIKK) .LT. ZLM) GO TO 344</td>
</tr>
<tr>
<td>00347</td>
<td>137* IF (ZIKK) .GT. ZLM) GO TO 344</td>
</tr>
<tr>
<td>00348</td>
<td>138* CALL HAE(XX,XY,ISW,XX,YY,XY)</td>
</tr>
<tr>
<td>00349</td>
<td>139* CONTINUE</td>
</tr>
<tr>
<td>00350</td>
<td>140* RETURN</td>
</tr>
<tr>
<td>00352</td>
<td>141* END</td>
</tr>
</tbody>
</table>

END OF Compilation: NO DIAGNOSTICS.
00202  40*  WRITE (6,991) (I*VS(I)),1*PERC(I),I=1,NVS
00213  41*  IF (ISKIP(I),NE.2) GO TO 12
00215  42*  WRITE (6,998) (I*VS(I)),1*PLRCB(I),I=1,NVS
00225  43*  12 CONTINUE
00227  44*  DO 10 N=1,NYS
00229  45*  DO 15 I=1,NXS
00231  45*  15 DEP(I,1) = C,0
00240  47*  THETA(I) = THETA(I)*RAD
00241  48*  TH = THETA(I)*RAD
00242  49*  TRD = .5*OLLPHI*PAD
00243  50*  IF (THETA(I) .LT. 180.0) THET = (THETA(I)+180.0)*RAD
00244  51*  IF (THETA(I) .GE. 180.0) THET = (THETA(I)-180.0)*RAD
00247  52*  OTMK(I) = J,0
00250  53*  DO 25 N=2,NXS
00253  54*  25 OTMK(I) = OTMK(I)*RAD
00256  55*  NTAD = 1
00259  56*  IF (ISKIP(I),EQ.2) NTAD = 2
00266  57*  IF (ISKIP(I),EQ.1) NTAD = 2
00270  58*  DO 73 J=NTAD,NTAD
00273  59*  NTAP = NVS
00274  60*  IF (JF,EQ.2) NTAP = NVS
00276  61*  LD 73 8=1+NTAP
00281  62*  IF (JF,EQ.2.OR.VS(I) .LT. 10.0) GO TO 35
00286  63*  WRITE (6,993) VS(I)
00290  64*  67*  ALTER
00297  68*  35 CONTINUE
00310  69*  NTAD = 1
00311  70*  NTAD = NVS
00312  71*  IF (ISKIP(I),NE.2) GO TO 45
00314  72*  IF (JF,EQ.2) GO TO 40
00316  73*  NTAD = NTAD+1
00317  74*  NTAD = NTAD
00320  75*  GO TO 45
00321  76*  DO 72 KK=1,NTAR
00324  77*  IF (JF,EQ.2) GO TO 50
00326  78*  S = 1.0
00330  79*  CALL SUP(S,KK,SIGEN(KK),1,1)
00337  80*  CALL UMA(S5,KK,1,UBHK)
00338  81*  C DETERMINE WC, SOURCES IN LINE SOURCE SIMULATION
00339  82*  DMK = ACCUM(S*SIGEN(KK),1,SNBAR*SBPT(1,6+VS(I)),UBHK)
00341  83*  IF (DMK,L1,10.0) DMK = 10.0
00343  84*  S = (Z*KK+1)-Z(KK)+CHM
00345  85*  NXCNI = 54+I
00350  86*  IF ((NXCI +L1,3) NXCI+3
00354  87*  IF (JF,EQ.1) WRITE (6,999) VS(I),KK,NXCNI
00356  88*  DMK = ACCUM(S*SIGEN(KK),1,SNBAR*SBPT(1,6+VS(I)),UBHK)
00357  89*  ST01 = Z(KK)
00360  90*  GO TO 95
00361  91*  50 NXCNI = 1
00366  92*  ST01 = 0.0
00369  93*  DMK = HH
00374  94*  55 DO 64 12=1,NXCNI
00378  95*  ST01 = ST01+MK
00379  96*  ZLL(12) = ST01
ERFX(1) = UBAR(KK)*TIMAV/(2.8284271*10X)

CALL ISO(1,1)
AVCON(1) = COS(1)/TIMAV*ERFX(1)
PASSM(1) = 4.3*SIGX*UBARK(KK)
AVXCON(1) = DOS(1)/PASSTM(1)

CONTINUE

C = DUS(1)*UBARK(KK)/(S0N2*SIGX)

*** SOLUTION OUTPUT SECTION ***

WRITE (6,940) KK, ZZL(K), Y0
IF (SKIP6) IEQ. 1) WRITE (6,946)
IF (SKIP7) IEQ. 2) WRITE (6,947)

110 WRITE (6,948)
LD 115 =1*NXK

115 WRITE (6,949) DXR(I), DOS(I), CON(I), AVCON(I), PASSTM(I), AVXCON(I)
C = K+1

IF (K.GT. NPTS) GO TO 410
IF (ZZL(K) .LT. Z(KK+1)) GO TO 20

RETURN

900 FORMAT ('O',12X,'CALCULATIONS FOR LAYER ',I3,': AT HEIGHT ',F10.5,CTLO7500)

1.EQ. C, ' PRECIPITATION SCAVENGING IS INCLUDED IN DOSAGE, CONCENTRATION', CONCTLO7500
1.EQ. 1, 'ITERATION, LTC')
905 FORMAT (12X,10H10H -- )
910 FORMAT (11H10H 10H -- )
912 FORMAT (10H10H 10H -- )

913 FORMAT (10H10H 10H -- )
914 FORMAT (10H10H 10H -- )
915 FORMAT (11H10H 10H -- )

100 FORMAT ('CONCENTRATION ALONGWIND CONCENTRATION TIME OF PASSAGE', ACLO900)
100 FORMAT ('CONCENTRATION CONCENTRATION')

END OF COMPILED: NO DIAGNOSTICS.
SUBROUTINE ISOXY

COMMON /PARAMS/ TESTNO(2), DATE(2), ISKIP(3), HXS, NYS, NZS, ND1, NC1

IXY00900

1

COMMON /PARAMS/ UBAR(3), SIGAP(3), CELTHP(3), STLP(3), THETA(30)

IXY01000

2

INDEX, HUX, NTS, NYS, NVR, XX(110), YY(100), ZZ(31), OXR(100), GELX(20)

IXY00950

3

ZELY(2), OS(120), UBAR(21), SIGAX(11), SIGEX(12), SIGAX(21), SIGEX(22), SIGAX(20), SIGEX(20)

IXY01050

4

SIGZ(20), SIGA(30), ETA(30), ZKN, T1MY, T2TAU, T2, T2D, TAU(21)

IXY01100

5

4*MT, XNZ, XLY, XLYRZ, ZL(110), ZY(100), DECAY, O1, T2L, T1L, LAMDA

IXY01150

6

SIGF(10), DI(15), CI(11), M1, J(M1), UT(10), JTOP(10), VS(20)

IXY01200

7

EPM(2), ABC(72), ABC(20), FNCI(20), H1, ALPHL(11), T1L(11), T2L, TAU, TALG

IXY01250

8

7ZRL, UBAR(20), SIGA(20), SIGEX(20), SIGE(20), THETA(20), T(20), DELPHI

IXY01300

9

 Com/ /PARAMS/ UBAR(30), SIGAP(30), CELTHP(30), STLP(30), THETA(30)

IXY01400

10

INDEX, HUX, NTS, NYS, NVR, XX(110), YY(100), ZZ(31), OXR(100), GELX(20)

IXY01450

11

ZELY(2), OS(120), UBAR(21), SIGAX(11), SIGEX(12), SIGAX(21), SIGEX(22), SIGAX(20), SIGEX(20)

IXY01500

12

SIGZ(20), SIGA(30), ETA(30), ZKN, T1MY, T2TAU, T2, T2D, TAU(21)

IXY01550

13

4*MT, XNZ, XLY, XLYRZ, ZL(110), ZY(100), DECAY, O1, T2L, T1L, LAMDA

IXY01600

14

SIGF(10), DI(15), CI(11), M1, J(M1), UT(10), JTOP(10), VS(20)

IXY01650

15

EPM(2), ABC(72), ABC(20), FNCI(20), H1, ALPHL(11), T1L(11), T2L, TAU, TALG

IXY01700

16

7ZRL, UBAR(20), SIGA(20), SIGEX(20), SIGE(20), THETA(20), T(20), DELPHI

IXY01750

17

Com/ /PARAMS/ UBAR(30), SIGAP(30), CELTHP(30), STLP(30), THETA(30)

IXY01800

18

INDEX, HUX, NTS, NYS, NVR, XX(110), YY(100), ZZ(31), OXR(100), GELX(20)

IXY01850

19

ZELY(2), OS(120), UBAR(21), SIGAX(11), SIGEX(12), SIGAX(21), SIGEX(22), SIGAX(20), SIGEX(20)

IXY01900

20

SIGZ(20), SIGA(30), ETA(30), ZKN, T1MY, T2TAU, T2, T2D, TAU(21)

IXY01950

21

4*MT, XNZ, XLY, XLYRZ, ZL(110), ZY(100), DECAY, O1, T2L, T1L, LAMDA

IXY02000

22

SIGF(10), DI(15), CI(11), M1, J(M1), UT(10), JTOP(10), VS(20)

IXY02050

23

EPM(2), ABC(72), ABC(20), FNCI(20), H1, ALPHL(11), T1L(11), T2L, TAU, TALG

IXY02100

24

7ZRL, UBAR(20), SIGA(20), SIGEX(20), SIGE(20), THETA(20), T(20), DELPHI

IXY02150

25

Com/ /PARAMS/ UBAR(30), SIGAP(30), CELTHP(30), STLP(30), THETA(30)

IXY02200

26

INDEX, HUX, NTS, NYS, NVR, XX(110), YY(100), ZZ(31), OXR(100), GELX(20)

IXY02250

27

ZELY(2), OS(120), UBAR(21), SIGAX(11), SIGEX(12), SIGAX(21), SIGEX(22), SIGAX(20), SIGEX(20)

IXY02300

28

SIGZ(20), SIGA(30), ETA(30), ZKN, T1MY, T2TAU, T2, T2D, TAU(21)

IXY02350

29

4*MT, XNZ, XLY, XLYRZ, ZL(110), ZY(100), DECAY, O1, T2L, T1L, LAMDA

IXY02400

30

SIGF(10), DI(15), CI(11), M1, J(M1), UT(10), JTOP(10), VS(20)

IXY02450

31

EPM(2), ABC(72), ABC(20), FNCI(20), H1, ALPHL(11), T1L(11), T2L, TAU, TALG

IXY02500

32

7ZRL, UBAR(20), SIGA(20), SIGEX(20), SIGE(20), THETA(20), T(20), DELPHI

IXY02550

33

Com/ /PARAMS/ UBAR(30), SIGAP(30), CELTHP(30), STLP(30), THETA(30)

IXY02600

34

INDEX, HUX, NTS, NYS, NVR, XX(110), YY(100), ZZ(31), OXR(100), GELX(20)

IXY02650

35

ZELY(2), OS(120), UBAR(21), SIGAX(11), SIGEX(12), SIGAX(21), SIGEX(22), SIGAX(20), SIGEX(20)

IXY02700

36

SIGZ(20), SIGA(30), ETA(30), ZKN, T1MY, T2TAU, T2, T2D, TAU(21)

IXY02750

37

4*MT, XNZ, XLY, XLYRZ, ZL(110), ZY(100), DECAY, O1, T2L, T1L, LAMDA

IXY02800

38

SIGF(10), DI(15), CI(11), M1, J(M1), UT(10), JTOP(10), VS(20)

IXY02850

39

EPM(2), ABC(72), ABC(20), FNCI(20), H1, ALPHL(11), T1L(11), T2L, TAU, TALG

IXY02900

40

7ZRL, UBAR(20), SIGA(20), SIGEX(20), SIGE(20), THETA(20), T(20), DELPHI

IXY02950

41

Com/ /PARAMS/ UBAR(30), SIGAP(30), CELTHP(30), STLP(30), THETA(30)

IXY03000

42

INDEX, HUX, NTS, NYS, NVR, XX(110), YY(100), ZZ(31), OXR(100), GELX(20)

IXY03050

43

ZELY(2), OS(120), UBAR(21), SIGAX(11), SIGEX(12), SIGAX(21), SIGEX(22), SIGAX(20), SIGEX(20)

IXY03100

44

SIGZ(20), SIGA(30), ETA(30), ZKN, T1MY, T2TAU, T2, T2D, TAU(21)

IXY03150

45

4*MT, XNZ, XLY, XLYRZ, ZL(110), ZY(100), DECAY, O1, T2L, T1L, LAMDA

IXY03200

46

SIGF(10), DI(15), CI(11), M1, J(M1), UT(10), JTOP(10), VS(20)

IXY03250

47

EPM(2), ABC(72), ABC(20), FNCI(20), H1, ALPHL(11), T1L(11), T2L, TAU, TALG

IXY03300

48

7ZRL, UBAR(20), SIGA(20), SIGEX(20), SIGE(20), THETA(20), T(20), DELPHI

IXY03350

49
NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2  H E CRAMER CO

00167  46a  60 DO 540 I=1:NDXR
00172  47a  J = 1
00173  48a  CALL EL(DX(I),0)
00174  48a  CALL SIGMA(DXR(I),0,0)
00175  50a  IF (SIGY) 340=540,61
00260  51a  61 IF (SIGZ .LE. 0.0,AND.IZMOD(KK) .EQ. 3) GO TO 540
00272  52a  CALL PCK(KK)
00283  53a  CALL VERT(I,KK)
00284  54a  TEMP1 = DX(I)/UPAR(KK)
00285  55a  DOS(I) = SIG1*(SIG2+SIG3)
00286  56a  IF (SKIP(KK) .LE. 1) DOS(I) = DOS(I)*EXP(-DECAY*TMP1)
00287  57a  IF (SKIP(KK) .LE. 2,OR.TM11 .GE. TMPO1) GO TO 62
00290  59a  IF (Z(KK) .GE. ZL1) GO TO 62
00294  59a  DOS(I) = DOS(I)*EXP1-LAMBDA*(TMPO1-TM11)
00295  61a  CONTINUE
00318  64a  CONT(I) = DOS(I)*ITBAR(KK)/(ITBAR2*SIGK)
00321  66a  TEMP2 = 2.*SIGY*SIGK
00322  68a  IF (SKIP(KK) .LE. 6,AND.SKIP(KK) .GE. 4) GO TO 530
00325  69a  DO 66 I=1,DI
00326  69a  BE = DOS(I)/DI
00327  69a  IF (BE .LE. 1.0) GO TO 66
00328  69a  PLT(I,J) = SORT(TMPO1+ALOG(I))
00337  70a  GO TO 66
00339  69a  65 PLT(I,J) = 3.0
00340  70a  CONTINUE
00345  71a  53 PLT(I,J) = 5.0
00347  72a  IF (SKIP(KK) .LE. 3) GO TO 540
00348  73a  U = CONT(I,J)
00349  74a  IF (U .LE. 1.0) GO TO 535
00350  75a  PLT(I,J) = SORT(TMPO1+ALOG(I))
00351  76a  GO TO 536
00352  77a  53 PLT(I,J) = 9.0
00353  78a  CONTINUE
00359  79a  54 CONTINUE
00360  80a  WRITE (6,901) ZL(K)
00361  81a  WRITE (6,908) I
00362  82a  51 WRITE (6,908) I
00363  83a  50 WRITE (6,908) I
00364  84a  DO 56V J=1:NDXR
00365  85a  WRITE (6,919) DXR(I),(N1,J),PLT(I,J),J=1:NDXR
00366  86a  570 IF (SKIP(KK) .LE. 3) GO TO 590
00367  87a  WRITE (6,911) I
00368  88a  DO 56V J=1:NDXR
00369  89a  WRITE (6,919) DXR(I),(N1,J),PLT(I,J),J=1:NDXR
00370  90a  590 CONTINUE
00371  91a  C
00377  92a  60 CONTINUE
00382  93a  K = K+1
00383  94a  IF (K .GT. NPTS) GO TO 640
00384  95a  IF (ZLKK .LT. Z(KK+1)) GO TO 20
00385  96a  CONTINUE
00386  97a  630 CONTINUE
00390  98a  640 WRITE (6,912)
00391  99a  RETURN
01333  99a  906 FORMAT (10X,"** PRECIPITATION SCAVENGING HAS BEEN INCLUDED IN DOSAGE")
01334  99a  1 AND CONCENTRATION IN CALCULATING ISOLETHS")
01335  99a  907 FORMAT (1H1,5X,10E2,4X,HEIGH T Z:Fig.2.2H*)
01336  99a  908 FORMAT (1H1,5X,201H DO SAGE ISOLETHS *)

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<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0122</td>
<td>37*</td>
<td>NAKLIST/NAK3/ALPHABETF/LUTAUL/TAUOL/ZRL</td>
</tr>
<tr>
<td>0122</td>
<td>30*</td>
<td>LUBAHL/SIGEL/SIGEL/THEAL</td>
</tr>
<tr>
<td>0123</td>
<td>39*</td>
<td>IF (IF .GT. 1) GO TO 2</td>
</tr>
<tr>
<td>0123</td>
<td>40*</td>
<td>ZERO OUT INPUT LISTS FOR PROCESSORS WHERE CORE IS NOT</td>
</tr>
<tr>
<td>0123</td>
<td>41*</td>
<td>INITIALLY TO ZERO 1147 IS LENGTH OF COMMON/PARAM./MINUS</td>
</tr>
<tr>
<td>0123</td>
<td>42*</td>
<td>12 KGM TESTING AND 2 FOR DATE</td>
</tr>
<tr>
<td>0125</td>
<td>43*</td>
<td>DO 1 I=1,1133</td>
</tr>
<tr>
<td>0130</td>
<td>44*</td>
<td>IZS(I) = 1</td>
</tr>
<tr>
<td>0132</td>
<td>45*</td>
<td>READ (S,1051)</td>
</tr>
<tr>
<td>0135</td>
<td>46*</td>
<td>RETURN</td>
</tr>
<tr>
<td>0135</td>
<td>47*</td>
<td>READ (5,1052)</td>
</tr>
<tr>
<td>0141</td>
<td>48*</td>
<td>WRITE (6,1460) TESTNO,DATE</td>
</tr>
<tr>
<td>0153</td>
<td>49*</td>
<td>NXS = NXS-1</td>
</tr>
<tr>
<td>0154</td>
<td>50*</td>
<td>LAM/DA = BLAM/DA</td>
</tr>
<tr>
<td>0155</td>
<td>51*</td>
<td>IF (NAX .GT. 31) GO TO 5</td>
</tr>
<tr>
<td>0155</td>
<td>52*</td>
<td>DEFAULT XX</td>
</tr>
<tr>
<td>0157</td>
<td>53*</td>
<td>NXS = 34</td>
</tr>
<tr>
<td>0160</td>
<td>54*</td>
<td>DO 1 I=1,NXS</td>
</tr>
<tr>
<td>0163</td>
<td>55*</td>
<td>4 XXX(I) = X5(I)</td>
</tr>
<tr>
<td>0165</td>
<td>56*</td>
<td>5 CONTINUE</td>
</tr>
<tr>
<td>0166</td>
<td>57*</td>
<td>IF (TAXY .GT. 0.0) GO TO 6</td>
</tr>
<tr>
<td>0166</td>
<td>58*</td>
<td>C DEFAULT TAXY</td>
</tr>
<tr>
<td>0170</td>
<td>59*</td>
<td>DEFAULT = 0.0</td>
</tr>
<tr>
<td>0171</td>
<td>60*</td>
<td>6 IF (DELPHI .GT. 0.0) GO TO 8</td>
</tr>
<tr>
<td>0171</td>
<td>61*</td>
<td>C DEFAULT DELPHI</td>
</tr>
<tr>
<td>0173</td>
<td>62*</td>
<td>DELPHI = 1.0</td>
</tr>
<tr>
<td>0174</td>
<td>63*</td>
<td>8 DO 16 I=1,NZ</td>
</tr>
<tr>
<td>0177</td>
<td>64*</td>
<td>IF (ALPHA(I) .GT. 0.0) GO TO 10</td>
</tr>
<tr>
<td>0177</td>
<td>65*</td>
<td>C DEFAULT ALPHA</td>
</tr>
<tr>
<td>0177</td>
<td>66*</td>
<td>ALPH(I) = 1.0</td>
</tr>
<tr>
<td>0179</td>
<td>67*</td>
<td>10 IF (UTA(I) .GT. 0.0) GO TO 12</td>
</tr>
<tr>
<td>0179</td>
<td>68*</td>
<td>C DEFAULT UTA</td>
</tr>
<tr>
<td>0179</td>
<td>69*</td>
<td>UTA(I) = 1.0</td>
</tr>
<tr>
<td>0181</td>
<td>70*</td>
<td>12 IF (SIGMA(I) .GT. 0.0) GO TO 14</td>
</tr>
<tr>
<td>0183</td>
<td>71*</td>
<td>C DEFAULT SIGMA</td>
</tr>
<tr>
<td>0183</td>
<td>72*</td>
<td>SIGMA = 1.0</td>
</tr>
<tr>
<td>0185</td>
<td>73*</td>
<td>14 IF (IKMD(I) .GT. 0.0) GO TO 16</td>
</tr>
<tr>
<td>0189</td>
<td>74*</td>
<td>C DEFAULT IKMD</td>
</tr>
<tr>
<td>0191</td>
<td>75*</td>
<td>IKMD = 0.0</td>
</tr>
<tr>
<td>0191</td>
<td>76*</td>
<td>16 CONTINUE</td>
</tr>
<tr>
<td>0193</td>
<td>77*</td>
<td>IF (RXY .GT. 0.0) GO TO 18</td>
</tr>
<tr>
<td>0195</td>
<td>78*</td>
<td>C DEFAULT RXY</td>
</tr>
<tr>
<td>0195</td>
<td>79*</td>
<td>RXY = 1.0</td>
</tr>
<tr>
<td>0197</td>
<td>80*</td>
<td>18 IF (RXZ .GT. 0.0) GO TO 20</td>
</tr>
<tr>
<td>0200</td>
<td>81*</td>
<td>C DEFAULT RXZ</td>
</tr>
<tr>
<td>0202</td>
<td>82*</td>
<td>RXZ = 1.0</td>
</tr>
<tr>
<td>0203</td>
<td>83*</td>
<td>20 IF (TXHAV .GT. 0.0) GO TO 24</td>
</tr>
<tr>
<td>0205</td>
<td>84*</td>
<td>C DEFAULT TIXAV</td>
</tr>
<tr>
<td>0206</td>
<td>85*</td>
<td>TIXAV = 1.0</td>
</tr>
<tr>
<td>0208</td>
<td>86*</td>
<td>24 IF (TPK .GT. 0.0) GO TO 26</td>
</tr>
<tr>
<td>0208</td>
<td>87*</td>
<td>C DEFAULT TPK</td>
</tr>
<tr>
<td>0210</td>
<td>88*</td>
<td>TPK = 1.0</td>
</tr>
<tr>
<td>0210</td>
<td>89*</td>
<td>26 IF (TSKIP(7) .EQ. 0.0) 15 SKIP(7) .EQ. 2) GO TO 27</td>
</tr>
<tr>
<td>0212</td>
<td>90*</td>
<td>C DEFAULT TSK</td>
</tr>
<tr>
<td>0214</td>
<td>91*</td>
<td>TSK = 2.0</td>
</tr>
<tr>
<td>0216</td>
<td>92*</td>
<td>27 IF (TPK .LT. TIXAV) NPTS = 0</td>
</tr>
<tr>
<td>0217</td>
<td>93*</td>
<td>C NPTS = INZ</td>
</tr>
<tr>
<td>0219</td>
<td>94*</td>
<td>NPTS = INZ</td>
</tr>
</tbody>
</table>
DO 26 I = 1, NNZ

C DEFAULT ZXL

DO 29 ZXL(I) = 2(I)

30 IF (NOXR .GT. 0) GO TO 34

DO 31 M = 34

DO 32 I = 1, NXL

C DEFAULT DAK

32 DAK(I) = DAK(I)

DO 34 I = 1, NXL

C CHECK MINIMUM LIMITS

IF (SIGAK(I) .LT. .5) SIGAK(I) = .5

IF (SIGEK(I) .LT. .1) SIGEK(I) = .1

IF (LARK(I) .LT. .1) LARK(I) = .1

CONTINUE

DO 27 CONTINUE

IF (IEXL .LT. 0) GO TO 75

IF (IEXK .EQ. 3) GO TO 40

C DETERMINE LAYER CHANGE PARAMETERS

ZAK = ZAK

II = -1

DO 30 I = 1, NBL

M = UBL(I) = UBL(I) .GT. 0.0 GO TO 42

C DEFAULT TAUOL

TAUOL = TAUOL

C REAASSIGN (S, NAM3)

C READ LAYER CHANGE PARAMETERS

IF (TAUOL .GT. 0.0) GO TO 42

C DEFAULT TAUOL

TAUOL = 60.0

C CONTINUE

IF (ZXL .LT. 0.0) GO TO 46

C DEFAULT ZXL

ZXL = 10.0

C CHECK MINIMUM VALUES

IF (SIGAK(I) .LT. .5) SIGAK(I) = .5
00357 151 IF (UBARL(I) .LT. 1) UARAL(I) = 1
00361 152 IF (SIGEL(I) .LT. 1) SIGEL(I) = 1
00365 154 NTAK = NNZ+1
00366 155 NTAL = NNZ+1
00366 156 C COMBINE ALFA AND BETA WITH ALPHL AND BETL
00367 157 DO 54 I=NTAK,NTAL
00368 158 ALPH(I) = ALPHL(I-NTZ)
00373 159 BETA(I) = BETL(I-NNZ)
00374 160 IF (TAZT(I-NNZ) .LT. 0.0) GO TO 54
00376 161 C DEFAULT TAST
00377 162 TAST(I-NNZ) = 1.0
00379 54 CONTINUE
00381 164 IF (Z(I) .LT. 0.0) GO TO 58
00383 165 C MINIMUM Z
00384 166 Z(I) = 2.0
00384 167 C CONTINUE
00385 168 S = (Z(I)/SARK)
00395 169 S1 = 1.0/ALOG(S)
00397 20 GO TO 170
00400 170 P = ALUG(UARK(2)/UARK(1))**51
00400 171 IF (U+1.0) 65,66,65
00400 65 P = -.999999
00400 66 P = -.999999
00400 172 C CONTINUE
00414 173 C CALCULATE UBAR FOR LAYER 1
00424 174 C USAK = 1/(1.0+P)*(Z(2)-ZRK)*ZRK**P1
00434 175 UAK = (1.0+P)*(Z(2)-ZRK)*ZRK**P1
00434 176 UAK = (1.0+P)*(Z(2)-ZRK)*ZRK**P1
00444 177 P = P**P1
00444 178 IF (NNZ.LT.2) GO TO 152
00444 179 UO = 1.0*123.0
00454 180 C CALCULATE UBAR FOR LAYERS 2 TO NNZ
00464 181 UBAR(I) = -.5*(UARK(I+1)+UARK(I))
00464 182 P = ALOG(S4GAK(2)/S4GAK(1))**51
00464 183 IF (P+1.0) 155,156,155
00464 155 F = -.999999
00464 156 F = -.999999
00464 157 CONTINUE
00473 185 C CALCULATE SIGAP FOR LAYER 1
00483 186 SIGAP(I) = ((SIGAK(I)+SIGAK(1))*(TAUK/TAUOK))**0.2+RAD)/(1.0+P)**
00493 187 (1.0+P)**(1.0+P)**(1.0+P)**(1.0+P)**(1.0+P)**
00503 188 P = P**P1
00503 189 IF (NNZ.LT.2) GO TO 162
00513 190 UO = 1.0*23.0
00523 191 C CALCULATE SIGAP FOR LAYERS 2 TO NNZ
00533 192 C SIGAP(I) = ((SIGAK(I)+SIGAK(1))*(TAUK/TAUOK))**0.2+RAD)*0.5
00543 193 SIGAP(I) = ((SIGAK(I)+SIGAK(1))*(TAUK/TAUOK))**0.2+RAD)*0.5
00553 194 SIGAP(I) = ((SIGAK(I)+SIGAK(1))*(TAUK/TAUOK))**0.2+RAD)*0.5
00563 195 IF (P+1.0) 165,166,165
00563 165 F = -.999999
00563 166 F = -.999999
00563 167 CONTINUE
00573 197 C CALCULATE SIGEP FOR LAYER 1
00583 198 SIGEP(I) = ((SIEGK(I)+SIEGK(1))*SIEGK(1))**0.5
00593 200 IZRK**(1.0+P)**(+RAD)
00603 201 IF (NNZ.LT.2) GO TO 172
00613 202 OP = P
00623 203 LO = 1.0*23.0
00633 204 C CALCULATE SIGEP FOR LAYERS 2 TO NNZ
00643 205 C SIGEP(I) = ((SIEGK(I)+SIEGK(1))*RAD)**0.5
00653 206 LO = 1.0*23.0
00663 207 J = 1
00673 208
00467 20a  C  CALCULATE THETA FOR ALL LAYERS
00470 20a  IF (AUS(THETAK(J)-THETAK(J+1)) .LT. 180.0) GO TO 178
00472 20a  IF (THETAK(J+1) .LT. 180.0) GO TO 175
00476 21a  THETAK(J) = THETAK(J+1)+360.0
00477 21a  CONTINUE
00480 21a  THETA(I) = (THETAK(J)+THETAK(J+1))*.5
00481 21a  IF (THETAK(J+1) .GE. 360.0) THETA(I) = THETA(I)-360.0
00481 21a  CONTINUE FOR ALL LAYERS
00483 21a  GO TO 180
00485 21a  CELTH(I) = (THETAK(J)+1)-THETAK(J)
00487 21a  GO 105 I=1+1NZ
00489 21a  CELU(I) = UJAKK(I+1)-UJAKK(I)
00491 21a  IF (ISKIP(I) .GT. 0) GO TO 250
00494 22a  IF (NOK .EQ. 0) GO TO 250
00496 22a  S = (Z(1)**I)/ZHL
00498 22a  SI = R**A**U*X(S)
00500 22a  P = ALOG(UJARL(2)/UJARL(1))*SI
00502 22a  IF (P + 1.0) 192,191,192
00504 23a  P = -9999999
00505 23a  CONTINUE
00507 23a  C  CALCULATE UJAR FOR NEW LAYER 1 (IF CONTAINS SURFACE)
00510 23a  UJAR(I+1,Z+1) = UJAR(I+1,1)/(1.0+P)*Z*(Z+1)-ZRL*2RL*P)*Z*(Z+1)...**
00512 23a  1.0+P)**ZRL=1.0+P)
00514 23a  GPM = P
00516 23a  GO TO 197
00518 23a  C  CALCULATE UJAR FOR NEW LAYER 1 (IF DOES-N'T CONTAIN SURFACE)
00520 23a  UJAR(I+1,Z+1) = UJAR(I+1)+UJAR(I+2)*0.5
00522 23a  GO TO 202
00524 23a  DO 260 I=2,NPK
00526 24a  J = I+2-1
00528 24a  C  CALCULATE UJAR FOR NEW LAYERS 2 TO NOK
00530 24a  UJAR(I+1,Z+1) = UJAR(I+1)+UJAR(I+2)*0.5
00532 24a  GO TO 210
00534 24a  IF (IUX .GT. 1) GO TO 210
00536 24a  P = ALOG(SIGEL(I+1)*SIGEL(I+1)*SI)
00538 24a  GO TO 205
00540 24a  P = -9999999
00542 24a  C  CALCULATE SIGEP FOR NEW LAYER 1 (IF CONTAINS SURFACE)
00545 24a  SIGEP(I+1,Z+1) = (SIGEL(I+1)/(1.0+P)*Z*(Z+1)-ZRL*2RL*P)*Z*(Z+1)...**
00547 24a  1.0+P)**ZRL=1.0+P)
00549 24a  GEP = P
00551 24a  GO TO 205
00553 24a  C  CALCULATE SIGEP FOR NEW LAYER 1 (IF DOES-N'T CONTAIN SURFACE)
00555 24a  SIGEP(I+1,Z+1) = (SIGEL(I+1)*SIGEL(I+1)+RAD)*0.5
00557 24a  DO 220 IUX .LT. 2) GO TO 222
00559 25a  C  CALCULATE SIGEP FOR NEW LAYERS 2 TO NOK
00561 25a  SIGEP(I+1,Z+1) = (SIGEL(I+1)*SIGEL(I+1)+RAD)*0.5
00563 25a  DO 230 IUX .LT. 1) GO TO 232
00565 27a  J = I+2-1
00567 27a  C  CALCULATE SIGEP FOR NEW LAYERS 2 TO NOK
00569 27a  SIGEP(I+1,Z+1) = (SIGEL(I+1)*SIGEL(I+1)+RAD)*0.5
00571 27a  DO 230 IUX .LT. 1) GO TO 232
00573 29a  C  CALCULATE THETA FOR NEW LAYERS 1 TO NOK
00575 29a  IF (AUS(THETAL(J)-THETAK(J+1)) .LT. 180.0) GO TO 228
00577 30a  IF (THETAL(J) .GT. THETAK(J+1)) GO TO 225
00579 30a  CONTINUE
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00720  322*  300  SAVE(I) = SAVE(I)+360.0
00721  322*  301  GO TO 330
00722  322*  310  IF (ABS(SAVE(I)-SAVE(I-1)) .GT. 180.0) GO TO 320
00723  322*  320  SAVE(I) = SAVE(I)-360.0
00724  322*  321  GO TO 290
00725  322*  330  CONTINUE
00726  322*  340  UIFI = DIFI+0.5*DELFHI
00727  322*  350  YY(I) = YY(I-1)+5.0
00728  337*  360  IF (YY(I) .GT. 360.0) YY(I) = YY(I)-360.0
00729  350  DO 350 I=1,NYS
00730  350  355  YY(I) = YY(I)+180.0
00731  360  CONTINUE
00732  360  WRITE (6,NAM2)
00733  370  IF (ISP (X) EQ. 3) WRITE (6,NAM3)
00734  380  RETURN
00735  390  C  MACHINE DEPENDENT STATEMENT ASSUMES SIX BYTES/WORD
00736  390  100  FORMAT ('**',X,** TITLE=',12A6,' DATE=',12A6,** /
00737  390  351*  390  END OF COMPILATION:  NO DIAGNOSTICS.
### NASA/HSCF Multilayer Diffusion Model: Version 2

**H E Granner CO**

**SUBROUTINE SGP**

<table>
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**Storage Used:**

- CGUE (1) 001321: DATA (0) 000601: BLANK COMMON (2) 000000

**COMMON Blocks:**

- 0003 PARAM 062173
- 0034 PARAMS 025610

**External References (Block, Name):**

- C005 HEXP5
- C006 SIN
- C007 COS
- C010 ATAN
- C011 SURF
- C012 EXP
- C013 NERR8

**Storage Assignment (Block, Type, Relative Location, Name):**

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**Date:** 031473  **Page:** 51
END OF COMPILED: NO DIAGNOSTICS.
### STORAGE USED: CUE(1) 0016159 DATA(1) 0006291 BLANK COMMON(2) 000000

**COMMON BLOCKS:**

- 0003 PARANT 0U2173
- 0004 PARA4S 0U5819

**EXTERNAL REFERENCES (BLOCK, NAME):**

- 0005 EL
- 0006 SISMA
- 0007 COS
- 0010 SORT
- 0011 ACOS
- 0012 SIN
- 0013 ALKPS6
- 0014 NEHR33

### STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME):

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**DATE** 031473 **PAGE** 55
04261 105* 14' LP = ALPH(A(1))XY(1)+SIGM(1)+SIGN(DEL)*2+(SIGY*COS(DEL)**2)) CRDL14000
04261 105* IF (LP*.LE. 1.0) LP = 1.0 CRDL14000
04264 100* IF (LP*.GE. 2.) GO TO 260 CRDL14000
04266 109* DETERMINE IF POINT LIES IN AREA BEFORE OR AFTER LAYER CHANGE CRDL14000
04267 110* IF (LP*.LE.51+THD) CRDL14000
04270 109* B = DEL CRDL14000
04271 113* U = UEL + U = 3.1415926-DEL CRDL14000
04273 114* U = B*tan(7.1415926-DEL) CRDL14000
04274 115* TANP1 = UAS(TAN)+XAST(M) CRDL14000
04275 130* DY = SIGN(TANP1)*DX+DX*(2.0*XST(M)+DX*COS(U)) CRDL14000
04276 117* IF (X5*.GT. DY) GO TO 176 CRDL14000
04300 116* IF (Y1*.GT. THD) GO TO 176 CRDL14000
04312 112* TXP2 = X5*X5 CRDL14000
04320 120* DXP = SIGN(TXP2)*TP01-(2.0*X5*XST(M)+COS(PHI)) CRDL14000
04324 121* B = (DXP*TP01-TP02)/(2.0*DXP*XST(M)) CRDL14000
04355 122* IF (B*.LT. 1.0) B = 1.0 CRDL14000
04377 123* IF (B*.GT. -1.0) B = -1.0 CRDL14000
04391 124* B = ACOS(B) CRDL14000
04401 125* S = APS(TAN)-THP) CRDL14000
04413 126* IF (UEL *.GE. 1.5707963) GO TO 182 CRDL14000
04415 127* IF (TANP1-THP) = 179.14000
04419 128* 179 IF (TPH1.TP1.chied.ANS(TPH1-THP).LT. 3.1415926) GO TO 181 CRDL14000
04422 129* IF (THP).LT. THP1.chied.ANS(TPH1-THP).GT. 3.1415926) GO TO 181 CRDL14000
04424 130* IF (TPH1. THP) GO TO 185 CRDL14000
04433 128* IF (S *.LT. 3.1415926) GO TO 185 CRDL14000
04450 131* IF (S *.GE. 3.1415926) GO TO 185 CRDL14000
04450 132* GO TO 186 CRDL14000
04453 133* IF (THP1,.GT. THP).GO TO 185 CRDL14000
04453 134* IF (S *.LT. 3.1415926) GO TO 185 CRDL14000
04453 135* IF (S *.GE. 3.1415926) GO TO 185 CRDL14000
04453 136* GO TO 186 CRDL14000
04453 137* IF (THP1. THP).GO TO 185 CRDL14000
04453 138* IF (S *.LT. 3.1415926) GO TO 185 CRDL14000
04453 139* IF (S *.GE. 3.1415926) GO TO 185 CRDL14000
04453 140* GO TO 186 CRDL14000
04453 141* GO TO 186 CRDL14000
04453 142* GO TO 186 CRDL14000
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04453 168* GO TO 186 CRDL14000
04453 169* GO TO 186 CRDL14000
04453 180* 180 IF (GAM *.LT. 0) CRDL14000
04453 181* 181 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 182* 182 IF (GAM,.LT. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 183* 183 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 184* 184 IF (GAM,.LT. 0) CRDL14000
04453 185* 185 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 186* 186 IF (GAM,.LT. 0) CRDL14000
04453 187* 187 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 188* 188 IF (GAM,.LT. 0) CRDL14000
04453 189* 189 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 190* 190 IF (GAM,.LT. 0) CRDL14000
04453 191* 191 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 192* 192 IF (GAM,.LT. 0) CRDL14000
04453 193* 193 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 194* 194 IF (GAM,.LT. 0) CRDL14000
04453 195* 195 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 196* 196 IF (GAM,.LT. 0) CRDL14000
04453 197* 197 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 198* 198 IF (GAM,.LT. 0) CRDL14000
04453 199* 199 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
04453 200* 200 IF (GAM,.LT. 0) CRDL14000
04453 201* 201 IF (GAM,.GE. 3.1415926) GAM = 6.2831853-GAM CRDL14000
END OF COMPILED: NO DIAGNOSTICS.
SUBROUTINE SIGMA(X,Y,MM)

C-49
I've processed a page from a document related to a scientific or technical context. The text appears to be a code snippet, possibly from a computer program or a mathematical model. Here is the plain text representation of the document:

```
00102  57*  40  TYP41 = (TET41(1)-TET41(2))/RAD
00103  50*  SIG41K = SQR((SIG41*(-SIN(P41)))**2+(SIG41*COS(P41)))**2)
00104  59*  SQ4A4 = ALPHA(1)*XRY*(SIG41K/(SIG41*ALPHA(1)*XRY))**2*(1.0/ALPHA(1))
00105  60*  1/ALPHA(1)
00106  61*  SIG41K = SQR((SIG41*(1.0+ALPHA(1)))/(SIG41*(1.0+ALPHA(1))))
00107  62*  SIG41 = SIG41*(1.0+ALPHA(1))
00108  63*  SIG41K = SIG41K/(2.0)
00109  64*  SIG41 = SIG41K*(SIG41+SIG41K)
00110  65*  SIG41 = SIG41K*(SIG41+SIG41K)
00111  66*  SIG41 = SIG41K*(SIG41+SIG41K)
00112  67*  SIG41 = SIG41K*(SIG41+SIG41K)
00113  68*  SIG41 = SIG41K*(SIG41+SIG41K)
00114  69*  CONTINUE
00115  70*  RETURN

END OF COMPILED NO DIAGNOSTICS
```
NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2  M E CRAVER CO

DATE 03/14/73  PAGE 64

00103  3*  INDEX, N, NK, NPFS, NWS, X (100), Y (100), Z (21), DMR (100), DELX (20),
         VRT005300
00103  4*  ZGELY (26), QGELY (26), UARLY (21), SIGAK (21), SIGEK (21), SIG0 (20), SIG0 (20), SIG0 (20),
         VRT005400
00103  5*  SIGUZ (20), ALFALPHA (30), PETA (30), 2FF, T rot, T rot, T rot, T rot, T rot, T rot, T rot, T rot,
         VRT005500
00103  6*  4XY, X6, X8, XLX, XLX, Z1 (20), Z1 (20), Z1 (20), Z1 (20), Z1 (20), Z1 (20), Z1 (20), Z1 (20), Z1 (20),
         VRT005600
00103  7*  TFASH (100), OI (10), C1 (1), C1 (1), C1 (1), C1 (1), C1 (1), C1 (1), C1 (1), C1 (1),
         VRT005700
00103  8*  ENTHC (20), ACCU, VRT20, RAC, FNCU (20), ALCM (10), LTEL (10), TAUJ (10),
         VRT005800
00103  9*  ZREL, UNREL (0), SIGEL (0), SIGEL (0), THETA (0), T (0), DELPHI
         VRT005900
00104  10*  VXVX, FNX, FNX, FXM, AXM, AXM, AXM, AXM, AXM, AXM, AXM, AXM, AXM
         VRT006000
00104  11*  INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100)
         VRT006100
00104  12*  INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100)
         VRT006200
00104  13*  INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100)
         VRT006300
00104  14*  INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100)
         VRT006400
00104  15*  INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100)
         VRT006500
00105  16*  INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100)
         VRT006600
00106  17*  INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100), INUX (100)
         VRT006700
00106  18*  C  ***** THIS ROUTINE CALCULATES VERTICAL AND VERTICAL REFLECTIONS
         VRT006800
00107  19*  STO2 = 0, 0
         VRT019000
00107  20*  N = IZ (100) (K)
         VRT019100
00107  21*  GO TO (56, 20, 5, 5)
         VRT019200
00112  22*  5 TQP1 = -0.5/2 SIGZ SIGZ
         VRT022000
00112  23*  STO2 = EXP (THQP1 * (H (KK) - ZZL (KK)) +2) + EXP (THQP1 * (H (KK) - Z (KK)) + ZZL (K))
         VRT022100
00113  24*  1 (K) +2
         VRT022200
00113  25*  10 STO3 = 0, 0
         VRT022300
00115  26*  20 TI = 0, 0
         VRT022400
00116  27*  30 TI = TI + 1, 0
         VRT022500
00117  28*  IF (SIGZ) > 35, 35, 40
         VRT022600
00122  29*  35 STO3 = 0, 0
         VRT022700
00123  30*  60 GO TO 60
         VRT022800
00124  31*  40 CONTINUE
         VRT022900
00125  32*  TR = 2.0 + TI * (Z (KK) - Z (KK))
         VRT032000
00126  33*  TLIM = ((11R (HK) + (Z2 - Z (KK)) - ZZL (KK)) +2) * TQP1
         VRT032100
00127  34*  IF (TR > 1.0) GT TLIM GO TO 60
         VRT032200
00131  35*  1 STO3 = STO3 + EXP (THQP1 * (TR + H (KK) + ZZL (KK)) +2) * TQP1
         VRT036000
00131  36*  1 TQP1 = TQP1 + 2 * TQP1
         VRT036100
00131  37*  2 * EXP (TR + H (KK) + ZZL (KK)) +2) * TQP1
         VRT036200
00132  38*  80 GO TO 30
         VRT036300
00133  39*  50 STO3 = 0, 0
         VRT036400
00134  40*  60 GO TO (70, 40, 0) + NN
         VRT040000
00135  41*  70 VREF = STO3
         VRT041000
00136  42*  VREF = STO3
         VRT042000
00137  43*  60 RETURN
         VRT043000
00140  44*  END

END OF COMPILATION:  NO DIAGNOSTICS.
NASAMSFC MULTILAYER DIFFUSION MODEL, VERSION 2  M E CRAMER CO

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00103  4*  2DELY(20)+Q(20)+UPARK(21)+SIGAK(21)+SIGEK(21)+SIGXO(20)+SIGYO(20)+ ACH50400
00106  5*  3SIGZ(27)+ALPHA(30)+ETA(30)+ZPK.+ImV+THE+TAUK+TAUK+TAUK+H(20)+ ACH50500
00108  6*  40XY.XF_;XLRY.XLPZ.27L(100)+1200(20)+CECAT+ZL1+TIM1+TIM1+ ACH50600
00102  7*  5IFLAG(10)+D(11)+C(11)+T(11)+JCT(10)+TOP(10)+VS(20).  ACH50700
00108  8*  6FIENC(20)+ACIL+VPA(20)+PFRCU(20)+HIV+ALPHAIL+TECL(10)+FLN+TAUL+ ACH50800
00106  9*  7RLI.RALI.LG(20)+SIGOL(20)+SOGOL(20)+THECL(10)+T(20)+DELPNH  ACH50900
00110  10*  COMPLI.RPA3%4+RBAK(35)+SIGAP(35)+CECLP(35)+SGLP(35)+THEA(35)+ ACH01000
00111  11*  10L(10)+C(10)+VEN+VREP+PEAK+SIG7+SIG6+SIGX+SUR2P+L+TH+I+KK+ ACH01100
00114  14*  2ST01+ST02+ST03+ST04+ST05+TRD+ILX+PAV+PLA+ITOP+XST(2)+SGLXK+ITAL(100)+ ACH01200
00117  13*  3S unfavorable.QUAL+TRR+PL1(15)+LH2(1)+II+SEP+YAP+YAP(100)+XGAMY+ANG(100)+ ACH01300
00129  14*  4USBAK(10)+L Пре(100)+ALPAK(100)+SIGARK(100)+SIGAK(100)+LAT+ ACH01400
00132  15*  5SIGYK+SIGL(1)+SIGAK(1)+ ACH01500
00132  16*  INTK-1G+TESTKO  ACH01600
00132  17*  REAL FUG+L+LAT+LAP3OA  ACH01700
00136  18*  C  **** THIS SUBROUTINE CACULATES L  ACH01800
00136  19*  C AND LATERAL TERM  ACH01900
00107  20*  20 RETURN  ACH02000
00108  21*  ENTRY EL(X,K)  ACH02100
00109  22*  IF (X.GT. 2) GO TO 24  ACH02200
00110  23*  IF (X.LT. 0) GO TO 23  ACH02300
00116  24*  L 0.2*AX(SDELU(KK))/BAR(KK)+X  ACH02400
00117  25*  IF (DELU(KK).LT.0.0) L 0.0  ACH02500
00121  26*  GO TO 30  ACH02600
00122  27*  L 0.2*AX(SDELU(JF))/BAR(JF)+X  ACH02700
00125  28*  IF (DELU(JF).LT.0.0) L 0.0  ACH02900
00125  29*  GO TO 25  ACH02500
00127  30*  L 0.2*AX(SDELU(M))/BAR(M)+X  ACH03000
00127  31*  IF (DELU(M).LT.0.0) L 0.0  ACH03100
00127  32*  CONTINUE  ACH03200
00131  33*  RETURN  ACH03300
00132  34*  ENTRY LATER(Y)  ACH03400
00135  35*  LAT Z EXP(-0.5*(Y/SIGY)**2)  ACH03500
00136  36*  40 RETURN  ACH03600
00137  37*  END  ACH03600

END OF COMPILATION:  NO DIAGNOSTICS.
NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2 H E CRAGER CO

SUBROUTINE WASMT ENTRY POINT 000310

STORAGE USED: COVE(1) 00003511 DATA(0) 00000501 BLANK COMM:(12) 000000

COMMON BLOCKS:
0003 PARAMT 002173
0004 PARAMS 002560

EXTERNAL REFERENCES (BLOCK NAME)
0005 COORD
0006 MWHU
0007 MIDU
0010 EXP
0011 TIME

STORAGE ASSIGNMENT (BLOCK TYPE RELATIVE LOCATION NAME)
0001 COVE061 10L COVE 000075 15L COVE 000011 20L COVE 000013 35L COVE 000027 5L COVE 000037 9L COVE 000077 ALPHAL COVE 000056 ALPHAM COVE 00001777 ALPHANL COVE 0000021 60L COVE 00001725 ACCUR COVE 0000056 ALPHAL COVE 00001622 B COVE 00001114 DETA COVE 0000064 CON COVE 0000074 DELTMAP COVE 00001456 DEPN COVE 00001203 H COVE 0000065 U COVE 0000052 ITAG COVE 0000046 JF

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SIGYNK = ANG(4)
A = UBAR(JF)
B = SIGYNK
C = 1.0
D = 1.K
E = 1.0
IF (ISKIP(7), EQ, 1) GO TO 15
G = TIMEST(1K-1)
GO TO 15
920 FORMAT (HE, 29H, *** KASHOUT DEPOSITION AT X=, F10.3, 4H, Y=, F10.3, 26H)
1H MAY BE OVER ESTIMATED ***)
END
NASA/MSFC MULTILAYER DIFFUSION MODEL: VERSION 2  

END OF COMPILATION: NO DIAGNOSTICS.
NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2  H E CRAVER CO

SUBROUTINE PEAK ENTRY POINT 000054

STORAGE USED: CGUE1(1) 0000611 DATA(1) 0000111 BLANK COMMON(2) 0000000

COMMON BLOCKS:

0003 PARMT 02173
0004 PARAMS 025510

EXTERNAL REFERENCES (BLOCK, NAME)

0005 MRH2S
0006 MRH3S

STORAGE ASSIGNMENT (BLOCK, TYPE, LOCATION, NAME)

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SUBROUTINE PEAK(N+K) PEK00100

00103 1* COMMON /PARMT/ TEST1(12),DATE(2),ISKIP(10),XYS,XZ,NDX,NDJ,NCI PEK00200
00103 2* INDXH,HIK,HPTS,HI5,HI7,HI8,HI9,HI10,HI11,HI12 PEK00300
00103 3* ZELEY(50),ZERO(50),UARX(50),X1(X1),X2(X2),X3(X3),X4(X4),X5(X5) PEK00400
00103 4*
END OF COMPILATION: NO DIAGNOSTICS.
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APPENDIX D
NASA/MSFC MULTILAYER COMPUTER PROGRAM EXAMPLE OUTPUT

The three example output listings given in this appendix show only a small part of the program capabilities, but give the basic form of all program output. Certain pages in the output listings have been omitted due to volume, but important material is retained.

D.1 EXAMPLE 1 OUTPUT LISTING

Example 1 gives the output from a problem where maximum centerline concentration and centerline dosage are calculated using a sea-breeze meteorological regime under normal launch conditions. The listing was produced by logic section 1 of the computer program using Model 4. A full explanation of this case is given in Section 6.2.1 of the main body of the report. Also, an example coding sheet of inputs for this case is given in Figure B-3 of Appendix B.

The case title is printed at the top of the listing followed by a complete list of all program inputs for detailed input verification. The program then produces a summary of the layer parameters including those applicable to the new layer structure used in Model 4. Accompanying the input summary are specific layer parameters used in the calculations. The main dosage and concentration listing is then printed, giving the locations and values at each calculation point within the layer. Logic section 1 is normally used for general grid pattern calculations, but in this case, the special option NYS=1 was selected which automatically places all calculations on the alongwind cloud axis.
<table>
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<th>DELX</th>
<th>CELY</th>
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**Note:** The table represents data from the NASA/MSFC Multilayer Diffusion Model, Version 2.
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<th>Variable</th>
<th>Value</th>
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</thead>
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<td>UB-RK</td>
<td>0.0000030E+00</td>
</tr>
<tr>
<td>SIUAK</td>
<td>0.0000030E+00</td>
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<td>SIUKA</td>
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<tr>
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<td>SI540</td>
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<tr>
<td>SI410</td>
<td>0.0000030E+00</td>
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</tbody>
</table>

**Note:** The given values are in scientific notation and seem to represent numerical data or parameters. Without more context, it's difficult to provide a more detailed interpretation.
**SA/MSC MULTI-LAYER DIFFUSION MODEL, VERSION 2**

**Inputs:**
- Layer 1:
  - **U** = 6.000
  - **W** = 8.000
- Layer 2:
  - **U** = 6.000
  - **W** = 8.000

**Calculated Input Parameters:**
- **U** = 6.1507
- **W** = 8.0000
- **DEL** = 0.0000
- **THET** = 45.0000

**Outputs:**
- **U** = 6.1507
- **W** = 8.0000
- **DEL** = 0.0000
- **THET** = 45.0000
**CALCULATION HEIGHT Z = 2.000** CLOUD AXIS IS AT 345,000 DEGREES AZIMUTH BEARING RELATIVE TO ORIGIN

---

**Y = 345.00**

- **DOSEAGE:** 0.7187786 + 2.0
  - **CONCENTRATION:** 0.120674 + 1.2
  - **TIME AVERAGE CONCENTRATION:** 0.1196803 + 0.0
  - **TIME OF PASSAGE:** 0.969233 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.740395 + 0.0

---

**Y = 395.00**

- **DOSEAGE:** 0.6232912 + 2.0
  - **CONCENTRATION:** 0.055182 + 1.0
  - **TIME AVERAGE CONCENTRATION:** 1.043073 + 0.0
  - **TIME OF PASSAGE:** 0.9712607 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.0450294 + 0.0

---

**Y = 445.00**

- **DOSEAGE:** 0.5670146 + 1.2
  - **CONCENTRATION:** 0.7703543 + 1.1
  - **TIME AVERAGE CONCENTRATION:** 0.945017 + 0.0
  - **TIME OF PASSAGE:** 0.9722702 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.5831765 + 0.0

---

**Y = 505.00**

- **DOSEAGE:** 0.528467 + 1.2
  - **CONCENTRATION:** 0.6568379 + 1.0
  - **TIME AVERAGE CONCENTRATION:** 0.8797451 + 0.0
  - **TIME OF PASSAGE:** 0.9735417 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.8482783 + 0.0

---

**Y = 555.00**

- **DOSEAGE:** 0.5287190 + 1.2
  - **CONCENTRATION:** 0.5587247 + 1.1
  - **TIME AVERAGE CONCENTRATION:** 0.8369465 + 0.0
  - **TIME OF PASSAGE:** 0.975928 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.916518 + 0.0

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**Y = 605.00**

- **DOSEAGE:** 0.4843239 + 1.2
  - **CONCENTRATION:** 0.7376662 + 1.1
  - **TIME AVERAGE CONCENTRATION:** 0.8106204 + 0.0
  - **TIME OF PASSAGE:** 0.9772083 + 1.2
  - **AVERAGE CLOUD CONCENTRATION:** 0.970823 + 0.0

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**Y = 655.00**

- **DOSEAGE:** 0.4375406 + 1.2
  - **CONCENTRATION:** 0.7202095 + 1.1
  - **TIME AVERAGE CONCENTRATION:** 0.9598663 + 0.0
  - **TIME OF PASSAGE:** 0.9796728 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.8906017 + 0.0

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**Y = 705.00**

- **DOSEAGE:** 0.4295890 + 1.2
  - **CONCENTRATION:** 0.5974981 + 1.1
  - **TIME AVERAGE CONCENTRATION:** 0.6325160 + 0.0
  - **TIME OF PASSAGE:** 0.980633 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.9217021 + 0.0

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**Y = 755.00**

- **DOSEAGE:** 0.4247463 + 1.2
  - **CONCENTRATION:** 0.549013 + 1.1
  - **TIME AVERAGE CONCENTRATION:** 0.9062442 + 0.0
  - **TIME OF PASSAGE:** 0.9927399 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.548494 + 0.0

---

**Y = 805.00**

- **DOSEAGE:** 0.4254261 + 1.2
  - **CONCENTRATION:** 0.525871 + 1.1
  - **TIME AVERAGE CONCENTRATION:** 0.1609276 + 0.0
  - **TIME OF PASSAGE:** 1.0062973 + 3.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.4316279 + 0.0

---

**Y = 855.00**

- **DOSEAGE:** 0.608909 + 2.0
  - **CONCENTRATION:** 0.2911451 + 0.0
  - **TIME AVERAGE CONCENTRATION:** 0.119131 + 0.0
  - **TIME OF PASSAGE:** 1.1026991 + 3.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.7278206 + 0.0

---

**Y = 905.00**

- **DOSEAGE:** 0.6021835 + 2.0
  - **CONCENTRATION:** 0.2510995 + 0.0
  - **TIME AVERAGE CONCENTRATION:** 0.1303951 + 0.0
  - **TIME OF PASSAGE:** 1.2513113 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.7459503 + 0.0

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**Y = 955.00**

- **DOSEAGE:** 0.6025633 + 2.0
  - **CONCENTRATION:** 0.2577948 + 0.0
  - **TIME AVERAGE CONCENTRATION:** 0.8783129 + 0.0
  - **TIME OF PASSAGE:** 1.3070943 + 2.0
  - **AVERAGE CLOUD CONCENTRATION:** 0.1693495 + 0.0

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**Y = 1005.00**

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  - **CONCENTRATION:** 0.2510995 + 0.0
  - **TIME AVERAGE CONCENTRATION:** 0.1303951 + 0.0
  - **TIME OF PASSAGE:** 1.2513113 + 2.0
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**INPUT DATA 2**

```
2 = 0.0430004663 USER AT BOTTOM = 1.0722, USER AT TOP = 9.6629, SIGMA AT BOTTOM = 5.4155, SIGMA AT TOP = 5.05000
SLICK AT BOTTOM = 5.1040, SIGMA AT TOP = 4.7002, SIGMA = 48.8593, STORM = 44.6500, STORM = 24.0700, THETA AT BOTTOM = 150.0000
SLICK AT TOP = 150.0000, 2 = 1.000000, ALPHAS = 1.00, DELTA = 1.00, DEL = 0.000000, DEL = 0.000000
```

**INPUT DATA 3**

```
2 = 0.0180005636 USER AT BOTTOM = 0.6722, USER AT TOP = 9.6629, SIGMA AT BOTTOM = 5.05000, SIGMA AT TOP = 4.05000
SLICK AT BOTTOM = 4.7925, SIGMA AT TOP = 4.05000, SIGMA = 70.4725, STORM = 74.4200, STORM = 28.0700, THETA AT BOTTOM = 150.0000
SLICK AT TOP = 150.0000, 2 = 2.000000, ALPHAS = 1.00, DELTA = 1.00, DEL = 0.000000, DEL = 0.000000
```

**CALCULATED INPUT PARAMETERS FOR MODELS 1, 2, 3**

```
SIGMA = 0.000000, SIGMA = 0.000000
```

**OUTPUT DATA 2**

```
```

**OUTPUT DATA 3**

```
```

**CALCULATED INPUT PARAMETERS FOR MODELS 1, 2, 3**

```
SIGMA = 0.000000, SIGMA = 0.000000
```

**OUTPUT DATA**

```
```
**LAYER 4**
**INPUT DATA**

\[<\text{equation}>\]

CALCULATED INPUT PARAMETERS FOR MODULES 1, 2, 3: **UBAR = 10.05°C, \theta = 152.50°C, DELTHP = 1,00000, DELU = 0.30000**

**LAYER 5**
**INPUT DATA**

\[<\text{equation}>\]

CALCULATED INPUT PARAMETERS FOR MODULES 1, 2, 3: **UBAR = 15.30°C, \theta = 155.60°C, DELTHP = 4.00000, DELU = 0.20000**

**LAYER 6**
**INPUT DATA**

\[<\text{equation}>\]

CALCULATED INPUT PARAMETERS FOR MODULES 1, 2, 3: **UBAR = 15.50°C, \theta = 165.50°C, DELTHP = 3.00000, DELU = 0.20000**

**LAYER 7**
**INPUT DATA**

\[<\text{equation}>\]

CALCULATED INPUT PARAMETERS FOR MODULES 1, 2, 3: **UBAR = 10.80°C, \theta = 165.80°C, DELTHP = 10.00000, DELU = 0.20000**

**LAYER 8**
**I:PUU DATA**

\[
\text{OF: } 0.13900000+06, \quad \text{USAR AT BOTTOM: 16.0000,} \quad \text{USAR AT TOP: 10.0000,} \quad \text{SIGAK AT BOTTOM: 4.450000,} \quad \text{SIGAK AT TOP: 4.390000,} \\
\text{SIGAK AT BOTTOM: 4.132000,} \quad \text{SIGAK AT TOP: 4.170000,} \quad \text{SIGAK 223.2600,} \quad \text{SIGAK 25.0000,} \quad \text{THETAK AT BOTTOM: 170.0000,} \quad \text{THETAK AT TOP: 100.0000,} \\
\text{DELTA: } 1.0000, \quad \text{DELTA} = 1.0000, \quad \text{DELTA} = 0.00000000, \quad \text{DELTA} = 0.00000000 \\
\text{DELTA} = 1.0000 \\
\]

CALCULATE INPUT PARAMETERS FOR MODELS 1,2,3: \text{USAR = 12.45°C,} \quad \text{THETA = 170.0000,} \quad \text{DELTAP = 10.00000,} \quad \text{DELU = +10000} \\
\text{SIGAK = 0.67318,} \quad \text{SIGEP = 0.67332}


**LAYER 9**

**I:PUU DATA**

\[
\text{OF: } 0.96100000+07, \quad \text{USAR AT BOTTOM: 15.9000,} \quad \text{USAR AT TOP: 10.0000,} \quad \text{SIGAK AT BOTTOM: 4.390000,} \quad \text{SIGAK AT TOP: 2.000000,} \\
\text{SIGAK AT BOTTOM: 4.170000,} \quad \text{SIGAK AT TOP: 1.000000,} \quad \text{SIGAK 223.7700,} \quad \text{SIGAK 144.3400,} \quad \text{THETAK AT BOTTOM: 180.0000,} \quad \text{THETAK AT TOP: 250.0900,} \\
\text{DELTA: } 1.0000, \quad \text{DELTA} = 1.0000, \quad \text{DELTA} = 0.0000, \quad \text{DELTA} = 0.00000000 \\
\text{DELTA} = 1.0000 \\
\]

CALCULATE INPUT PARAMETERS FOR MODELS 1,2,3: \text{USAR = 12.45°C,} \quad \text{THETA = 264.0000,} \quad \text{DELTAP = 40.60000,} \quad \text{DELU = -90000} \\
\text{SIGAK = 0.65399,} \quad \text{SIGEP = 0.65927}

**CALCULATION HEIGHT Z = 900.000, CLOUD AXIS IS AT 240.000 DEGREES AZIMUTH DURING RELATIVE TO ORIGIN**

\[
\text{**X: } 400.00 \\
\text{**Y: } 24.00, \quad \text{DOSAGES: } 0.14900000+04, \quad \text{CONCENTRATION: } 1.36720000+04, \quad \text{TIME AVERAGE CONCENTRATION: } 0.26994000+01 \\
\text{TIME OF PASSAGE: } 7.52000000+02, \quad \text{AVERAGE CLOUD CONCENTRATION: } 0.11137200+01 \\
\]

\[
\text{**X: } 600.00 \\
\text{**Y: } 24.00, \quad \text{DOSAGES: } 1.15720000+04, \quad \text{CONCENTRATION: } 1.34951000+04, \quad \text{TIME AVERAGE CONCENTRATION: } 0.25029500+01 \\
\text{TIME OF PASSAGE: } 7.52000000+02, \quad \text{AVERAGE CLOUD CONCENTRATION: } 0.19986400+01 \\
\]

\[
\text{**X: } 700.00 \\
\text{**Y: } 24.00, \quad \text{DOSAGES: } 0.13820000+04, \quad \text{CONCENTRATION: } 1.21825000+04, \quad \text{TIME AVERAGE CONCENTRATION: } 0.25830200+01 \\
\text{TIME OF PASSAGE: } 7.52000000+02, \quad \text{AVERAGE CLOUD CONCENTRATION: } 0.18886400+01 \\
\]

\[
\text{**X: } 800.00 \\
\text{**Y: } 24.00, \quad \text{DOSAGES: } 1.14000000+04, \quad \text{CONCENTRATION: } 1.25665000+04, \quad \text{TIME AVERAGE CONCENTRATION: } 0.22334200+01 \\
\text{TIME OF PASSAGE: } 7.52000000+02, \quad \text{AVERAGE CLOUD CONCENTRATION: } 0.17017600+01 \\
\]

\[
\text{**X: } 900.00 \\
\text{**Y: } 24.00, \quad \text{DOSAGES: } 1.16718000+04, \quad \text{CONCENTRATION: } 1.28933100+04, \quad \text{TIME AVERAGE CONCENTRATION: } 0.21118000+01 \\
\text{TIME OF PASSAGE: } 7.52000000+02, \quad \text{AVERAGE CLOUD CONCENTRATION: } 0.16093500+01 \\
\]

\[
\text{**X: } 1000.00 \\
\text{**Y: } 24.00, \quad \text{DOSAGES: } 1.11001000+04, \quad \text{CONCENTRATION: } 1.27376100+04, \quad \text{TIME AVERAGE CONCENTRATION: } 0.19996700+01 \\
\text{TIME OF PASSAGE: } 7.52000000+02, \quad \text{AVERAGE CLOUD CONCENTRATION: } 0.15053900+02 \\
\]

\[
\text{**X: } 1200.00 \\
\text{**Y: } 24.00, \quad \text{DOSAGES: } 1.10346000+04, \quad \text{CONCENTRATION: } 1.24531000+04, \quad \text{TIME AVERAGE CONCENTRATION: } 0.17559400+01 \\
\text{TIME OF PASSAGE: } 7.52000000+02, \quad \text{AVERAGE CLOUD CONCENTRATION: } 0.14089300+02 \\
\text{**X: } 1500.00 \\
\]
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<tr>
<th>Time</th>
<th>Voltage</th>
<th>Concentration</th>
<th>Time Average Concentration</th>
<th>Date</th>
<th>Page</th>
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<td>03/17/73</td>
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**Note:** The numbers represent the time of passage and voltage levels with corresponding time average concentrations.
<table>
<thead>
<tr>
<th>Time of Passage</th>
<th>Passage 1 (1500-00)</th>
<th>Passage 2 (2600-00)</th>
<th>Passage 3 (0400-00)</th>
<th>Passage 4 (1100-00)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Passage</td>
<td>Passage 1 (1500-00)</td>
<td>Passage 2 (2600-00)</td>
<td>Passage 3 (0400-00)</td>
<td>Passage 4 (1100-00)</td>
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<tr>
<td>Time of Passage</td>
<td>Passage 1 (1500-00)</td>
<td>Passage 2 (2600-00)</td>
<td>Passage 3 (0400-00)</td>
<td>Passage 4 (1100-00)</td>
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<tr>
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<td>Passage 1 (1500-00)</td>
<td>Passage 2 (2600-00)</td>
<td>Passage 3 (0400-00)</td>
<td>Passage 4 (1100-00)</td>
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<td>Passage 4 (1100-00)</td>
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</tbody>
</table>

**SA/SFE MULTILAYER DIFFUSION MODEL, VERSION 2**

**PAGE 350**

**DATE 03/12/93**

**Page 14**
D. 2 EXAMPLE 2 OUTPUT LISTING

Example 2 gives the output listing for the calculation of maximum center-line concentration and centerline dosage using Model 3 for the sea-breeze meteorological regime. Logic Section 2 of the computer program is used in this example. An example problem input coding sheet is shown in Appendix B, Figure B-4. The first part of the output listing has the same form as Example 1 with the exception that summaries of the parameters for all layers are produced before the dosage and concentration tables. This case is explained in full in Section 6 in the main body of the report.
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<th>NC1</th>
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<td>0.00E+03</td>
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DATE 03/14/73
DATE=March 11 73
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D-19
NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2. H. E. CRAMER CO.

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**** LAYER 1 ****

** INPUT DATA **

Q = 41000.000°C, ZR=2.000, UBAR AT BOTTOM = 6.923%, UBAR AT TOP = 5.923%, SICAK AT BOTTOM = 8.00000,
SICAK AT TOP = 7.30000, SIGEK AT BOTTOM = 0.00000, SIGEK AT TOP = 0.00000, TIM = 151.000°C, TAUH = 600.000,
SIGX = 5.000000, SIGY = 1.000000, SIGZ = 11.000°C, THETAK AT BOTTOM = 1.10000°C, THETAK AT TOP = 0.00000°C, Z = 2.000
ALPHA = 1.00, ETA = 1.00, H = 550.000, DELX = 0.00000°C, DELY = 0.00000°C, DELZ = 0.00000°C, DELPHI = 180.000°C, I2MAD = 3.000000, TIM = 1.000000
Z = 100.000, LAM = 0.00000, TIM = 100.000, XHR = 100.000, XLR = 100.000, DELU = 4.000000

CALCULATED INPUT PARAMETERS FOR MODELS 1, 2, 3 ***** UBAR = 5.923%, THETA = 151.000°C, DELPHI = 30.000000, DELU = 4.000000,
SIGAP = 0.00001, SIGEP = 0.000000

---
**NASA/MSC MULTILAYER MODEL**

- Calculations for Layer 1: at Height 2,000 with Cloud Axis at 345,000 Degrees Relative to Source.

### Radial Distance (500,000) Dosage

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<th>DOSAGE</th>
<th>CONCENTRATION</th>
<th>ALONGWIND CONCENTRATION</th>
<th>TIME OF PASSAGE</th>
<th>AVERAGE</th>
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<td>.99665119 +01</td>
<td>.10426765 +01</td>
<td>.10767864 +03</td>
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**D-22**

### Calculations for Layer 1: at Height 550,000 with Cloud Axis at 345,000 Degrees Relative to Source.

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<th>AVERAGE</th>
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**Average**: 1.1594064 +02
Example 3 is an output listing of dosage and concentration, for the sea-breeze meteorological regime, over a 180-degree sector about the alongwind cloud axis. Values in this listing at YY = 345 degrees are the same as those listed in Example 1.
**NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2**  
H. E. CRAMER CO

---

**INPUT DATA**

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<thead>
<tr>
<th>Parameter</th>
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<tr>
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<tr>
<td>( \theta L )</td>
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**LAYER 1**

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**INPUT DATA**

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<tr>
<td>( \theta L )</td>
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</tr>
</tbody>
</table>

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**CALCULATED INPUT PARAMETERS FOR MODELS 1,2,3**

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**CALCULATED INPUT PARAMETERS FOR LAYER CHANGE MODELS**

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**DATE 03/473**  
**PAGE 77**
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**Conclusion:**

The data presented above shows the dosage and concentration patterns for the NASA/MSC MULTILAYER DIFFUSION MODEL, Version 2, HE CRAMER CO. The calculations were performed at a calculation height of 2.90°, with the cloud axis at 345,000 degrees azimuth bearing relative to the origin.
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**NASOMFSC MULTILAYER DIFFUSION MODEL, VERSION 2 H E CRABER CO**

**DATE 031473**

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*** LAYER 2 ***

** INPUT DATA **

\[
G = \frac{1}{3} \theta \delta \eta \nu \sigma \alpha \beta \gamma \delta \theta \\
\text{SIG} = 0.0659, \text{SIG-P} = 0.0657
\]

*** LAYER 3 ***

** INPUT DATA **

\[
G = \frac{1}{3} \theta \delta \eta \nu \sigma \alpha \beta \gamma \delta \theta \\
\text{SIG} = 0.08196, \text{SIG-P} = 0.08194
\]
NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2  H E CRANE  CO

****** LAYER 4 ******

** INPUT DATA **

\[ q = 0.2790000 \times 10^{-2}, \text{ USBAR AT BOTTOM= } 9.90000, \text{ USBAR AT TOP= } 10.29^\circ C, \text{ SIGAK AT BOTTOM= } 4.85000, \text{ SIGAK AT TOP= } 4.71000 \]
\[ \Sigma EK AT BOTTOM= 4.63000, \Sigma EK AT TOP= 4.47000, \text{ SIGOX= } 104.310^\circ C, \Sigma IY= 104.230, \Sigma IZ= 28.87000, \text{ THEKAT AT BOTTOM=152.00000 } \]
\[ 1Z=001=1 \]

CALCULATED INPUT PARAMETERS FOR MODELS 1,2,3  

** LAYER 5 ******

** INPUT DATA **

\[ q = 0.4550000 \times 10^{-2}, \text{ USBAR AT BOTTOM= } 10.2900, \text{ USBAR AT TOP= } 10.43^\circ C, \text{ SIGAK AT BOTTOM= } 4.71000, \text{ SIGAK AT TOP= } 4.61000 \]
\[ \Sigma EK AT BOTTOM= 4.47000, \Sigma EK AT TOP= 4.37000, \text{ SIGOX= } 133.900^\circ C, \Sigma IY= 133.950, \Sigma IZ= 28.67000, \text{ THEKAT AT BOTTOM=153.00000 } \]
\[ 1Z=001=1 \]

CALCULATED INPUT PARAMETERS FOR MODELS 1,2,3  

** LAYER 6 ******

** INPUT DATA **

\[ q = 0.7770000 \times 10^{-2}, \text{ USBAR AT BOTTOM= } 10.6300, \text{ USBAR AT TOP= } 10.56^\circ C, \text{ SIGAK AT BOTTOM= } 4.61000, \text{ SIGAK AT TOP= } 4.52000 \]
\[ \Sigma EK AT BOTTOM= 4.37000, \Sigma EK AT TOP= 4.29000, \text{ SIGOX= } 163.736^\circ C, \Sigma IY= 163.740, \Sigma IZ= 28.64000, \text{ THEKAT AT BOTTOM=157.00000 } \]
\[ 1Z=001=1 \]

CALCULATED INPUT PARAMETERS FOR MODELS 1,2,3  

** LAYER 7 ******

** INPUT DATA **

\[ q = 0.1120000 \times 10^{-2}, \text{ USBAR AT BOTTOM= } 10.6700, \text{ USBAR AT TOP= } 10.56^\circ C, \text{ SIGAK AT BOTTOM= } 4.52000, \text{ SIGAK AT TOP= } 4.45000 \]
\[ \Sigma EK AT BOTTOM= 4.39000, \Sigma EK AT TOP= 4.23000, \text{ SIGOX= } 193.400^\circ C, \Sigma IY= 193.490, \Sigma IZ= 28.87000, \text{ THEKAT AT BOTTOM=160.00000 } \]
\[ 1Z=001=1 \]

CALCULATED INPUT PARAMETERS FOR MODELS 1,2,3  

\[ \text{SIGAP = } 0.07426, \text{ SIGEP = } 0.07436 \]
*** LAYER 8 ***

** INPUT DATA **

\[ Q = 0.1390000 \times 0.8, \text{ UBAR at BOTTOM} = 10,000, \text{ UBAR at TOP} = 10,920, \text{ SIGMA at BOTTOM} = 4,45000, \text{ SIGMA at TOP} = 4,39000 \]
\[ SIGMA at BOTTOM = 4,13000, \text{ SIGMA at TOP} = 4,17000, \text{ SIGMA at} = 223,2600, \text{ SIGMA at} = 223,2600, \text{ SIGMA at} = 28,8700, \text{ THEKAT at BOTTOM} = 170,000 \]
\[ THEKAT at TOP = 100,000, \text{ Z} = 700,000, \text{ ALPHAt} = 10,000, \text{ BETA} = 10,000, \text{ H} = 0.000, \text{ DELX} = 0.000000, \text{ DELY} = 0.000000 \]

**CALCULATED INPUT PARAMETERS FOR MODELS 1,2,3***

\[ UBAR = 10,05000, \text{ THEK} = 175,00000, \text{ DELTHP} = 10,00000, \text{ DELU} = 10,00000 \]
\[ SIGMA = 0.073500, \text{ SIGMA} = 0.073500 \]

*** LAYER 9 ***

** INPUT DATA **

\[ Q = 0.9610000 \times 0.07, \text{ UBAR at BOTTOM} = 10,000, \text{ UBAR at TOP} = 10,00000, \text{ SIGMA at BOTTOM} = 4,390000, \text{ SIGMA at TOP} = 2,000000 \]
\[ SIGMA at BOTTOM = 4,170000, \text{ SIGMA at TOP} = 19,00000, \text{ SIGMA at} = 182,77000, \text{ SIGMA at} = 182,77000, \text{ SIGMA at} = 144,34000, \text{ THEKAT at BOTTOM} = 180,000 \]
\[ THEKAT at TOP = 230,0000, \text{ Z} = 800,0000, \text{ ALPHAt} = 1,000, \text{ BETA} = 1,000, \text{ H} = 0.000, \text{ DELX} = 0.000000, \text{ DELY} = 0.000000 \]

**CALCULATED INPUT PARAMETERS FOR MODELS 1,2,3***

\[ UBAR = 10,95000, \text{ THEK} = 204,00000, \text{ DELTHP} = 48,00000, \text{ DELU} = 9,00000 \]
\[ SIGMA = 0.059200, \text{ SIGMA} = 0.059200 \]

**CALCULATION HEIGHT Z: 800.000% CLOUD AXIS IS AT 24,000 DEGREES AZIMUTH BEARING RELATIVE TO ORIGIN**

\[ X = 500.00 \]

\[ Y = 24,000, \text{ DOSAGE} = .1594679+94, \text{ CONCENTRATION} = .3626779+24, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .2649454+01 \]
\[ Y = 255,000, \text{ DOSAGE} = .0300000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 260,000, \text{ DOSAGE} = .0200000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 265,000, \text{ DOSAGE} = .0000000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 270,000, \text{ DOSAGE} = .0000000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 275,000, \text{ DOSAGE} = .0000000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 280,000, \text{ DOSAGE} = .0000000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 285,000, \text{ DOSAGE} = .0000000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 290,000, \text{ DOSAGE} = .0000000, \text{ CONCENTRATION} = .0000000, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .0000000 \]
\[ Y = 295,000, \text{ DOSAGE} = .0483527+32, \text{ CONCENTRATION} = .1124873+41, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .8073087+01 \]
\[ Y = 300,000, \text{ DOSAGE} = .0483527+32, \text{ CONCENTRATION} = .1124873+41, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .8073087+01 \]
\[ Y = 305,000, \text{ DOSAGE} = .6008739+02, \text{ CONCENTRATION} = .1587736+01, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .1101439+00 \]
\[ Y = 310,000, \text{ DOSAGE} = .6008739+02, \text{ CONCENTRATION} = .1587736+01, \text{ TIME MEAN ALONGWIND CONCENTRATION} = .1101439+00 \]
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**X = 600.00**
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</table>
**NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2 H E CRASHER CO**

**TIME OF PASSAGE = 0.000000**  
**AVERAGE ALONGWIND CONCENTRATION = 0.000000**

<table>
<thead>
<tr>
<th>Y</th>
<th>DOSAGE</th>
<th>CONCENTRATION</th>
<th>TIME MEAN ALONGWIND CONCENTRATION</th>
</tr>
</thead>
<tbody>
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<td>0.000000000</td>
</tr>
</tbody>
</table>

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**INPUT DATA**

Q = 5400000000*6. UBAR AT BOTTOM 10.000000, UBAR AT TOP = 15.000000, SIGMA AT BOTTOM 2.000000, SIGMA AT TOP = 1.000000

SIGMA AT BOTTOM 1.900000, SIGMA AT TOP = 0.900000, SIGMA = 93.000000, SIGMA 1/2 = 144.380000, THEETAK AT BOTTOM = 228.000000

**THEETAK AT TOP** = 290.000000, Z = 1300.000000, ALPHAP = 10.000000, BETA = 1.000000, H = 1.000000, DELTA = 0.0000000000, DELTA = 0.0000000000

**ZMODE = 1**

CALCULATED INPUT PARAMETERS FOR MODELS 1, 2, 3

**SICAP = 1.000000, SICEM = 0.0207**

---

**CALCULATION HEIGHT Z = 1500.000000, CLOUD AXIS IS AT 54.000000 DEGREES AZIMUTH HEARING RELATIVE TO ORIGIN**

**X = 500.00**

<table>
<thead>
<tr>
<th>Y</th>
<th>DOSAGE</th>
<th>CONCENTRATION</th>
<th>TIME MEAN ALONGWIND CONCENTRATION</th>
</tr>
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<td><strong>Y = 59.000</strong></td>
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<td><strong>Y = 270.000</strong></td>
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**TIME OF PASSAGE**

**AVERAGE ALONGWIND CONCENTRATION**
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<th>Concentration (µg)</th>
<th>Mean ALG Concentration (µg)</th>
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**Dosage** = 0.0000000 | **Concentration** = 0.0000000 | **Mean Concentration** = 0.0000000 | **Time of Passage** = 0.0000000 | **Average Alumina Concentration** = 0.0000000
NASA/MSFC MULTILAYER DIFFUSION MODEL, VERSION 2 HE CRAMER CO

DATE 031473 PAGE 276

** TIME OF PASSAGES: .00000000, AVERAGE ALONGWIND CONCENTRATION: .00000000
** Y = 155.000, DOSAGES = .00000000, CONCENTRATION = .00000000, TIME MEAN ALONGWIND CONCENTRATION = .00000000
TIME OF PASSAGES: .00000000, AVERAGE ALONGWIND CONCENTRATION: .00000000

**** LAYER 11 ****

** INPUT DATA, **

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SIGMA AT BOTTOM = 93.00, SIGMA AT TOP = 95.00, SIGMA AT TOP = 93.00, SIGMA AT TOP = 93.00, SIGMA AT TOP = 93.00, SIGMA AT TOP = 93.00, SIGMA AT TOP = 93.00, SIGMA AT TOP = 93.00, SIGMA AT TOP = 93.00
THETA AT TOP = 250.0000, Z = 1800.0000, ALPHA = 1.50, BETA = 1.50, N = 600, DELX = .00000000, DELY = .00000000
2MOU = 1
Z AT TOP = 2200.0000

CALCULATED INPUT PARAMETERS FOR MODELS 1, 2, 3, 4, 5, UBAR = 12.4500, THETA = 245.0000, DELTHP = 10.0000, DELU = 1.1000

** SIGAP = .01655, SIGSEP = .01655

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** CALCULATION HEIGHT Z = 1800.0000, CLOUD AXIS IS AT 65.000 DEGREES AZIMUTH BEARING RELATIVE TO ORIGIN

** Y = 65.000, DOSAGES = .3310386560, CONCENTRATION = .17710314-01, TIME MEAN ALONGWIND CONCENTRATION = .55323142-03
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D-59
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APPENDIX E

METEOROLOGICAL AND SOURCE INPUTS

Meteorological and source model inputs used in the example calculations described in Section 6 are given in Tables E-1 through E-6. Tables E-1 and E-2 contain inputs respectively for the use of Model 4 and Model 3 in predicting concentration and dosage downwind from a normal launch during a sea-breeze meteorological regime at Kennedy Space Center. Model inputs for the use of Model 5 in predicting deposition due to precipitation scavenging and air concentration with depletion due to precipitation scavenging for a normal launch during a cold front passage at Kennedy Space Center are given in Table E-3. Table E-4 contains inputs for Model 6 for use in predicting deposition due to gravitational settling for a normal launch during a cold front passage at Kennedy Space Center. Finally, Tables E-5 and E-6 contain inputs respectively for the use of Model 4 and Model 3 in predicting concentration and dosage downwind from an on-pad abort during a post-cold front meteorological regime at Kennedy Space Center.

The source inputs in the tables were calculated using the procedures described in Section 6 of the report. Meteorological inputs of mean wind speed, and wind direction were obtained from the rawinsonde and NASA 150-Meter Ground Wind Tower profiles given in Section 6.

Values of the standard deviation of azimuth wind angle fluctuations at the reference height \( z_R \) \( \left( \sigma_{AR} \right) \) were obtained from measurements made with bi-directional vanes when such information was available. When no measurements of this type were available, estimates based on climatology were made by experienced diffusion meteorologists. The following general rules were used to specify the vertical profiles of \( \sigma_A \).
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1. These parameters are for layer step change and the layer number should refer to the new layer structure where new layers are formed from two or more initial layers.
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TABLE E-4

METEOROLOGICAL AND SOURCE INPUT PARAMETERS FOR MODEL 6 (GRAVITATIONAL DEPOSITION) AND FOR A NORMAL LAUNCH DURING A COLD FRONT PASSAGE AT KENNEDY SPACE CENTER
<table>
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<th>Parameter</th>
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<th>Default Value</th>
<th>Atz &lt;sub&gt;R&lt;/sub&gt; Only</th>
<th>Common to all Layers</th>
<th>Layer</th>
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<td></td>
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<td>deg</td>
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<td>( \tau_K )</td>
<td>sec</td>
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1 These parameters are for layer step change and the layer number should refer to the new layer structure where new layers are formed from two or more initial layers.
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1. These parameters are for layer step change and the layer number should refer to the new layer structure where new layers are formed from two or more initial layers.
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<th>Parameter</th>
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<th>Layer</th>
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(2) These parameters are independent of the layers and the spaces are for their respective distribution.
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<th>Layer 8</th>
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<td>$\sigma_{EBK}$</td>
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2 These parameters are independent of the layers and the spaces are for their respective distribution.
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<th>At zR Only</th>
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**TABLE E-5**

METEOROLOGICAL AND SOURCE INPUT PARAMETERS FOR MODEL 4 AND FOR AN ON-PAD ABORT DURING A POST-COLD FRONT METEOROLOGICAL REGIME AT KENNEDY SPACE CENTER
<table>
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<th>Units</th>
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<th>At ( z_R ) Only</th>
<th>Common to all Layers</th>
<th>Layer</th>
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<td>2.74 ( \times 10^7 )</td>
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<tr>
<td>( \tau_K )</td>
<td>sec</td>
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</tr>
<tr>
<td>( \tau_{0K} )</td>
<td>sec</td>
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<tr>
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<td>11</td>
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<td>Common to all Layers</td>
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</tr>
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<td>m</td>
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1 These parameters are for layer step change and the layer number should refer to the new layer structure where new layers are formed from two or more initial layers.
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1 These parameters are for layer step change and the layer number should refer to the new layer structure where new layers are formed from two or more initial layers.
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<td>Layer</td>
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<tr>
<td>( \alpha_L )</td>
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<tr>
<td>( \beta_L )</td>
<td>sec</td>
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<tr>
<td>( \tau_L )</td>
<td>sec</td>
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<tr>
<td>( \tau_{oL} )</td>
<td>sec</td>
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<tr>
<td>( z_{RL} )</td>
<td>m</td>
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<tr>
<td>( u_{BL} )</td>
<td>m sec(^{-1} )</td>
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<tr>
<td>( u_{TL} )</td>
<td>m sec(^{-1} )</td>
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<tr>
<td>( \sigma_{ABL}(\tau_{oL}) )</td>
<td>deg</td>
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<tr>
<td>( \sigma_{ATL}(\tau_{oL}) )</td>
<td>deg</td>
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<tr>
<td>( \sigma_{ABK}(\tau_{oK}) )</td>
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<tr>
<td>( \sigma_{ATK}(\tau_{oK}) )</td>
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</tbody>
</table>

1 These parameters are for layer step change and the layer number should refer to the new layer structure where new layers are formed from two or more initial layers.
In the surface mixing layer \((z < H_m)\):

1. If the wind speed is constant or decreases with height in the layer, \(\sigma_A^{\{\tau_{0K}\}}\) is held constant with height in the layer.

2. If the wind speed increases with height, \(\sigma_A^{\{\tau_{0K}\}}\) is decreased with height according to the relationship:

\[
\sigma_A^{\{\tau_{0K}, z\}} = \sigma_{AR}^{\{\tau_{0K}\}} \left(\frac{z}{z_R}\right)^{-p}
\]  \hspace{1cm} (E-1)

where

\[
p = \text{wind profile exponent}
\]

\[
\begin{align*}
p &= \frac{\varepsilon n \left[\bar{u}_{TK}/\bar{u}_R\right]}{\varepsilon n \left[z_{TK}/z_R\right]} \\
&= \frac{\varepsilon n \left[z_{TK}/z_R\right]}{\varepsilon n \left[\bar{u}_{TK}/\bar{u}_R\right]}
\end{align*}
\]  \hspace{1cm} (E-2)

\(\bar{u}_{TK}\) = mean wind speed at the top of the layer \(z_{TK}\)

\(\bar{u}_R\) = mean wind speed at the reference height \(z_R\)

In layers above the surface mixing layer \((z > H_m)\):

1. If the wind speed is constant or decreases with height in a stable layer, \(\sigma_A^{\{\tau_{0K}\}}\) is decreased linearly with height from the value at the base of the layer to a value of one degree at the top of the layer.

2. If the wind speed is constant or decreases with height in the unstable layer, \(\sigma_A^{\{\tau_{0K}\}}\) is held constant with height in the layer.
If the wind speed increases with height in an unstable or stable layer, \( A_{\text{\text{\footnotesize{\text{\^\i}}} }} \) is decreased with height according to the relationship

\[
A_{\text{\text{\footnotesize{\text{\^\i}}} }}(z) = A_{\text{\text{\footnotesize{\text{\^\i}}} }}(z) - P_K \left( \frac{z}{z_{\text{\text{\footnotesize{\text{\^\i}}} }}} \right)
\]

where

\[
P_K = \frac{\ln \left( \frac{\bar{u}_{\text{\text{\footnotesize{\text{\^\i}}} }} / \bar{u}_{\text{\text{\footnotesize{\text{\^\i}}} }} }{\bar{z}_{\text{\text{\footnotesize{\text{\^\i}}} }} / z_{\text{\text{\footnotesize{\text{\^\i}}} }}} \right)}{\xi n \left( \frac{\bar{z}_{\text{\text{\footnotesize{\text{\^\i}}} }} / z_{\text{\text{\footnotesize{\text{\^\i}}} }}}{z_{\text{\text{\footnotesize{\text{\^\i}}} }} / z_{\text{\text{\footnotesize{\text{\^\i}}} }}} \right)}
\]

\( \bar{u}_{\text{\text{\footnotesize{\text{\^\i}}} }} \) = mean wind speed at the base of the layer \( z_{\text{\text{\footnotesize{\text{\^\i}}} }} \)

It should be noted that \( \sigma_{A_{\text{\text{\footnotesize{\text{\^\i}}} }}} \) is not permitted to be less than one degree.

Values of the standard deviation of elevation wind angle fluctuations are set equal to \( \sigma_{A_{\text{\text{\footnotesize{\text{\^\i}}} }}} \); that is,

\[
\sigma_E = \sigma_{A_{\text{\text{\footnotesize{\text{\^\i}}} }}} \left( \frac{\tau_{\text{\text{\footnotesize{\text{\^\i}}} }}}{\tau_{\text{\text{\footnotesize{\text{\^\i}}} }}} \right)^{1/5}
\]

where

\[
\tau_{\text{\text{\footnotesize{\text{\^\i}}} }} = \text{reference time period over which } \sigma_{A_{\text{\text{\footnotesize{\text{\^\i}}} }}} \text{ is measured}
\]

\[
\tau_{\text{\text{\footnotesize{\text{\^\i}}} }} = \text{source function time in the layer}
\]

In the calculations, \( \tau_{\text{\text{\footnotesize{\text{\^\i}}} }} \) was set equal to the time \( t_{\text{\footnotesize{\text{\^\i}}} } \) required for the exhaust cloud to reach stabilization which is given by the expression

\[
t_{\text{\footnotesize{\text{\^\i}}} } = \pi/s^{1/2}
\]

when the instantaneous cloud rise formula given by Equation (3-3) in the report is used. The values of the diffusion parameters \( \alpha \) and \( \beta \) were set equal to unity in all cases.