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**A MODEL FOR CALCULATING ,
DISPERSION AND DEPOSITION OF SMALL PARTICLES
FROM A LOW LEVEL POINT SOURCE (U)**

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Stanley B. Mellisen

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ABSTRACT

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A mathematical model for estimating concentrations and ground deposition densities from a low level point source of particulates up to 20 μm in diameter has been developed. The model applies K theory to account for vertical dispersion and Gaussian spread to account for lateral dispersion. Results for the limiting case of zero terminal velocity with negligible retention at the ground are compared directly to field experimental data for a source near ground level to establish the validity of using Gaussian lateral dispersion from an elevated source. The vertical dispersion function and lower boundary condition for an existing line source model were applied in the present point source model. Previous comparison to ground deposition densities measured in various field experiments indicate that estimates from the line source model are reasonable, although further experiments would be useful. (Canada)

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LIST OF SYMBOLS

A	constant to account for variations in eddy diffusivity due to atmospheric stability
B	sublayer Stanton number
C(x,z)	total dosage for an instantaneous line source, $g \ s \ m^{-3}$, or steady state concentration from a continuous line source, $g \ m^{-3}$
C(x,y,z)	total dosage for an instantaneous point source $g \ s \ m^{-3}$, or steady state concentration from a continuous point source $g \ m^{-3}$
D	drop diameter, mm
E	efficiency of retention or capture by the substrate
F(x,z)	vertical flux of diffusing material, $g \ m^{-2}$ for an instantaneous source and $g \ m^{-2} \ s^{-1}$ for a continuous source
h	release height of line source, m
H	upper boundary of the turbulent boundary layer, m

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$K(z)$	coefficient of vertical eddy diffusivity at height z , $m^2 s^{-1}$
Δz	length of the same order as the roughness length of the substrate z_0 , m.
p	exponent in power law wind velocity profile
P_a	mean transport velocity between the turbulent atmosphere and the rough surface, $m s^{-1}$
P_s	apparent mean transport velocity through the horizontal plane at $z=0$ $m s^{-1}$
Q	source strength, $g m^{-1}$ for an instantaneous line source and $g m^{-1} s^{-1}$ for a continuous line source
Q_p	source strength g for an instantaneous point source and $g s^{-1}$ for a continuous point source
q	terminal velocity of particles, $m s^{-1}$
$R(z)$	vertical diffusive resistance of the atmosphere at height z , $m^{-1} s$
S	total surface area of the roughness element per unit horizontal area

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$u(z)$	mean horizontal wind speed in x direction at height z, m s^{-1}
x	horizontal down wind distance, m
y	horizontal crosswind distance, m
z	vertical height above ground, m
σ_y, σ_z	crosswind and vertical plume standard deviations, m
w	contamination density, $g\ m^{-2}$ from an instantaneous source and $g\ m^{-2}\ s^{-1}$ from a continuous line source

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INTRODUCTION

1. A mathematical model which includes the effect of atmospheric diffusion on dispersion and settling was developed at the Defence Research Establishment Suffield [1,2]. Calculation of airborne concentrations and mass deposition densities downwind of an elevated line source of non-evaporating spray or solid particles can be calculated from this model. Knowledge of aerial concentration and mass deposition density from a low level point source is also useful in applications related to chemical and biological defence. Therefore, the line source model has been extended to calculate these quantities from a point source. The purpose of this report is to describe this point source model and to provide some comparison to previously available data from field experiments of other workers.

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OUTLINE OF THE LINE SOURCE MODEL

2. The differential equation, boundary conditions and functional forms for the wind velocity profile, transport velocity to the rough surface, and particle terminal velocity were stated previously [1,2], but are provided for convenience. The details of the solutions are shown elsewhere [1,2].

Differential Equation

3. The equation used to describe turbulent diffusion of monodisperse particulate matter in the atmosphere from a uniform infinite crosswind line source is:

$$u(z) \partial C(x,z) / \partial x = \partial / \partial z \{ K(z) \partial C(x,z) / \partial z \} + q \partial C(x,z) / \partial z \quad (1)$$

where C = total dosage for an instantaneous source
= steady state concentration from a continuous source
x = horizontal downwind distance
z = vertical height above ground
K(z) = the coefficient of eddy diffusivity at z
u(z) = mean horizontal wind speed at z
q = terminal velocity of the particles

This equation and its boundary conditions have been discussed by Calder [3], who indicated the problems in stating the lower boundary condition with regard to the transport of material through this boundary of the turbulent atmosphere to the ground or substrate. Monaghan and McPherson [4] have proposed an equation for the transport of vapour to rough natural surfaces based on work by Chamberlain [5] which relates the trans-

port of vapour to the substrate in terms of windspeed at 2 m above ground, the roughness and specific area of the substrate, and an absorption velocity, characteristic of the vapour, into the roughness elements of the substrate. This equation has been modified to include the terminal velocity of particulate matter and its retention by the roughness elements. As for the case of vapour diffusion, it is assumed that the turbulent airstream is bounded by the non-turbulent atmosphere which acts as a lid to vertical diffusion.

Boundary Conditions

4. The vertical flux $F(x,z)$ of diffusing material is given by:

$$F(x,z) = -\{K(z)\partial C(x,z)/\partial z + qC\}, \quad (2)$$

where F is positive in the direction of increasing z , and therefore,

$$u(z)\partial C(x,z)/\partial x = -\partial F(x,z)/\partial z \quad (3)$$

At the upper boundary $z = H$,

$$\lim_{z \rightarrow H} F = 0 \quad (4)$$

At the lower boundary,

$$\lim_{z \rightarrow 0} \{-F(x,z)\} = ES(P_a + q/S) \lim_{z \rightarrow 0} C(x,z), \quad (5a)$$

$$= E(P_s + q) \lim_{z \rightarrow 0} C(x, z), \quad (5b)$$

where E is the efficiency of retention (or capture), S is the total surface area of the roughness elements per unit horizontal area, P_a is the mean transport velocity of material between the turbulent atmosphere and the rough surface. P_s is the apparent mean transport velocity through the horizontal plane at $z = 0$.

The upper and lower boundary conditions are given by:

$$\lim_{z \rightarrow H} \{K(z) \partial C(x, z) / \partial z + qC(x, z)\} = 0 \quad (6)$$

and

$$\lim_{z \rightarrow 0} \{K(z) \partial C(x, z) / \partial z + qC(x, z)\} = ES(P_a + q/S) \lim_{z \rightarrow 0} C(x, z) \quad (7a)$$

$$= E(P_s + q) \lim_{z \rightarrow 0} C(x, z) \quad (7b)$$

Boundary Condition for a Material Source

5. Assuming a line source, then from mass balance considerations in equation (1)

$$\lim_{x \rightarrow 0} C(x, z) = Q\delta(x-h)/u(h) \quad (8)$$

where Q is source strength (mass per unit length for an instantaneous line source), h is release height and δ is the Dirac delta function.

Functional Forms of $u(z)$, P_s , q

6. a. A number of functional forms for $u(z)$ have been proposed. In this model a power-law form is used:

$$u(z) = u(2) \left\{ (z + \Delta l) / (2 + \Delta l) \right\}^p \quad (9)$$

where z is in metres, p is a function of atmospheric stability and Δl is a length of the same order as the roughness length z_0 .

$K(z)$ is given by:

$$K(z) = A(z + \Delta l)u(2) \quad (10)$$

where A is a constant dependent upon atmospheric stability. Monaghan and McPherson [4] have published values of A , Δl and p for stable to slightly unstable conditions by fitting their vapour diffusion model to field data and Pasquill's data on vapour cloud height. P_a is related to the reciprocal of the sublayer Stanton number B by the approximate equation:

$$P_a = u_* / B^{-1} S \quad (11)$$

Since u_* is approximately a factor of 10 less than $u(2)$

$$P_a = 0.1u(2)/B^{-1}S \quad (12)$$

Chamberlain (1966) suggests values of B^{-1} between 5 and 8 for grass with S equal to approximately 2. Hence the equation:

$$P_a = 0.01 u(2) \quad (13)$$

is used for all stability categories.

- b. Thom [6] quotes values of B^{-1} for a variety of rough surfaces which range from 5 for grassland to 2 for a pine forest. Thus, if P_a is assumed to be the same for all these surfaces, S varies from 2 for grassland to 5 for the forest. Suggested values of A , Δz , p , $u(2)$ and H are given in Table I for various Pasquill atmospheric stability categories.
- c. Assuming the particulate is a liquid of approximately unit specific gravity and diameter D , Best's equation [7] for terminal velocity can be used:

$$\begin{aligned} q &= A\{1 - \exp(-BD^C)\}; \\ q &= 9.43 \{1 - \exp[-(D/1.77)^{1.147}]\} \\ &\text{for } 0.3 \leq D \leq 6.0 \\ q &\text{ is in m }^{-1} \text{ for } D \text{ in mm.} \end{aligned} \quad (14)$$

Below $D = 0.3$ mm equations for fluid drag on spheres are used.

SOLUTIONS OF EQUATIONSNumerical Methods

7. The diffusion equations are solved by finite difference methods using a Crank-Nicolson formulation to reduce the difference scheme to a tridiagonal matrix which is inverted by the Gauss elimination method using a digital computer. Errors in discretization are reduced by subdividing the atmosphere vertically into equal increments of diffusive resistance R rather than height, using the relationship

$$R(z) = \int_0^z dz/K(z) \text{ or } dR(z)/dz = 1/K(z). \quad (15)$$

8. This procedure also economizes on computer storage. The equations are solved for $C(x,z)$ and deposition of particulate in the substrate. In the latter case, equation (7) will give rate of deposition for a continuous source or deposition density (mass/unit horizontal area = ω) for an instantaneous source. As stated previously, the details are described elsewhere [1,2].

TABLE I
VALUES OF CONSTANTS

CONSTANTS

STABILITY CATEGORY	$\underline{A}$	$\frac{\Delta \ell}{m}$	$\underline{p}$	$\frac{u(2)}{m/s}$	$\frac{H}{m}$
C	0.08	0.025	0.2	2-4	1000
D	0.04	0.025	0.23	≥ 3	500
E	0.03	0.025	0.3	1.5-3	200
F	0.02	0.025	0.5	1.5-2	100

$\Delta \ell$ is given for grassland

POINT SOURCE MODELDescription and Justification of the Method

10. The extension of the line source model was accomplished by applying Gaussian lateral distribution to the solution calculated from the K theory line source model. The justification for this is that in practical applications the lateral distribution over simple terrain without major obstacles is Gaussian [8]. This applies only to gaseous clouds or particles small enough so that they follow the air movement with negligible slip. Since particle dispersion as well as gas dispersion is considered, sensitivity tests for the effect of particle size on airborne concentrations and mass deposition densities were performed by comparing results for various sizes of particles up to 20 μm diameter. In this way the assumption that particles closely follow the air flow can be verified.

11. Vertical distributions are approximately Gaussian only for some elevated sources, yet it is common practice to assume the distribution from pollutants emitted near the surface is also Gaussian [8]. The Gaussian vertical distribution assumes that the coefficient, K, is independent of height which is not generally realistic. The vertical diffusion coefficient as given by equation (10), with constants A and Δl given in Table I, is realistic for open prairie terrain without major obstacles [1,2,4].

12. The condition of conservation of mass, called the continuity condition, must be satisfied. As for the line source model, the x direction is downwind, and z vertical. The direction designated by y is horizontal and 90° to the left of the x direction. A different meaning

was used for y in the line source model, but since it does not appear explicitly in this report, it can be used in the conventional manner. The continuity conditions which assume no turning of wind with height are given as follows. For a single continuous line source at right angles to the mean wind direction the continuity condition is (steady conditions)

$$Q_p = \int_{-\infty}^{\infty} C(x,z) u(z) dz \quad (16)$$

where Q is the source strength in mass per unit length per unit time, $C(x,z)$ is the concentration.

For a single continuous point source the continuity condition is (steady conditions)

$$Q_p = \iint_{-\infty}^{\infty} C(x,y,z) u(z) dy dz \quad (17)$$

where Q_p is the source strength in units of mass per unit time and $C(x,y,z)$ is the concentration. Equations (16) and (17) must be satisfied for all distances x downwind.

13. Almost all the solutions to equations (16) and (17) are based on the same general forms [8]. Three independent dispersion functions, $G(x)$, $H(y)$ and $I(z)$ that are independent of each other, are assumed. The continuity conditions, equations (16) and (17) can be satisfied by the solutions for the following equations. For the continuous line source

$$C(x,y) = \frac{Q I(z)}{u(z)} \quad (18)$$

and for the point source

$$C(x,y,z) = \frac{Q_p H(y) I(z)}{u(z)} \quad (19)$$

where H and I also depend upon x [8].

14. Solutions (16) and (17) require that the dispersion functions act independently. This is usually the case, to a good approximation [8]. The most serious exception occurs when the wind direction changes with height. In that case H(y) varies with height and therefore also depends on z. Most observations of vapour dispersion indicate that K(z) increases with distance from the source [8]. The reason is that in the atmosphere there are eddies of all sizes. As the plume grows, larger eddies become relatively more important, so K(z) must be allowed to increase with travel time or distance. If the source is at or near the surface, the centre of gravity of the plume will rise with downwind distance. Therefore, since K(z) varies directly with height as shown in equations (10), the effective value K(z) will increase with distance, even if it is assumed to vary with height only, and the solutions of (1) for $q = 0$, which represent dispersion of a gaseous cloud, are quite realistic [8]. For particulate dispersion, the terminal velocity is greater than zero, which corresponds to $q > 0$ in equation 1. Therefore the height of the centre of gravity of the plume rises less with downwind distance. In the atmosphere, the characteristic vertical dimension of eddies is of the same order as the distance above the ground [9]. Therefore the effective value of K(z) can be expected to increase less with down wind distance for particulates with considerable terminal velocity than for gases. Again the physics is compatible with equation (10) in which K(z) is proportional to height.

15. Assuming then that I(z) is given by K theory and H(y) is a

Gaussian distribution, the line source solution outlined in paragraphs 3 to 8 with $q = 0$ in equation (10) can be applied to calculate concentrations downwind of a point source as follows. Substituting equation (18) into equation (19) gives

$$C(x,y,z) = \frac{Q_p C(x,z) H(y)}{Q} \quad (20)$$

where $H(y)$ is given by the basic form of the Gaussian lateral distribution as follows

$$H(y) = \frac{1}{\sqrt{2\pi} \sigma_y} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \quad (21)$$

The term σ_y is the standard deviation of y . Actual values of σ_y are given by the numerical expressions developed by Briggs [8,10,11] who revised the Pasquill-Gifford diagrams developed from observations over smooth terrain. These are shown in Table II. The plume width is approximately $4 \sigma_y$ as 95% of the dispersed material is located within the $2 \sigma_y$ to each side of the centre of the distribution.

TABLE II

FORMULAS FOR $\sigma_y(x)$ AND $\sigma_z(x)$ ($10^2 < x < 10^4$ m)

Pasquill Type	$\sigma_y(m)$	$\sigma_z(m)$
Open-Country Conditions		
A	$0.22x(1+0.0001x)^{-\frac{1}{2}}$	$0.20x$
B	$0.16x(1+0.0001x)^{-\frac{1}{2}}$	$0.12x$
C	$0.11x(1+0.0001x)^{-\frac{1}{2}}$	$0.08x(1+0.0002x)^{-\frac{1}{2}}$
D	$0.08x(1+0.0001x)^{-\frac{1}{2}}$	$0.06x(1+0.0015x)^{-\frac{1}{2}}$
E	$0.06x(1+0.0001x)^{-\frac{1}{2}}$	$0.03x(1+0.0003x)^{-1}$
F	$0.04x(1+0.0004x)^{-\frac{1}{2}}$	$0.016x(1+0.0003x)^{-1}$
Urban Conditions		
A-B	$0.32x(1+0.0004x)^{-\frac{1}{2}}$	$0.24x(1+0.001x)^{\frac{1}{2}}$
C	$0.22x(1+0.0004x)^{-\frac{1}{2}}$	$0.20x$
D	$0.16x(1+0.0004x)^{-\frac{1}{2}}$	$0.14x(1+0.0003x)^{-\frac{1}{2}}$
E-F	$0.11x(1+0.0004x)^{-\frac{1}{2}}$	$0.08x(1+0.00015x)^{-\frac{1}{2}}$

Gaussian lateral spread is a good approximation for gaseous clouds, but there is no evidence that it is suitable for particulate clouds with considerable terminal velocity. However, the concentrations calculated for a gaseous cloud can be shown to be close to those for particles with diameters up to 20 μm , which is a size range of interest in practical applications. This is accomplished by comparing concentrations and mass deposition densities calculated for various particle sizes with the line source model. Calculated results, provided later, will show that the differences are small enough so that practical estimates can also be made from the point source model. The mass desposition density for a particle is not necessarily the same as for a gas, but this can be accounted for independently of lateral spread by providing the appropriate retention factor, E , in the lower boundary condition given by equations (7a) and (7b). A non-reactive gas such as argon or helium is not absorbed at all by dry deposition, but once a particle encounters a surface it is considered to have been absorbed [12]. Here $E=0$ for the non-reactive gas and $E=1$ for the particle.

CALCULATED RESULTS AND COMPARISON TO EXPERIMENT

16. In this section calculated results are shown from the K theory line source model and the point source model using K theory for the vertical dispersion function and Gaussian distribution for the lateral spread. The results for both types of sources are compared, to a set of values based on carefully constructed diffusion experiments at Preston, England in the 1930's under J.G. Sutton [8,13]. Also the ground level concentration along the wind direction from a gaseous point source with no retention is compared to the results calculated using Gaussian distributions both horizontally and vertically.

17. The line source model "DIFF", was applied using a Fortran computer program [1] on the DRES Honeywell CP-6 system. The point source model "DIFFP" was applied in a similar way. The program, which was developed by modifying the one for the line source, is described in Appendix A. The ground level concentrations using only Gaussian dispersion was calculated from the following equation [8,11]

$$C(x,0,0) = \frac{Q_p}{\pi \sigma_y \sigma_z u(h)} \exp \frac{-h^2}{2\sigma_z^2} \quad (22)$$

Equation (22) is used with the dispersion functions, σ_y and σ_z , given in Table II. These dispersion functions were originally intended for use in estimating ground level concentrations from elevated stack sources [11] and have been developed over many years with industrial applications in mind.

18. The set of values, based on the Porton experiments [13], are repeated for convenience as follows:

a. Experimental Data for Adiabatic Gradient Conditions

The following data are the mean results of many trials with both smoke and gas clouds over level grass land. No difference could be detected between the rates of diffusion of gases and smokes.

- (1) The concentration at any point in a continuously generated cloud is directly proportional to the strength of the source, provided that the source itself does not materially interfere with the natural air flow (e.g. by producing intense local convection currents).

- (2) For a given strength of source the mean concentration at any point in a continuously generated cloud is approximately inversely proportional to the mean wind speed measured at a fixed height.
- (3) The time-mean width of the cloud from a continuous point source measured at ground level, is about 35 m at 100 m downwind of the source and shows only very small variations with the mean wind speed.
- (4) The time-mean height of the cloud from an infinite crosswind continuous line source is about 10 m at 100 m downwind of the source and shows only very small variations with wind speed.
- (5) The central (peak) mean concentration from a continuous point source decreases with distance downwind, x , according to the law
concentration $\propto x^{-1.76}$
- (6) The peak (i.e. ground level) mean concentration from an infinite crosswind continuous line source decreases with distance downwind, x , according to the law
concentration $\propto x^{-0.9}$
- (7) The absolute values of the peak mean concentrations at 100 m downwind are as follows:

Type of Source	Strength	Mean Wind at 2 m Height	Peak Concentration
Continuous Point	1 g sec^{-1}	5 m sec^{-1}	2 mg m^{-3}
Continuous infinite line (across wind)	$1 \text{ g sec}^{-1} \text{ m}^{-1}$	5 m sec^{-1}	35 mg m^{-3}

The above data constitutes a standard set of values to which any theory of atmospheric diffusion must conform. It is unfortunate that as yet no corresponding set has been published for non-adiabatic temperature gradients, but it should be emphasized that the general unsteadiness and erratic behaviour of the light winds which are associated with both large lapse rates and large inversions make the experimental study of atmospheric diffusion in these conditions a matter of considerable difficulty.

b. Width and Height of Clouds

The width of a cloud from a continuous point source is the distance between points on the skirts of the crosswind concentration curve at which the concentrations is a fixed fraction, normally one-tenth, of the peak value. Similarly, the height of the cloud is defined as the vertical distance from the ground to the point at which the concentration has fallen to one-tenth of the value on the ground.

19. Downwind concentrations from a line source at 1 m height calculated from the DRES K theory model and from Sutton's mean field trial data are shown in Figure 1. The wind speed at 2 m height is 5 m s^{-1} in neutral atmospheric stability. The terminal velocity, q , was set to zero in equations (1) to simulate a gaseous cloud in the mathematical model. The field trial results were obtained from the peak mean concentration at 100 m and the law for decrease of concentration with downwind distance. Similar results for a point source are shown in Figure 2. Calculated results are also shown for various point source release heights in Figure 3 from the present K theory model with Gaussian lateral spread, and in Figure 4 from Gaussian dispersion given by equation (22). Concentrations 100 m downwind of a line source at 1 m height are shown as functions of height for various retention efficiencies in Figures 5 and 6, for comparison to Sutton's cloud height data. Similar results are shown for a point source for use in practical applications in Figures 7 and 8.

20. The effect of particle size on concentration and ground deposition density from a line source is shown in Figures 9, 10 and 11. Concentrations shown start at 30 m downwind, but one should note that less reliability is expected at short distances than at distances greater than 100 m from the source. The effect of fluctuations have not yet smoothed out, and concentrations vary rapidly with distance at short distances. Figures 9, 10 and 11 compare calculated results for $20 \text{ }\mu\text{m}$ diameter particles to particles of less than $1 \text{ }\mu\text{m}$ diameter. The terminal velocity of the $20 \text{ }\mu\text{m}$ particle was calculated using equations for fluid drag on spheres [14]. The velocity which was obtained assuming unit specific gravity was 0.01216 m s^{-1} . The terminal velocity of particles less than $1 \text{ }\mu\text{m}$ diameter was assumed to be zero. The downwind concentrations are shown in Figure 9 for two atmospheric stability categories, D and F and the ground deposition densities are shown in Figure 10 for stability D and Figure 11 for stability F.

21. As mentioned previously, particles small enough so that their terminal velocity is negligible and which therefore follow the air flow will still not produce the same downwind concentrations as nonreacting gaseous clouds. The reason is that they are affected by the ground surface in different ways. Particles are assumed to have a retention efficiency, E , of 1 and nonreactive gaseous clouds have a retention efficiency of 0. The effect of various retention efficiencies on downwind concentration from a point source is shown in Figure 12. Peak downwind concentrations from a low level point source of particles which follow the air flow are shown in Figure 13 for four atmospheric stability categories. Similarly, peak ground contamination densities are shown in Figure 14.

22. Downwind concentrations from a low level point source of 5 μm and 20 μm diameter particles are shown for four atmospheric stability categories in Figures 15 and 16, respectively. Ground deposition densities for these two particle sizes are shown in Figures 17 to 20. The calculations were performed for particles of unit specific gravity using the point source K theory model with Gaussian lateral spread.

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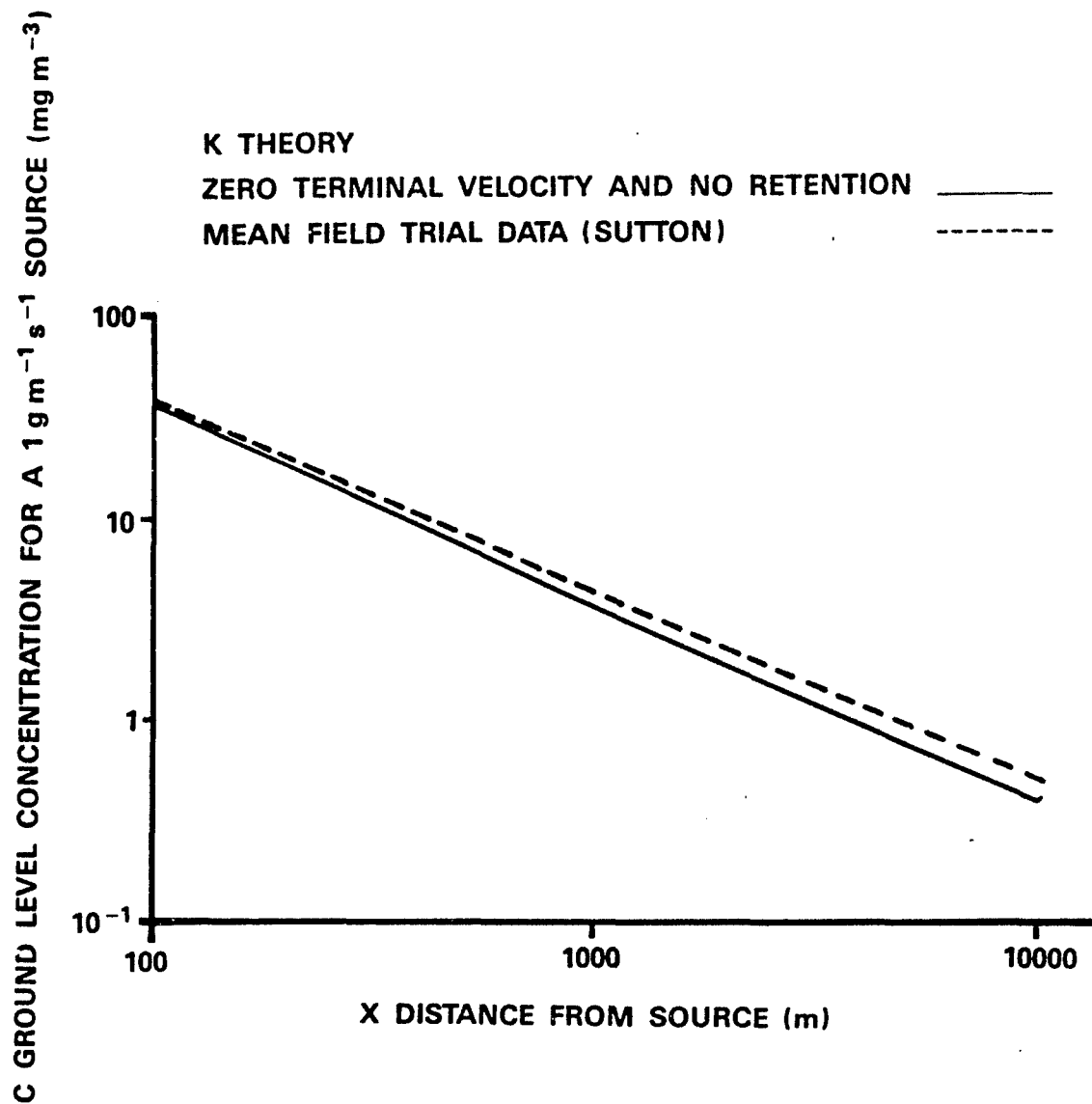


Figure 1
DOWNWIND CONCENTRATIONS FROM A LINE SOURCE AT
1 m HEIGHT IN NEUTRAL ATMOSPHERIC STABILITY WITH
2 m WIND SPEED OF 5 m s^{-1}

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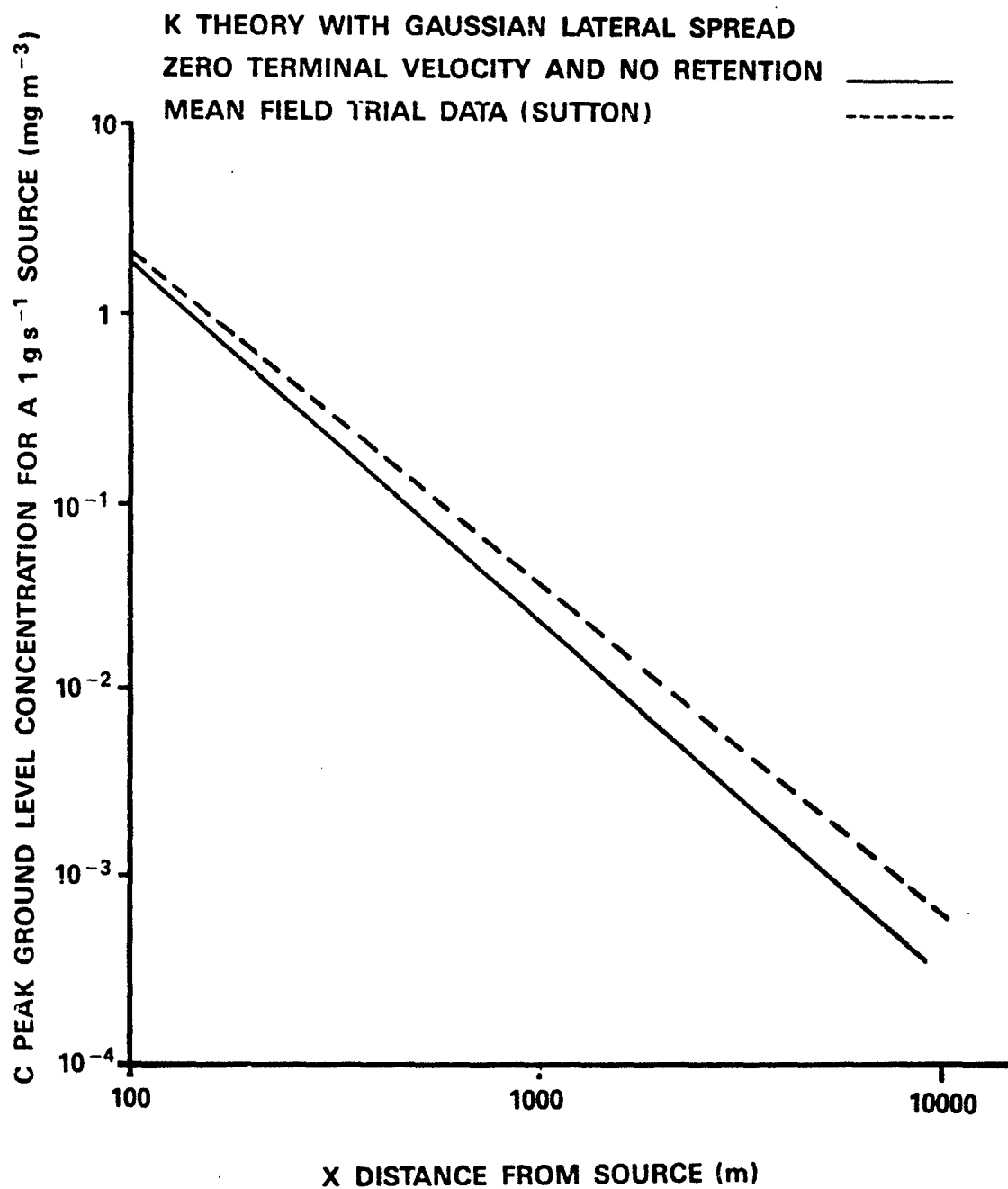


Figure 2

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE
AT 1 m HEIGHT IN NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}

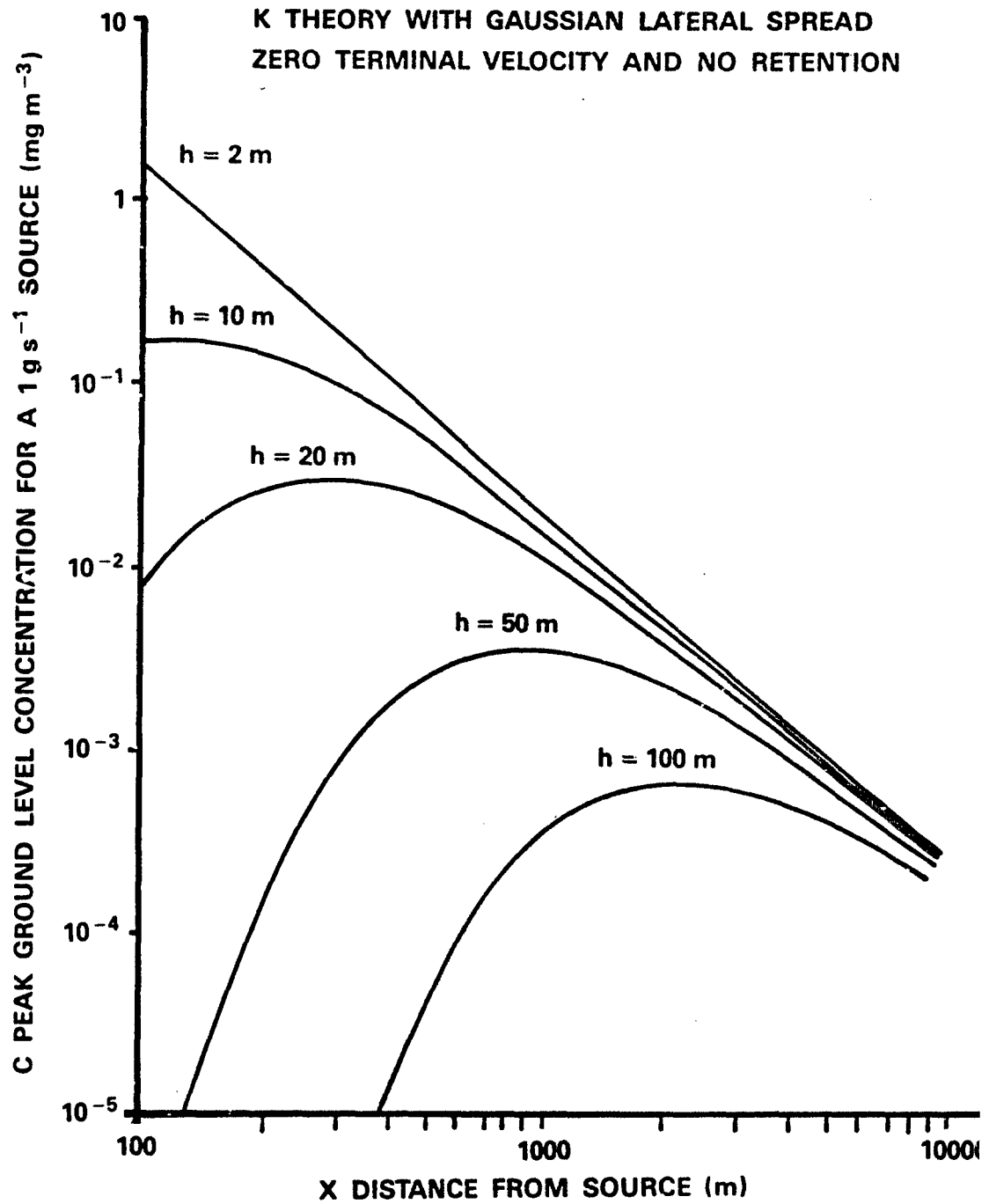


Figure 3
DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT
VARIOUS HEIGHTS IN NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}

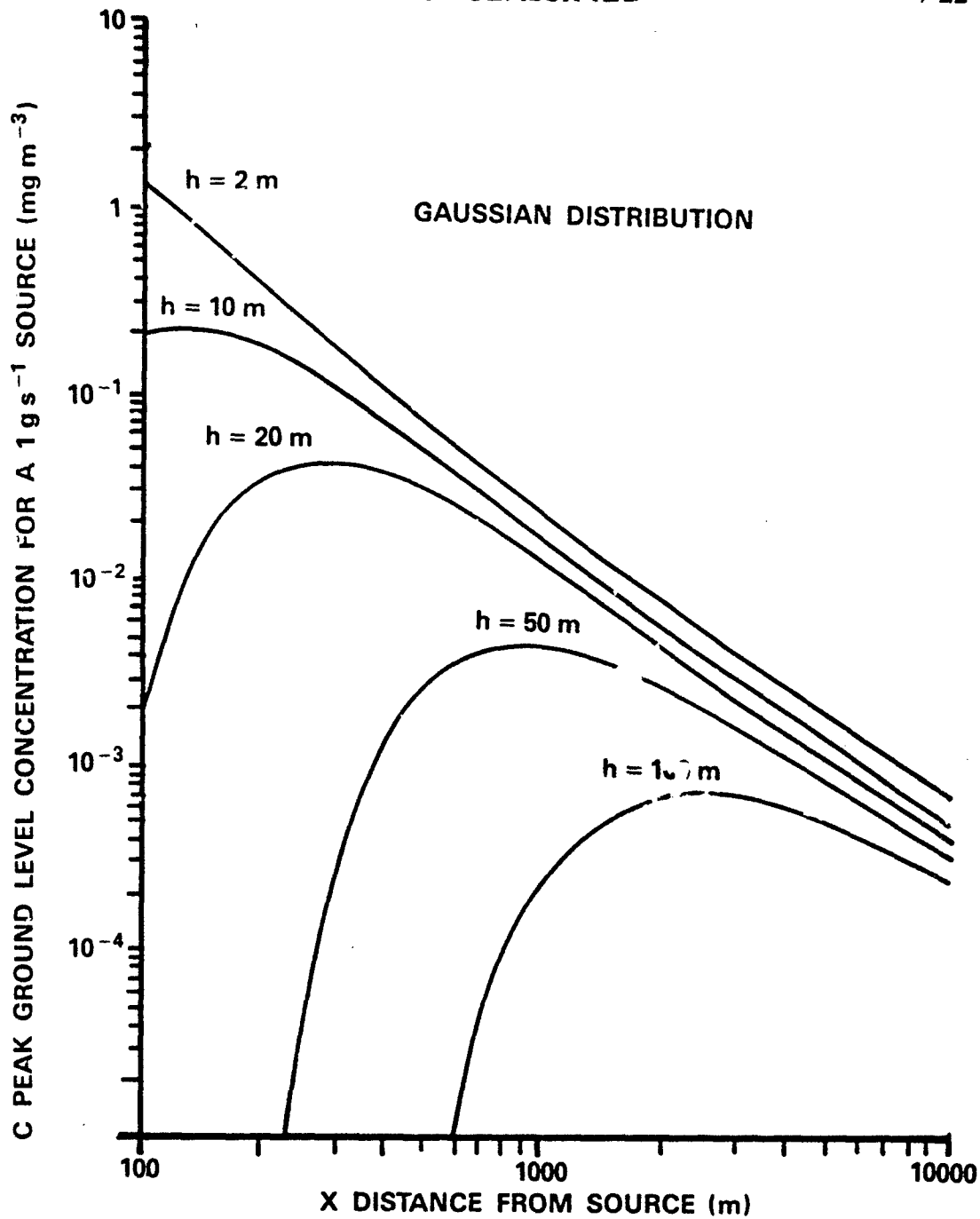
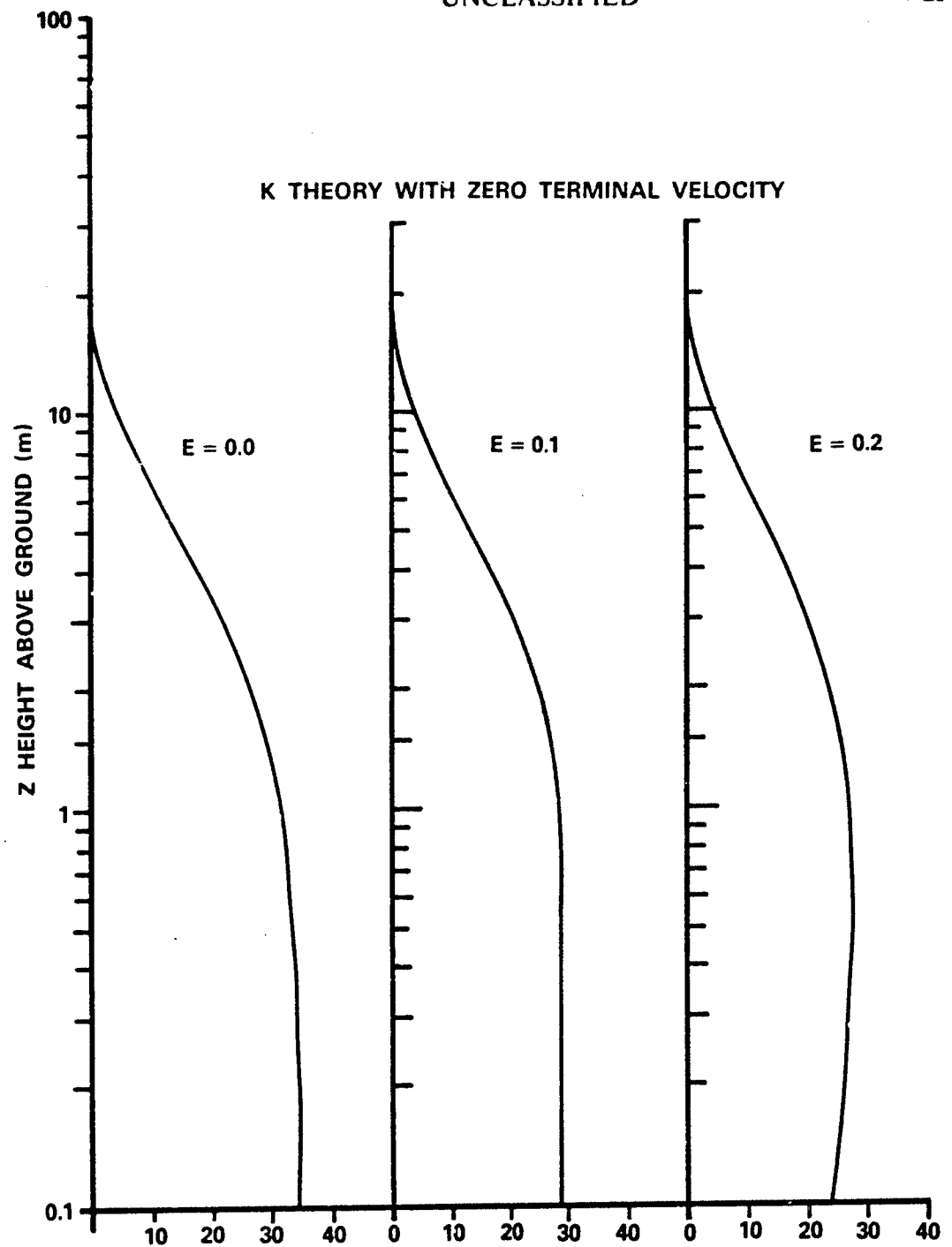


Figure 4

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT
VARIOUS HEIGHTS IN NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}



C PEAK CONCENTRATION AT VARIOUS HEIGHTS FOR A $1 \text{ g m}^{-1} \text{ s}^{-1}$ SOURCE (mg m^{-3})

Figure 5

CONCENTRATIONS 100 m DOWNWIND OF A LINE SOURCE
AT 1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES
IN NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}

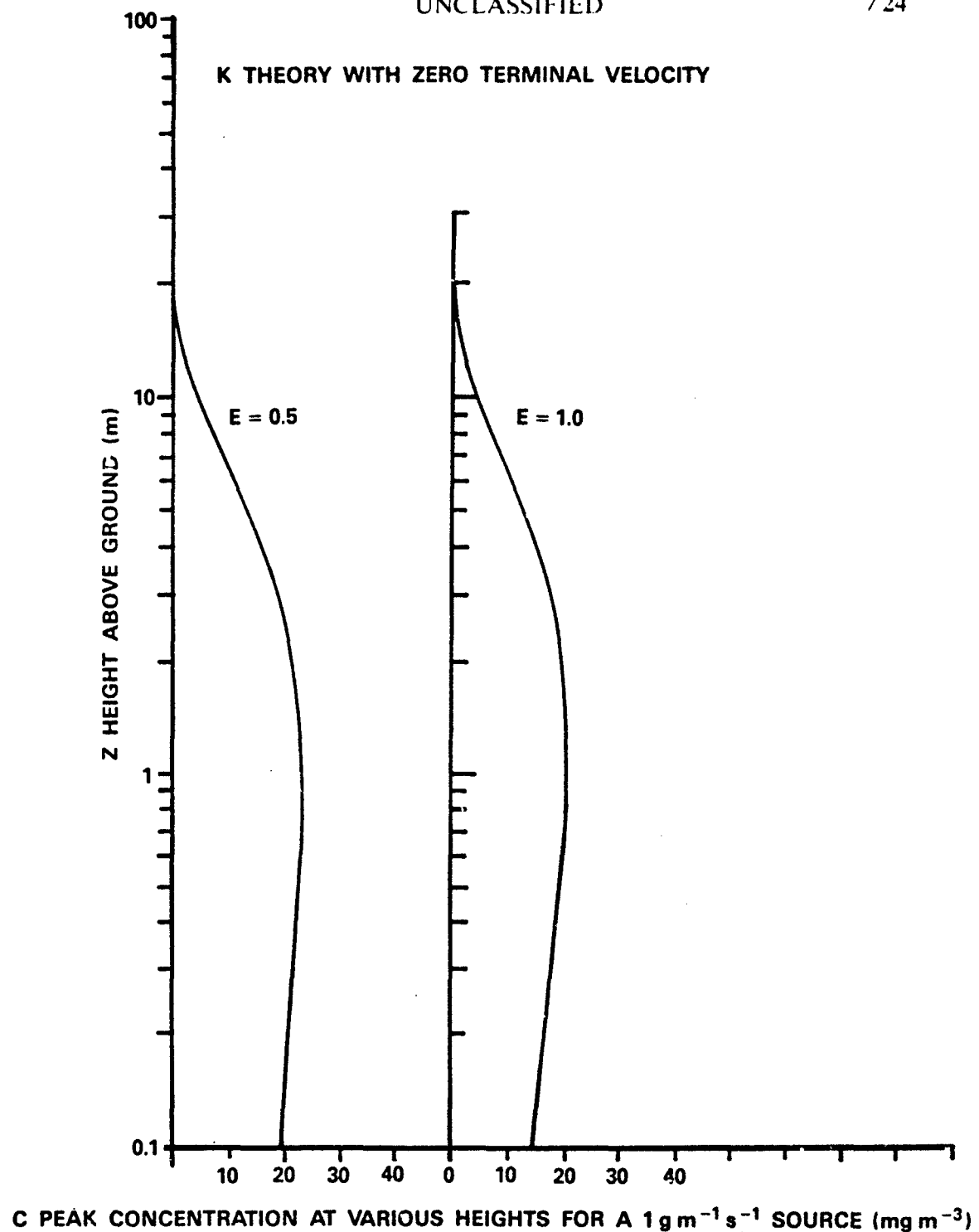
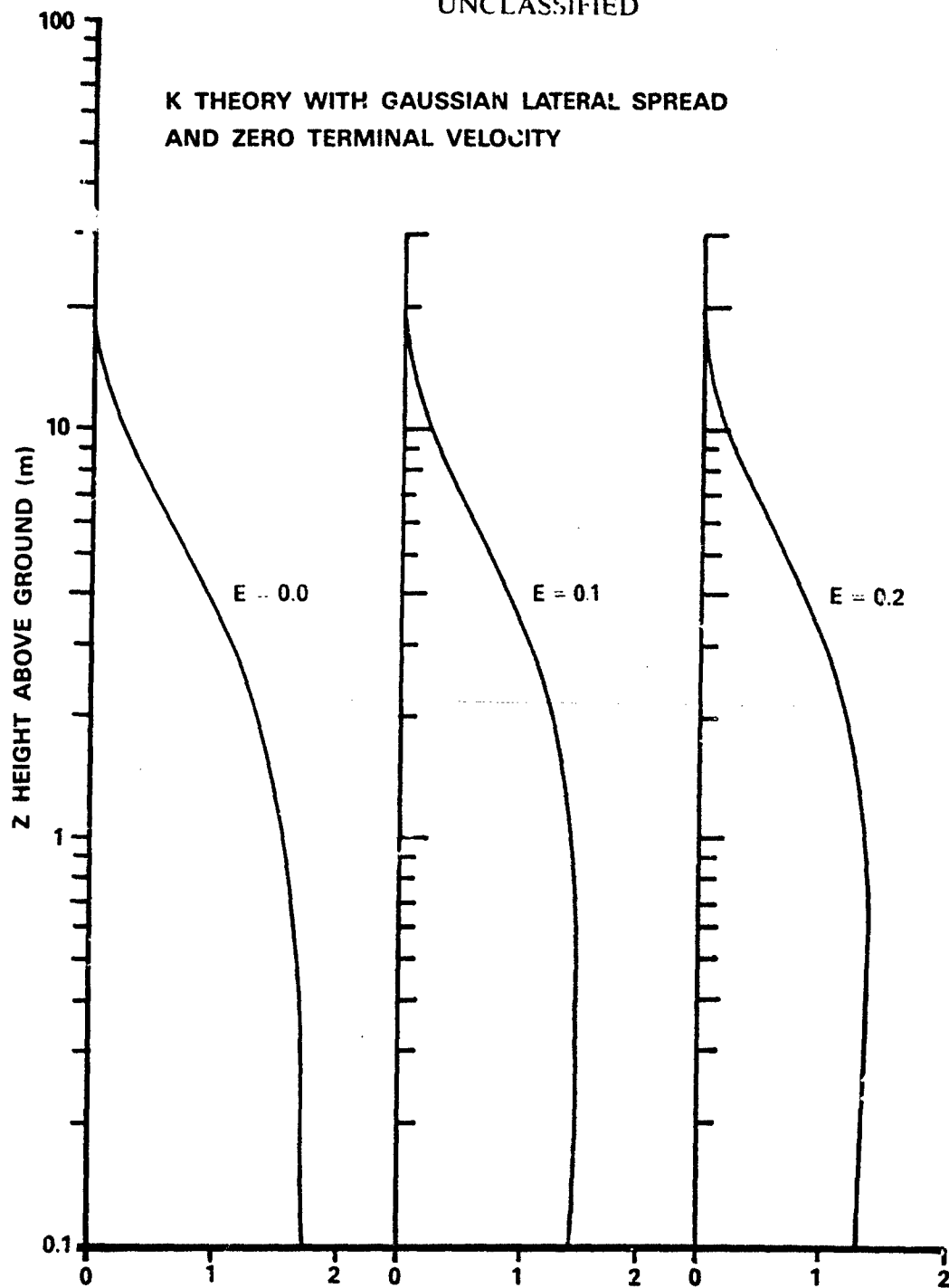


Figure 6

**CONCENTRATIONS 100 m DOWNWIND OF A LINE SOURCE
AT 1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES
IN NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}**



C PEAK CONCENTRATION AT VARIOUS HEIGHTS FOR A 1 g s^{-1} SOURCE (mg m^{-3})

Figure 7

**PEAK CONCENTRATIONS 100 m DOWNWIND OF A POINT
SOURCE AT 1 m HEIGHT* WITH VARIOUS RETENTION
EFFICIENCIES IN NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}**

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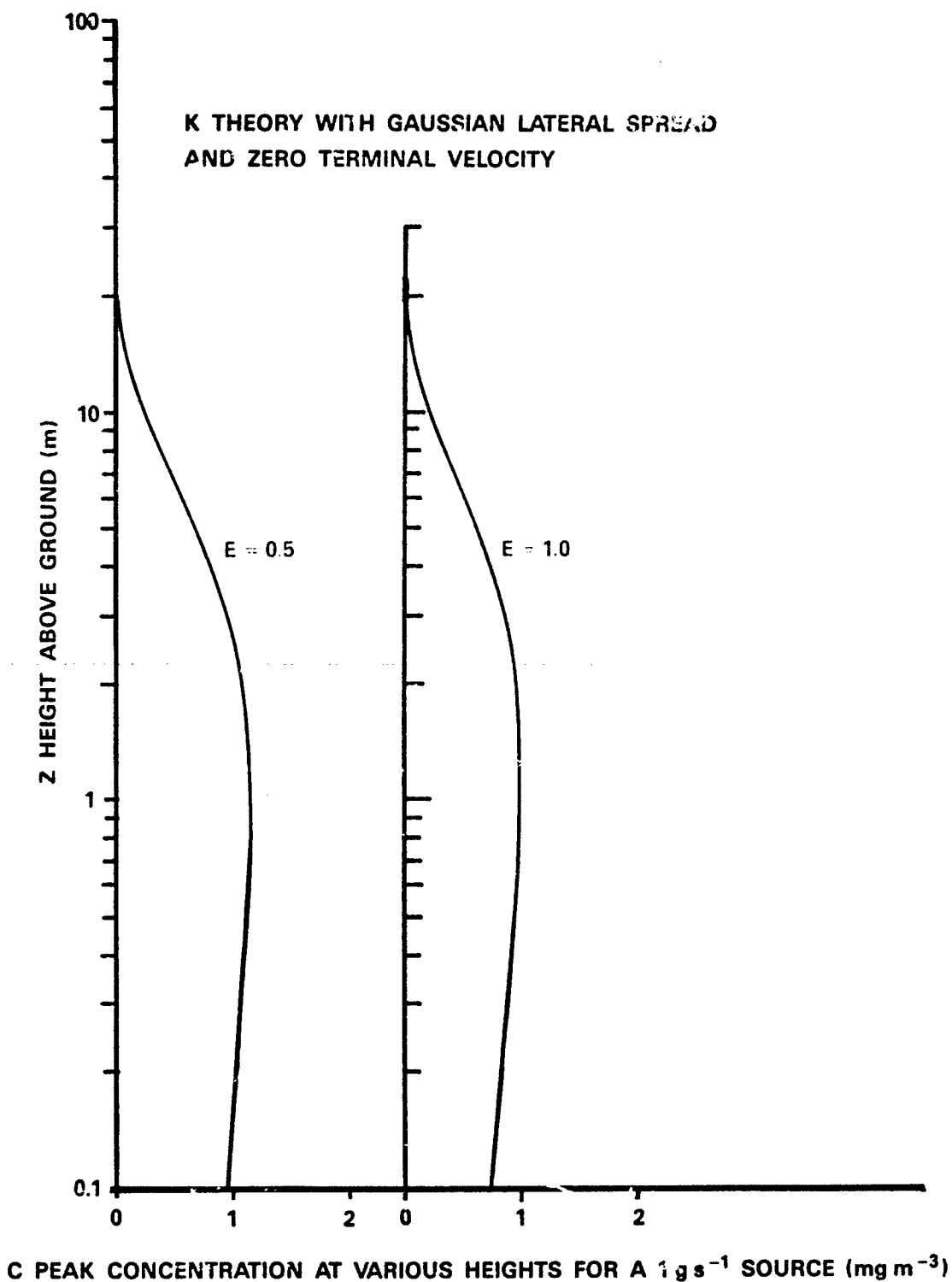


Figure 8

PEAK CONCENTRATIONS 100 m DOWNWIND OF A POINT
SOURCE AT 1 m HEIGHT WITH VARIOUS RETENTION
EFFICIENCIES IN NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}

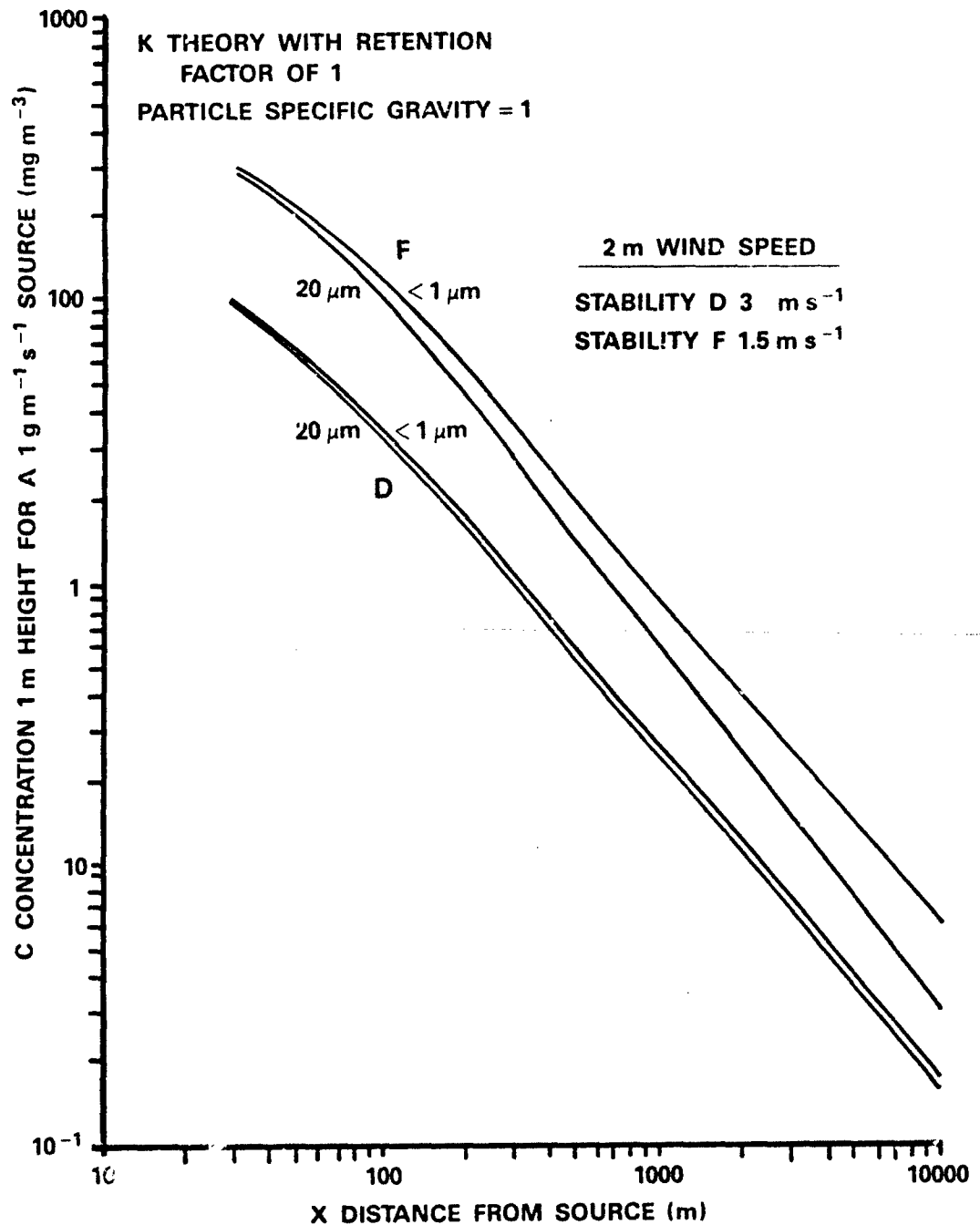


Figure 9

DOWNWIND CONCENTRATIONS OF MONODISPERSE
PARTICULATE FROM A LINE SOURCE AT 1 m HEIGHT
IN TWO ATMOSPHERIC STABILITY CONDITIONS

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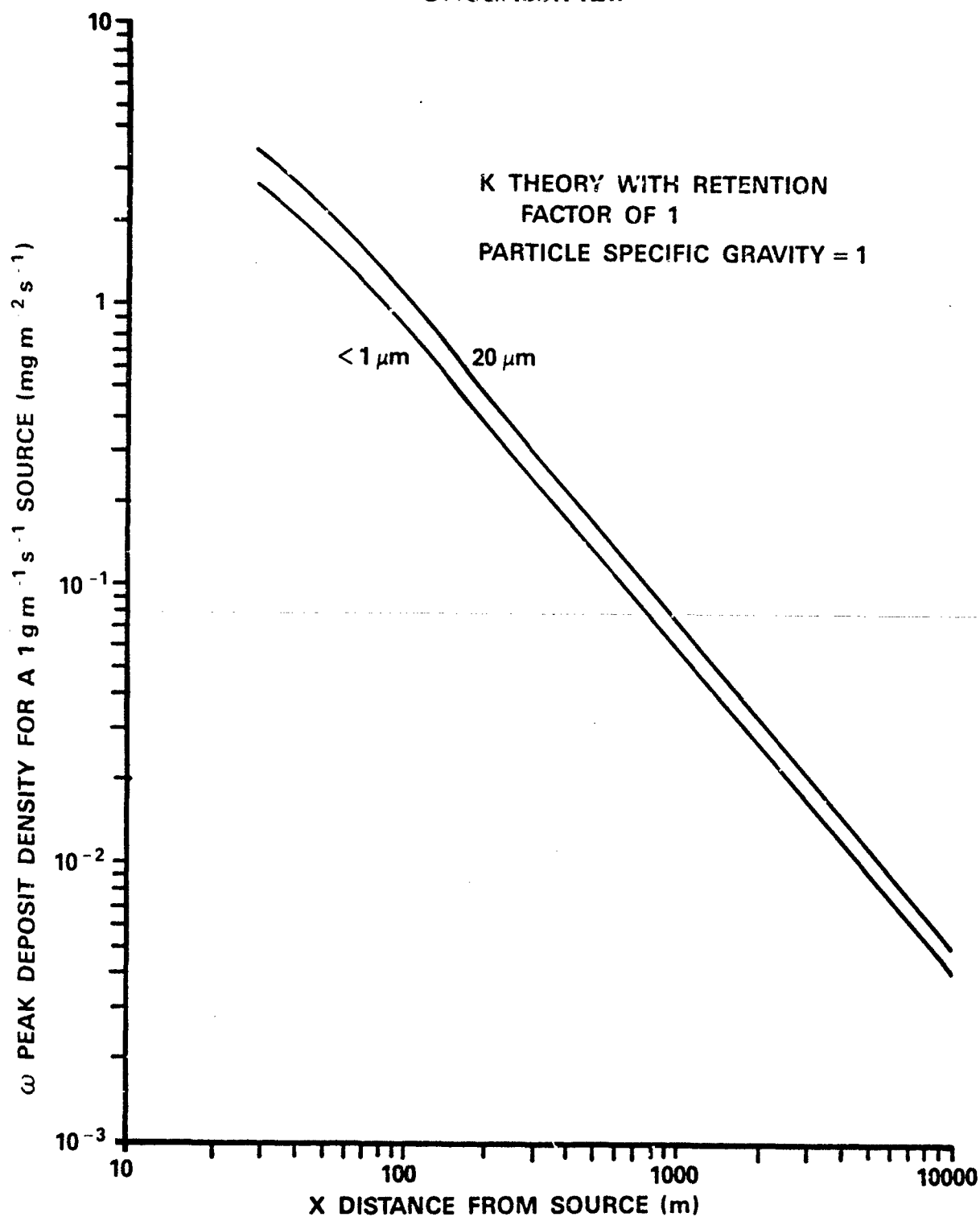


Figure 10

GROUND DEPOSITION OF MONODISPERSE PARTICULATE
FROM A LINE SOURCE AT 1 m HEIGHT IN STABILITY
CATEGORY D WITH 2 m WIND SPEED OF 3 m s^{-1}

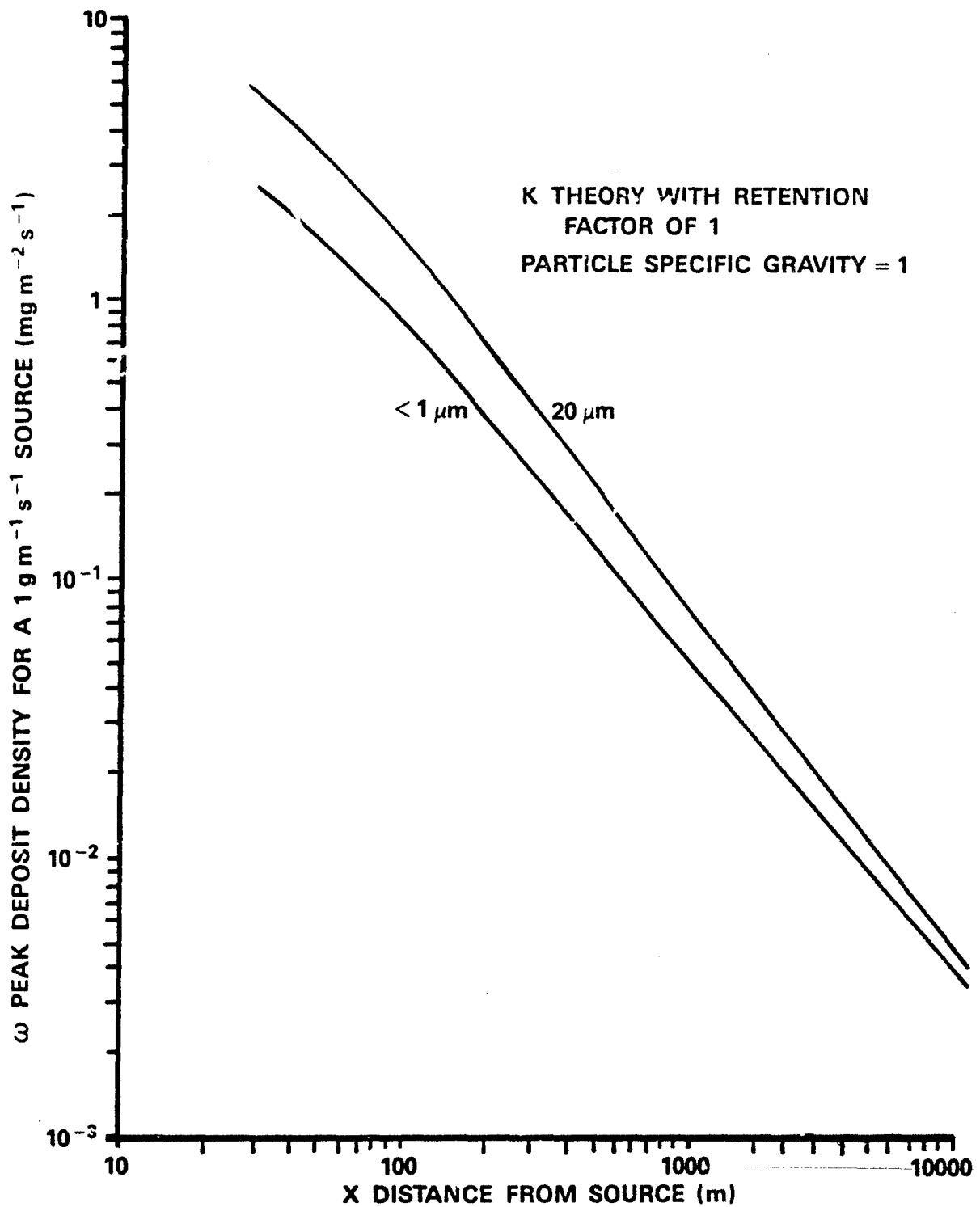


Figure 11

GROUND DEPOSITION OF MONODISPERSE PARTICULATE
FROM A LINE SOURCE AT 1 m HEIGHT IN STABILITY
CATEGORY F WITH 2 m WIND SPEED OF 1.5 m s^{-1}

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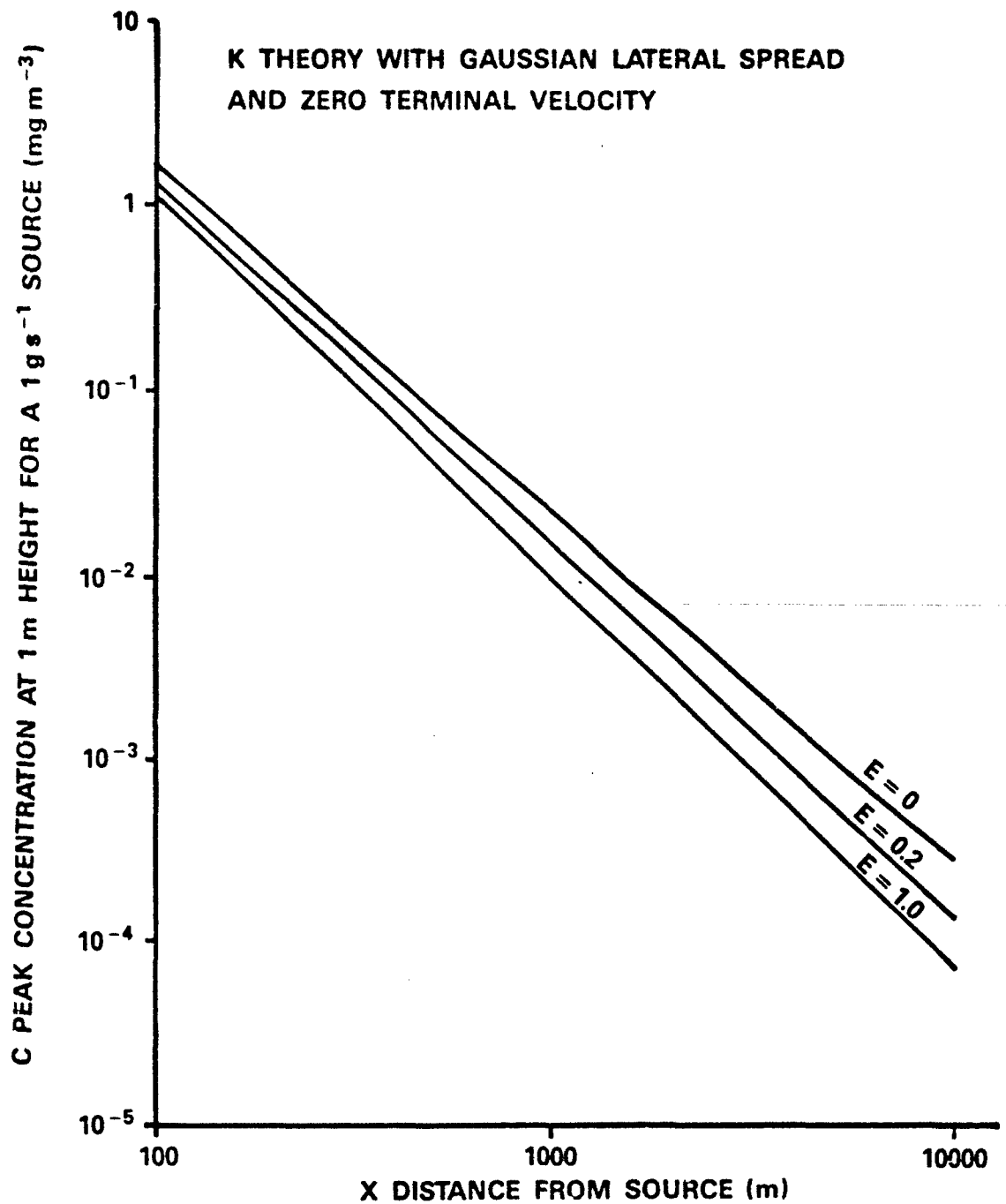


Figure 12

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT
1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES IN
NEUTRAL ATMOSPHERIC STABILITY
WITH 2 m WIND SPEED OF 5 m s^{-1}

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K THEORY WITH GAUSSIAN LATERAL
SPREAD, ZERO TERMINAL VELOCITY
AND RETENTION EFFICIENCY OF 1

2 m WIND SPEED

STABILITY C 3 m s⁻¹

STABILITY D 3 m s⁻¹

STABILITY E 1.5 m s⁻¹

STABILITY F 1.5 m s⁻¹

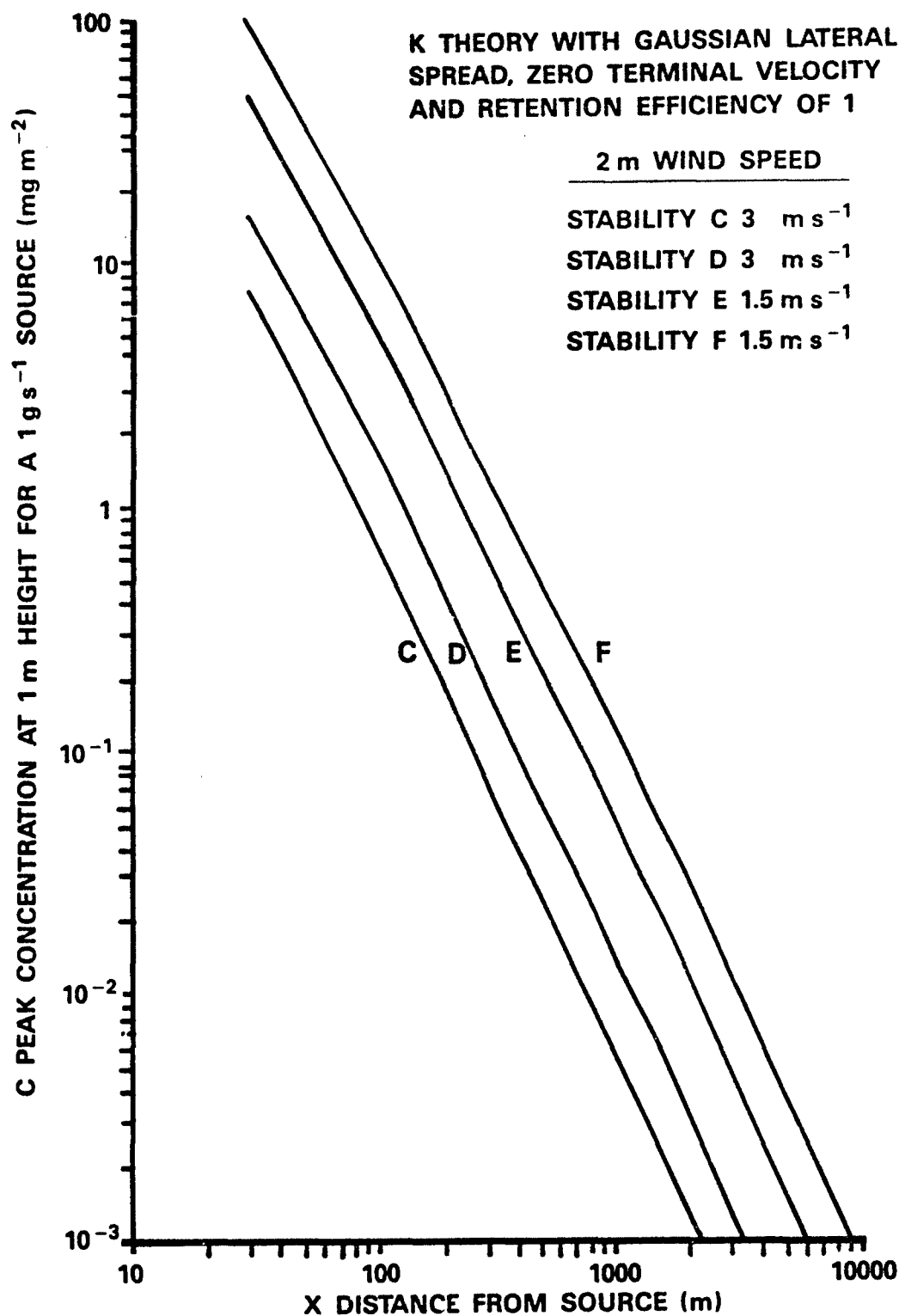


Figure 13

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE
AT 1 m HEIGHT IN VARIOUS ATMOSPHERIC
STABILITY CONDITIONS
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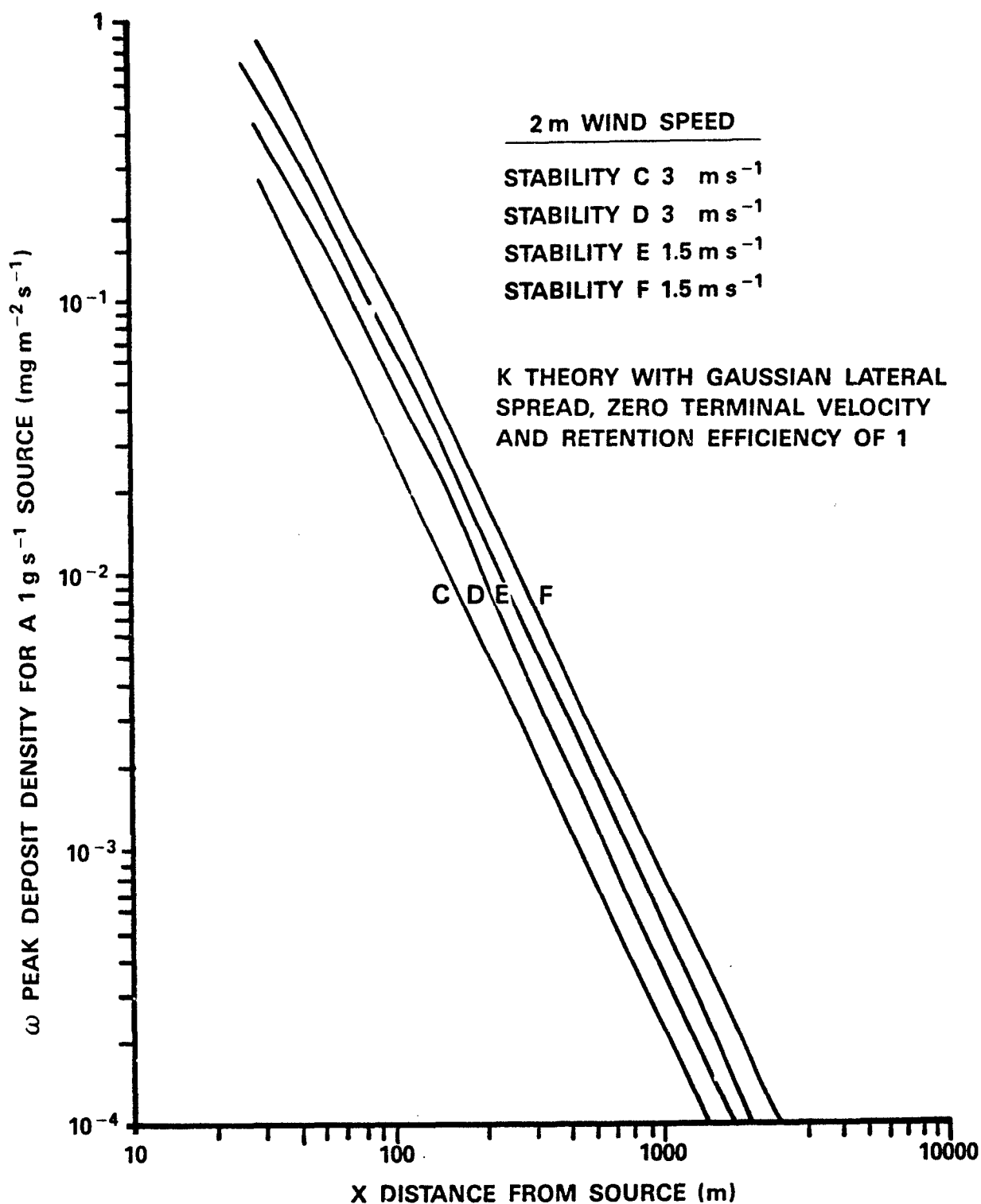


Figure 14

GROUND DEPOSITION FROM A POINT SOURCE AT 1 m
HEIGHT IN VARIOUS ATMOSPHERIC STABILITY CONDITIONS

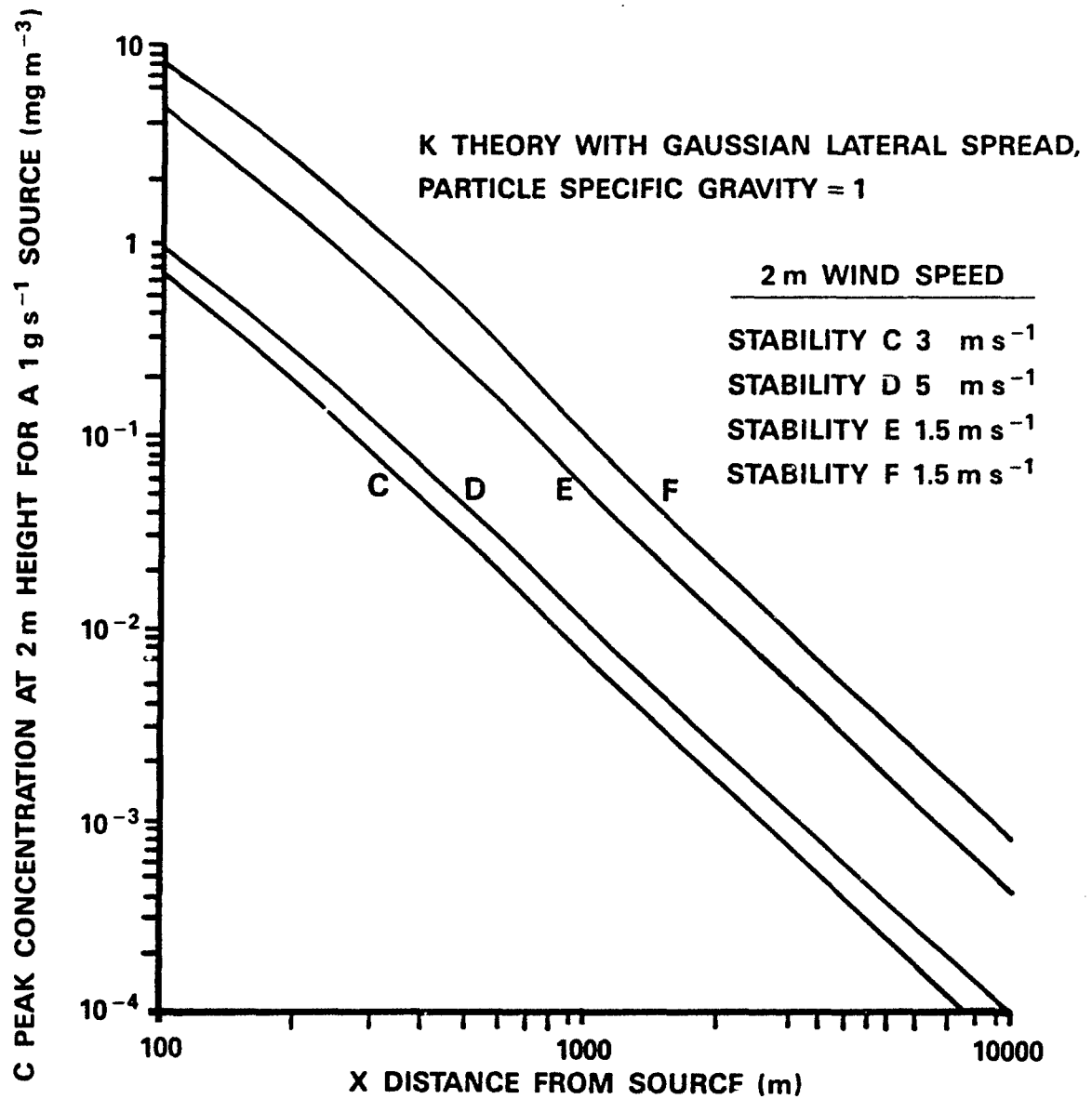


Figure 16

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE OF
20 μm PARTICLES AT 3 m HEIGHT IN VARIOUS
ATMOSPHERIC STABILITY CONDITIONS

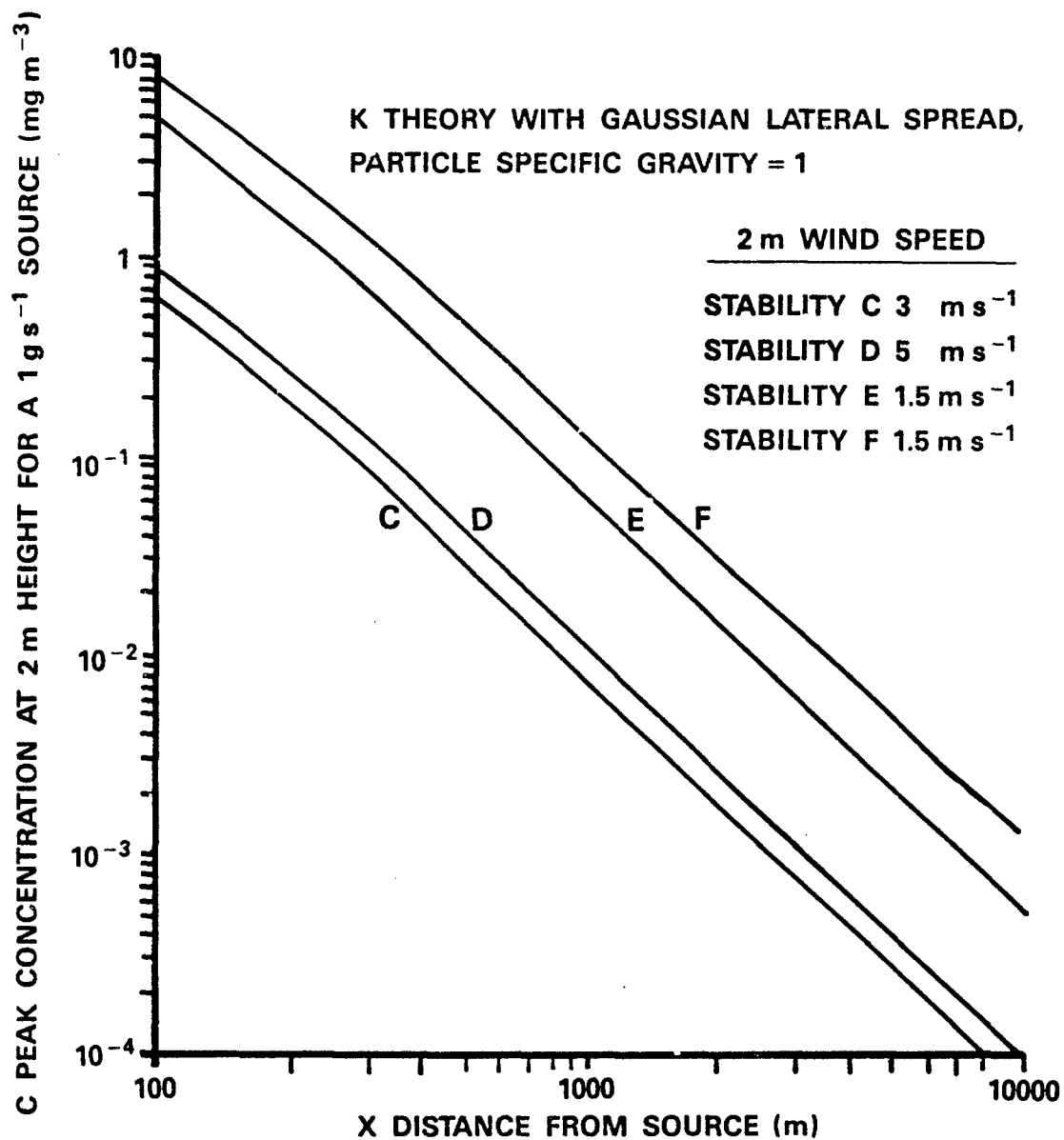


Figure 15

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE OF
5 μm PARTICLES AT 3 m HEIGHT IN VARIOUS ATMOSPHERIC
STABILITY CONDITIONS

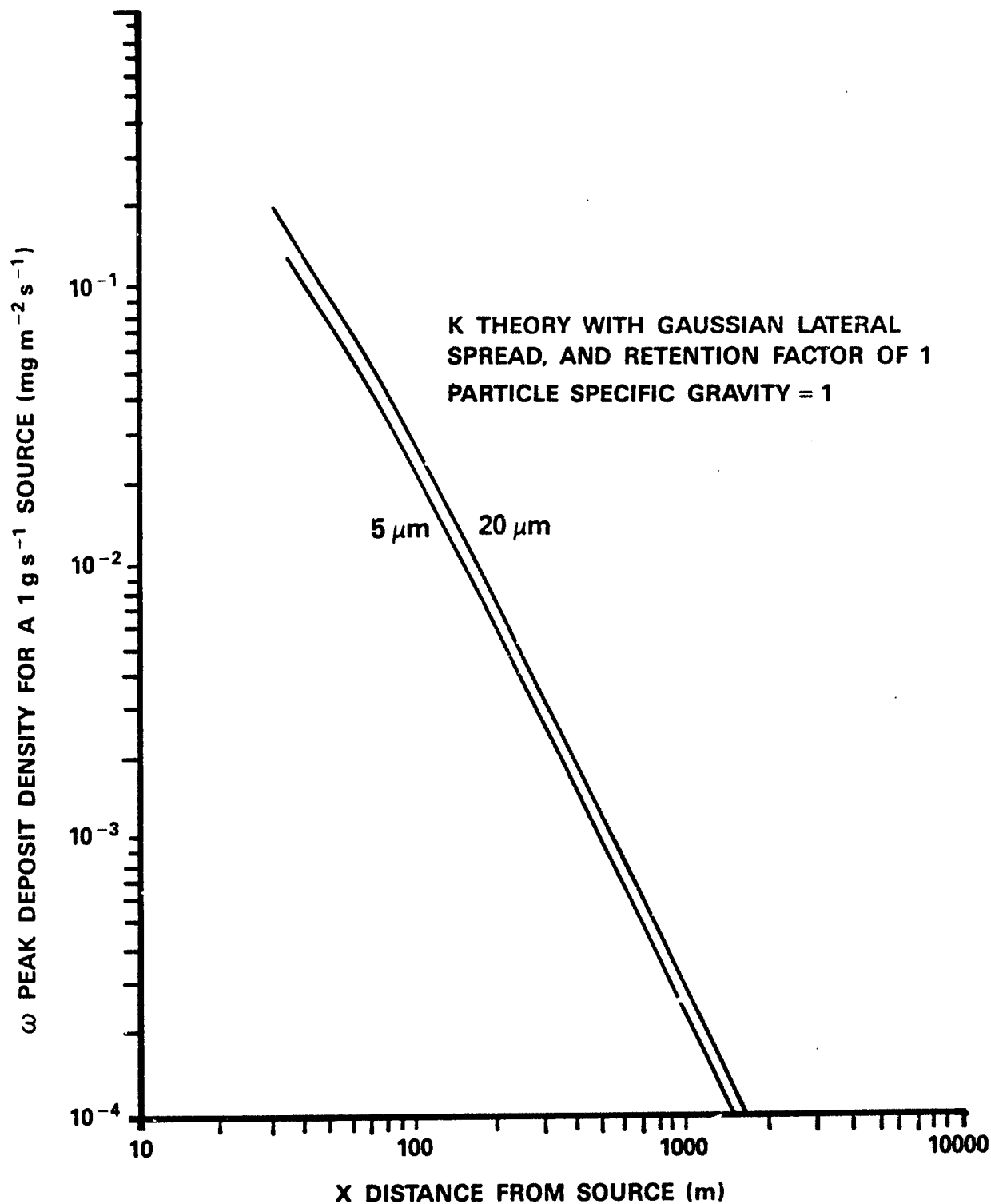


Figure 17

GROUND DEPOSITION OF MONODISPERSE PARTICULATE
FROM A POINT SOURCE AT 3 m HEIGHT IN STABILITY
CATEGORY C WITH 2 m WIND SPEED OF 3 m s^{-1}
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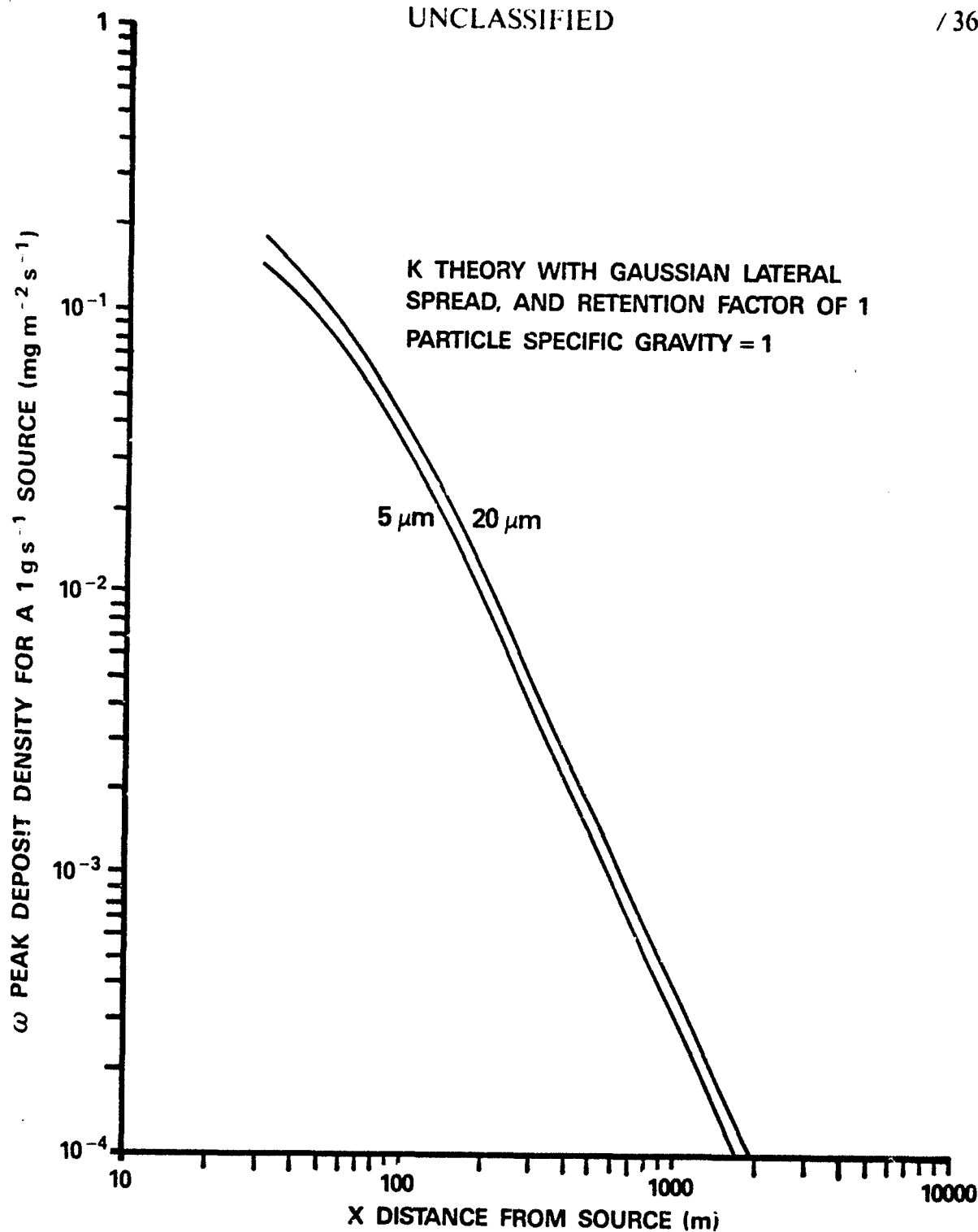


Figure 18

GROUND DEPOSITION OF MONODISPERSE PARTICULATE
FROM A POINT SOURCE AT 3 m HEIGHT IN NEUTRAL
ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

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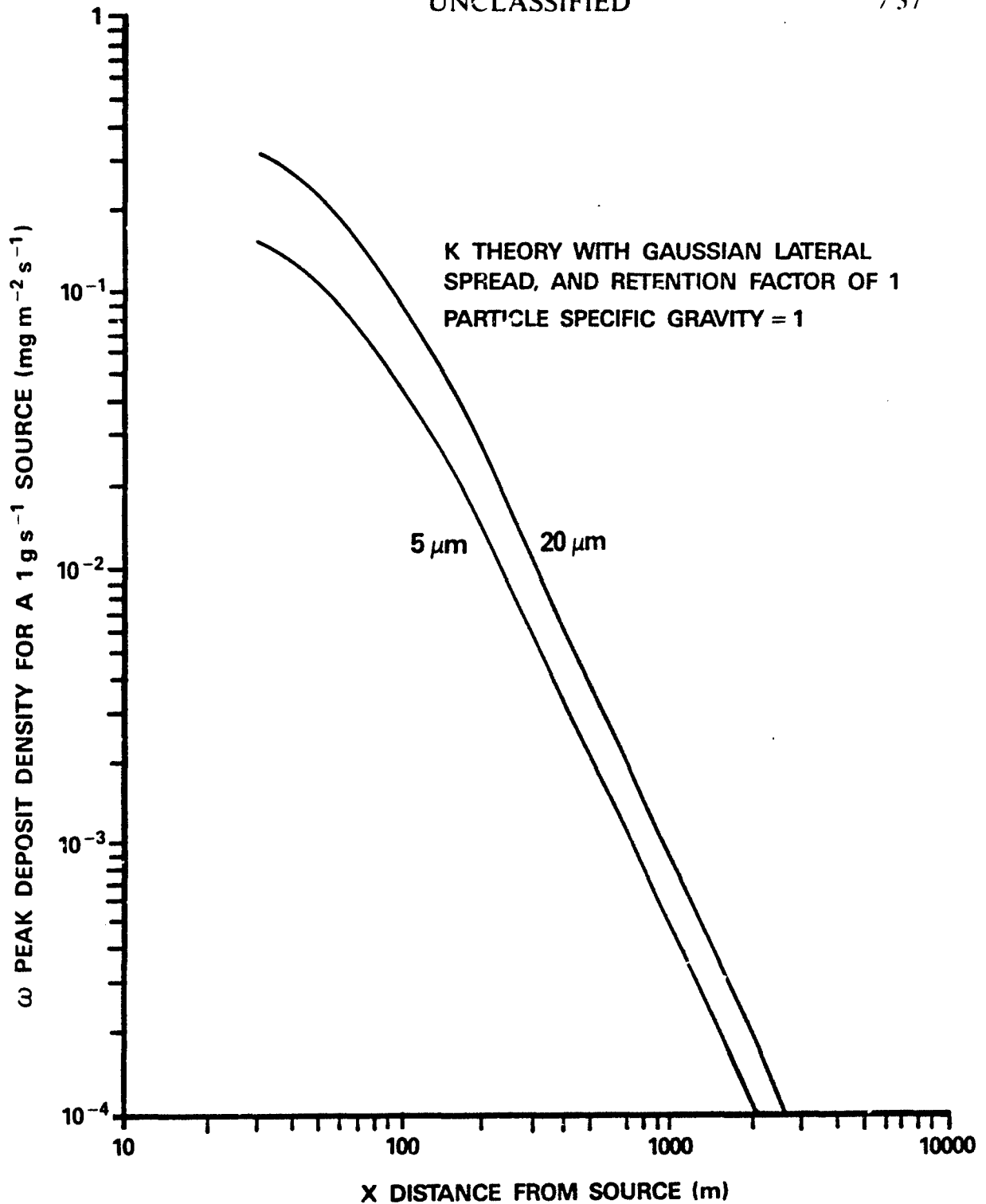


Figure 19

GROUND DEPOSITION OF MONODISPERSE PARTICULATE
FROM A POINT SOURCE AT 3m HEIGHT IN STABILITY
CATEGORY E WITH 2m WIND SPEED OF 1.5 m s^{-1}

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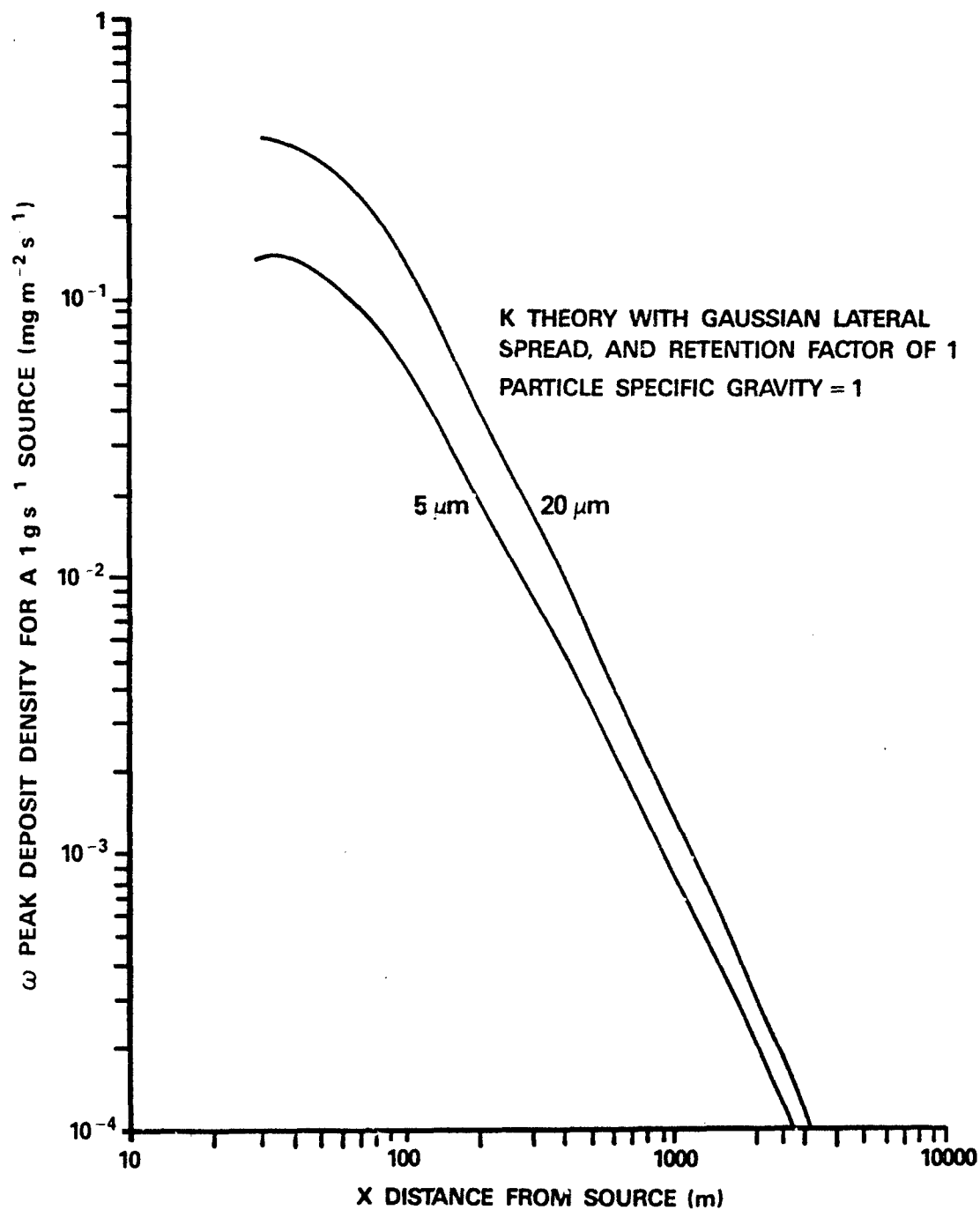


Figure 20

GROUND DEPOSITION OF MONODISPERSE PARTICULATE
FROM A POINT SOURCE AT 3 m HEIGHT IN STABILITY
CATEGORY F WITH 2 m WIND SPEED OF 1.5 m s^{-1}

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DISCUSSION OF RESULTS

23. The results for the K theory line source model agree favorably with Sutton's mean field trial data. As shown in Figure 1, the peak concentration at 100 m downwind is 35 mg m^{-3} for both. At longer downwind distances the calculated results are lower than those given by mean field trial data. The difference gradually increases until at 1000 m the calculated value is 90% of that computed from Sutton's criteria and 70% at 10000 m downwind. The calculated cloud height at 100 m downwind of a line source is 11 m as compared to 10 m from the mean field trial data. The calculated height is obtained from Figure 5, with retention efficiency $E = 0$, where the concentration has fallen to one-tenth of the value on the ground.

24. The results for the point source model using K theory for vertical dispersion and Gaussian lateral spread agree favorably with the mean field trial data, although less so than for the line source. The calculated peak concentration at 100 m downwind was 1.76 g m^{-3} as compared to 2 g m^{-3} from Sutton's mean field trial data. This corresponds to a calculated value which is 88% of the measured value. The difference gradually increases until the calculated value is 75% of that computed from Sutton's criteria at 1000 m and 50% at 10000 m. The calculated cloud width 100 m downwind of the point source using equation (21) with σ_y from Table II is 34 m, as compared to 35 m from the mean field trial data. The criteria used for the cloud width was that specified by Sutton as the distance between points on the crosswind concentration curve at which the concentration has fallen to one tenth of the peak value. Using the criteria that the cloud width is $4 \sigma_y$, as previously described, the calculated value is 32 m. The cloud height for a point source was not specified for the mean field trial data, but

the calculated value as shown in Figure 7 for retention efficiency, $E=0$, is the same as for the line source. This is to be expected since the same K theory is used for vertical dispersion.

25. Comparison of Figures 3 and 4 indicate that the downwind location of the maximum ground level concentration for the two methods of calculation is in good agreement for all release heights. The difference in the values of the concentration is greatest for a release height of 20 m where K theory model with Gaussian spread gives results about 75% of that by Gaussian dispersion. The former model tends to give higher concentrations upwind of the peak and lower concentrations downwind of the peak. There is no general agreement on the best method to model elevated sources [8]. A review of various models is described by Gifford [15].

26. The agreement between theory and experiment is favorable for the line source. The calculated results in Figures 5 and 6 also show the behavior of concentration as a function of height for various retention efficiencies. As retention efficiency increases, the height at which the maximum concentration occurs increases, but the maximum concentration, itself decreases. This is also true for a point source as shown in Figures 7 and 8, which uses the same K theory for vertical dispersion.

27. The concentrations at the source height downwind of a low level line source is not affected appreciably by particle size less than 20 μm in neutral atmospheric stability. Figure 9 indicates that the concentrations of 20 μm particles are not less than 90% of the concentrations for particles less than 1 μm in size over the whole downwind distance range considered. For atmospheric stability F, which

is the "worst case", the differences are considerably greater. The reason is that the plume travels close to the ground at all distances, so that even small differences in terminal velocity affect the number of particles which come into contact with the ground and thus are removed by retention. Figure 9 indicates that the difference between concentrations of 20 μm particles and particles less than 1 μm in diameter, gradually increases with downwind distance. The concentrations of 20 μm particles are 85% at 100 m, 65% at 1000 m and 50% at 10000 m of the concentration of particles less than 1 μm in diameter. The ground deposition densities of 20 μm particles are not less than 75% of those of the smallest particles over the whole distance range in atmospheric stability D, but vary gradually from 50% at 100 m to 90% at 10000 m. For the wind speeds considered, which are realistic in practical applications, the ground deposition densities are nearly equal at 10000 m for the two atmospheric stability categories.

28. Figure 12 indicates that concentrations of particles which follow the flow are lower than those of non reacting vapors downwind from a point source. The difference increases gradually as is shown by comparing the results for $E=0$ and $E=1$. The concentration for $E=0.2$ is about midway, on the logarithmic scale, between those for the other two retention efficiencies. Figures 13 and 14 give concentrations and ground deposition densities downwind of a point source using zero terminal velocity. They can be used as a good approximation for particles smaller than 5 μm in diameter. The concentrations for particles between 5 and 20 μm in diameter can be estimated by comparing Figures 15 and 16. A feel for the difference in ground deposition densities downwind of a point source for various small particle sizes is given in Figures 17 to 20, where the calculated results for 5 and 20 μm particles are shown for four atmospheric stability categories.

29. Some comparisons of calculated ground contamination densities for the line source model to field data for particles 30 μm and larger [1,2,16,17] indicate that this model can be used with reasonable confidence. The predicted location of the downwind peak agrees with experiment but the calculated peak ground deposit densities are lower. The point source model which uses the same vertical dispersion function and lower boundary condition is supported by these results to a certain extent, although further experiments would be useful.

CONCLUSIONS

30. A mathematical model has been developed from which concentrations and ground contamination densities from a low level point source of particles less than 20 μm in diameter can be calculated. Confidence in the model to predict concentrations accurately is supported by experimental data for gaseous clouds, for which the model can be applied using the limiting case of zero terminal velocity. Calculations for particles within the specified size range show that the effect of particle size is small enough so that predictions of concentrations can be made with sufficient accuracy for many practical applications. Ground contamination densities can also be calculated for the same range of particle sizes. Reasonable confidence in their accuracy is supported by comparisons with experiments reported previously [1,2,16,17].

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APPENDIX A
COMPUTER PROGRAM
"DIFFP"
WITH SAMPLE RESULTS

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A1. The computer program for calculating concentrations and ground contamination densities downwind of a point source using K theory for vertical dispersion and Gaussian lateral dispersion was developed from the line source program. The program called DIFFP is therefore very similar to the program DIFF, from which it was developed. The data input required to execute the program is shown in Table A1, with required atmospheric constants in Table A2. Sample output and a listing of the program immediately follow the table. The program for the line source, which contains several subroutines, is difficult to understand for the uninitiated because it is not thoroughly annotated. The modification to account for lateral spread from a point source was handled as simply and straightforwardly as possible with minimal modifications.

A2. The modifications required to calculate concentrations and ground deposition densities downwind of a point source were all made in the subroutine PPOUT, the last subroutine in the program. A short algorithm was inserted to calculate the standard deviation: σ_y , and the associated Gaussian lateral dispersion function at any distance downwind. The concentrations and ground deposition densities were then obtained by multiplying the concentrations and ground deposition densities for the line source calculated earlier in the program by the lateral dispersion function. The program was set up to calculate results for any one lateral crosswind position, y , at each downwind distance. The peak values are given by setting $y = 0$. Off axis values which are symmetric about the axis are less according to the Gaussian lateral distribution.

A3. The algorithm for calculating the Gaussian lateral dispersion function is shown in lines 506 to 526 in the program listing. The modified dosages are calculated in lines 532 to 534 and the modified ground contamination densities are calculated in lines 541 to 543. Line 545 was inserted to include values of the lateral dispersion functions in the output results. Also line 499 was modified to include the new functions in DIMENSION statements and a few FORMAT statements were added.

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TABLE A1
DATA INPUT FOR DIFFUSION PROGRAM, DIFFP

RECORD	VARIABLES	FORMAT	NOTES
1	PA,M,S,A,DL, Q,E, SOURC	8F10.0	PA=0.01 U(2). U(2) is 2 m windspeed (m s^{-1}). S=2.0 for open ground; 5.0 for forest. Q is terminal velocity of droplets or particles (m s^{-1}). E is retention factor of substrate; the value is 1 for complete retention SOURC is line source strength, mass per unit length (g m^{-1}). M=p,A, DL=Δx are given in Table A2).
2	(1) X0,DY,H, HH, U2M, 8F10.0		X0 is the maximum downwind distance considered. DY = 0.01 (2) H is the height of the atmospheric lid (see Table I). HH is the effective release height (m). U2M is 2 m windspeed (m s^{-1}) (see Table A2).
3	THETA,NZ(IC,ICI)	F10.0,3I3	THETA = 0.5 NZ is the size of the vertical array (usually 48 but ≥ 100). IC and ICI were used to "debug" the program and to provide auxiliary information: no entry required. Their use is described in foot note (3) below.

TABLE A1

DATA INPUT FOR DIFFUSION PROGRAM, DIFF

continued

RECORD	VARIABLES	FORMAT	NOTES
5	NUMOX,NOVES, (ICZX,IK)	412	NUMOX is the number of down wind distances for output (maximum 20) NOVES is the number of height intervals in print out. This is further described in the notes with record 7. ICZX, IK are used only to provide auxiliary information. No entry is required. Their use is described in foot note (3) below.
6	XOUT(I), I=1,NUMOX	8F10.0	Downwind distance from spray line (m). Maximum number of positions is twenty.
7a,b,c....	STATZ(I), ENDZ(I), ZOUIN(I)	8F10.0	STATZ and ENDZ are bottom and top of chosen interval of height, NOVES. ZOUIN is height increment. Thus 0.0, 10.0, 2.0 will give values of dosage at Z = 0.0, 2.0, 4.0 10.0 m. This permits height increments to be varied from one interval to the next. One record is needed for each interval. Total number is NOVES records (not to exceed 25).
8			Not used unless ICZX $\geq$ 1(3)

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TABLE A-1

DATA INPUT FOR DIFFUSION PROGRAM, DIFF

continued

RECORD	VARIABLES	FORMAT	NOTES
9	YC IPSC	F10.0, I3	YC is crosswind coordinate (m). IPSC is 1,2,3,4 for stability categories CDEF.
9	YC IPSC	F10.0, I3	YC is crosswind coordinate (m). IPSC is 1,2,3,4 for stability categories CDEF.

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FOOTNOTES

- (1) X_0 must exceed $XOUT(NUMOX)$ card 6.
(2) The calculated output position may vary slightly from the chosen $XOUT(I)$ in card 6, because DY is a logarithmic increment of downwind distance.

(3) $IC = 0, ICI = 0, ICZX = 0, IK = 0$
No auxiliary information in output.
 $IC = 1, ICI = 0, ICZX = 0, IK = 0$
Run parameters output
DR NZ DY NY THETA
H HR RH
HH HHR RHH IHH
Matrix constants output
ALPHA BETA GAMMA LAMBA A1 D1
 $IC = 2, ICI = 0, ICZX = 0, IK = 0$
As for $IC = 1$ plus:
Output controls
Vertical intervals
START END INCREMENT for each interval
Vertical array
Z RZ ID THETA (portion of full increment for Bessel's interpolation formula)
Horizontal output positions
X X-OUT IY

$IC = 3, ICI \geq 0, ICZX = 0, IK = 0$
As for $IC = 2$ with the other three variables equal to zero.

$IC = 4, ICI \geq 0, ICZX \geq 0, IK \geq 0$
As for $IC = 2$ and 3 in the two preceding modes, except that no main results are printed out. Moreover, no downwind concentrations and ground contaminations are calculated in the program.

$IC = 3, ICI \geq 0, ICZX = 0, IK = 0$
As for $IC = 3$ $ICI = 0$ except that vertical profile and matrix interrogation is printed out for iteration intervals separated by the value of ICI . For example, if $ICI = 10$, iterations 10, 20, 30....are printed out until the specified maximum value of downwind distance has been reached. This mode results in a large array of numbers printed out at each iteration determined by ICI and could result in a great deal of output paper from the printer.

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IC = 2, IC1 = 0, ICZX $\geq$ 0, IK $\geq$ 0

ICZX = 1: Peak concentrations and vertical locations of peaks in the transformed plane for downwind positions IK·DY starting at Y = DY are printed out. For example, if DY = 0.01, IK = 3, values are printed out at DY = 0.01, 0.04, 0.07.....

ICZX = 2: As for ICZX = 1 except that concentrations are also given at one user specified height, Z, at the same downwind positions. An extra data record is needed if ICZX $\geq$ 1, which specifies heights Z, as follows. XZ(I), FORMAT 2F10.0. Only one value of ZX(I) is required if ICZX = 2.

ICZX = 3: As for ICZX = 2 except that concentrations are printed out at two user specified heights, Z. Peak concentrations are not given.

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TABLE A2

VALUES OF CONSTANTS

CONSTANTS

STABILITY CATEGORY	<u>A</u>	<u>Δz</u> m	<u>p</u>	<u>$u(2)$</u> m s ⁻¹	<u>H</u> m
C	0.08	0.025	0.2	2-4	1000
D	0.04	0.025	0.23	≥3	500
E	0.03	0.025	0.3	1.5-3	200
F	0.02	0.025	0.5	1.5-2	100

Δz is given for grassland

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A MATHEMATICAL MODEL DESIGNED TO DESCRIBE THE DOWNWIND
TRAVEL AND VERTICAL PROFILE OF PARTICULATE MATTER FROM AN ELEVATED SOURCE

STABILITY D, 0 MICRONS E=1.0, HH=1.0, NZ=96, DY=0.001

PA= .03000 (AIR PERMEABILITY)
W= .25 (WIND PROFILE PARAMETER)
S = 2.000 (TOTAL SPECIFIC AREA)
A = .0400 (VON KARMANS CONSTANT/10)
DL = .025 (ROUGHNESS LENGTH)
Q = .00000 (TERMINAL VELOCITY)
E = 1.000 (RETENTION FACTOR)
SOURCE= 1000.00 (SOURCE STRENGTH)
U(2)= 3.00 (2 METRE WIND)

H	ATMOSPHERIC LID	HH	RELEASE HEIGHT	XO	DOWNWIND DISTANCE
500.000		1.000		11000.000	

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YC = .0 (CROSSWIND COORDINATE)
IPSC = 2 (STABILITY CATEGORY INDICATOR)
IPSC = 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F.

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A-10

DOWNWIND CONCENTRATIONS

VERTICAL GRID Z (I)	X			X			X		
	29.86			40.02			49.83		
	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
0.00	7.337733	5.255587	2.781650	1.934432	1.934432	1.934432	1.934432	1.934432	1.934432
0.10	13.068968	7.594209	4.972005	3.462055	3.462055	3.462055	3.462055	3.462055	3.462055
0.20	14.834575	8.678974	5.696511	3.974404	3.974404	3.974404	3.974404	3.974404	3.974404
0.30	15.302993	9.250112	6.089270	4.258229	4.258229	4.258229	4.258229	4.258229	4.258229
0.40	16.291758	9.577352	6.325249	4.434517	4.434517	4.434517	4.434517	4.434517	4.434517
0.50	16.523041	9.758921	6.467836	4.546911	4.546911	4.546911	4.546911	4.546911	4.546911
0.60	16.581516	9.842765	6.547793	4.616496	4.616496	4.616496	4.616496	4.616496	4.616496
0.70	16.516153	9.856387	6.582653	4.655234	4.655234	4.655234	4.655234	4.655234	4.655234
0.80	16.358392	9.917297	6.583528	4.670556	4.670556	4.670556	4.670556	4.670556	4.670556
0.90	16.129939	9.737484	6.557952	4.667861	4.667861	4.667861	4.667861	4.667861	4.667861
1.00	15.846604	9.625610	6.511355	4.550494	4.550494	4.550494	4.550494	4.550494	4.550494
2.00	11.750143	7.691420	5.477157	4.067045	4.067045	4.067045	4.067045	4.067045	4.067045
3.00	7.668650	5.523948	4.185252	3.253541	3.253541	3.253541	3.253541	3.253541	3.253541
4.00	4.622694	3.730556	3.031898	2.482837	2.482837	2.482837	2.482837	2.482837	2.482837
5.00	2.623734	2.408656	2.118716	1.833947	1.833947	1.833947	1.833947	1.833947	1.833947
6.00	1.473290	1.500120	1.436733	1.320847	1.320847	1.320847	1.320847	1.320847	1.320847
7.00	.736261	.906541	.950747	.931712	.931712	.931712	.931712	.931712	.931712
8.00	.369525	.533917	.616125	.645658	.645658	.645658	.645658	.645658	.645658
9.00	.180352	.307576	.392091	.440566	.440566	.440566	.440566	.440566	.440566
10.00	.096031	.173848	.245566	.296554	.296554	.296554	.296554	.296554	.296554
15.00	.001743	.008228	.019820	.035033	.035033	.035033	.035033	.035033	.035033
20.00	.000033	.000334	.001347	.003497	.003497	.003497	.003497	.003497	.003497
25.00	.000001	.000014	.000087	.000324	.000324	.000324	.000324	.000324	.000324
30.00	.000000	.000001	.000006	.000030	.000030	.000030	.000030	.000030	.000030
MASS IN AIR	90.558710	88.204316	86.397723	94.892037	94.892037	94.892037	94.892037	94.892037	94.892037
MASS ON GROUND	9.434784	11.790629	13.598165	15.114532	15.114532	15.114532	15.114532	15.114532	15.114532
TOTAL	99.993494	99.994945	99.995888	99.996569	99.996569	99.996569	99.996569	99.996569	99.996569
DEPOSIT DENSITY	.440264	.255335	.166899	.116066	.116066	.116066	.116066	.116066	.116066
CROSSWIND FUNCTION	.167268	.124853	.100326	.093618	.093618	.093618	.093618	.093618	.093618

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DOWNWIND CONCENTRATIONS

VERTICAL GRID Z (I)	79.75			99.81			199.67			400.19		
	X	Y	CONCENTRATION	X	Y	CONCENTRATION	X	Y	CONCENTRATION	X	Y	CONCENTRATION
.30			1.077891			.677672			.156898			.035505
.10			1.932568			1.216443			.282361			.063985
.20			2.224671			1.402851			.326919			.074241
.30			2.391218			1.511071			.353765			.090537
.40			2.499057			1.582909			.372470			.035029
.50			2.572172			1.633314			.386432			.088477
.60			2.622097			1.669435			.397262			.091241
.70			2.655303			1.695282			.405856			.093520
.80			2.675854			1.713350			.412767			.095436
.90			2.686475			1.725308			.418359			.097029
1.00			2.689103			1.732334			.422887			.098476
2.00			2.480591			1.654677			.435606			.105664
3.00			2.111311			1.466089			.420918			.106094
4.00			1.725566			1.252292			.395302			.105754
5.00			1.372635			1.044475			.364874			.103058
6.00			1.069763			.855852			.332711			.099559
7.00			.820011			.691450			.300563			.095497
8.00			.619830			.552054			.269478			.091113
9.00			.462865			.436290			.240078			.086554
10.00			.341968			.341722			.212717			.081922
15.00			.066352			.090592			.109000			.059745
20.00			.011104			.021121			.051664			.041533
25.00			.001704			.004529			.023153			.027914
30.00			.000251			.000923			.009942			.013276
MASS IN AIR			82.503744			80.675738			75.277887			70.354345
MASS ON GROUND			17.493709			19.322260			24.721189			29.645238
TOTAL			99.997453			99.997992			99.999076			99.999584
DEPOSIT DENSITY			.064673			.040660			.009414			.002130
CROSSWIND FUNCTION			.062774			.050213			.025223			.012709

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DOWNWIND CONCENTRATIONS

VERTICAL GRID Z (1)	X		X		X	
	599.50	CONCENTRATION	800.64	CONCENTRATION	1000.58	CONCENTRATION
						1995.91
						CONCENTRATION
						.001175
						.002121
						.002466
						.002680
						.002936
						.002958
						.003058
						.003143
						.003217
						.003281
						.003339
						.003705
						.003900
						.004021
						.004100
						.004152
						.004185
						.004203
						.004210
						.004202
						.004108
						.003922
						.003695
						.003443
						60.863346
MASS IN AIR	67.729655		65.954220		64.642622	
MASS ON GROUND	32.270083		34.045592		35.357232	
TOTAL	99.999738		99.999812		99.999854	
DEPOSIT DENSITY	.000392		.000484		.000502	
CROSSWIND FUNCTION	.008564		.006473		.005227	

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A-1

DOWNWIND CONCENTRATIONS

	X	X	X	X
	3998.99	6000.33	7998.19	10005.02
VERTICAL GRID Z(1)	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	.000284	.000127	.000072	.000047
.10	.000513	.000229	.000131	.000085
.20	.000596	.000266	.000152	.000099
.30	.000648	.000289	.000165	.000108
.40	.000685	.000306	.000175	.000114
.50	.000716	.000320	.000183	.000119
.60	.000741	.000331	.000189	.000123
.70	.000761	.000340	.000194	.000127
.80	.000779	.000348	.000199	.000130
.90	.000795	.000355	.000203	.000132
1.00	.000810	.000362	.000207	.000135
2.00	.000902	.000404	.000231	.000151
3.00	.000954	.000427	.000245	.000160
4.00	.000929	.000444	.000254	.000166
5.00	.001014	.000456	.000262	.000171
6.00	.001034	.000466	.000267	.000175
7.00	.001048	.000473	.000272	.000178
8.00	.001060	.000479	.000276	.000181
9.00	.001069	.000484	.000279	.000183
10.00	.001075	.000489	.000282	.000185
15.00	.001089	.000501	.000291	.000191
20.00	.001083	.000505	.000295	.000195
25.00	.001064	.000503	.000296	.000196
30.00	.001039	.000499	.000296	.000197
MASS IN AIR	57.448135	55.431580	53.826098	52.456897
MASS ON GROUND	42.523803	44.341965	45.563396	46.479138
TOTAL	99.971938	99.773545	99.389494	98.936035
DEPOSIT DEASITY	.000017	.000008	.000004	.000003
CROSSWIND FUNCTION	.001475	.001051	.000936	.000705

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A MATHEMATICAL MODEL DESIGNED TO DESCRIBE THE DOWNWIND
TRAVEL AND VERTICAL PROFILE OF PARTICULATE MATTER FROM AN ELEVATED SOURCE

STABILITY 2, 20 MICRONS E=1.0, HH=1.0, NZ=95, DY=0.001

PA= .03000 (AIR PERMEABILITY)
M= .23 (WIND PROFILE PARAMETER)
S = 2.000 (TOTAL SPECIFIC AREA)
A = .0400 (VON KARMAN'S CONSTANT/10)
DL = .025 (ROUGHNESS LENGTH)
Q = .01215 (TERMINAL VELOCITY)
E = 1.000 (RETENTION FACTOR)
SOURCE= 1000.00 (SOURCE STRENGTH)
U(2)= 3.06 (2 METRE WIND)

H	HH	XO
ATMOSPHERIC LID	RELEASE HEIGHT	DOWNWIND DISTANCE
500.000	1.000	11000.000

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YC = .0 (CROSSWIND COORDINATE)
IPSC = 2 (STABILITY CATEGORY INDICATOR)
IPSC = 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F.

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DOWNWIND CONCENTRATIONS

VERTICAL GRID Z (I)	29.86			40.02			49.83			59.82		
	X	CONCENTRATION	X	CONCENTRATION	X	CONCENTRATION	X	CONCENTRATION	X	CONCENTRATION	X	CONCENTRATION
.00		8.135571		4.694683		3.057705		2.120272		2.120272		2.120272
.10		13.958597		8.072143		5.26077		3.656268		3.656268		3.656268
.20		15.571646		9.034967		5.909110		4.110834		4.110834		4.110834
.30		16.305073		9.497727		6.230181		4.344209		4.344209		4.344209
.40		16.635822		9.732923		6.405420		4.477802		4.477802		4.477802
.50		16.732376		9.836148		6.496283		4.553600		4.553600		4.553600
.60		16.675553		9.852896		6.531843		4.592068		4.592068		4.592068
.70		16.511227		9.808772		6.528359		4.603560		4.603560		4.603560
.80		16.268412		9.719830		6.495962		4.595427		4.595427		4.595427
.90		15.966392		9.596924		6.441455		4.571947		4.571947		4.571947
1.00		15.620917		9.447810		6.369675		4.536460		4.536460		4.536460
2.00		11.263195		7.345935		5.214996		3.861843		3.861843		3.861843
3.00		7.232477		5.192639		3.922775		3.041425		3.041425		3.041425
4.00		4.312238		3.468697		2.812493		2.295928		2.295928		2.295928
5.00		2.428414		2.221616		1.948504		1.682136		1.682136		1.682136
6.00		1.305177		1.375151		1.313011		1.203802		1.203802		1.203802
7.00		.674676		.827063		.864536		.844800		.844800		.844800
8.00		.337558		.485291		.559003		.582076		.582076		.582076
9.00		.164374		.278748		.353937		.396418		.396418		.396418
10.00		.078281		.157194		.221089		.266070		.266070		.266070
15.00		.001581		.007400		.017716		.031164		.031164		.031164
20.00		.000030		.000300		.001202		.003102		.003102		.003102
25.00		.000001		.000012		.000078		.000287		.000287		.000287
30.00		.000000		.000001		.000005		.000027		.000027		.000027
MASS IN AIR		87.207223		84.075493		81.682702		79.681698		79.681698		79.681698
MASS ON GROUND		12.785572		15.918937		18.312783		20.314545		20.314545		20.314545
TOTAL		99.992794		99.994429		99.995485		99.996243		99.996243		99.996243
DEPOSIT DENSITY		.587063		.338768		.220644		.152999		.152999		.152999
CROSSWIND FUNCTION		.157269		.124853		.100326		.083618		.083618		.083618

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DOWNWIND CONCENTRATIONS

VERTICAL GRID Z (1)	X			X			X		
	79.76			99.81			199.67		
	CONCENTRATION			CONCENTRATION			CONCENTRATION		
.00	1.176233		.737020				.108921		.037945
.10	2.031947		1.274695				.292897		.065710
.20	2.290852		1.439711				.332113		.074666
.30	2.428686		1.529556				.354457		.079887
.40	2.512254		1.585871				.369367		.083475
.50	2.564638		1.622992				.380068		.086145
.60	2.596639		1.647596				.388051		.088227
.70	2.614223		1.663359				.394125		.089900
.80	2.621062		1.672529				.393785		.091270
.90	2.619511		1.676592				.402350		.092408
1.00	2.611520		1.676583				.405042		.093363
2.00	2.345030		1.538801				.406011		.097463
3.00	1.964956		1.339630				.386104		.097105
4.00	1.582581		1.148721				.358556		.094895
5.00	1.253335		.950181				.328123		.091678
6.00	.970464		.773477				.297136		.087907
7.00	.739969		.521527				.266887		.083815
8.00	.556876		.493989				.238115		.079556
9.00	.414319		.388903				.211246		.075235
10.00	.305141		.303603				.186479		.070925
15.00	.058609		.079599				.094292		.050963
20.00	.009763		.018452				.044327		.035081
25.00	.001495		.003946				.019759		.023413
30.00	.000220		.000803				.008455		.015248
MASS IN AIR	76.553376		74.158229				67.132955		60.788980
MASS ON GROUND	23.443847		25.839596				32.866047		39.210576
TOTAL	99.997223		99.997825				99.999006		99.999556
DEPOSIT DENSITY	.084977		.053183				.012189		.002731
CROSSWIND FUNCTION	.062774		.050213				.025223		.012708

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DOWNWIND CONCENTRATIONS

VERTICAL GRID Z (I)	X			X			X		
	599.50	800.64	1000.58	1998.91	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	.015854	.008520	.005290	.001224	.009193	.005193	.002127	.002422	.002596
.10	.027540	.014804	.010459	.011208	.018041	.011731	.002719	.002813	.002898
.20	.031316	.016840	.011208	.012128	.018877	.012445	.002951	.003004	.003050
.30	.033534	.018041	.011208	.012445	.019511	.012706	.003091	.003336	.003455
.40	.035073	.019511	.012128	.012706	.020014	.012927	.003520	.003557	.003576
.50	.036231	.020014	.012445	.013116	.020775	.013116	.003572	.003567	.003550
.60	.037145	.020775	.012706	.013281	.021072	.013281	.003410	.003213	.003005
.70	.037392	.020775	.012927	.014577	.021329	.014577	.002785		
.80	.038513	.020775	.013116	.014699	.022735	.014699			
.90	.039040	.020775	.013281	.014887	.023200	.014887			
1.00	.039492	.020775	.013422	.014932	.023120	.014932			
2.00	.041300	.020775	.014332	.014332	.023120	.014332			
3.00	.042312	.020775	.014332	.014332	.023120	.014332			
4.00	.042068	.020775	.014332	.014332	.023120	.014332			
5.00	.041405	.020775	.014332	.014332	.023120	.014332			
6.00	.040483	.020775	.014332	.014332	.023120	.014332			
7.00	.039390	.020775	.014332	.014332	.023120	.014332			
8.00	.038185	.020775	.014332	.014332	.023120	.014332			
9.00	.036905	.020775	.014332	.014332	.023120	.014332			
10.00	.035579	.020775	.014332	.014332	.023120	.014332			
15.00	.028916	.020775	.014332	.014332	.023120	.014332			
20.00	.022594	.020775	.014332	.014332	.023120	.014332			
25.00	.017316	.020775	.014332	.014332	.023120	.014332			
30.00	.013039	.020775	.014332	.014332	.023120	.014332			
MASS Y4 AIR	57.433974	55.175961	53.514113	48.757586					
MASS ON GROUND	62.565748	64.823840	66.485733	51.242295					
TOTAL	99.999722	99.999801	99.999846	99.999821					
DEPOSIT DENSITY	.001144	.000615	.000382	.000093					
CROSSWIND FUNCTION	.005564	.006473	.005227	.002733					

UNCLASSIFIED

DOWNWIND CONCENTRATIONS

VERTICAL GRID Z (I)	X			X			X		
	3998.99			6000.33			7998.19		
	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	.000293	.000130	.000074	.000074	.000074	.000074	.000074	.000074	.000074
.10	.000509	.000226	.000129	.000129	.000129	.000129	.000129	.000129	.000129
.20	.000579	.000257	.000146	.000146	.000146	.000146	.000146	.000146	.000146
.30	.000621	.000276	.000157	.000157	.000157	.000157	.000157	.000157	.000157
.40	.000651	.000289	.000164	.000164	.000164	.000164	.000164	.000164	.000164
.50	.000674	.000299	.000170	.000170	.000170	.000170	.000170	.000170	.000170
.60	.000692	.000307	.000175	.000175	.000175	.000175	.000175	.000175	.000175
.70	.000707	.000314	.000179	.000179	.000179	.000179	.000179	.000179	.000179
.80	.000720	.000319	.000182	.000182	.000182	.000182	.000182	.000182	.000182
.90	.000732	.000325	.000185	.000185	.000185	.000185	.000185	.000185	.000185
1.00	.000742	.000329	.000187	.000187	.000187	.000187	.000187	.000187	.000187
2.00	.000804	.000357	.000203	.000203	.000203	.000203	.000203	.000203	.000203
3.00	.000836	.000372	.000212	.000212	.000212	.000212	.000212	.000212	.000212
4.00	.000857	.000382	.000218	.000218	.000218	.000218	.000218	.000218	.000218
5.00	.000871	.000389	.000222	.000222	.000222	.000222	.000222	.000222	.000222
6.00	.000881	.000394	.000225	.000225	.000225	.000225	.000225	.000225	.000225
7.00	.000887	.000398	.000228	.000228	.000228	.000228	.000228	.000228	.000228
8.00	.000892	.000401	.000230	.000230	.000230	.000230	.000230	.000230	.000230
9.00	.000895	.000403	.000231	.000231	.000231	.000231	.000231	.000231	.000231
10.00	.000897	.000405	.000233	.000233	.000233	.000233	.000233	.000233	.000233
15.00	.000894	.000409	.000236	.000236	.000236	.000236	.000236	.000236	.000236
20.00	.000872	.000407	.000237	.000237	.000237	.000237	.000237	.000237	.000237
25.00	.000856	.000402	.000235	.000235	.000235	.000235	.000235	.000235	.000235
30.00	.000829	.000395	.000233	.000233	.000233	.000233	.000233	.000233	.000233
MASS IN AIR	44.516177	42.128112	40.347251	40.347251	40.347251	40.347251	40.347251	40.347251	40.347251
MASS ON GROUND	55.461016	57.706082	59.206017	59.206017	59.206017	59.206017	59.206017	59.206017	59.206017
TOTAL	99.979195	99.834194	99.553268	99.553268	99.553268	99.553268	99.553268	99.553268	99.553268
DEPOSIT DENSITY	.000021	.000009	.000005	.000005	.000005	.000005	.000005	.000005	.000005
CROSSWIND FUNCTION	.001475	.001051	.000836	.000836	.000836	.000836	.000836	.000836	.000836

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1 - 1.000 C
2 - 2.000 C
3 - 3.000 C
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42 - 42.000 C
43 - 43.000 C
44 - 44.000 C
45 - 45.000 C
46 - 46.000 C

STARTED DIFFP FROM DIFF JAN21/87

EDITOR TEST MAY 25/83
REAL M,LAMA
DIMENSION ZZ(25),ID(25),RD(25),ZX(2),IR(2),RIR(2),YOUT(20),IY(20)
DIMENSION CS(25),30(25,7),PERA(20),PERG(20),TOT(20),DOSE(25,4)
DIMENSION CD(20)
COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
COMMON CV(100),RZ(100)

MAINLINE PROGRAM FOR PARTICULATE DIFFUSION
6 READ(5,100) PA,M,S,A,DL,Q,E,SOURC
IF(M)1,1,2
1 CALL EXIT
2 READ(5,100) XO,DY,H,HH,U2M
READ(5,101) THETA,NZ,IC,IC1
NY= IFIX(CALOG(XC/H + 1))/DY + 0.71
IF(U2M) 3,3,4
3 U2M=1.0
4 CALL PPARM(X0)
CALL PCONS(THETA,NY,RH,RHH,L,ALPA,BETA,GAMA,LAMA,A11,D11)
CALL POUTP(IC,IK,INN,ZZ,ID,RD,ICZX,ZX,IR,RIR,IY,YOUT,NUMOX)
I1=1
I2=0
J1=1
J2=1
J3=0

GRDM=0.0
GRDM1=0.0
WRITE(6,102)
102 FORMAT(1H1)
IF(IC-4) 5,6,6
5 DO 7 J=1,NY
J3=J3+1
CALL PTRID(J,ALPA,BETA,GAMA,LAMA,A11,D11,THETA,IC,IC1,J3)
CALL PMBAG(ICZX,RH,RHH,AIRM,GRDM,GRDM1,PERAR,PERGD,TOTAL,PEAK,PZ,
1 CS,COFAC,IR,RIR,J)

IF(ICZX) 8,8,9
9 IF(J-11) 8,10,10
10 I1=I1+IK

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47 - 47.000 I2=I2+1
48 - 48.000 CALL PBALOC(ICZX,I2,PEAK,PZ,CS,J,DY,PERAR,PERGD,TOTAL,COFAC,ZX,BO)
49 - 49.000 8 IF(J2-NUMOX) 11,11,12
50 - 50.000 11 IF(J-IY(J2)) 12,13,18
51 - 51.000 13 PERA(J2)=PERAR
52 - 52.000 PERG(J2)=PERGD
53 - 53.000 TOT(J2)=TOTAL
54 - 54.000 CALL BESIN(CV,NZ,ID,RD,INN,CS)
55 - 55.000 CD(J1)=CS(1)+COFAC+U2M+A+E*(PA+Q/S)*S
56 - 56.000 DO 14 I=1,INN
57 - 57.000 DOSE(I,J1)=CS(I)+COFAC
58 - 58.000 14 CONTINUE
59 - 59.000 IF(J1-4) 15,16,16
60 - 60.000 15 IF(J2-NUMOX) 17,16,16
61 - 61.000 16 CALL PPOUT(J1,J2,DOSE,ZZ,INN,YOUT,PERA,PERG,TOT,CD)
62 - 62.000 J1=0
63 - 63.000 17 J1=J1+1
64 - 64.000 J2=J2 + 1
65 - 65.000 GO TO 12
66 - 66.000 18 CONTINUE
67 - 67.000 WRITE (5,103)
68 - 68.000 GO TO 6
69 - 69.000 12 CONTINUE
70 - 70.000 7 CONTINUE
71 - 71.000 GO TO 6
72 - 72.000 100 FORMAT(2F10.0)
73 - 73.000 101 FORMAT(10.0,3I3)
74 - 74.000 103 FORMAT(1H1,4X,'DY IS TOO LARGE FOR SOME INTERVAL OF XOUT(I),'//
75 - 75.000 14X,'OR XOUT(I) HAS NOT BEEN SPECIFIED IN ORDER OF INCREASING MAGNI
76 - 76.000 1TDE.')
77 - 77.000 END
78 - 78.000 SUBROUTINE PPARM(XO)
79 - 79.000 REAL M
80 - 80.000 DIMENSION HEAD(80)
81 - 81.000 COMMON PA,M,S,A,DL,Q,E,SOURCE,U2M,DR,DY,H,HH,NZ
82 - 82.000 C
83 - 83.000 C
84 - 84.000 PEAD(5,100) (HEAD(I),I=1,80)
85 - 85.000 WRITE(6,200)
86 - 86.000 WRITE(6,201) (HEAD(I),I=1,80)
87 - 87.000 WRITE(6,202) PA
88 - 88.000 WRITE(6,203) M
89 - 89.000 WRITE(6,204) S
90 - 90.000 WRITE(6,205) A
91 - 91.000 WRITE(6,206) DL
92 - 92.000 WRITE(6,207) Q
93 - 93.000 WRITE(6,208) E
94 - 94.000 WRITE(6,209) SOURC

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95 - 95.000 WRITE(6,210) U2M
96 - 96.000 WRITE(6,211)
97 - 97.000 WRITE(6,212) N,HH,XC
98 - 98.000 100 FORMAT(30A1)
99 - 99.000 200 FORMAT(1H1,32X,'A MATHEMATICAL MODEL DESIGNED TO DESCRIBE THE DOWN
100 - 100.000 1WIND,/,23X,'TRAVEL AND VERTICAL PROFILE OF PARTICULATE MATTER FRO
101 - 101.000 2M AN ELEVATED SOURCE',/)
102 - 102.000 201 FORMAT(20X,80A1,/)
103 - 103.000 202 FORMAT(40X,'PA= ',F7.5,4X,'(AIR PERMEABILITY)')
104 - 104.000 203 FORMAT(40X,'M= ',F5.2,7X,'(WIND PROFILE PARAMETER)')
105 - 105.000 204 FORMAT(40X,'S= ',F5.3,6X,'(TOTAL SPECIFIC AREA)')
106 - 106.000 205 FORMAT(40X,'A= ',F6.4,5X,'(VON KARMANS CONSTANT/10)')
107 - 107.000 206 FORMAT(40X,'DL= ',F6.3,5X,'(ROUGHNESS LENGTH)')
108 - 108.000 207 FORMAT(40X,'Q= ',F7.5,5X,'(TERMINAL VELOCITY)')
109 - 109.000 208 FORMAT(40X,'E= ',F7.3,5X,'(RETENTION FACTOR)')
110 - 110.000 209 FORMAT(40X,'SOURC= ',F8.2,1X,'(SOURCE STRENGTH)')
111 - 111.000 210 FORMAT(40X,'U(2)= ',F5.2,5X,'(2 METPE WIND)')
112 - 112.000 211 FORMAT(//,49X,'H',29X,'HH',8X,'X0',/,44X,'ATMOSPHERIC RELEASE DOW
113 - 113.000 1WIND,/,48X,'L10 HEIGHT DISTANCE')
114 - 114.000 212 FORMAT(//,44X,3(F10.3))
115 - 115.000 RETURN
116 - 116.000 END
117 - 117.000 SUBROUTINE PCONS(THETA,NY,RH,QHH,IC,ALPA,BETA,GAMA,LAMA,A11,D11)
118 - 118.000 REAL N,LAMA,NU
119 - 119.000 COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
120 - 120.000 COMMON CV(100),RZ(100)
121 - 121.000 C
122 - 122.000 C
123 - 123.000 C
124 - 124.000 C
125 - 125.000 DETERMINE DELTA R
126 - 126.000 DR = ALOG((H + DL)/DL)/FLOAT(NZ-1)
127 - 127.000 HHR = ALOG((HH + DL)/DL)
128 - 128.000 HK = ALOG((H + DL)/(HH + DL))
129 - 129.000 HR = ALOG((H + DL)/DL)
130 - 130.000 H1 = FLOAT(HZ)-HK/DR-(HHR-FLOAT(IFIX(HHR)))
131 - 131.000 IHH = IFIX(H1 + 0.001)
132 - 132.000 DR = HHR/FLGAT(IHH-1)
133 - 133.000 NZ = IFIX(HR/DR + 0.5) + 1
134 - 134.000 RH = FLOAT(NZ-1)*DR
135 - 135.000 RHH = FLOAT(IHH-1)*DR
136 - 136.000 RZ(1)=0.0
137 - 137.000 CV(1)=0.0
138 - 138.000 DO 1 I=2,NZ
139 - 139.000 RZ(I)=RZ(I-1) + DR
140 - 140.000 CV(I)=0.0
141 - 141.000 1 CONTINUE
142 - 142.000 CV(IHH)=1.0

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143 - 143.000 C
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187 - 187.000 C
188 - 188.000 C
189 - 189.000 C
190 - 190.000 C

NORMALIZE
DL=DL/H
Q=Q/(U2M*A)
PA=PA/(U2M*A)

CONSTANTS FOR THE MATRIX
NU=(A/DL)*(H*DL/(2.*H*DL))*(-M)
ALPA=NU*THETA*DY/DR**2.
BETA=NU*THETA*DY*Q/DR
GAMA=NU*(1.-THETA)*DY/DR**2.
LAMA=NU*(1.-THETA)*DY*Q/DP
A11=E*(PA+Q/S)*S*NU*THETA*DY/DR
D11=E*(PA+G/S)*S*NU*(1.-THETA)*DY/DR

IF(IC-1) 2,3,3
2 RETURN

PRINT OUT RUN PARAMETERS AND MATRIX CONSTANTS
3 WRITE(6,200)
WRITE(6,201) DR,NZ,DY,NY,THETA
WRITE(6,202) H,HR,RH
WRITE(6,203) HH,MHR,RHH,IHH
WRITE(6,204)
WRITE(6,205) ALPA,BETA,GAMA,LAMA,A11,D11
200 FORMAT(/,32X,'RUN PARAMETERS',/,39X,'DR',8X,'NZ',8X,'DY',8X,'NY',
16X,'THETA')
201 FORMAT(36X,F7.3,4X,I4,5X,F7.3,4X,I5,4X,F7.3)
202 FORMAT(/,40X,'H',8X,'HR',8X,'RH',/,34X,F10.3,2X,F7.3,4X,F7.3)
203 FORMAT(/,39X,'HH',7X,'MHR',7X,'RHH',7X,'IHH',/,35X,F9.3,1X,F7.3,3X
1,F7.3,3X,I5)
204 FORMAT(/,32X,'MATRIX CONSTANTS',/,37X,'ALPHA',6X,'BETA',5X,'GAMA
1',6X,'LAMA',6X,'A11',9X,'D11',/)
205 FORMAT(34X,5F10.4)
RETURN

END
SUBROUTINE PCUTP(IC,IK,K,ZZ,IO,RD,ICIX,ZY,IR,RIR,IY,YOUT,NUMOX)
REAL M
DIMENSION XCUT(20),STATZ(10),ENDZ(10),ZOUIN(10),ZZ(1),RZZ(25)
DIMENSION ID(1),RND(1),ZX(1),IR(1),RIR(1),RZX(2),IY(1),YOUT(1)
COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,MH,NZ
COMMON CV(100),PZ(100)
THIS SUBROUTINE SETS UP PRINTOUT CONTROLS
READ(5,100) HUMCX,NOVES,ICIX,IK
READ(5,101) (XOUT(I),I=1,NUMOX)
READ(5,102) (STATZ(I),ENDZ(I),ZOUIN(I),I=1,NOVES)

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191 - 191.000      IF(IK) 1,1,2
192 - 192.000      1 IK=1
193 - 193.000      2 CONTINUE
194 - 194.000      C
195 - 195.000      C
196 - 196.000      C
197 - 197.000      Z OUTPUT ARRAY SET UP
198 - 198.000      K=1
199 - 199.000      DO 3 J=1,MOVES
200 - 200.000      IF(K-1) 4,4,5
201 - 201.000      5 IF(IFIX(10.*(STATZ(J)+0.005)) - IFIX(10.*(ZZ(K)+0.005))) 4,6,7
202 - 202.000      7 K=K+1
203 - 203.000      4 ZZ(K)=STATZ(J)
204 - 204.000      6 DO 9 I=1,25
205 - 205.000      K=K+1
206 - 206.000      ZZ(K)=ZZ(K-1) + ZOUIN(J)
207 - 207.000      IF(IFIX(10.*(ZZ(K)+0.005)) - IFIX(10.*(ZZ(K-1) + 0.005))) 9,9,10
208 - 208.000      10 IF(IFIX(10.*(ZZ(K)+0.005)) - IFIX(10.*(ENDZ(J) + 0.005))) 8,3,3
209 - 209.000      8 CONTINUE
210 - 210.000      GO TO 11
211 - 211.000      9 K=K-1
212 - 212.000      3 CONTINUE
213 - 213.000      11 CONTINUE
214 - 214.000      C
215 - 215.000      L=1
216 - 216.000      DO 12 I=1,K
217 - 217.000      RZ(I)=ALOG((ZZ(I)/H+DL)/DL)
218 - 218.000      DO 13 J=L,NZ
219 - 219.000      IF(RZ(I)-RZ(J)) 14,15,16
220 - 220.000      14 ID(I)=J-1
221 - 221.000      15 ID(I)=J
222 - 222.000      RD(I)=(RZ(I)-RZ(J))/DR
223 - 223.000      GO TO 19
224 - 224.000      16 CONTINUE
225 - 225.000      13 CONTINUE
226 - 226.000      19 L=J
227 - 227.000      12 CONTINUE
228 - 228.000      DO 40 I=1,K
229 - 229.000      ZZ(I)=ZZ(I)+0.0001
230 - 230.000      40 CONTINUE
231 - 231.000      C
232 - 232.000      IF(ICZX-1) 20,20,21
233 - 233.000      C
234 - 234.000      C
235 - 235.000      21 L=ICZX-1
236 - 236.000      READ(5,102) (Y(I),I=1,L)
237 - 237.000      DO 22 I=1,L
238 - 238.000      RZX(I)=ALOG((ZX(I)/H+DL)/DL)

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READ HEIGHTS FOR HORIZONTAL PROFILE AND TRANSFORM TO R,Y PLANE

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239 - 239.000      DO 23 J=1,NZ
240 - 240.000      IF(RZX(I)-RZ(J)) 25,24,23
241 - 241.000      25 IF(RZ(J)-RZX(I)-0.5*DR) 24,24,26
242 - 242.000      23 CONTINUE
243 - 243.000      24 IR(I)=J
244 - 244.000      RIR(I)=(RZ(J)-RZX(I))/DR
245 - 245.000      GO TO 22
246 - 246.000      26 IR(I)=J+1
247 - 247.000      RIR(I)=(RZ(J)-RZX(I))/DR
248 - 248.000      22 CONTINUE
249 - 249.000 C
250 - 250.000      20 DO 30 I=1,NUMOX
251 - 251.000      YX=ALOG(XOUT(I)/H + 1.)/DY
252 - 252.000      IYX=IFIX(YX)
253 - 253.000      RYX=YX-FLOAT(IYX)
254 - 254.000      IF(RYX-0.5) 31,31,32
255 - 255.000      31 IY(I)=IYX
256 - 256.000      GO TO 33
257 - 257.000      32 IY(I)=IYX + 1
258 - 258.000      33 YOUT(I)=H*(EXP(FLOAT(IY(I))*DY) - 1.)
259 - 259.000      30 CONTINUE
260 - 260.000 C
261 - 261.000      IF(IC-2) 34,35,35
262 - 262.000      34 RETURN
263 - 263.000 C
264 - 264.000 C      PRINT OUT OUTPUT CONTROLS
265 - 265.000      35 WRITE(6,200)
266 - 266.000      WRITE(6,201) (STATZ(I),ENDZ(I),ZOUTIN(I),I=1,MOVES)
267 - 267.000      WRITE(6,202)
268 - 268.000      WRITE(6,203) (Z2(I),RZ2(I),ID(I),RD(I),I=1,K)
269 - 269.000      WRITE(6,204)
270 - 270.000      WRITE(6,205) (XOUT(I),YOUT(I),IY(I),I=1,NUMOX)
271 - 271.000      IF(ICZX-1) 36,36,37
272 - 272.000 C
273 - 273.000 C      PRINT OUT OUTPUT CONTROLS FOR HORIZONTAL PROFILE
274 - 274.000      37 WRITE(6,206)
275 - 275.000      WRITE(6,207) (ZX(I),RZX(I),IR(I),RIR(I),I=1,L)
276 - 276.000 C
277 - 277.000      100 FORMAT(4I2)
278 - 278.000      101 FORMAT(8F10.0)
279 - 279.000      102 FORMAT(3F10.0)
280 - 280.000      200 FORMAT(1H1,32X,'Z OUTPUT CONTROLS',//,33X,'A) INTERVALS',//,37X,'ST
281 - 281.000      1ART      END      INCREMENT',//)
282 - 282.000      201 FORMAT(37X,F6.2,3X,F6.2,4X,F6.2)
283 - 283.000      202 FORMAT(//,33X,'B) ARRAY',//,39X,'Z
284 - 284.000      1//)
285 - 285.000      203 FORMAT(35X,F6.3,2X,F8.3,4X,F8.3,4X,F6.4)
286 - 286.000      204 FORMAT(//,32X,'X OUTPUT',//,39X,'X

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ID THETA,
 RZ ID X-OUT
 IY',//)

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287 - 287.000 205 FORMAT(3X,F10.4,F10.4,4X,I4)
288 - 288.000 206 FORMAT(/,3X,'X VS Z OUTPUT CONTROLS',/,39X,'2X',7X,'PIX',8X,'IR',
289 - 289.000 16X,'THETA',/)
290 - 290.000 207 FORMAT(35X,F8.3,2X,F8.3,3X,I4,7X,F5.2)
291 - 291.000 36 RETURN
292 - 292.000 END
293 - 293.000 SUBROUTINE PTRID(J,ALPHA,BETA,GAMA,LAMA,A11,D11,THETA,IC,IC1,J3)
294 - 294.000 REAL M,LAMA
295 - 295.000 DIMENSION XI(100),D(100),W(100),G(100),QG(100),CG(100)
296 - 296.000 COMMON PA,M,S,A,DL,Q,E,SOURCE,U2M,DN,DY,M,HH,NZ
297 - 297.000 COMMON CV(100),RZ(100)
298 - 298.000 C
299 - 299.000 C THIS SUBROUTINE INVERTS THE MATRIX
300 - 300.000 C XI(1)=EXP((FLOAT(J)-1.+(1.-THETA))*.DY)
301 - 301.000 D(1)=(GAMA + LAMA)*CV(2) -(GAMA + D11 - 1./XI(1))*CV(1)
302 - 302.000 K=NZ-1
303 - 303.000 C
304 - 304.000 DO 1 I=2,K
305 - 305.000 XI(I)=EXP(-(FLCAT(I)-1.)*(M+1.)*.DR)*XI(1)
306 - 306.000 D(I)=(GAMA + LAMA)*CV(I+1) -(2.*GAMA + LAMA - 1./XI(I))*CV(I) +
307 - 307.000 1 GAMA*CV(I-1)
308 - 308.000 1 CONTINUE
309 - 309.000 XI(NZ)=EXP(-(FLOAT(NZ)-1.)*(M+1.)*.DR)*XI(1)
310 - 310.000 D(NZ)= -(GAMA + LAMA*(1. - 1./XI(NZ))*CV(NZ) + GAMA*CV(NZ-1)
311 - 311.000 C
312 - 312.000 B= -(ALPHA + BETA)
313 - 313.000 C= - ALPHA
314 - 314.000 W(1)=ALPHA + A11 + 1./XI(1)
315 - 315.000 G(1)=D(1)/W(1)
316 - 316.000 C
317 - 317.000 DO 2 I=2,NZ
318 - 318.000 QG(I-1) = B/W(I-1)
319 - 319.000 W(I)=2.*ALPHA + BETA + 1./XI(I) - C*QG(I-1)
320 - 320.000 IF(I-NZ) 3,4,4
321 - 321.000 4 W(I) = W(I) - ALPHA + BETA
322 - 322.000 3 G(I)=(D(I)-C*G(I-1))/W(I)
323 - 323.000 2 CONTINUE
324 - 324.000 C
325 - 325.000 CV(NZ)=G(NZ)
326 - 326.000 DO 5 I=1,K
327 - 327.000 L=NZ-I
328 - 328.000 C/(L)=G(L) - 9Q(L)*CV(L+1)
329 - 329.000 5 CONTINUE
330 - 330.000 IF(IC-3) 6,7,7
331 - 331.000 6 RETURN
332 - 332.000 C
333 - 333.000 C INTERROGATE MATRIX
334 - 334.000 7 IF(J3-IC1) 6,8,6

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335 - 335.000      8 J3=0
336 - 336.000      DO 9 I=1,NZ
337 - 337.000      9 CG(I)=ALOG(CV(I)+1.)/O.69315
338 - 338.000      WRITE(6,100)
339 - 339.000      WRITE(6,101) J
340 - 340.000      WRITE(6,102)
341 - 341.000      WRITE(6,103) (I,CV(I),CG(I),G(I),XI(I),W(I),G(I),I=1,NZ)
342 - 342.000      100 FORMAT(1M1,52X,'VERTICAL PROFILE',/,48X,'AND MATRIX INTERROGATION',
343 - 343.000      1)
344 - 344.000      101 FORMAT(/,53X,'ITERATION=',I5,/)
345 - 345.000      102 FORMAT(24X,'I',7X,'CV',4X,'LN(CV+1)/LN(2)',5X,'D',10X,'XI',11X,'W',
346 - 346.000      1,11X,'G',/)
347 - 347.000      103 FORMAT(22X,I3,1X,E12.5,2X,F9.6,1X,E12.5)
348 - 348.000      RETURN
349 - 349.000      END
350 - 350.000      SUBROUTINE PHBAG(I,IX,MH,PHM,AIRM,GROM,GROM1,PERAR,PERGD,TOTAL,
351 - 351.000      1 PEAK,PZ,CS,COFAC,IR,RIR,J)
352 - 352.000      REAL M
353 - 353.000      DIMENSION IR(25),RIR(2),CS(25)
354 - 354.000      COMMON PA,M,S,A,DL,Q,E,SOURCE,U2M,DR,DY,M,MH,NZ
355 - 355.000      COMMON CV(100),RZ(100)
356 - 356.000      C
357 - 357.000      C
358 - 358.000      SUBROUTINE TO CALCULATE PEAKS AND MASS BALANCES
359 - 359.000      CK1=((M+DL)/(2.*MH+DL))-M DR=DL
360 - 360.000      CK2= DY*A-E*(PA+Q/S )=S
361 - 361.000      CK3= DL*DR-EXP(MH*(M+1.))*((M+DL)/(2.*MH+DL))-MH)
362 - 362.000      COFAC=SOURCE/(U2M*M+CK3)
363 - 363.000      C
364 - 364.000      C
365 - 365.000      MASS IN THE AIR
366 - 366.000      AIRM=O.5*(CV(1) + EXP(RH*(M+1.)))*CV(NZ))
367 - 367.000      K=NZ-1
368 - 368.000      DO 1 I=2,K
369 - 369.000      AIRM=AIRM + EXP((FLOAT(I)-1.)*DR*(M+1.))*CV(I)
370 - 370.000      C
371 - 371.000      C
372 - 372.000      PASS ON THE GROUND
373 - 373.000      GROM2=O.5*(CV(1)+EXP(FLOAT(J)*DY)*CK2)
374 - 374.000      GROM= (GROM1 + GROM2) + GROM
375 - 375.000      GROM1= GROM2
376 - 376.000      C
377 - 377.000      C
378 - 378.000      PERCENT IN AIR, AND ON THE GROUND
379 - 379.000      PERAR=100.*AIRM/CK3
380 - 380.000      PERGD=100.*GROM/CK3
381 - 381.000      TOTAL=PERAR + PERGD
382 - 382.000      IF(IC2X) 2,2,3
383 - 383.000      2 RETURN

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383 - 393.000 C
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429 - 439.000 C
430 - 440.000 C

      CALCULATE AND LOCATE PEAK CONCENTRATION
      4 PEAK=CV(1)
      DO 6 I=2,NZ
      IF(CV(I)-PEAK) 7,7,8
      8 PEAK=CV(I)
      6 CONTINUE
      7 IF(CV(1)-PEAK) 9,10,10
      10 II=1
      PZ=PEAK(1)
      GO TO 11
      9 II=I-1
      D=(RZ(II-1)*2.-RZ(II)*2.)*(RZ(II)-RZ(II+1))-(RZ(II)*2.-RZ(II+1)*
      11)*2.)*(RZ(II-1)-RZ(II))
      V=(CV(II-1)-CV(II))*(RZ(II)-RZ(II+1))-(CV(II)-CV(II+1))*(RZ(II-1)-
      12)*2.)*(RZ(II))
      V=V/D
      B=(RZ(II-1)*2.-RZ(II)*2.)*(CV(II)-CV(II+1))-(CV(II)*2.-RZ(II+1)*
      13)*2.)*(CV(II-1)-CV(II))
      B=B/D
      C=CV(II) - V*(RZ(II)*2.) - B*(RZ(II))
      PZ = -B/(2.*V)
      PEAK = V*(PZ*2.) + B*(PZ + C)
      11 GO TO (12,5,5),ICZX
      5 L=ICZX-1
      INTERPOLATE TO FIND HORIZONTAL PROFILE
      CALL BESIN(CV,NZ,IR,RIN,L,CS)
      12 CONTINUE
      RETURN
      END
      SUBROUTINE BESIN(CG,NZ,IARRY,N,CS)
      DIMENSION CV(100),CS(25),IARRY(1),RARRY(1),CG(100)
      THIS ROUTINE APPLIES BESSEL'S INTERPOLATION FUNCTION
      TO CALCULATE CONCENTRATION AT SPECIFIED HEIGHTS
      DO 8 I=1,NZ
      8 CV(I)=ALOG(CG(I)+1.)
      DO 9 J=1,N
      I=IARRY(J)
      TH=RARRY(J)
      B2=TH*(TH-1.)/4.
      B3=TH*(TH-0.5)*(TH-1.)/6.
      B4=(TH+1.)*TH*(TH-1.)*(TH-2.)/48.
      IF(I=NZ) 2,3,3
      3 CS(J)=CV(NZ)
      GO TO 1

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431 - 431.000      2 CS(J)=0.5*(CV(I) + CV(I+1)) + (TM-0.5)*(CV(I+1)-CV(I))
432 - 432.000      IF(I-1) 1,1,4
433 - 433.000      4 IF(I-(N2-1)) 5,1,1
434 - 434.000      5 CS(J)=CS(J) + B2*(CV(I+2)-CV(I+1)-CV(I)-1)) + B3*(CV(I+2)-
435 - 435.000      1 3.-CV(I+1) + 3.*CV(I) - CV(I-1))
436 - 436.000      IF(I-2) 1,1,6
437 - 437.000      6 IF(I-(N2-2)) 7,1,1
438 - 438.000      7 CS(J)=CS(J) + B4*(CV(I+3)-3.*CV(I+2)+2.*CV(I+1)+2.*CV(I)-3.*CV(I-1
439 - 439.000      1) + CV(I-2))
440 - 440.000      1 CONTINUE
441 - 441.000      CS(J)=EXP(CS(J))-1.
442 - 442.000      IF(CS(J)) 10,9,5
443 - 443.000      10 CS(J)=0.0
444 - 444.000      9 CONTINUE
445 - 445.000      RETURN
446 - 446.000      END
447 - 447.000      SUBROUTINE PBALC(ICZX,I2,PEAK,PZ,CS J,DY,PERAR,PERGO,TOTAL,COFAC,
448 - 448.000      1 ZX,BO)
449 - 449.000      DIMENSION BO(25,7),CS(25),ZX(2)
450 - 450.000      C
451 - 451.000      C
452 - 452.000      C
453 - 453.000      GO TO (1,1,2),ICZX
454 - 454.000      1 BO(12,1)=PEAK
455 - 455.000      BO(12,3)=PZ
456 - 456.000      GO TO (3,4,2),ICZX
457 - 457.000      3 BO(12,2)=0.0
458 - 458.000      GO TO 5
459 - 459.000      4 BO(12,2)=CS(1)
460 - 460.000      GO TO 5
461 - 461.000      2 BO(12,1)=CS(1)
462 - 462.000      BO(12,2)=CS(2)
463 - 463.000      BO(12,3)=0.0
464 - 464.000      5 BO(12,4)=FLOAT(J)=DY
465 - 465.000      BO(12,5)=PERAR
466 - 466.000      BO(12,6)=PERGO
467 - 467.000      BO(12,7)=TOTAL
468 - 468.000      IF(I2-25) 5,7,7
469 - 469.000      7 WRITE(6,200) COFAC
470 - 470.000      GO TO (8,8,9),ICZX
471 - 471.000      9 WRITE(6,201)
472 - 472.000      GO TO (10,11,9),ICZX
473 - 473.000      11 WRITE(6,202) ZX(1)
474 - 474.000      GO TO 10
475 - 475.000      9 WRITE(6,203) ZX(1),ZX(2)
476 - 476.000      10 WRITE(6,204)
477 - 477.000      WRITE(6,205) ((BO(I,K),K=1,7),I=1,I2)
478 - 478.000      I2=J

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479 - 479.000 6 CONTINUE
480 - 480.000 200 FORMAT(1H1,42X,'NORMALIZING FACTOR C(0)=',F9.4)
481 - 481.000 201 FORMAT(43X,'PEAK C(1) GIVEN IN COL. 1')
482 - 482.000 202 FORMAT(43X,'C(J) AT Z=',F7.3,'IN COL. 2')
483 - 483.000 203 FORMAT(43X,'C(J) AT Z=',F7.3,'IN COL. 1',/,43X,'C(J) AT Z=',F7.3,
484 - 484.000 1,'IN COL. 2')
485 - 485.000 204 FORMAT(/,27X,'C(1)/C(0) C(2)/C(0) PEAK RZ',7X,'Y',4X,'MASS IN M
486 - 486.000 1ASS ON TCTAL',/,62X,'AIR GROUND',/)
487 - 487.000 205 FORMAT(25X,F10.6,F10.6,2X,F7.3,1X,F9.4,2X,F6.2,4X,F6.2,4X,F6.2)
488 - 488.000 RETURN
489 - 489.000 END
490 - 490.000 C
491 - 491.000 C MODIFIED DEC 12/76
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SUBROUTINE PPOUT(J1,J2,DOSE,ZZ,INN,YOUT,PERA,PERG,TOT,CD)
  OUTPUT SUBROUTINE FOR MAIN RESULTS
  DIMENSION YOUT(1),ZZ(1),DOSE(25,4),PERA(1),PERG(1),TOT(1)
  DIMENSION CD(1),GAUSS(20),POOSE(25,20),PCD(20)
  K1=J2-J1+1
  K2=J2

  CALCULATE LATERAL DISPERSION FUNCTION
  YC IS CROSSWIND COORDINATE
  IPSC IS 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F

  IF (J2 - J1) 41,40,41
  40 READ(3,109)YC,IPSC
  WRITE(6,111)YC
  WRITE(6,112)IPSC
  WRITE(6,113)

  41 CONTINUE
  DO 60 I=K1,K2
  SIGF = 1.0/(1.0+0.0001*YOUT(I))*0.5
  GO TO (51,52,53,54)IPSC
  51 SIGY = 0.11*YOUT(I)*SIGF
  GO TO 55
  52 SIGY = 0.08*YOUT(I)*SIGF
  GO TO 55
  53 SIGY = 0.06*YOUT(I)*SIGF
  GO TO 55
  54 SIGY = 0.04*YOUT(I)*SIGF
  55 PI = 3.14159265358979323846264
  60 GAUSS(I) = EXP(-YC**2/(2.*SIGY**2))/(SQRT(2.0*PI)*SIGY)

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527 - 524.000 WRITE(6,101)
528 - 525.000 WRITE(6,102) (VCUT(I),I=K1,K2)
529 - 526.000 WRITE(6,103)
530 - 527.000 DO 4 I=1,INH
531 - 528.000 C APPLY LATERAL DISPERSION FUNCTION
532 - 529.000 DO 3 J=K1,K2
533 - 530.000 K3 = J-K1+1
534 - 531.000 3 PDOSE(I,J)=DOSE(I,K3)*GAUSS(J)
535 - 532.000 WRITE(6,104) Z(I),(PDOSE(I,J),J=K1,K2)
536 - 533.000 4 CONTINUE
537 - 534.000 WRITE(6,105) (PERA(I),I=K1,K2)
538 - 535.000 WRITE(6,106) (PERG(I),I=K1,K2)
539 - 536.000 WRITE(6,107) (TOT(I),I=K1,K2)
540 - 537.000 C APPLY LATERAL DISPERSION FUNCTION
541 - 538.000 DO 5 I = K1,K2
542 - 539.000 K3 = I-K1+1
543 - 540.000 5 PCD(I)=CD(K3)*GAUSS(I)
544 - 541.000 WRITE(6,108)(PCD(I),I=K1,K2)
545 - 542.000 WRITE(6,110)(GAUSS(I),I=K1,K2)
546 - 543.000 101 FORMAT(1H1,48X,'DOWNWIND CONCENTRATIONS')
547 - 544.000 102 FORMAT(/,11X,4(22X,'X'),/,13X,4(14X,F9.2))
548 - 545.000 103 FORMAT(/,4X,'VERTICAL GRID',4(10X,'CONCENTRATION'),/,9X,'Z(I)')
549 - 546.000 104 FORMAT(7X,F6.2,2X,4(10X,F13.6))
550 - 547.000 105 FORMAT(/,6X,'MASS IN AIR',8X,F13.6,3(10X,F13.6))
551 - 548.000 106 FORMAT(/,3X,'MASS ON GROUND',8X,F13.6,3(10X,F13.6))
552 - 549.000 107 FORMAT(/,8X,'TOTAL',2X,4(10X,F13.6))
553 - 550.000 108 FORMAT(/,3X,'DEPOSIT DENSITY',7X,F13.6,3(10X,F13.6))
554 - 551.000 109 FORMAT(F10.0,I3)
555 - 552.000 110 FORMAT(/,3X,'CROSSWIND FUNCTION',4X,F13.6,3(10X,F13.6))
556 - 552.100 111 FORMAT(/,40X,'YC =',F7.1,3X,'(CROSSWIND COORDINATE)')
557 - 552.200 112 FORMAT(40X,'IPSC =',I3,5X,'(STABILITY CATEGORY INDICATOR)')
558 - 552.300 113 FORMAT(40X,'IPSC = 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F.')
559 - 553.000 RETURN
560 - 554.000 END

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13. ABSTRACT A mathematical model for estimating concentrations and ground deposit densities from a low level point source of particulates up to 20 μ m in diameter has been developed. The model applies K theory to account for vertical dispersion and Gaussian spread to account for lateral dispersion. Results for the limiting case of zero terminal velocity with negligible retention at the ground are compared directly to field experimental data for a source near ground level and to establish Gaussian dispersion from an elevated source. The vertical dispersion function and lower boundary condition for an existing line source model were applied in the present point source model. Previous comparison to ground deposit densities measured in various field experiments indicate that estimates from the line source model are reasonable, although further experiments would be useful.		

KEY WORDS

Diffusion Models
Aerosols - Dispersion
Aerosols - Settling
Atmospheric Dispersion
Liquid Drops

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