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PTPLU—A Single Source Gaussian Dispersion Algorithm

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PTPLU - A SINGLE SOURCE GAUSSIAN DISPERSION ALGORITHM

User's Guide

by

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AFFILIATION

Mr. Thomas E. Pierce and Mr. D. Bruce Turner are meteorologists in the Meteorology and Assessment Division, Environmental Protection Agency, Research Triangle Park, North Carolina. They are on assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. (Mr. Pierce is now employed by NUS Corporation, Gaithersburg, Maryland) Mr. Joseph A. Catalano and Mr. Frank V. Hale III are employed by Aerocomp, Inc., Costa Mesa, California.

FOREWORD

Within the Office of Air, Land, and Water Use, the Environmental Sciences Research Laboratory conducts a research program in the physical sciences to detect, define, and quantify the effects of air pollution on urban, regional, and global atmospheres and the subsequent impact on water quality and land use. This includes research and development programs designed to quantitate the relationships between emissions of pollutants from all types of sources, air quality, and atmospheric effects.

The Meteorology and Assessment Division conducts research programs in environmental meteorology to describe the roles and interrelationships of atmospheric processes and airborne pollutants in effective air, water, and land resource management. Developed air quality simulation models (in the FORTRAN computer language) are made available to dispersion model users in computer-readable form by availability of a magnetic tape from NTIS (see preface).

PTPLU is a dispersion algorithm made available in 1981. The program is based upon Gaussian dispersion concepts of steady-state modeling. Limitations are imposed on use of the algorithm by the assumptions that pollutants are nonreactive and that one wind vector and one stability class are representative of the area being modeled. Despite these limitations, PTPLU provides a useful short-term algorithm to obtain the highest concentration and corresponding distance for point sources.

K. L. Demerjian
Director
Meteorology and Assessment Division

PREFACE

One area of research within the Meteorology and Assessment Division is development, evaluation, validation, and application of models for air quality simulation, photochemistry, and meteorology. The models must be able to describe air quality and atmospheric processes affecting the dispersion of airborne pollutants on scales ranging from local to global. Within the Division, the Environmental Operations Branch adapts and evaluates new and existing meteorological dispersion models and statistical technique models, tailors effective models for recurring user application, and makes these models available through EPA's UNAMAP system.

PTPLU is a screening model that uses Gaussian plume modeling techniques. PTPLU is designed for low-cost, detailed screening of point sources to determine maximum one-hour concentrations and also to determine if it is necessary to use one of the more intricate models.

Although attempts are made to thoroughly check computer programs with a wide variety of input data, errors are occasionally found. Revisions may be obtained as they are issued by completing and sending the form on the last page of this guide.

This document is divided into three parts. Sections 1 through 3 are directed to managers and project directors who may wish to become acquainted with the model. Sections 4 and 5 are directed to engineers, meteorologists, and other scientists who are required to become familiar with the workings of a model. Since a number of nonmeteorologists will be using this screening model, Appendix A, Modeling Concepts, presents some of the basic concepts of air pollution meteorology. Together with a Glossary, this should provide the less-experienced user sufficient background to apply the model. Finally, sections 6, 7, and 8 are directed to programmers and data processing professionals, who are often required to implement and run the model. These sections employ the standard terminology of the computer industry.

Comments and suggestions regarding this publication should be directed to

Chief, Environmental Operations Branch
Meteorology and Assessment Division (MD-80)
Environmental Protection Agency
Research Triangle Park, NC 27711.

Technical questions regarding use of the model may be asked by calling (919) 541-4564. Users within the Federal Government may call FTS 629-4564. Copies of the user's guide are available from the National Technical Information Service (NTIS), Springfield, VA 22161.

The magnetic tape containing FORTRAN source code for PTPLU is contained (along with other dispersion models) in UNAMAP (Version 4), which may be ordered as PB 81 164 600 from Computer Products, NTIS, Springfield, VA 22161 (phone number: (703) 487-4763).

ABSTRACT

PTPLU (from PoinT PLUme) is an improved model for estimating the location of the maximum short-term concentration from a single point source as a function of stability and wind speed. The algorithm is similar to PTMAX, which was first released in May 1973. Among the improvements in this version are options for the estimation of gradual plume rise, stack downwash, and buoyancy-induced dispersion. Maximum concentrations and their corresponding downwind distances are calculated for two sets of wind speeds: winds assumed to be constant with height and winds assumed to increase with height. For the latter case, wind speed is extrapolated from anemometer height to stack top using a power-law wind profile. PTPLU is based on the point-source solutions of the Gaussian plume equations. It uses Briggs' plume rise equations, Pasquill stability classes, and Pasquill-Gifford dispersion parameters. Multiple reflections are considered until the vertical dispersion parameter is 1.6 times the mixing height; uniform mixing is assumed thereafter. No fumigation or chemical reactions are considered. A built-in test example is provided with the interactive version of the program. This document describes the input, processing, and output of both the batch and interactive versions of the program.

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SYMBOLS AND ABBREVIATIONS

Dimensions are abbreviated as follows:
m = mass, l = length, t = time, τ = temperature.

d	-- stack inside diameter (l)
F	-- buoyancy flux parameter (l^4/t^3)
g	-- acceleration due to gravity (l/t^2)
H	-- effective height of plume (l)
h	-- stack height above ground (l)
h'	-- stack height adjusted for stack downwash (l)
L	-- mixing height (l)
p	-- wind-profile exponent
Q	-- emission rate (m/t)
s	-- stability parameter (t^{-2})
T	-- ambient air temperature (τ)
T_s	-- stack gas temperature (τ)
u	-- wind speed at stack top (l/t)
v_s	-- stack gas exit velocity (l/t)
x	-- downwind distance (l)
x_f	-- distance to final rise (l)
x^*	-- distance at which atmospheric turbulence begins to dominate entrainment (l)
y	-- crosswind distance (l)
z	-- receptor height above ground (l)
Δh	-- plume rise (l)
ΔT	-- temperature difference between ambient air and stack gas (τ)
$(\Delta T)_c$	-- temperature difference for crossover from momentum to buoyancy-dominated plume (τ)
$\partial\theta/\partial z$	-- vertical potential temperature gradient of a layer of air (τ/l)
π	-- pi, 3.14159
e	-- base of natural logarithms, 2.71828
σ_y	-- lateral dispersion parameter (l)
σ_{ye}	-- effective lateral dispersion (l)
σ_{yo}	-- buoyancy-induced lateral dispersion (l)
σ_z	-- vertical dispersion parameter (l)
σ_{ze}	-- effective vertical dispersion (l)
σ_{zo}	-- buoyancy-induced vertical dispersion (l)
χ_p	-- concentration due to a point source (m/l^3)

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. William B. Petersen and Mr. John S. Irwin for helpful comments regarding aspects of the work presented here. Support of Aerocomp by the Environmental Protection Agency Contract No. 68-02-3442 is also gratefully acknowledged.

SECTION 1

INTRODUCTION

PTPLU (from PoinT PLUme) provides a method for estimating maximum ground-level concentrations from a single point source. The algorithm is based on Gaussian plume modeling assumptions incorporating the Pasquill-Gifford (P-G) dispersion parameters. Briggs' plume rise equations (Briggs, 1969) are employed by the model to determine the effective height of pollutant release.

Three technical options are available with PTPLU. Stack downwash may be considered, as well as buoyancy-induced dispersion and gradual plume rise. In addition, anemometer height, wind-profile exponents, and mixing height can be specified on input.

The routines employed to estimate dispersion by PTPLU have been extracted from MPTER (Multiple Point source algorithm with TERrain adjustments) (Pierce and Turner, 1980), which is in turn based on point-source segments of the rural version of RAM (Turner and Novak, 1978). PTPLU provides an economical and technically sound approach to estimating maximum concentrations for comparison with ambient air quality standards and for use in air pollution research.

Modeling the effects of the release of inert pollutants into the atmosphere usually follows a three-step procedure. First, simple screening steps are performed using a hand calculator or air quality nomograms. This simple screening method is, as a rule, sufficiently conservative to ensure that maximum concentrations will not be underestimated. If results of the simple screening indicate a potential air quality problem, a more detailed screening is warranted. This intermediate step usually involves the use of simple computer models to quantify the effects of pollutant release on air quality. A more elaborate procedure is followed when detailed screening indicates that a more refined analysis is required. For sources with significant potential effects, computation continues, using models better suited for handling multiple sources, multiple receptors, and topographic effects. The user is referred to the "Guideline on Air Quality Models" (U. S. Environmental Protection Agency, 1978) in selecting the models appropriate for regulatory applications.

The model described herein is suited for the intermediate step of detailed screening. If concentrations are low, no detailed modeling will then be required. In this manner, resources are conserved, and only potentially troublesome sources are left for analysis with the more refined models.

The Environmental Operations Branch of EPA supports the User's Network for Applied Modeling of Air Pollution--a set of models commonly known by the acronym UNAMAP. A brief description of the latest version of UNAMAP is available from the Environmental Operations Branch.

SECTION 2

DATA-REQUIREMENTS CHECKLIST

PTPLU requires data on options, sources, meteorology, and receptors. The user must indicate whether any of three options--gradual rise, stack downwash, or buoyancy-induced dispersion--is to be employed. Information required on the sources includes the following:

- source strength (grams per second),
- physical stack height (meters),
- stack gas temperature (kelvin),
- stack gas velocity (meters per second), and
- stack inside diameter (meters).

The meteorological data needed to compute maximum concentrations are as follows:

- ambient air temperature (kelvin),
- mixing height (meters),
- wind-profile exponents, and
- anemometer height (meters).

The only input required for receptors is the uniform height above ground of the receptors (in meters).

Because the maximum concentration is directly proportional to the emission rate of the source, care should be exercised to accurately determine this parameter. The mixing height and ambient air temperature should be representative of the vicinity of the source.

SECTION 3

FEATURES AND LIMITATIONS

As noted previously, PTPLU is an upgraded version of program PTMAX released in mid-1973 (UNAMAP Version 1). Since then, several larger models have been developed, such as CRSTER (U. S. Environmental Protection Agency, 1977), RAM, and MPTER. Certain features of these more complex models suitable for detailed screening have been transferred to PTPLU. Hence, a number of features not found in PTMAX are now available in PTPLU. These improvements are as follows:

- calculations using wind speeds at anemometer height and wind speeds extrapolated to stack top;
- optional gradual plume rise;
- optional stack downwash;
- optional buoyancy-induced dispersion;
- three modes of operation: batch, interactive with a paper terminal, and interactive with a video display;
- input of anemometer height;
- input of mixing height;
- input of wind-profile exponents;
- calculations for any number of single sources in one run; and
- consideration of momentum-dominated as well as buoyancy-dominated plumes.

PTPLU still retains some of the limitations of PTMAX, however. Among these are the following:

- predetermined wind speeds,
- unsuitability for complex terrain,
- no consideration of building downwash,

- no provision for calculating the effect of multiple point sources,

- no consideration of fumigation, and

- no consideration of pollutant removal or chemical reactions.

The model is most applicable within 10 km of the source. Beyond this distance, the estimates are expected to be less accurate, due to mesoscale influences such as wind direction shear with height and changing meteorological conditions during the time of transport.

As a screening model, PTPLU can be applied to single sources for the following:

- monitoring-network design,

- prevention of significant deterioration,

- new source review,

- fuel-conversion studies,

- control technology evaluation, and

- combustion-source permit applications.

PTPLU is primarily useful in determining the maximum one-hour concentration from a point source and the meteorological conditions associated with the maximum. Maximum concentrations are computed for 49 different combinations of wind speed and stability.

PTPLU can also be used in selecting the distances used as input into the models CRSTER and MPTER for generation of polar coordinate receptor arrays.

SECTION 4

TECHNICAL DESCRIPTION

PTPLU is a Gaussian plume dispersion model designed to screen maximum concentrations from single point sources. Persons not familiar with Gaussian point source modeling techniques and plume rise estimates are referred to Appendix A.

PTPLU determines the distance to and the magnitude of maximum concentrations from a point source for 49 internally generated combinations of wind speed and stability. PTPLU is based on the following modeling assumptions:

- the wind speed existing at stack top applies to both plume rise and dilution;
- plume rise is calculated using methods suggested by Briggs;
- the pollutant release is continuous at a rate specified by the user;
- calculations are made as if the atmosphere has reached a steady-state condition; and
- for unstable and neutral conditions, complete eddy reflection is calculated both from the ground and from the stable layer aloft given by the mixing height.

In calculating maximum concentrations, PTPLU is much like the PTMAX algorithm (Turner and Busse, 1973). However, PTPLU calculates concentrations for both wind speeds constant with height and wind speeds extrapolated to stack top. In addition to the user-supplied wind-profile exponents, PTPLU allows for optional calculations due to the effect of 1) gradual plume rise, 2) stack downwash, and 3) buoyancy-induced dispersion. Any one of these processes can alter the distance or magnitude of maximum concentration. Thus, the user is offered more flexibility in screening analyses.

The distance to maximum concentration is determined by an iterative sequential search. For each combination of wind speed and stability, the maximum concentration is selected from 16 fixed distances (0.1, 0.3, 0.5, 0.7, 1, 2, 3, 5, 7, 10, 15, 20, 30, 40, 50, and 100 km). This distance then becomes the start for the iterative search for the maximum. Calculations begin with increments appropriate to the starting point (+0.1 km for starting points 0.1-0.7 km, +1 km for starting points 1-7 km, +10 km for starting points 10-50 km, and -10 km for the 100-km starting point). Iterations proceed back and forth in one-tenth increments until the increment reaches one meter. If the distance of the maximum exceeds 100 km, the search ceases and a warning message is printed.

Figure 1 illustrates the technique used to find the maximum concentration and the distance to the maximum. In the initial step, a concentration is calculated sequentially at each of the 16 fixed distances noted above, and an absolute maximum is selected from the 16 values. The chosen maximum is represented by point 1 in Figure 1. The iterative search begins here, moving from right to left in fixed increments along the curve. Concentrations are computed using this increment until a lower concentration is encountered. At this point the direction is reversed and this point becomes the starting point for the next iteration, with a new distance increment reduced by an order of magnitude from the previous one. As indicated in Figure 1, the next two iterations yield starting points at points 3 and 4. The search for the absolute maximum ceases when the increment has been reduced to one meter.

Gradual plume rise (option 1) is available as an optional calculation in PTPLU. Although the 2/3 dependence for rising plumes determines average plume height with distance quite well, the dispersive processes that occur during buoyant rise are thought to be different from those that occur during steady-state transport. The P-G dispersion parameters represent horizontal and vertical dispersion about a horizontal plume, which may or may not be appropriate for estimating dispersion about a bent-over plume. By making computations with and without gradual plume rise, identification of potentially high concentrations is possible. When gradual rise is not employed, computations use only the final effective plume height.

Stack-top downwash (option 2) can be considered using the methods of Briggs. In such an analysis, a height increment is deducted from the physical height before momentum or buoyancy rise is determined. Use of this option primarily affects computations from stacks having small ratios of exit velocity to wind speed.

Buoyancy-induced dispersion calculations (option 3) are offered because emitted plumes undergo a certain amount of growth during the plume rise phase. This is due to the turbulent motions associated with conditions of plume release and the turbulent entrainment of ambient air. During the initial growth phases of release, the plume is assumed to be nearly symmetrical

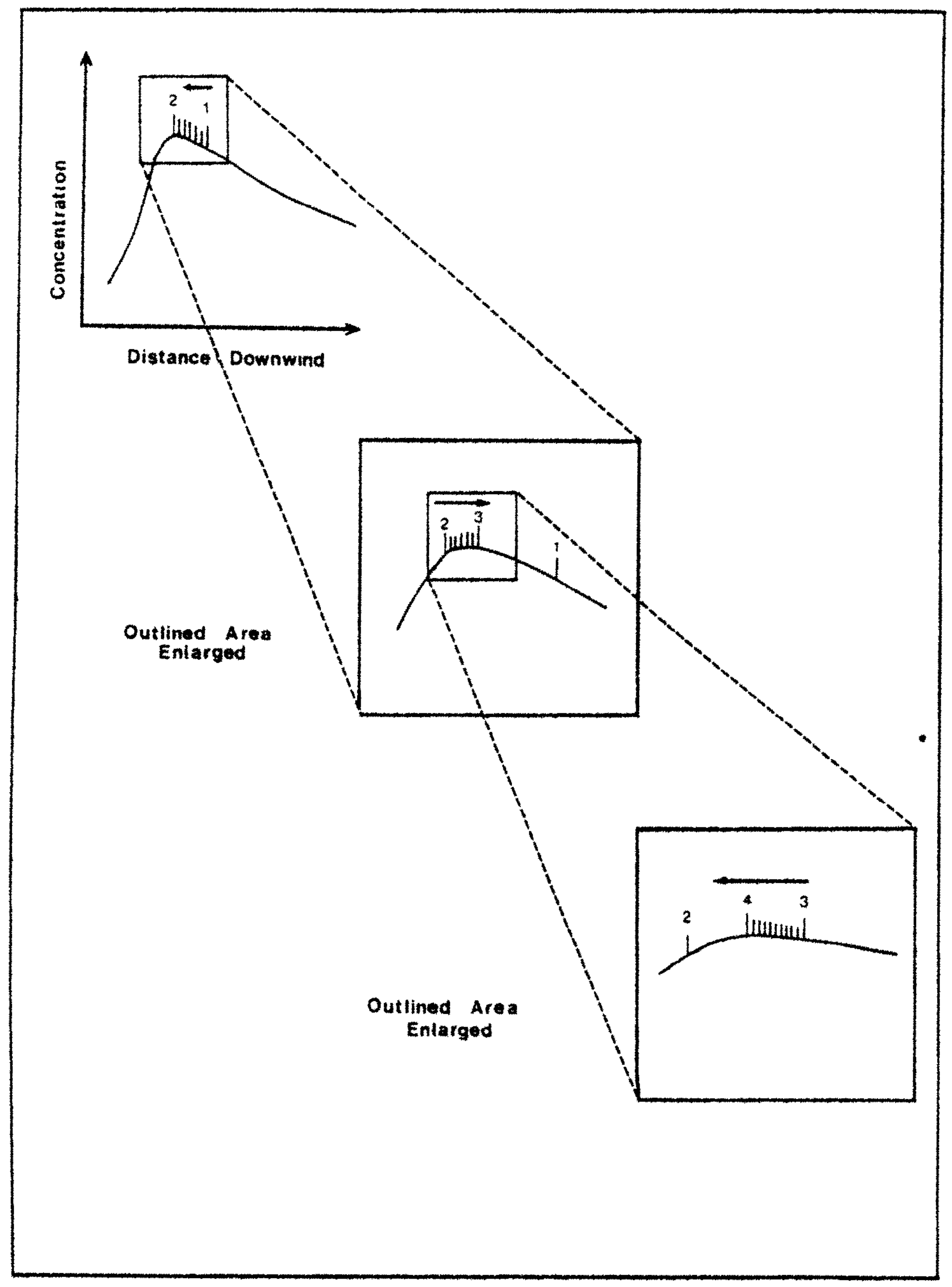

Figure 1. Iterative search routine used by PTPLU.

about its centerline; hence, the buoyancy-induced dispersion in the horizontal direction is modeled as equal to that in the vertical direction. The contribution by buoyant plume rise to the total dispersion is small compared with the dispersion caused by atmospheric turbulence. The maximum effects on ground-level concentrations occur for short heights of release combined with large plume rise, but, in general, buoyancy-induced dispersion has little effect on maximum surface concentrations from elevated releases.

To simulate increased wind speed with height, PTPLU requires the input of wind-profile exponents for each stability class. With this feature, maximum concentrations are computed for both wind speed at anemometer height and wind speed extrapolated to stack top.

The three options and the additional calculations for extrapolated wind speeds allow more flexibility and realism in identifying maximum concentrations. When employing PTPLU as a screening model for regulatory applications, the user is advised to contact the regional meteorologist or modeling contact about the proper specifications of options and wind-profile exponents.

SECTION 5

PROGRAM OVERVIEW AND STRUCTURE

PTPLU may be run either in batch mode or interactively. There are two interactive versions: one with minimal output, quite useful for terminals using paper, and one with expanded output useful for terminals with video display.

The interactive version consists of the batch version (modified to serve as a subroutine) and a set of subroutines for preparing the input to the model. The program is menu-driven so that the user may select for execution any one of a number of routines. Routines are available for entering or modifying (any number of times) meteorology, receptor height, options, source parameters, and run title. The user may also invoke a subroutine to display the current input data. After the data have been prepared in this interactive manner, the model may be executed. When each subroutine has finished execution, the user is presented with the original menu. The interactive session is completed by selecting "END" on the menu.

There are two versions of the interactive routines within the program, and the first action of the user is to select which version is to be used. One version produces unabridged output with full headings and data descriptions. The other produces abridged output with little data description. The unabridged version is designed for use with a visual-display output device. In such an output medium, length of output has little effect on running time or cost. The abridged version is designed for use with a hard-copy device, in which case length of output affects both running time and cost. In addition, the output of the unabridged version assists a new user by means of full data descriptions, whereas the abridged version is more useful to an experienced user who is familiar with the operation of the program and can work with abbreviated output.

The program contains default data, which serve as both a template for the user and a built-in test data set. The default data represent a hypothetical source of medium height. The default source parameters are as follows: source strength of 2750 g/s, physical stack height of 165 m, exit temperature of 425 K, exit velocity of 38 m/s, and inside stack diameter of 4.5 m. The remaining default data were selected as being typical. All options default to 1 (use option). Ambient air temperature and mixing height default to 293 K and 2000 m, respectively. Anemometer height is taken as 10 m. Wind-profile exponents default to 0.07, 0.07, 0.10, 0.15, 0.35, and 0.55 for stability classes A through F, respectively. These values correspond to a roughness parameter of 0.03 m. The height of the receptor defaults to zero (ground level).

When the interactive routines are expecting numeric input from the user, care must be taken that data of the proper type are entered. The entry of alphabetic characters when numeric data are expected can result in a FORTRAN error and termination of the program. If this arrangement is not satisfactory, it may be possible to add a routine that reads numeric data as alphanumeric data, checks the format of the input, and either converts the alphanumeric data to a number or produces an error message under program control. Alternatively, on many systems, the ERR= option of the FORTRAN language could be used to process this error (the notable exception being IBM OS systems).

The subroutines of the model (PH, TPMX, PHX, RCON, and PSIG) are identical in the batch and interactive versions. The main routine of the batch version has been transformed into subroutine PTPLU of the interactive version. The conversion involved replacing read statements with subroutine parameters and assignment statements. Also, the format of the output was modified for use with a 79-character visual display. Aside from these changes of input and output, subroutine PTPLU is identical to the main routine of the batch version.

PROGRAM MODULES

IPTPLU -- Main module of the interactive version. IPTPLU invokes either LPTPLU or SPTPLU depending on the type of output desired--long form for CRT runs, short form for hard-copy terminals.

IPLDIS -- Prints model input parameters as currently available in memory.

IPLMET -- Allows substitution of meteorological parameters.

IPLOPT -- Allows changing of options.

IPLREC -- Allows changing of receptor height.

IPLSOR -- Allows modification of source parameters.

IPLTTL -- Provides a way to change the title.

LPTPLU -- Unabridged interactive version of PTPLU. Provides a menu-driven means to prepare input and execute the model.

PH -- Calculates specific plume rise parameters for a given wind speed.

PHX -- Calculates gradual plume rise, if the option is employed.

PSIG -- Calculates the lateral and vertical dispersion parameters as a function of distance from the source and stability class.

PTPLU -- Main module of the batch version and a subroutine of the interactive version. PTPLU produces all printed output (input parameters, calculated parameters, and output tables), calculates the plume rise as a function of wind speed, and controls the input to TPMX in order to produce the maximum concentration tables.

RCON -- Calculates the relative concentration (concentration divided by source strength) under a given set of conditions (solves the appropriate Gaussian equation).

SPLDIS -- Abridged display of interactive input data.

SPLMET -- Abridged modification of interactive meteorological data.

SPLOPT -- Abridged modification of interactive options.

SPLREC -- Abridged modification of receptor height.

SPLSOR -- Abridged modification of source data.

SPLTTL -- Abridged modification of run title.

SPTPLU -- Abridged interactive version of PTPLU. Provides a terse menu-driven means to prepare input and execute the model.

TPMX -- Searches for the distance to the maximum concentration by calling RCON, first at a set of fixed distances and then at incremental distances.

Figure 2 shows the structure of the batch version of PTPLU.

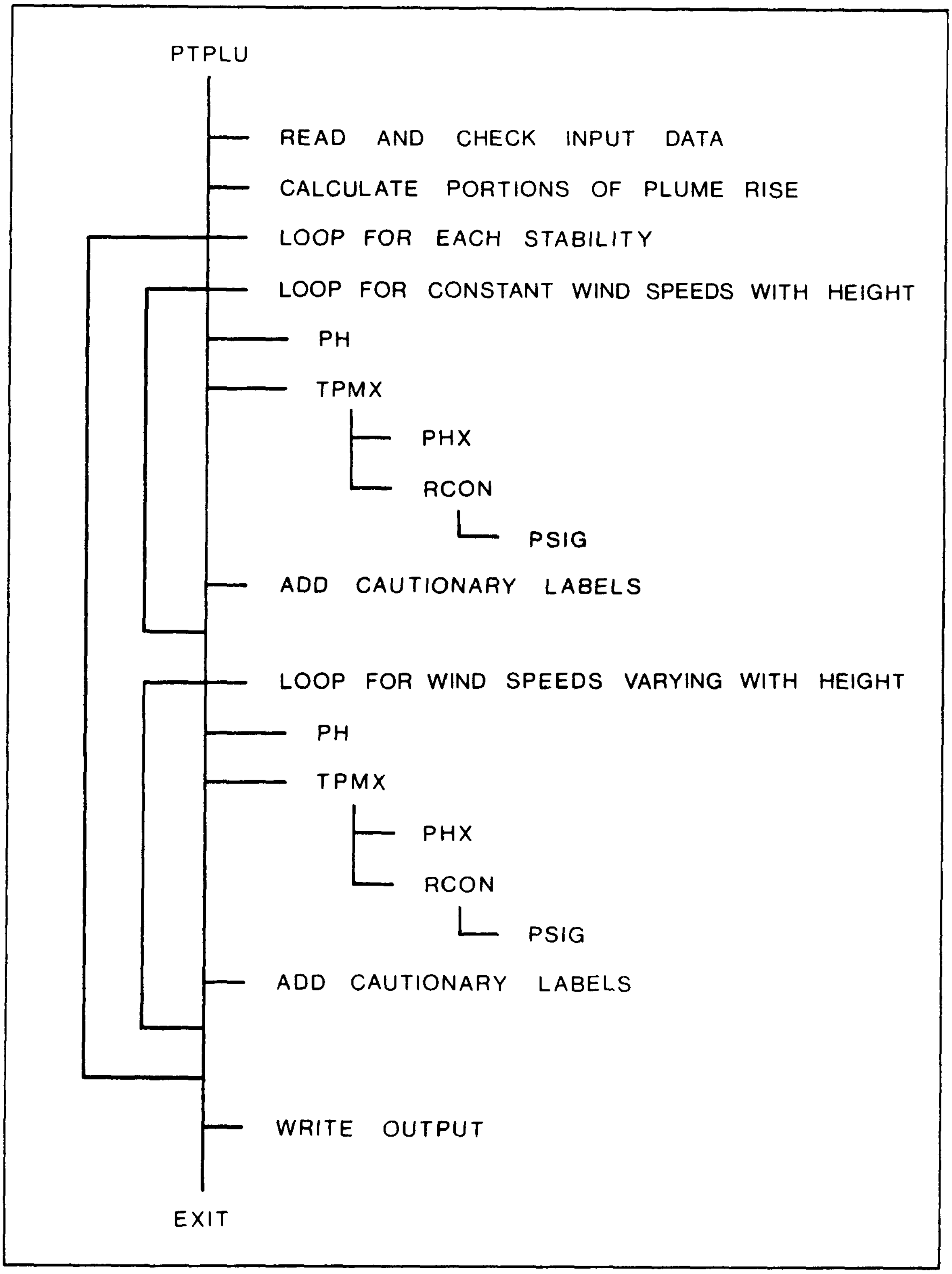

Figure 2. Structure of batch version of PTPLU.

SECTION 6

INPUT DATA PREPARATION

Table 1 (below) applies to input preparation for the batch execution mode. Data requirements are identical to those of the interactive mode. Data fields follow a free form (i.e., they are separated by commas). The input data should conform to the variable-name type. That is, decimals should be included for all values corresponding to real variables.

TABLE 1. RECORD INPUT SEQUENCE*

Record type	Variable name	Variable description
1	IOPT(1)	Gradual plume rise option
	IOPT(2)	Stack downwash option
	IOPT(3)	Buoyancy-induced dispersion option (1 = use option, 0 = do not use option)
	T	Ambient air temperature (kelvin) (default value is 293 K)
	HL	Mixing height (meters)
	Z	Receptor's elevation above ground (meters)
2	HANE	Anemometer height (meters)
	PL	Wind-profile exponents (6 values)
3	ALP	80-character title
4	Q	Source strength (grams per second)
	HP	Physical stack height (meters)
	TS	Stack gas temperature (kelvin)
	VS	Stack gas velocity (meters per second)
	D	Stack diameter (meters)

* Record Types 3 and 4 may be repeated (as a pair) any number of times.

When one of the interactive versions is used, the data are entered by the user in response to requests from the program. The same parameters are required for the batch and interactive versions.

SECTION 7

EXECUTION OF THE MODEL AND SAMPLE TEST

PTPLU produces an error-free compile on IBM MVS and Univac EXEC 8 computers. Execution results are comparable to within 0.2% for these two systems. The program can also be used in mini and microcomputers having comparable accuracy. A sample job stream for the batch version is presented below.

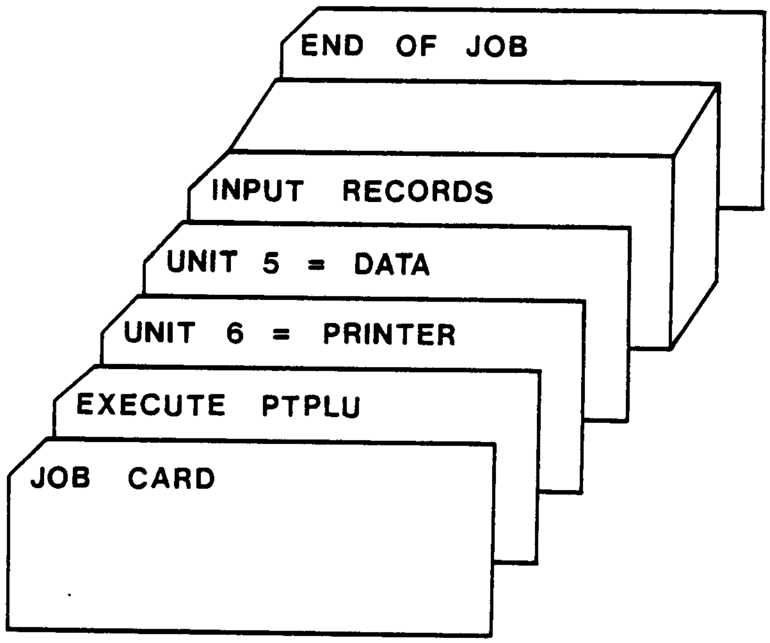

Figure 3. Sample job stream for batch version of PTPLU.

Test data for the batch version are as follows:

```
0,1,1,278.,1500.,2.
7.,.07,.07,.10,.15,.35,.55
PTPLU EXAMPLE RUN - INPUT BY T. PIERCE  12/29/80
1000.,200.,450.,20.,5.
```

A job stream for a Univac EXEC 8 system might have the following form:

```
@RUN,R/R JOB-ID,ETC
@ASG,A MODELS*LOAD.
@XQT MODELS*LOAD.PTPLU
(input records shown above)
@FIN
```

The following is a sample job stream for an IBM system under OS or MVS:

```
//JOBID    JOB  (PROJ,ACCT,OTHER),CLASS=A,TIME=1
//XPTPLU   EXEC PGM=PTPLU,TIME=(,05)
//STEPLIB  DD   DSN=USER.MODELS.LOAD,DISP=SHR
//FT06F001 DD   SYSOUT=A
//FT05F001 DD   *
(input records shown above)
/*
//
```

A sample job stream for a CDC system under Scope 3.14 may look as follows:

```
XX,T05,P4.
USER,HALE,EPA.
PROJECT,*PRJ*XX.
ATTACH,LIB,MODELSLIB,ID=XX.
LIBRARY,LIB.
PTPLU.
*
(input records shown above)
*
```

A schematic illustrating the various sections of the two-page output resulting from the batch version is shown in Figure 4. Model outputs include a heading (A in Figure 4) that indicates the program name and source. Section B displays the input parameters. Section C gives two calculated values, volumetric flow and the buoyancy flux parameter used for plume rise. Section D contains the output, with results for the assumption of constant wind speed with height on the left and those for extrapolated wind speed with height on the right. For each combination of wind speed and stability, the maximum concentration, the distance of the maximum, and the plume effective height at this distance are given. Section E contains qualifying footnotes that may be referred to in section D. Figure 5 gives the batch run output of the sample test.

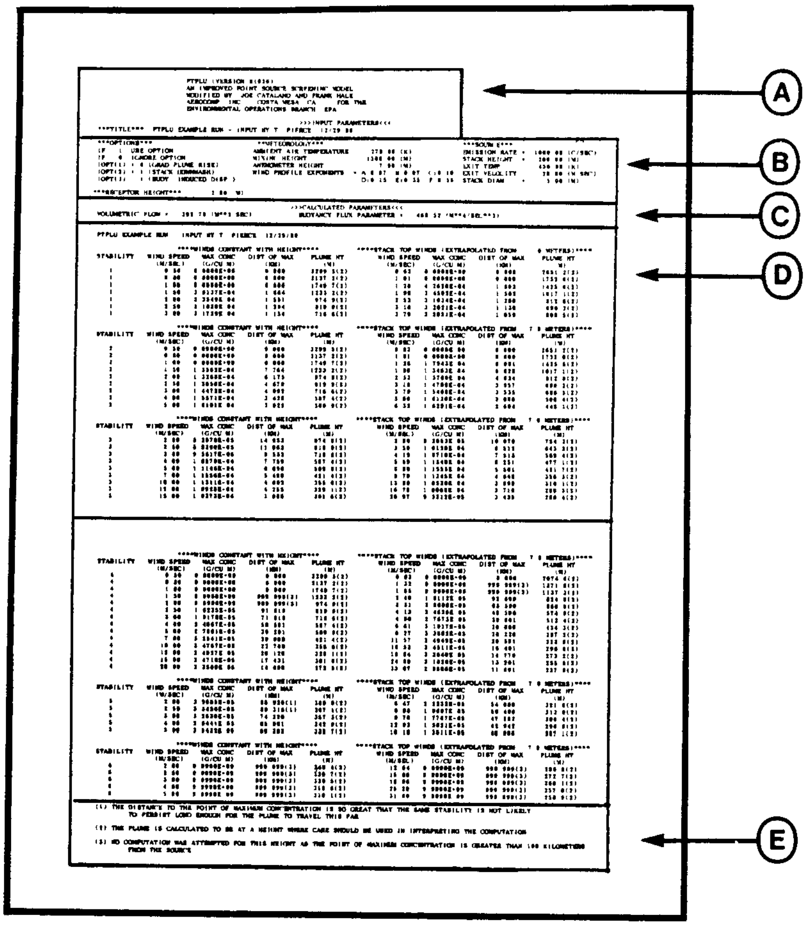

Figure 4. Schematic of batch output of PTPLU.

In the interactive version, a sample test is built into the program. The only step involved in running the sample test is selecting "RUN" from the main menu. The output resulting from the unabridged interactive version using this built-in test data set is given in Figure 6, where, as illustration, all interactive options are exercised. Users may verify the proper execution of the program by comparing their results with those given in Figure 6.

PTPLU (VERSION 81036)
AN IMPROVED POINT SOURCE SCREENING MODEL
MODIFIED BY: JOE CATALANO AND FRANK HALE
AEROCOMP, INC. - COSTA MESA, CA FOR THE
ENVIRONMENTAL OPERATIONS BRANCH, EPA

>>>INPUT PARAMETERS<<<

TITLE PTPLU EXAMPLE RUN - INPUT BY T. PIERCE 12/29/80

OPTIONS
IF - 1, USE OPTION
IF = 0, IGNORE OPTION
IOPT(1) = 0 (GRAD PLUME RISE)
IOPT(2) - 1 (STACK DOWNWASH)
IOPT(3) = 1 (BUOY. INDUCED DISP.)

METEOROLOGY
AMBIENT AIR TEMPERATURE = 278.00 (K)
MIXING HEIGHT = 1500.00 (M)
ANEMOMETER HEIGHT = 7.00 (M)
WIND PROFILE EXPONENTS = A:0.07, B:0.07, C:0.10
D:0.15, E:0.35, F:0.55

SOURCE
EMISSION RATE = 1000.00 (G/SEC)
STACK HEIGHT = 200.00 (M)
EXIT TEMP. = 450.00 (K)
EXIT VELOCITY = 20.00 (M/SEC)
STACK DIAM. = 5.00 (M)

RECEPTOR HEIGHT = 2.00 (M)

>>>CALCULATED PARAMETERS<<<

VOLUMETRIC FLOW = 392.70 (M**3/SEC)
BUOYANCY FLUX PARAMETER = 468.52 (M**4/SEC**3)

PTPLU EXAMPLE RUN - INPUT BY T. PIERCE 12/29/80

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 7.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
1	0.50	0.0000E+00	0.000	3299.5(2)	0.63	0.0000E+00	0.000	2651.2(2)
1	0.80	0.0000E+00	0.000	2137.2(2)	1.01	0.0000E+00	0.000	1732.0(2)
1	1.00	0.0000E+00	0.000	1749.7(2)	1.26	4.2626E-04	1.693	1425.6(2)
1	1.50	3.9137E-04	1.664	1233.2(2)	1.90	3.4502E-04	1.582	1017.1(2)
1	2.00	3.3549E-04	1.551	974.9(2)	2.53	3.1034E-04	1.280	812.8(2)
1	2.50	3.1038E-04	1.294	819.9(2)	3.16	3.2021E-04	1.130	690.2(2)
1	3.00	3.1729E-04	1.154	716.6(2)	3.79	3.2851E-04	1.059	608.5(2)

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 7.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
2	0.50	0.0000E+00	0.000	3299.5(2)	0.63	0.0000E+00	0.000	2651.2(2)
2	0.80	0.0000E+00	0.000	2137.2(2)	1.01	0.0000E+00	0.000	1732.0(2)
2	1.00	0.0000E+00	0.000	1749.7(2)	1.26	1.7943E-04	8.001	1425.6(2)
2	1.50	1.5562E-04	7.764	1233.2(2)	1.90	1.3483E-04	6.628	1017.1(2)
2	2.00	1.3268E-04	6.175	974.9(2)	2.53	1.3700E-04	4.634	812.8(2)
2	2.50	1.3650E-04	4.679	819.9(2)	3.16	1.4700E-04	3.957	690.2(2)
2	3.00	1.4472E-04	4.092	716.6(2)	3.79	1.5400E-04	3.535	608.5(2)
2	4.00	1.5571E-04	3.428	587.4(2)	5.06	1.6120E-04	3.006	506.4(2)
2	5.00	1.6101E-04	3.025	509.9(2)	6.32	1.6291E-04	2.684	445.1(2)

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 7.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
3	2.00	8.2078E-05	14.653	974.9(2)	2.80	9.2853E-05	10.070	754.2(2)
3	2.50	8.8390E-05	11.063	819.9(2)	3.50	1.0128E-04	8.512	643.3(2)
3	3.00	9.5617E-05	9.533	716.6(2)	4.19	1.0710E-04	7.513	569.4(2)
3	4.00	1.0570E-C4	7.759	587.4(2)	5.59	1.1349E-04	6.251	477.1(2)
3	5.00	1.1146E-04	6.696	509.9(2)	6.99	1.1555E-04	5.501	421.7(2)
3	7.00	1.1556E-04	5.499	421.4(2)	9.79	1.1345E-04	4.648	358.3(2)
3	10.00	1.1311E-04	4.602	355.0(2)	13.98	1.0538E-04	3.999	310.1(2)
3	12.00	1.0928E-04	4.255	329.1(2)	16.78	1.0068E-04	3.716	289.3(2)
3	15.00	1.0373E-04	3.886	301.6(2)	20.97	9.3312E-05	3.435	268.4(2)

Figure 5. Batch output of PTPLU.

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 7.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
4	0.50	0.0000E+00	0.000	3299.5(2)	0.83	0.0000E+00	0.000	2074.6(2)
4	0.80	0.0000E+00	0.000	2137.2(2)	1.32	9.9990E+09	999.999(3)	1371.6(2)
4	1.00	0.0000E+00	0.000	1749.7(2)	1.65	9.9990E+09	999.999(3)	1137.3(2)
4	1.50	9.9990E+09	999.999(3)	1233.2(2)	2.48	1.6112E-05	92.609	824.9(2)
4	2.00	9.9990E+09	999.999(3)	974.9(2)	3.31	2.0808E-05	63.590	668.6(2)
4	2.50	1.6235E-05	91.619	819.9(2)	4.13	2.4628E-05	48.590	574.9(2)
4	3.00	1.9170E-05	71.819	716.6(2)	4.96	2.7673E-05	39.601	512.4(2)
4	4.00	2.4067E-05	50.581	587.4(2)	6.61	3.1917E-05	30.000	434.3(2)
4	5.00	2.7801E-05	39.291	509.9(2)	8.27	3.3882E-05	26.220	387.5(2)
4	7.00	3.2541E-05	29.980	421.4(2)	11.57	3.4949E-05	20.591	333.9(2)
4	10.00	3.4767E-05	22.760	355.0(2)	16.53	3.4511E-05	16.401	290.8(2)
4	12.00	3.4927E-05	20.120	329.1(2)	19.84	3.3640E-05	14.770	273.2(2)
4	15.00	3.4718E-05	17.431	301.6(2)	24.80	3.1826E-05	13.201	255.5(2)
4	20.00	3.3589E-05	14.690	272.5(2)	33.07	2.8586E-05	11.691	237.9(2)

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 7.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
5	2.00	3.9085E-05	88.920(1)	380.0(2)	6.47	2.2232E-05	54.680	321.8(2)
5	2.50	3.5456E-05	80.318(1)	367.1(2)	8.08	1.9687E-05	50.490	313.0(2)
5	3.00	3.2630E-05	74.220	357.3(2)	9.70	1.7767E-05	47.282	306.4(2)
5	4.00	2.8441E-05	65.981	342.9(2)	12.93	1.5021E-05	42.942	296.6(2)
5	5.00	2.5432E-05	60.382	332.7(2)	16.16	1.3611E-05	40.000	287.1(2)

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 7.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
6	2.00	9.9990E+09	999.999(3)	349.4(2)	12.64	9.9990E+09	999.999(3)	280.8(2)
6	2.50	9.9990E+09	999.999(3)	338.7(2)	15.80	9.9990E+09	999.999(3)	272.7(2)
6	3.00	9.9990E+09	999.999(3)	330.5(2)	18.96	9.9990E+09	999.999(3)	266.1(2)
6	4.00	9.9990E+09	999.999(3)	318.6(2)	25.28	9.9990E+09	999.999(3)	257.0(2)
6	5.00	9.9990E+09	999.999(3)	310.1(2)	31.60	9.9990E+09	999.999(3)	250.9(2)

(1) THE DISTANCE TO THE POINT OF MAXIMUM CONCENTRATION IS SO GREAT THAT THE SAME STABILITY IS NOT LIKELY TO PERSIST LONG ENOUGH FOR THE PLUME TO TRAVEL THIS FAR.

(2) THE PLUME IS CALCULATED TO BE AT A HEIGHT WHERE CARE SHOULD BE USED IN INTERPRETING THE COMPUTATION.

(3) NO COMPUTATION WAS ATTEMPTED FOR THIS HEIGHT AS THE POINT OF MAXIMUM CONCENTRATION IS GREATER THAN 100 KILOMETERS FROM THE SOURCE

Figure 5. (continued)

```
 DO YOU WISH TO USE THE ABRIDGED VERSION?
NO

           IPTPLU - IMPROVED POINT SOURCE SCREENING MODEL - VERSION 81035
           THE INTERACTIVE VERSION OF PTPLU DEVELOPED UNDER CONTRACT BY
           AEROCOMP, INC. - COSTA MESA, CA      FOR THE
           ENVIRONMENTAL OPERATIONS BRANCH, EPA

   1 CHANGE OPTIONS
   2 CHANGE METEOROLOGY
   3 CHANGE RECEPTOR ELEVATION
   4 CHANGE SOURCE CHARACTERISTICS
   5 CHANGE TITLE
   6 DISPLAY INPUT DATA
   7 RUN
   8 END

 ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
1

 PRESENT OPTIONS ARE:
  1  COMPUTE GRADUAL RISE
  2  COMPUTE DOWNWASH
  3  COMPUTE BUOYANCY INDUCED DISPERSION

 CHANGE WHICH OPTION? (4 TO DISPLAY; 5 TO RETURN TO MENU)
5

   1 CHANGE OPTIONS
   2 CHANGE METEOROLOGY
   3 CHANGE RECEPTOR ELEVATION
   4 CHANGE SOURCE CHARACTERISTICS
   5 CHANGE TITLE
   6 DISPLAY INPUT DATA
   7 RUN
   8 END

 ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
2

 PRESENT METEOROLOGY:
   1  AMBIENT AIR TEMPERATURE (K): 293.0
   2  MIXING HEIGHT (M):  2000.0
   3  ANEMOMETER HEIGHT (M):  10.0
   4  WIND PROFILE EXPONENTS:
        0.07 0.07 0.10 0.15 0.35 0.55

 CHANGE WHICH ITEM? (5 TO DISPLAY; 6 TO RETURN TO MENU)
1
 ENTER NEW AIR TEMPERATURE (K):
293.0

 CHANGE WHICH ITEM? (5 TO DISPLAY; 6 TO RETURN TO MENU)
2
```

Figure 6. Output of unabridged interactive version of PTPLU.

```
 ENTER NEW MIXING HEIGHT (M):
2000.0

 CHANGE WHICH ITEM? (5 TO DISPLAY; 6 TO RETURN TO MENU)
3
 ENTER NEW ANEMOMETER HEIGHT (M):
10.0

 CHANGE WHICH ITEM? (5 TO DISPLAY; 6 TO RETURN TO MENU)
4
 ENTER NEW WIND PROFILE EXPONENTS (SIX):
 07,.07,.10,.15,.35,.55

 CHANGE WHICH ITEM? (5 TO DISPLAY; 6 TO RETURN TO MENU)
5

 PRESENT METEOROLOGY:
   1  AMBIENT AIR TEMPERATURE (K): 293.0
   2  MIXING HEIGHT (M):  2000.0
   3  ANEMOMETER HEIGHT (M):  10.0
   4  WIND PROFILE EXPONENTS:
       0.07 0.07 0.10 0.15 0.35 0.55

 CHANGE WHICH ITEM? (5 TO DISPLAY; 6 TO RETURN TO MENU)
6

  1 CHANGE OPTIONS
  2 CHANGE METEOROLOGY
  3 CHANGE RECEPTOR ELEVATION
  4 CHANGE SOURCE CHARACTERISTICS
  5 CHANGE TITLE
  6 DISPLAY INPUT DATA
  7 RUN
  8 END

 ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
3

 PRESENT HEIGHT OF RECEPTORS IS (M):     0.0
 ENTER NEW RECEPTOR HEIGHT (M)
0.0

  1 CHANGE OPTIONS
  2 CHANGE METEOROLOGY
  3 CHANGE RECEPTOR ELEVATION
  4 CHANGE SOURCE CHARACTERISTICS
  5 CHANGE TITLE
  6 DISPLAY INPUT DATA
  7 RUN
  8 END

 ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
4
```

Figure 6. (continued)

```
 PRESENT SOURCE CHARACTERISTICS ARE:
   1  SOURCE STRENGTH (G/SEC):  2750.0
   2  PHYSICAL HEIGHT OF STACK (M):  165.0
   3  STACK GAS TEMPERATURE (K): 425.0
   4  STACK GAS VELOCITY (M/SEC):  38.0
   5  INSIDE STACK DIAMETER (M):  4.5

 CHANGE WHICH CHARACTERISTIC? (6 TO DISPLAY; 7 TO RETURN)
1
 ENTER NEW SOURCE STRENGTH (G/SEC):
2750.0

 CHANGE WHICH CHARACTERISTIC? (6 TO DISPLAY; 7 TO RETURN)
2
 ENTER NEW PHYSICAL STACK HEIGHT (M):
165.0

 CHANGE WHICH CHARACTERISTIC? (6 TO DISPLAY; 7 TO RETURN)
3
 ENTER NEW STACK GAS TEMPERATURE (K):
425.0

 CHANGE WHICH CHARACTERISTIC? (6 TO DISPLAY; 7 TO RETURN)
4
 ENTER NEW STACK GAS VELOCITY (M/SEC):
38.0

 CHANGE WHICH CHARACTERISTIC? (6 TO DISPLAY; 7 TO RETURN)
5
 ENTER NEW INSIDE STACK DIAMETER (M):
4.50

 CHANGE WHICH CHARACTERISTIC? (6 TO DISPLAY; 7 TO RETURN)
6

 PRESENT SOURCE CHARACTERISTICS ARE:
   1  SOURCE STRENGTH (G/SEC):  2750.0
   2  PHYSICAL HEIGHT OF STACK (M):  165.0
   3  STACK GAS TEMPERATURE (K): 425.0
   4  STACK GAS VELOCITY (M/SEC):  38.0
   5  INSIDE STACK DIAMETER (M):  4.5

 CHANGE WHICH CHARACTERISTIC? (6 TO DISPLAY; 7 TO RETURN)
7

  1 CHANGE OPTIONS
  2 CHANGE METEOROLOGY
  3 CHANGE RECEPTOR ELEVATION
  4 CHANGE SOURCE CHARACTERISTICS
  5 CHANGE TITLE
  6 DISPLAY INPUT DATA
  7 RUN
  8 END
```

Figure 6. (continued)

```
 ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
5

 PRESENT TITLE IS:
 *** TEST OF PTPLU ***
 CHANGE TO: (NOT MORE THAN 60 CHARACTERS)
DEMONSTRATION OF INTERACTIVE SESSION SUBMITTED BY T. CHICO

   1 CHANGE OPTIONS
   2 CHANGE METEOROLOGY
   3 CHANGE RECEPTOR ELEVATION
   4 CHANGE SOURCE CHARACTERISTICS
   5 CHANGE TITLE
   6 DISPLAY INPUT DATA
   7 RUN
   8 END

 ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
6

 CURRENT INPUT DATA:

    OPTIONS:
       COMPUTE GRADUAL RISE
       COMPUTE DOWNWASH
       COMPUTE BUOYANCY INDUCED DISPERSION
    METEOROLOGY:
       AMBIENT AIR TEMPERATURE (K): 293.0
       MIXING HEIGHT (M):  2000.0
       ANEMOMETER HEIGHT (M):  10.0
       WIND PROFILE EXPONENTS:  0.07 0.07 0.10 0.15 0.35 0.55
    RECEPTOR HEIGHT (M):    0.0
    SOURCE CHARACTERISTICS:
       SOURCE STRENGTH (G/SEC):  2750.0
       PHYSICAL HEIGHT OF STACK (M):  165.0
       STACK GAS TEMPERATURE (K): 425.0
       STACK GAS VELOCITY (M/SEC):  38.0
       INSIDE STACK DIAMETER (M):  4.5
    TITLE:
       DEMONSTRATION OF INTERACTIVE SESSION SUBMITTED BY T. CHICO

 ENTER M TO RETURN TO MENU
M

   1 CHANGE OPTIONS
   2 CHANGE METEOROLOGY
   3 CHANGE RECEPTOR ELEVATION
   4 CHANGE SOURCE CHARACTERISTICS
   5 CHANGE TITLE
   6 DISPLAY INPUT DATA
   7 RUN
   8 END

 ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
7
```

Figure 6. (continued)

```
PTPLU -- IMPROVED MODEL FOR SCREENING MAXIMUM CONCENTRATIONS -- VERSION 81035

***TITLE***
DEMONSTRATION OF INTERACTIVE SESSION SUBMITTED BY T. CHICO

***OPTIONS***
IF = 1, USE OPTION
IF = 0, IGNORE OPTION
IOPT(1) = 1  (GRAD PLUME RISE)
IOPT(2) = 1  (STACK DOWNWASH)
IOPT(3) = 1  (BUOY. INDUCED DISP.)

***METEOROLOGY***
AMBIENT AIR TEMPERATURE =   293.00 (K)
MIXING HEIGHT           =  2000.00 (M)
ANEMOMETER HEIGHT       =    10.00 (M)
WIND PROFILE EXPONENTS  = A:0.07, B:0.07, C:0.10
                          D:0.15, E:0.35, F:0.55

***RECEPTOR HEIGHT***   =      0.00 (M)

***SOURCE***
EMISSION RATE =  2750.00 (G/SEC)
STACK HEIGHT  =   165.00 (M)
EXIT TEMP.    =   425.00 (K)
EXIT VELOCITY =    38.00 (M/SEC)
STACK DIAM.   =     4.50 (M)

>>>CALCULATED PARAMETERS<<<

VOLUMETRIC FLOW =    604.36 (M**3/SEC)
BUOYANCY FLUX PARAMETER =    585.91 (M**4/SEC**3)


DEMONSTRATION OF INTERACTIVE SESSION SUBMITTED BY T. CHICO

****WINDS CONSTANT WITH HEIGHT****
STABILITY   WIND SPEED   MAX CONC     DIST OF MAX     PLUME HT
             (M/SEC)     (G/CU M)        (KM)           (M)
   1           0.50     0.0000E+00       0.000        2276.0(2)
   1           0.80     0.0000E+00       0.000        2380.3(2)
   1           1.00     8.5341E-04       1.971        1937.2(2)
   1           1.50     7.2139E-04       1.839        1346.5(2)
   1           2.00     8.1207E-04       1.152         900.2(2)
   1           2.50     9.7610E-04       1.042         715.1(2)
   1           3.00     1.0968E-03       0.967         601.1(2)

****STACK TOP WINDS (EXTRAPOLATED FROM  10.0 METERS)****
STABILITY   WIND SPEED   MAX CONC     DIST OF MAX     PLUME HT
             (M/SEC)     (G/CU M)        (KM)           (M)
   1           0.61     0.0000E+00       0.000        2365.5(2)
```

Figure 6. (continued)

1	0.97	8.6173E-04	1.974	1985.6(2)
1	1.22	7.9007E-04	1.931	1621.5(2)
1	1.83	7.4371E-04	1.205	995.2(2)
1	2.43	9.5698E-04	1.054	734.4(2)
1	3.04	1.1053E-03	0.962	593.6(2)
1	3.65	1.2024E-03	0.899	506.4(2)

****WINDS CONSTANT WITH HEIGHT****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
2	0.50	0.0000E+00	0.000	2276.0(2)
2	0.80	0.0000E+00	0.000	2380.3(2)
2	1.00	3.6782E-04	10.381	1937.2(2)
2	1.50	2.7921E-04	8.514	1346.5(2)
2	2.00	2.9739E-04	5.786	1051.1(2)
2	2.50	3.3243E-04	4.858	873.9(2)
2	3.00	3.6094E-04	4.264	755.7(2)
2	4.00	4.0207E-04	3.511	608.1(2)
2	5.00	4.2822E-04	3.053	519.4(2)

****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
2	0.61	0.0000E+00	0.000	2365.5(2)
2	0.97	3.7696E-04	10.369	1985.6(2)
2	1.22	3.1362E-04	10.025	1621.5(2)
2	1.83	2.8484E-04	6.337	1136.0(2)
2	2.43	3.2815E-04	4.954	893.2(2)
2	3.04	3.6306E-04	4.222	747.6(2)
2	3.65	3.8972E-04	3.728	650.5(2)
2	4.87	4.2541E-04	3.103	529.1(2)
2	6.08	4.4524E-04	2.723	456.3(2)

****WINDS CONSTANT WITH HEIGHT****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
3	2.00	1.8735E-04	14.212	1051.1(2)
3	2.50	2.1485E-04	11.631	873.9(2)
3	3.00	2.3785E-04	9.980	755.7(2)
3	4.00	2.7289E-04	7.956	608.1(2)
3	5.00	2.9702E-04	6.750	519.4(2)
3	7.00	3.2415E-04	5.389	418.2(2)
3	10.00	3.3578E-04	4.380	342.2(2)
3	12.00	3.3386E-04	3.990	312.7(2)
3	15.00	3.2435E-04	3.599	283.1(2)

****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
3	2.65	2.2207E-04	11.084	834.5(2)
3	3.31	2.5008E-04	9.217	700.6(2)
3	3.97	2.7203E-04	7.996	611.3(2)
3	5.29	3.0253E-04	6.483	499.7(2)
3	6.62	3.2060E-04	5.582	432.8(2)

Figure 6. (continued)

3	9.27	3.3497E-04	4.565	356.3(2)
3	13.24	3.3062E-04	3.806	298.9(2)
3	15.88	3.2074E-04	3.513	276.6(2)
3	19.85	3.0259E-04	3.218	254.3(2)

****WINDS CONSTANT WITH HEIGHT****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
4	0.50	0.0000E+00	0.000	2276.0(2)
4	0.80	0.0000E+00	0.000	2380.3(2)
4	1.00	9.9990E+09	999.999(3)	1937.2(2)
4	1.50	9.9990E+09	999.999(3)	1346.5(2)
4	2.00	9.9990E+09	999.999(3)	1051.1(2)
4	2.50	3.8419E-05	99.338	873.9(2)
4	3.00	4.6683E-05	76.209	755.7(2)
4	4.00	6.1618E-05	51.671	608.1(2)
4	5.00	7.4276E-05	38.990	519.4(2)
4	7.00	9.2719E-05	28.710	418.2(2)
4	10.00	1.0637E-04	20.774	342.2(2)
4	12.00	1.1080E-04	17.950	312.7(2)
4	15.00	1.1334E-04	15.293	283.1(2)
4	20.00	1.1179E-04	12.771	253.6(2)

****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
4	0.76	0.0000E+00	0.000	2492.7(2)
4	1.22	9.9990E+09	999.999(3)	1619.8(2)
4	1.52	9.9990E+09	999.999(3)	1328.9(2)
4	2.28	9.9990E+09	999.999(3)	940.9(2)
4	3.05	4.7410E-05	74.688	746.9(2)
4	3.81	5.8910E-05	55.160	630.5(2)
4	4.57	6.9087E-05	43.631	553.0(2)
4	6.09	8.5636E-05	30.961	456.0(2)
4	7.61	9.6420E-05	26.493	397.8(2)
4	10.66	1.0815E-04	19.710	331.3(2)
4	15.23	1.1339E-04	15.131	281.4(2)
4	18.27	1.1285E-04	13.470	262.0(2)
4	22.84	1.0937E-04	11.871	242.6(2)
4	30.45	1.0377E-04	10.150	220.9(2)

****WINDS CONSTANT WITH HEIGHT****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
5	2.00	1.3457E-04	68.893(1)	362.4(2)
5	2.50	1.2444E-04	61.581	348.2(2)
5	3.00	1.1633E-04	56.252	337.4(2)
5	4.00	1.0392E-04	49.083	321.7(2)
5	5.00	9.4705E-05	44.291	310.4(2)

****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
5	5.34	9.2100E-05	42.981	307.3(2)

Figure 6. (continued)

5	6.67	8.3409E-05	40.000	297.1(2)
5	8.00	7.6437E-05	40.000	289.3(2)
5	10.67	6.5760E-05	40.000	278.0(2)
5	13.34	5.7935E-05	39.984	269.9(2)

****WINDS CONSTANT WITH HEIGHT****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
6	2.00	9.9990E+09	999.999(3)	328.8(2)
6	2.50	9.9990E+09	999.999(3)	317.1(2)
6	3.00	9.9990E+09	999.999(3)	308.1(2)
6	4.00	9.9990E+09	999.999(3)	295.0(2)
6	5.00	9.9990E+09	999.999(3)	285.7(2)

****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****

STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
6	9.35	9.9990E+09	999.999(3)	263.0(2)
6	11.68	9.9990E+09	999.999(3)	256.0(2)
6	14.02	9.9990E+09	999.999(3)	250.6(2)
6	18.69	9.9990E+09	999.999(3)	242.8(2)
6	23.37	9.9990E+09	999.999(3)	237.2(2)

(1) THE DISTANCE TO THE POINT OF MAXIMUM CONCENTRATION IS SO GREAT THAT THE SAME STABILITY IS NOT LIKELY TO PERSIST LONG ENOUGH FOR THE PLUME TO TRAVEL THIS FAR.

(2) THE PLUME IS CALCULATED TO BE AT A HEIGHT WHERE CARE SHOULD BE USED IN INTERPRETING THE COMPUTATION.

(3) NO COMPUTATION WAS ATTEMPTED FOR THIS HEIGHT AS THE POINT OF MAXIMUM CONCENTRATION IS GREATER THAN 100 KILOMETERS FROM THE SOURCE.

1 CHANGE OPTIONS
2 CHANGE METEOROLOGY
3 CHANGE RECEPTOR ELEVATION
4 CHANGE SOURCE CHARACTERISTICS
5 CHANGE TITLE
6 DISPLAY INPUT DATA
7 RUN
8 END

ENTER SELECTION (1,2,3,4,5,6,7 OR 8)
8
PTPLU RUN TERMINATED AT USER REQUEST

Figure 6. (continued)

Three cautionary messages are given by the program: one pertains to the probability that the stability will change before the plume can reach the estimated point of maximum concentration; one is for elevated plumes; and one pertains to maximum concentrations occurring at extreme distances. Effective heights of more than 200 m are regarded as extreme and are tagged with a cautionary message. Distances to maximum concentrations greater than 100 km are considered to be beyond the scope of this model. These calculations are tagged; the concentrations are shown as 9.9990E+09 g/m^3, and the distances are shown as 999.999 km.

To determine the probability that the stability will change before the plume can travel to the estimated point of maximum concentration, the distance to the maximum is divided by the wind speed (assuming a uniform wind speed at all points under consideration), yielding an estimated travel time. If this travel time is greater than the threshold value for the stability considered, the corresponding distance is tagged. Travel-time threshold values employed by the program are as follows:

Stability	Travel time
A	4.0 hours
B	6.0 hours
C	8.0 hours
D	277.5 hours
E	8.0 hours
F	8.0 hours

SECTION 8

EXAMPLE CALCULATION

The following example illustrates the application of PTPLU. A 40-meter stack emits 151 g/s of a pollutant. The stack diameter is 2.68 m, the exit velocity is 20.0 m/s, and the stack gas temperature is 350 K. It is desired to determine the maximum concentration, to find the distance at which it occurs, and to see, in general, how concentration varies with wind speed and stability. For the options, ambient temperature, mixing height, receptor elevation, anemometer height, and wind speed power-law exponents, users are referred to the batch output of Figure 7.

The maximum concentration is selected as the largest concentration in column 7 of output section D (see Figure 4 for designation of output sections). The concentrations in this column can also be plotted as a function of wind speed, to give an overall picture of the dependency of pollutant concentrations on wind speed and stability.

Portions of this example are used in the sensitivity analysis presented in Appendix C.

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PTPLU (VERSION 81036)
 AN IMPROVED POINT SOURCE SCREENING MODEL
 MODIFIED BY: JOE CATALANO AND FRANK HALE
 ALROCOMP, INC. - COSTA MESA, CA      FOR THE
 ENVIRONMENTAL OPERATIONS BRANCH, EPA

                                  >>>INPUT PARAMETERS<<<
***TITLE***  EXAMPLE CALCULATION - SECTION 8 OF USER'S GUIDE

***OPTIONS***                     ***METEOROLOGY***                                    ***SOURCE***
IF = 1, USE OPTION                AMBIENT AIR TEMPERATURE =   293.00 (K)               EMISSION RATE =   151.00 (G/SEC)
IF - 0, IGNORE OPTION             MIXING HEIGHT           =  1500.00 (M)               STACK HEIGHT  =    40.00 (M)
IOPT(1) = 1 (GRAD PLUME RISE)     ANEMOMETER HEIGHT       =    10.00 (M)               EXIT TEMP.    =   350.00 (K)
IOPT(2) - 0 (STACK DOWNWASH)      WIND PROFILE EXPONENTS  = A:0.07, B:0.07, C:0.10     EXIT VELOCITY =    20.00 (M/SEC)
IOPT(3) = 0 (BUOY. INDUCED DISP.)                           D:0.15, E:0.35, F:0.55     STACK DIAM.   =     2.68 (M)

***RECEPTOR HEIGHT*** =      0.00 (M)

                                  >>>CALCULATED PARAMETERS<<<
VOLUMETRIC FLOW =   112.82 (M**3/SEC)          BUOYANCY FLUX PARAMETER =    57.35 (M**4/SEC**3)


EXAMPLE CALCULATION - SECTION 8 OF USER'S GUIDE
```

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
1	0.50	2.5584E-04	1.426	919.0(2)	0.55	2.4954E-04	1.282	837.7(2)
1	0.80	2.7610E-04	1.042	589.4(2)	0.88	2.8469E-04	0.999	538.6(2)
1	1.00	2.9586E-04	0.945	479.5(2)	1.10	3.0440E-04	0.906	438.8(2)
1	1.50	3.3066E-04	0.796	333.0(2)	1.65	3.3845E-04	0.764	305.9(2)
1	2.00	3.5270E-04	0.707	259.7(2)	2.20	3.5928E-04	0.681	239.4(2)
1	2.50	3.6700E-04	0.648	215.8(2)	2.75	3.7219E-04	0.624	199.5
1	3.00	3.8693E-04	0.555	179.1	3.31	4.0344E-04	0.531	162.5

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
2	0.50	8.6753E-05	5.712	919.0(2)	0.55	9.0815E-05	4.990	837.7(2)
2	0.80	1.1703E-04	3.551	589.4(2)	0.88	1.2496E-04	3.270	538.6(2)
2	1.00	1.3585E-04	2.940	479.5(2)	1.10	1.4466E-04	2.712	438.8(2)
2	1.50	1.7501E-04	2.107	333.0(2)	1.65	1.8518E-04	1.950	305.9(2)
2	2.00	2.0575E-04	1.679	259.7(2)	2.20	2.1641E-04	1.559	239.4(2)
2	2.50	2.3028E-04	1.418	215.8(2)	2.75	2.4086E-04	1.320	199.5
2	3.00	2.5000E-04	1.241	186.5	3.31	2.6014E-04	1.158	172.9
2	4.00	2.7878E-04	1.016	149.9	4.41	2.8738E-04	0.953	139.7
2	5.00	2.9741E-04	0.879	127.9	5.51	3.0410E-04	0.828	119.8

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
3	2.00	1.5711E-04	3.343	259.7(2)	2.30	1.7218E-04	2.944	231.3(2)
3	2.50	1.8160E-04	2.728	215.8(2)	2.87	1.9728E-04	2.415	193.0
3	3.00	2.0224E-04	2.325	186.5	3.45	2.1791E-04	2.068	167.5
3	4.00	2.3432E-04	1.830	149.9	4.59	2.4877E-04	1.640	135.6
3	5.00	2.5703E-04	1.538	127.9	5.74	2.6940E-04	1.388	116.5
3	7.00	2.8382E-04	1.210	102.8	8.04	2.9119E-04	1.106	94.7
3	10.00	2.9750E-04	0.969	83.9	11.49	2.9793E-04	0.898	78.3
3	12.00	2.9747E-04	0.877	76.6	13.78	2.9419E-04	0.818	71.9
3	15.00	2.9085E-04	0.786	69.3	17.23	2.8332E-04	0.739	65.5

Figure 7. Batch output of example calculation.

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
4	0.50	9.9990E+09	999.999(3)	919.0(2)	0.62	1.1091E-05	98.419	754.0(2)
4	0.80	1.6511E-05	60.481	589.4(2)	0.98	2.2524E-05	41.362	486.2(2)
4	1.00	2.3036E-05	40.220	479.5(2)	1.23	3.1073E-05	29.491	397.0(2)
4	1.50	3.9940E-05	21.551	333.0(2)	1.85	5.1505E-05	15.612	278.0(2)
4	2.00	5.6601E-05	13.842	259.7(2)	2.46	7.1708E-05	10.160	218.5(2)
4	2.50	7.2915E-05	10.000	215.8(2)	3.08	8.9369E-05	7.819	182.8
4	3.00	8.7243E-05	8.086	186.5	3.69	1.0524E-04	6.197	159.0
4	4.00	1.1252E-04	5.618	149.9	4.92	1.3204E-04	4.390	129.2
4	5.00	1.3348E-04	4.314	127.9	6.16	1.5290E-04	3.429	111.4
4	7.00	1.6431E-04	3.000	102.8	8.62	1.7899E-04	2.553	91.0
4	10.00	1.8725E-04	2.252	83.9	12.31	1.9511E-04	1.916	75.7
4	12.00	1.9439E-04	1.953	76.6	14.77	1.9803E-04	1.686	69.7
4	15.00	1.9810E-04	1.669	69.3	18.47	1.9640E-04	1.468	63.8
4	20.00	1.9449E-04	1.402	62.0	24.62	1.8654E-04	1.260	57.8

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
5	2.00	1.8946E-04	9.923	131.0	3.25	1.5788E-04	7.988	117.4
5	2.50	1.7455E-04	8.963	124.5	4.06	1.4443E-04	7.259	111.8
5	3.00	1.6286E-04	8.280	119.5	4.87	1.3395E-04	6.715	107.6
5	4.00	1.4532E-04	7.298	112.2	6.50	1.1837E-04	5.968	101.4
5	5.00	1.3251E-04	6.644	107.0	8.12	1.0711E-04	5.466	97.0

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (G/CU M)	DIST OF MAX (KM)	PLUME HT (M)
6	2.00	1.2707E-04	19.741	115.5	4.29	1.0491E-04	14.999	98.5
6	2.50	1.2143E-04	17.010	110.1	5.36	9.6261E-05	13.952	94.4
6	3.00	1.1662E-04	15.082	105.9	6.43	8.9407E-05	12.821	91.1
6	4.00	1.0748E-04	14.999	99.9	8.57	7.9123E-05	11.280	86.5
6	5.00	9.8931E-05	14.410	95.6	10.72	7.1622E-05	10.241	83.1

(1) THE DISTANCE TO THE POINT OF MAXIMUM CONCENTRATION IS SO GREAT THAT THE SAME STABILITY IS NOT LIKELY TO PERSIST LONG ENOUGH FOR THE PLUME TO TRAVEL THIS FAR.

(2) THE PLUME IS CALCULATED TO BE AT A HEIGHT WHERE CARE SHOULD BE USED IN INTERPRETING THE COMPUTATION.

(3) NO COMPUTATION WAS ATTEMPTED FOR THIS HEIGHT AS THE POINT OF MAXIMUM CONCENTRATION IS GREATER THAN 100 KILOMETERS FROM THE SOURCE.

Figure 7. (continued)

REFERENCES

Briggs, G. A. 1969. Plume Rise. USAEC Critical Review Series. TID-25075, National Technical Information Service, Springfield, VA. 81 pp.

Pierce, T. E., and D. B. Turner. 1980. User's Guide for MPTER: A Multiple Point Gaussian Dispersion Algorithm with Optional Terrain Adjustment. EPA-600/8-80-016, U. S. Environmental Protection Agency, Research Triangle Park, NC. 247 pp.

Turner, D. B., and A. D. Busse. 1973. Users' Guides to the Interactive Versions of Three Point Source Dispersion Programs: PTMAX, PTDIS, and PTMTP. U. S. Environmental Protection Agency, Research Triangle Park, NC.

Turner, D. B., and J. H. Novak. 1978. User's Guide for RAM, Volume I, Algorithm Description and Use. EPA-600/8-78-016a, U. S. Environmental Protection Agency, Research Triangle Park, NC. 70 pp.

U. S. Environmental Protection Agency. 1977. User's Manual for Single Source (CRSTER) Model. Monitoring and Data Analysis Division, EPA-450/2-77-013. Research Triangle Park, NC.

U. S. Environmental Protection Agency. 1978. Guideline on Air Quality Models. EPA-450/2-78-027, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC. 83 pp.

APPENDIX A

MODELING CONCEPTS

BASIC CONCEPTS

Meteorological factors of wind and turbulence are important in the dispersion process. The dispersion of pollutants emitted into the atmosphere depends on the turbulent mixing that takes place between the polluted air and its cleaner surroundings. This turbulent mixing occurs primarily through eddy dispersion by the circular motions (eddies) that exist in many sizes in the atmosphere, which tend to break portions from the volume of polluted air and mix them with clean air.

In addition to meteorological factors, other factors are significant in modeling the dispersion process and pollutant concentrations. Source characteristics and surface roughness features, as well as topography, are among the interrelated factors that determine the pollutant concentration field.

Source-Related Factors

An important parameter related to pollutant concentrations is the rate of emission of the pollutant from the source. Concentrations are directly proportional to emission rate, usually expressed as mass per unit time. The effective height of release is also important. Roughly, the maximum ground-level concentration is inversely proportional to the square of the height of release. The effective height of release is the combination of physical release height and any additional rise due to buoyancy or momentum effects. The buoyancy of a hot plume will usually dominate over the effect of momentum. Buoyant plume rise is affected by the excess of the stack gas temperature above the ambient air temperature and the volume flow of stack gases. Buoyant rise also decreases with increasing wind speed and is affected by the thermal stability of the air above the plume. Momentum rise is important for plumes with little excess temperature and is proportional to stack gas velocity and stack diameter.

Over relatively flat terrain, a higher effective stack height decreases ground-level concentrations and causes the maximum concentration to occur farther from the source. Effective heights are raised by increasing the physical stack height, the stack gas temperature, the volume of exit gases (without decreasing the exit temperature), or the stack gas exit velocity.

Meteorological Factors

Wind direction is a primary variable in determining concentrations at specific receptors, because it determines whether transport takes place from the source towards the general direction of the receptor. Concentrations from line and area sources are less sensitive to wind direction than are concentrations from point sources.

Wind speed dilutes air pollutants from continuous sources as the plume emerges from the stack. With increasing wind speed, the pollutant concentrations in the plume become more dilute.

Both mechanical production of turbulence and buoyant production or loss of turbulence are important in pollutant dispersion. Mechanical turbulence results from wind flow over objects. The number, size, and spacing of the objects or roughness elements influence the growth of mechanical turbulence. When roughness elements are close together, like trees in a forest, mechanical turbulence is not enhanced, because a new interface forms, allowing the air to flow smoothly over the objects. Mechanical turbulence is enhanced in regions where large objects like mountains or skyscrapers disturb the general air flow. In general, an increase of wind speed will increase the mechanical turbulence.

In light-wind situations, the heating or cooling of the earth's surface increases the importance of buoyantly produced turbulence to dispersion processes. As the sun heats the surface, the air next to the surface is heated and rises buoyantly. During times of strong surface heating, commonly referred to as unstable conditions, buoyant turbulence is produced by the rising thermals of heated air, further amplifying the mechanical turbulence. Furthermore, strong surface heating leads to superadiabatic lapse rates (see Glossary) which encourage the formation of convective cells. Rising thermals are carried upwards in narrow convective updrafts. A general region of subsiding air surrounds these narrow columns. Thus, in unstable conditions, a plume spreads over a relatively large vertical distance.

At nighttime, radiant heat loss at the surface cools the air near the ground. In such situations, commonly referred to as stable conditions, a temperature inversion exists. Further, buoyant turbulence is not produced, and mechanically induced turbulence is suppressed. Thus, a plume spreads little vertically in stable conditions.

In a temperature structure where the air is neither heated nor cooled, turbulence is neither amplified nor suppressed. These conditions are commonly referred to as neutral.

Pasquill (1961) devised a method for classifying turbulence in terms of atmospheric conditions into six stability categories, ranging from very unstable (class A), to neutral (class D), to moderately stable (class F) (see Table A-1). For PTPLU, the dispersion due to atmospheric turbulence is assumed to be related to the Pasquill stability classes.

Wind speed generally increases with height above the surface, and this increase depends on both surface roughness and atmospheric stability. A power-law profile of the form

$$u(z) = u(z_a)(z/z_a)^p$$

is frequently used to approximate this increase. The wind speed at a height z above the ground is $u(z)$; $u(z_a)$ is the wind speed measured at the anemometer height, z_a, above the ground; and p is a function of stability. For a more detailed discussion of wind profiles, see Irwin (1979).

Another condition that affects vertical dispersion is the thickness of the neutral or unstable layer, often referred to as the mixing layer. At the top of the convective layer, an inversion usually exists, tending to damp out vertical motions and limiting the extent to which pollutants can spread vertically. The strength and depth of the inversion are also important; if the inversion is weak or shallow, pollutants may still diffuse through it.

The mixing height varies both seasonally and diurnally. It is typically high in summer and at mid-day and low in winter, and it frequently is undefined at night (when a surface-based inversion exists). For a climatological summary of mixing heights across the United States see Holzworth (1972).

Further Considerations

Usually, the wind turns with height, due primarily to friction of the wind with the ground. Friction causes slowing of the wind near the surface, which causes the low-level flow to deviate toward low pressure. This results in a clockwise turning of the wind with height. Other forces also cause turning of the wind with height. Within a barotropic atmosphere (in which the surfaces of constant pressure are also surfaces of constant density), the wind direction is constant with height, except near the surface, where frictional effects take place. The atmosphere is usually not barotropic; when surfaces of constant pressure and constant density do not coincide, the atmosphere is said to be baroclinic. In such an atmosphere, the wind direction must vary with height, since colder air is advected (transported horizontally) into warmer surroundings (or warmer air into colder surroundings). During cold-air advection, the wind direction backs (counterclockwise rotation) with height, and during warm-air advection, the wind direction veers (clockwise rotation) with height. Vertical wind shear causes portions of a polluted plume that has dispersed to different altitudes to be transported away from the source in different directions, resulting in additional horizontal spreading or dispersion. Because effects of wind direction shear are ignored in the model presented here, estimates of concentration directly downwind of sources are likely to be higher than concentrations actually observed at distances greater than 10 km from the source. Methods to account for the effect of wind direction shear are discussed by Pasquill (1976).

Besides causing wind direction shear, the frictional effect also causes a wind speed shear, with the wind speed decreasing near the earth's surface (to zero at the surface). Under stable conditions, the increase of speed with height to the wind speed of the free atmosphere may take place through a shallow layer, only 100 to 200 m thick. This also tends to be the case if the surface is smooth. Under conditions of instability or large surface roughness, the transition takes place through a much deeper layer. The combined effects of stability and surface roughness result in different patterns of wind speed with time of day at different heights. For example, wind speeds near the ground (10 m) generally exhibit a nighttime minimum and a daytime maximum. At greater heights (e.g., 200 m above ground), wind speeds may reach a minimum (maximum surface friction effect) during mid-afternoon and a maximum (nearest the free atmosphere speed) at night.

In considering buoyant production or suppression of turbulence as reflected in the vertical temperature structure, it is important to realize that the layer adjacent to the ground surface characterizes the state of the atmosphere. For instance, when conditions are very unstable, the temperature structure through the well-mixed convective layer (typically on the order of 1000 to 2000 m thick) is nearly adiabatic, indicating that turbulent motion is neither suppressed nor enhanced. Only within the near-surface layer (typically 100 m thick or less) is the temperature structure superadiabatic. If one attempted to specify the state of the atmosphere using the temperature structure in the higher layers, one would erroneously conclude that the atmosphere was nearly neutral, when in fact it was convectively unstable. During stable conditions, the temperature structure above the surface-based inversion is often nearly adiabatic. Hence, during stable conditions, the temperature structure within the layers aloft may not truly reflect how stable the entire dispersion layer is. Therefore, in considering ground-level concentrations from point sources, it is important to examine the surface layer near the ground to properly determine the influences of buoyant production or loss of turbulent kinetic energy on dispersion through the surface layer.

Information about conditions above the ground is by no means useless. On the contrary, detailed structures of temperature and wind velocity with height are extremely useful for assessing air pollution transport and dispersion; but they are most useful when interpreted with near-surface measurements.

Air pollution simulations are frequently complicated by local flows. Uneven solar heating on the sides of valleys or cold-air drainage at night can cause small-scale circulations that may make analysis of meteorological measurements difficult. For example, during the Lewiston, Idaho -- Clarkston, Washington study (U. S. Department of Health, Education, and Welfare, 1964), maximum ground-level concentrations were observed at a receptor down-valley from the source at the time when surface wind measurements indicated an up-valley flow. Thorough analysis, revealed that the high concentrations were due to the fumigation (rapid downward mixing) of the detached plume, which had been flowing down-valley during the night. The plume was not mixed downward to the valley floor until the winds had already shifted to up-valley.

Another cause of local circulations is land-water interfaces, which can produce land and sea breezes, due to horizontal temperature differences, especially during periods of light general wind flow.

The effects of local flow are sufficiently complex to require a special modeling approach for each condition.

GAUSSIAN EQUATIONS FOR ESTIMATING CONCENTRATIONS

In using the Gaussian plume model, one assumes that pollutant concentrations from a continuously emitted plume are proportional to emission rate, and are diluted by the wind at the point of emission at a rate inversely proportional to the wind speed. One also assumes that the time-averaged (over approximately one hour) pollutant concentrations crosswind and in the vertical near the source are closely described by Gaussian or normal distributions. The standard deviations of a plume concentration in these two directions are empirically related to the levels of turbulence in the atmosphere and increase with distance from the source.

In its simplest form, the Gaussian model is based on the assumption that the pollutant does not undergo chemical reactions or other removal processes during its transport from the source. Furthermore, pollutants reaching the ground or the top of the mixing height as the plume grows are assumed to be eddy-reflected back toward the plume centerline.

The three Gaussian equations given below are based on a coordinate scheme with the origin at the base of the stack, x downwind from the source, y crosswind, and z vertical; Figure A-1 illustrates the coordinate system. These equations include four components, from left to right in Eq. A1: 1) concentrations are proportional to emission rate, 2) the released effluent is diluted by the wind passing the point of release, 3) the effluent is spread horizontally, resulting in a Gaussian or normal (bell-shaped) crosswind distribution downwind, and 4) the effluent is spread vertically. Vertical spread also results in a normal vertical distribution near the source, which at greater downwind distances is modified by eddy reflection at the ground and, if appropriate, by eddy reflection at the mixing height.

The following symbols are used:

χ_p -- concentration (grams per cubic meter),

Q -- emission rate (grams per second),

u -- wind speed (meters per second),

σ_y -- standard deviation of plume concentration distributed in the horizontal (evaluated at distance x and for the appropriate stability) (meters),

σ_z -- standard deviation of plume concentration distributed in the vertical (evaluated at distance x and for the appropriate stability) (meters),

L -- mixing height (meters),

H -- effective height of emission (meters),

z -- receptor height above ground (meters), and

y -- crosswind distance from plume centerline (meters).

The concentration, χ_p, at a receptor at (x,y,z) from the continuous emission from a point source located at (0,0,H) is given by one of the three following equations.

For stable conditions or unlimited mixing,

$$\chi_p = Q \cdot 1/u \cdot g_1/(\sqrt{2\pi}\ \sigma_y) \cdot g_2/(\sqrt{2\pi}\ \sigma_z), \qquad \text{(A1)}$$

where

$$g_1 = \exp(-0.5\ y^2/\sigma_y^2), \text{ and}$$

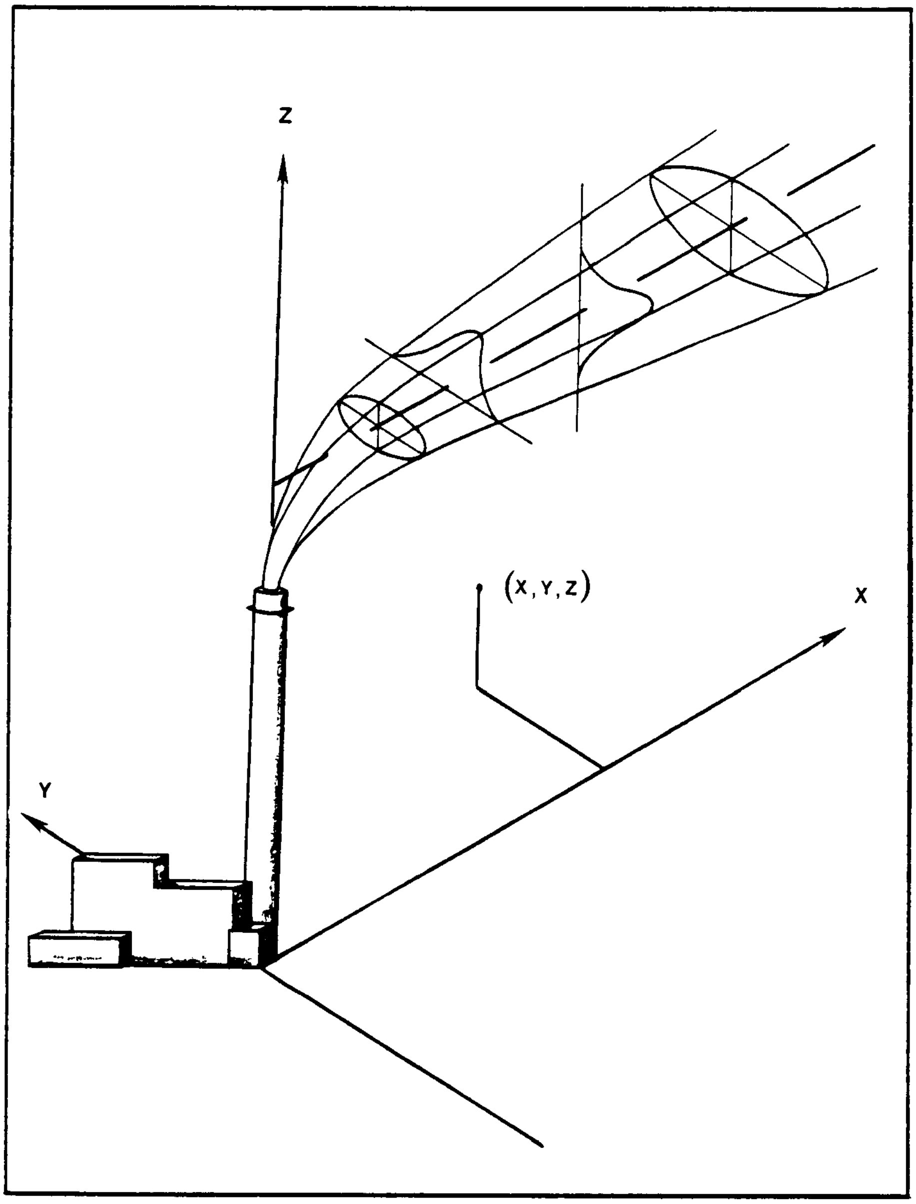

Figure A-1. Coordinate system showing Gaussian distributions in the horizontal and vertical.

$$g_2 = \exp[-0.5(z-H)^2/\sigma_z^2] + \exp[-0.5(z+H)^2/\sigma_z^2].$$

Note that if $y = 0$, or $z = 0$, or both z and H are 0, this equation simplifies greatly.

For unstable or neutral conditions, where σ_z is greater than 1.6 L,

$$\chi_p = Q \cdot 1/u \cdot g_1/(\sqrt{2\pi}\ \sigma_y) \cdot 1/L. \quad \text{(A2)}$$

For unstable or neutral conditions, provided that both H and z are less than L, where σ_z is less than or equal to 1.6 L,

$$\chi_p = Q \cdot 1/u \cdot g_1/(\sqrt{2\pi}\ \sigma_y) \cdot g_3/(\sqrt{2\pi}\ \sigma_z), \quad \text{(A3)}$$

where

$$g_3 = \sum_{N=-\infty}^{\infty} \{\exp[-0.5(z-H+2NL)^2/\sigma_z^2] + \exp[-0.5(z+H+2NL)^2/\sigma_z^2]\}.$$

(This infinite series converges rapidly, and evaluation with N varying from -4 to +4 is usually sufficient.)

When estimates are calculated by hand, Eq. A1 is frequently applied until $\sigma_z = 0.8$ L, and then Eq. A2 is applied for all distances where σ_z exceeds 0.8 L. This causes an inflection point in a plot of concentrations with distance. Adding Eq. A3, which includes multiple eddy reflections, and changing the criteria for use of Eq. A2 to situations where σ_z is greater than 1.6 L results in a smooth transition to uniform mixing, regardless of source or receptor height. Values must be obtained for the dispersion parameters in the above equations. In his original discussions of dispersion and in his subsequent writings, Pasquill (1961, 1974, 1976) emphasized the desirability of using direct measurements of turbulent intensity to characterize atmospheric dispersion. Typically, we lack the required turbulence measurements and resort to other methods of estimating the parameters. Although not expressed as standard deviations for use with Gaussian equations, Pasquill (1961) provided some estimates of dispersion qualified by, "for use in the likely absence of special measurements of wind structure there was clearly a need for broad estimates of θ and h in terms of routine meteorological data." Pasquill's parameters of spreading are θ and h. Gifford (1960) transformed Pasquill's parameters to σ_y and σ_z for use with Gaussian equations. Commonly referred to as the Pasquill-Gifford (P-G) dispersion parameters, these are discussed later in this appendix.

By differentiating Eq. A1 with respect to distance, x, and setting the derivative equal to zero, an equation for maximum concentration can be derived:

$$\chi_{max} = 2Q\sigma_z/\sigma_y e\pi u H^2;$$

the distance to maximum concentration is the distance where $\sigma_z = H/\sqrt{2}$. However, this equation is correct only if the ratio of σ_z/σ_y is constant with distance (see Pasquill (1974), p. 273, for further details). For the P-G parameter values, the ratio is not constant, and maximum concentrations, if required, are determined using iterative methods.

PLUME RISE FOR POINT SOURCES

The use of the methods of Briggs to estimate plume rise and effective height of emission are discussed below.

First, actual or estimated wind speed at stack top, u(h), is assumed to be available.

Stack Downwash

To consider stack downwash, the physical stack height is modified following Briggs (1973, p. 4). The h' is found from

$$h' = h + 2\{[v_s/u(h)] - 1.5\}d \quad \text{for} \quad v_s < 1.5u(h), \qquad \text{(A4)}$$

$$h' = h \text{ for } v_s \geq 1.5u(h),$$

where h is physical stack height (meters), v_s is stack gas velocity (meters per second), and d is inside stack-top diameter (meters). This h' is used throughout the remainder of the plume height computation. If stack downwash is not considered, h' = h in the following equations.

Buoyancy Flux

For most plume rise situations, the value of the Briggs buoyancy flux parameter, F (m^4/s^3) is needed. The following equation is equivalent to Briggs' (1975, p. 63) Eq. 12:

$$F = (g v_s d^2 \Delta T)/(4T_s), \qquad \text{(A5)}$$

where $\Delta T = T_s - T$, T_s is stack gas temperature (kelvin), and T is ambient air temperature (kelvin).

Unstable or Neutral: Crossover Between Momentum and Buoyancy

For cases with stack gas temperature greater than or equal to ambient air temperature, it must be determined whether the plume rise is dominated by momentum or buoyancy. The crossover temperature difference $(\Delta T)_c$ is determined for 1) F less than 55 and 2) F greater than or equal to 55. If the difference between stack gas temperature and ambient air temperature, ΔT, exceeds or equals the $(\Delta T)_c$, plume rise is assumed to be buoyancy dominated;

if the difference is less than $(\Delta T)_c$, plume rise is assumed to be momentum dominated (see below).

The crossover temperature difference is found by setting Briggs' (1969, p. 59) Eq. 5.2 equal to the combination of Briggs' (1971, p. 1031) Eqs. 6 and 7 and solving for ΔT. For F less than 55,

$$(\Delta T)_c = 0.0297 v_s^{1/3} T_s / d^{2/3}. \qquad \text{(A6)}$$

For F equal to or greater than 55,

$$(\Delta T)_c = 0.00575 v_s^{2/3} T_s / d^{1/3}. \qquad \text{(A7)}$$

Unstable or Neutral: Buoyancy Rise

For situations where ΔT exceeds or is equal to $(\Delta T)_c$ as determined above, buoyancy is assumed to dominate. The distance to final rise x_f (in kilometers) is determined from the equivalent of Briggs' (1971, p. 1031) Eq. 7, and the distance to final rise is assumed to be $3.5x^*$, where x^* is the distance at which atmospheric turbulence begins to dominate entrainment. For F less than 55,

$$x_f = 0.049 F^{5/8}. \qquad \text{(A8)}$$

For F equal to or greater than 55,

$$x_f = 0.119 F^{2/5}. \qquad \text{(A9)}$$

The plume height, H (in meters), is determined from the equivalent of the combination of Briggs' (1971, p. 1031) Eqs. 6 and 7. For F less than 55,

$$H = h' + 21.425 F^{3/4} / u(h). \qquad \text{(A10)}$$

For F equal to or greater than 55,

$$H = h' + 38.71 F^{3/5} / u(h). \qquad \text{(A11)}$$

Unstable or Neutral: Momentum Rise

For situations where the stack gas temperature is less than the ambient air temperature, it is assumed that the plume rise is dominated by momentum. Also, if ΔT is less than $(\Delta T)_c$ from Eq. A6 or A7, it is assumed that the plume rise is dominated by momentum. The plume height is calculated from Briggs' (1969, p. 59) Eq. 5.2:

$$H = h' + 3 d v_s / u(h). \qquad \text{(A12)}$$

Briggs (1969) suggests that this equation is most applicable when

v_s/u is greater than 4. Since momentum rise occurs quite close to the point of release, the distance to final rise is set equal to zero.

Stability Parameter

For stable situations, the stability parameter s is calculated from the equation (Briggs, 1971, p. 1031):

$$s = g(\partial\theta/\partial z)/T. \qquad (A13)$$

As an approximation, for stability class E (or 5), $\partial\theta/\partial z$ is taken as 0.02 K/m, and for stability class F (or 6), $\partial\theta/\partial z$ is taken as 0.035 K/m.

Stable: Crossover Between Momentum and Buoyancy

For cases with stack gas temperature greater than or equal to ambient air temperature, it must be determined whether the plume rise is dominated by momentum or buoyancy. The crossover temperature difference $(\Delta T)_c$ is found by setting Briggs' (1975, p. 96) Eq. 59 equal to Briggs' (1969, p. 59) Eq. 4.28, and solving for ΔT. The result is

$$(\Delta T)_c = 0.019582 v_s T\ s^{1/2}. \qquad (A14)$$

If the difference between stack gas temperature and ambient air temperature (ΔT) exceeds or equals $(\Delta T)_c$, the plume rise is assumed to be buoyancy dominated; if ΔT is less than $(\Delta T)_c$, the plume rise is assumed to be momentum dominated.

Stable: Buoyancy Rise

For situations where ΔT is greater than or equal to $(\Delta T)_c$, buoyancy is assumed to dominate. The distance to final rise (in kilometers) is determined by the equivalent of a combination of Briggs' (1975, p. 96) Eqs. 48 and 59:

$$x_f = 0.0020715 u(h) s^{-1/2}. \qquad (A15)$$

The plume height is determined by the equivalent of Briggs' (1975, p. 96) Eq. 59:

$$H = h' + 2.6\{F/[u(h)s]\}^{1/3}. \qquad (A16)$$

The stable buoyancy rise for calm conditions (Briggs, 1975, pp. 81-82) is also evaluated:

$$H = h' + 4F^{1/4}s^{-3/8}. \qquad (A17)$$

The lower of the two values obtained from Eqs. A16 and A17 is taken as the final effective height.

By setting Eqs. A16 and A17 equal to each other and solving for u(h), one can determine the wind speed that yields the same plume rise for the wind conditions (A16) as does the equation for calm conditions (A17). This wind speed is

$$u(h) = (2.6/4)^3 F^{1/4} s^{1/8}$$

$$= 0.2746 F^{1/4} s^{1/8}. \qquad (A18)$$

For wind speed less than or equal to this value, Eq. A17 should be used for plume rise; for wind speeds greater than this value, Eq. A16 should be used.

Stable: Momentum Rise

When the stack gas temperature is less than the ambient air temperature, it is assumed that the plume rise is dominated by momentum. If ΔT is less than $(\Delta T)_c$ as determined by Eq. A14, it is also assumed that the plume rise is dominated by momentum. The plume height is calculated from Briggs' (1969, p. 59) Eq. 4.28:

$$H = h' + 1.5\{(v_s^2 d^2 T)/[4T_s u(h)]\}^{1/3} s^{-1/6}. \qquad (A19)$$

The equation for unstable or neutral momentum rise (A12) is also evaluated. The lower result of these two equations is used as the resulting plume height.

All Conditions: Distance Less than Distance to Final Rise (Gradual Rise)

Where gradual rise is to be estimated for unstable, neutral or stable conditions, if the distance upwind from receptor to source x (in kilometers), is less than the distance to final rise, the equivalent of Briggs' (1971, p. 1030) Eq. 2 is used to determine plume height:

$$H = h' + (160F^{1/3}x^{2/3})/u(h). \qquad (A20)$$

This height is used only for buoyancy-dominated conditions; should it exceed the final rise for the appropriate condition, the final rise is substituted instead.

DISPERSION PARAMETERS

PTPLU uses the method presented by Pasquill (1961) to estimate the dispersion potential of the atmosphere. In this method, six stability categories are specified in terms of wind speed and solar radiation. Stability categories are given in Table A-1. Class A is the most unstable and class F the most stable.

TABLE A-1. KEY TO STABILITY CATEGORIES FROM PASQUILL (1961)*

Surface wind speed (at 10m) (m/s)	Day			Night†	
	Incoming solar radiation			Thinly overcast or 4/8 or more low cloud	3/8 or less cloud
	Strong	Moderate	Slight		
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

* The neutral class, D, should be used for overcast conditions during day or night.

† Night refers to the period from one hour before sunset to one hour after sunrise.

The lateral and vertical dispersion parameters are those computed by Gifford (1960) from the original plume spreading parameters reported by Pasquill (1961). The relevant background of the P-G curves is summarized by Pasquill (1976) and is given in Table A-2. It should be noted from Table A-2 that vertical dispersion estimates were based on surface release of material.

The algorithms employed by PTPLU to evaluate the horizontal and vertical dispersion parameters are discussed next. Similar algorithms are employed by MPTER, RAM, PTDIS, and PTMTP.

One of the assumptions of Gaussian plume modeling is that concentrations within the plume vary vertically and horizontally according to a normal distribution, with the maximum concentrations along the plume centerline. In converting plume dimensions to standard deviations, Gifford assumed that the edge of the plume is equivalent to the point where the concentration is 1/10 of the centerline concentration at the same distance from the source. This is equivalent to 2.15 σ.

Vertical Dispersion

The P-G curves describing the vertical spread of plumes have been shown to fit an exponential equation of the form

$$\sigma_z = ax^b,$$

where x is the downwind distance. Values of a and b vary with stability class and range of downwind distance. The vertical dispersion parameter is set to 5000 m for stability class A at distances greater than 3.11 km and for stability class B at

TABLE A-2. BASIS AND SCOPE OF THE ORIGINAL P-G CURVES FROM PASQUILL (1976)

Crosswind spread	
Source height	Any (within mixed layer).
Sampling time	3 min.
Basis for x = 0.1 to 1 km	Preliminary statistics of wind direction fluctuation for a surface roughness length of 3 cm.
Basis for x = 10 to 100 km	Extrapolation of short-range data in the light of limited special observations of tracer dispersion over level terrain of mixed roughness (implied roughness length of 30 cm).
Vertical spread	
Source height	Effectively zero (surface release of material), but offered as usable for any height in a mixed layer, in the absence of strong evidence to the contrary.
Sampling time	Any. For elevated sources up to about 100 m, the limiting sampling time is roughly proportional to the height of the source; if the height of the source is above 100 m, the sampling time is roughly 10 min.
Basis for x = 0.1 to 1 km	Properties of the wind profile over a surface of small roughness (roughness length of 3 cm), with guidance from dispersion studies, especially in regard to the effect of thermal stratification.
Basis for x = 10 to 100 km	As for the crosswind spread, with guidance from early data on the properties of the vertical component of turbulence at heights throughout the mixed layer.

distances greater than 35 km. Table A-3 shows the constants employed by PTPLU. It should be noted that the program limits the vertical dispersion parameter to 5000 m.

Lateral Dispersion

Lateral dispersion has been estimated at 0.1 km and 100 km by measuring the half-angle from the plume centerline to the edge of the plume at 2.15 standard deviations. Lateral dispersion for any downwind distance less than 100 km can be estimated by linear interpolation, with the half-angle as the ordinate and the logarithm of the downwind distance as the abscissa. The tangent of this angle is 2.15 standard deviations divided by the downwind distance. Using these facts, the horizontal dispersion parameter (in meters) can be obtained from the interpolated half-angle as follows:

$$\sigma_y = 1000 \text{ x } \tan(\theta)/2.15,$$

where x is the downwind distance in kilometers.

The half-angles (degrees) employed by the model at 0.1 km and 100 km for each stability class are

Stability class	0.1 km	100 km
A	30.0	12.50
B	22.5	10.00
C	15.0	7.50
D	10.0	5.00
E	7.5	3.75
F	5.0	2.50

Figure A-2 graphically represents the equations for the half-angle. Although commom logarithms are used in this figure, the program employs the natural logarithm of downwind distance for the abscissa. Therefore, the corresponding values to 0.1 and 100 km are -2.30 and 4.6. As an example, the equation used to determine the half-angle for stability A is obtained as follows:

$$\theta = a \ln(x) + b,$$

where

$$a = [(12.50 - 30.0)/(4.6 + 2.3)]$$
$$b = 30 + 2.3a,$$

and

$$\theta = -2.5334 \ln(x) + 24.167.$$

TABLE A-3. CONSTANTS FOR THE VERTICAL DISPERSION PARAMETER EQUATION

Stability class	Distance (km)	a	b
A	< 0.1	122.80	0.9447
	0.1 - 0.15	158.08	1.0542
	0.15 - 0.2	170.22	1.0932
	0.2 - 0.25	179.52	1.1262
	0.25 - 0.3	217.41	1.2644
	0.3 - 0.4	258.89	1.4094
	0.4 - 0.5	346.75	1.7283
	> 0.5	453.85	2.1166
B	< 0.2	90.673	0.93198
	0.2 - 0.4	98.483	0.98332
	> 0.4	109.300	1.09710
C		61.141	0.91465
D	< 0.3	34.459	0.86974
	0.3 - 1	32.093	0.81066
	1 - 3	32.093	0.64403
	3 - 10	33.504	0.60486
	10 - 30	36.650	0.56589
	> 30	44.053	0.51179
E	< 0.1	24.260	0.83660
	0.1 - 0.3	23.331	0.81956
	0.3 - 1	21.628	0.75660
	1 - 2	21.628	0.63077
	2 - 4	22.534	0.57154
	4 - 10	24.703	0.50527
	10 - 20	26.970	0.46713
	20 - 40	35.420	0.37615
	> 40	47.618	0.29592
F	< 0.2	15.209	0.81558
	0.2 - 0.7	14.457	0.78407
	0.7 - 1	13.953	0.68465
	1 - 2	13.953	0.63227
	2 - 3	14.823	0.54503
	3 - 7	16.187	0.46490
	7 - 15	17.836	0.41507
	15 - 30	22.651	0.32681
	30 - 60	27.074	0.27436
	> 60	34.219	0.21716

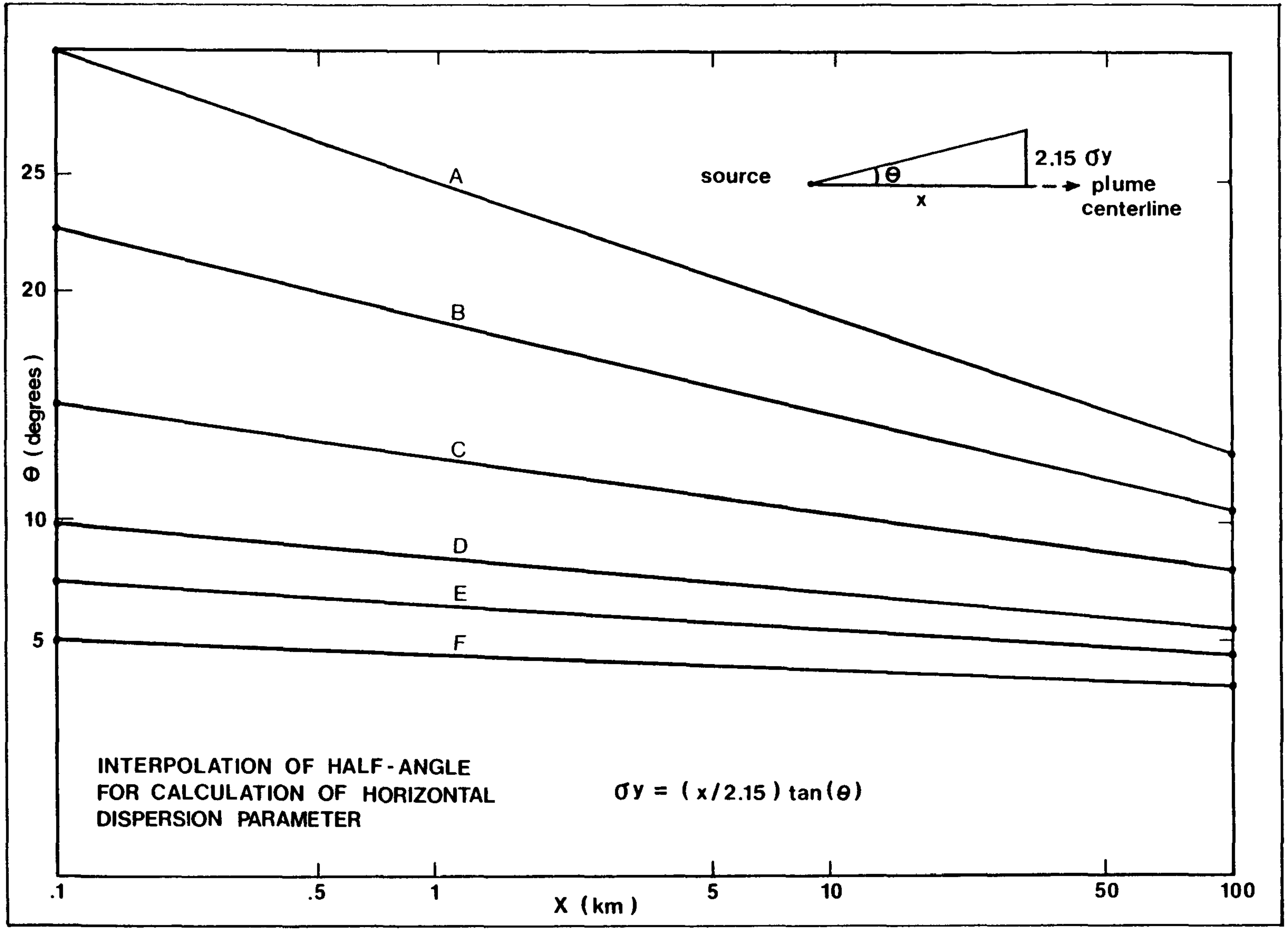

Figure A-2. Estimation of lateral dispersion parameter.

The constants a and b for each stability class are as follows:

Stability class	a	b
A	-2.5334	24.167
B	-1.8096	18.333
C	-1.0857	12.500
D	-0.72382	8.3333
E	-0.54287	6.2500
F	-0.36191	4.1667

BUOYANCY-INDUCED DISPERSION

For strongly buoyant plumes, entrainment as the plume ascends through the ambient air contributes to both vertical and horizontal spread. Pasquill (1976) suggests that this induced dispersion, σ_{zo}, can be approximated by the plume rise divided by 3.5. The effective dispersion can then be determined by adding variances:

$$\sigma_{ze} = (\sigma_{zo}^2 + \sigma_z^2)^{1/2},$$

where σ_{ze} is the effective dispersion, and σ_z is the dispersion due to ambient turbulence levels. At the distance of final rise and beyond, the induced dispersion is constant, based on the height of final rise. At distances closer to the source, gradual plume rise is used to determine the induced dispersion.

Since in the initial growth phases of release, the plume is nearly symmetrical about its centerline, buoyancy-induced dispersion in the horizontal direction, σ_{yo}, equal to that in the vertical direction, is used:

$$\sigma_{yo} = \Delta h/3.5.$$

To yield an effective lateral dispersion value, σ_{ye}, this expression is combined with that for dispersion due to ambient turbulence:

$$\sigma_{ye} = (\sigma_{yo}^2 + \sigma_y^2)^{1/2}.$$

REFERENCES

Briggs, G. A. 1969. Plume Rise. USAEC Critical Review Series, TID-25075, National Technical Information Service, Springfield, VA. 81 pp.

Briggs, G. A. 1971. Some Recent Analyses of Plume Rise Observation. In: Proceedings of the Second International Clean Air Congress, H. M. Englund and W. T. Beery, eds. Academic Press, New York. pp. 1029-1032.

Briggs, G. A. 1973. Diffusion Estimation for Small Emissions. NOAA Atmos. Turb. and Diff. Lab., Contribution File No. (Draft) 79. Oak Ridge, TN. 59 pp.

Briggs, G. A. 1975. Plume rise predictions. In: Lectures on Air Pollution and Environmental Impact Analysis, D. A. Haugen, ed. Amer. Meteorol. Soc., Boston, MA. pp. 59-111.

Gifford, F. A. 1960. Atmospheric dispersion calculations using the generalized Gaussian plume model. Nucl. Safety 2: 56-59.

Holzworth, G. C. 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. Office of Air Programs, U. S. Environmental Protection Agency, Research Triangle Park, NC. 118 pp.

Irwin, J. S. 1979. A theoretical variation of the wind profile power-law exponent as a function of surface roughness and stability. Atmos. Environ. 13: 191-194.

Pasquill, F. 1961. The estimation of dispersion of windborne material. Meteorol. Magazine 90: 33-49.

Pasquill, F. 1974. Atmospheric Diffusion, 2nd ed. John Wiley and Sons, New York. 429 pp.

Pasquill, F. 1976. Atmospheric Dispersion Parameters in Gaussian Plume Modeling. Part II. Possible Requirements for Change in the Turner Workbook Values. EPA-600/4-76-030b, U. S. Environmental Protection Agency, Research Triangle Park, NC. 44 pp.

U. S. Department of Health, Education, and Welfare. 1964. A Study of Air Pollution in the Interstate Region of Lewiston, Idaho, and Clarkson, Washington. Public Health Service Pub. No. 999-AP-8, Cincinnati, OH. 154 pp.

APPENDIX B

INDEXED LISTING OF FORTRAN SOURCE STATEMENTS (BATCH)

The source code and a cross-referenced listing of the batch version of PTPLU follow. The cross-referenced listing contains all references to statement labels, subprograms, and variables that appear in the source program. Statement numbers appear first in the listing and are in numerical order. Variables, arrays, etc., appear second and are in alphabetical order.

```
C     PTPLU VERSION 81036                                                PLB00010
C     THIS IS THE BATCH VERSION OF PTPLU.                                PLB00020
C                                                                        PLB00030
C     PTPLU ABSTRACT:                                                    PLB00040
C        PTPLU FEATURES SEVERAL IMPROVEMENTS OF THE PTMAX                PLB00050
C        ALGORITHM. THE ANALYSIS OF CONCENTRATION HAS BEEN               PLB00060
C        EXPANDED TO INCLUDE COMPUTATIONS BASED ON INCREASED             PLB00070
C        WIND SPEED WITH HEIGHT FROM USER INPUT WIND PROFILE             PLB00080
C        EXPONENTS. OTHER FEATURES INCLUDE OPTIONS FOR CALCULATION       PLB00090
C        OF GRADUAL PLUME RISE, STACK DOWNWASH, AND INITIAL              PLB00100
C        PLUME SIZE DUE TO BUOYANCY INDUCED DISPERSION.                  PLB00110
C                                                                        PLB00120
C     PTPLU AUTHORS:                                                     PLB00130
C        THOMAS E. PIERCE AND D. BRUCE TURNER                            PLB00140
C        (ON ASSIGNMENT FROM NOAA)                                       PLB00150
C        ENVIRONMENTAL OPERATIONS BRANCH (MD - 80)                       PLB00160
C        METEOROLOGY AND ASSESSMENT DIVISION, ESRL                       PLB00170
C        ENVIRONMENTAL PROTECTION AGENCY                                 PLB00180
C                                                                        PLB00190
C     PTPLU MODIFIED BY:                                                 PLB00200
C        JOE CATALANO AND FRANK HALE                                     PLB00210
C        AEROCOMP, INC.                                                  PLB00220
C        3303 HARBOR BLVD.                                               PLB00230
C        COSTA MESA, CA  92626                                           PLB00240
C                                                                        PLB00250
C     PTPLU SUPPORTED BY:                                                PLB00260
C        ENVIRONMENTAL OPERATIONS BRANCH                                 PLB00270
C        MAIL DROP 80, EPA                                               PLB00280
C        RESRCH TRI PK, NC 27711                                         PLB00290
C                                                                        PLB00300
C        PHONE: (919) 541-4564   FTS 629-4564                            PLB00310
C                                                                        PLB00320
C         PTPLU INPUT:                                                   PLB00330
C        DATA IN CARD TYPES  1,2 AND 4 MUST BE SEPARATED BY A SPACE      PLB00340
C        OR A COMMA TO BE COMPATIBLE WITH UNIVAC'S FREE FORMAT.          PLB00350
C        ADDITIONAL SOURCES CAN BE COMPUTED WITH EXTRA INPUT OF CARD     PLB00360
C        TYPES 3 AND 4. TWO BLANK DATA CARDS FOLLOW TO TERMINATE         PLB00370
C        EXECUTION.                                                      PLB00380
C                                                                        PLB00390
C     <<<<<< CARD TYPE ONE (FREE FORMAT) >>>>>>                          PLB00400
C  VARIABLE      DESCRIPTION                                             PLB00410
C   IOPT(1)      GRADUAL RISE OPTION     0: DO NOT COMPUTE GRADUAL RISE  PLB00420
C                                        1: COMPUTE GRADUAL RISE         PLB00430
C   IOPT(2)      STACK DOWNWASH OPTION   0: DON'T COMPUTE DOWNWASH       PLB00440
C                                        1: DO COMPUTE DOWNWASH          PLB00450
C   IOPT(3)      BUOYANCY INDUCED DISPERSION                             PLB00460
C                                        0: NONE COMPUTED                PLB00470
C                                        1: USE PASQUILL'S TECHNIQUE     PLB00480
C   T            AMBIENT AIR TEMPERATURE (DEG, K)                        PLB00490
C   HL           MIXING HEIGHT (METERS)                                  PLB00500
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```
C   Z             RECEPTOR ELEVATION (ABOVE GRND SFC, IN METERS)      PLB00510
C                                                                     PLB00520
C    <<<<<< CARD TYPE TWO (FREE FORMAT) >>>>>>                        PLB00530
C          ****************************************************       PLB00540
C          *                IMPORTANT MESSAGE                 *       PLB00550
C          *      CALCULATIONS SUBMITTED TO SATISFY REGULATORY *      PLB00560
C          *  REQUIREMENTS MAY REQUIRE CERTAIN PARAMETER VALUES *     PLB00570
C          *  FOR WIND PROFILE EXPONENTS AND THE USE OF CERTAIN *     PLB00580
C          *  OPTIONS. CHECK WITH THE APPROPRIATE EPA REGIONAL  *     PLB00590
C          *  OFFICE TO INSURE THAT ACCEPTABLE PARAMETER VALUES *     PLB00600
C          *  ARE USED IN YOUR RUN.                             *     PLB00610
C          ****************************************************       PLB00620
C   HANE          ANEMOMETER HEIGHT (METERS)                          PLB00630
C                 NORMAL HEIGHT IS TEN METERS                         PLB00640
C   PL(I,I=1,6)   WIND PROFILE EXPONENTS                              PLB00650
C                 (SIX VALUES CORRESPONDING TO EACH STABILITY CLASS)  PLB00660
C                                                                     PLB00670
C    <<<<<< CARD TYPE THREE (20A4) >>>>>>                             PLB00680
C   ALP           ALPHANUMERIC DATA FOR OUTPUT HEADING (80 CHARACTERS) PLB00690
C                                                                     PLB00700
C    <<<<<< CARD TYPE FOUR (FREE FORMAT) >>>>>>                       PLB00710
C     Q       SOURCE STRENGTH  (G/SEC)                                PLB00720
C     HP      PHYSICAL STACK HEIGHT  (M)                              PLB00730
C     TS      STACK GAS TEMPERATURE  (DEG K)                          PLB00740
C     VS      STACK GAS VELOCITY  (M/SEC)                             PLB00750
C     D       STACK DIAMETER  (M)                                     PLB00760
C                                                                     PLB00770
C          PTPLU FLOW RELATIONS                                       PLB00780
C                                                                     PLB00790
C                     PTPLU                                           PLB00800
C                       |                                             PLB00810
C                       | * READ AND CHECK INPUT DATA                 PLB00820
C                       |                                             PLB00830
C                       | * CALCULATE PORTIONS OF PLUME RISE          PLB00840
C                       |                                             PLB00850
C               -------| - LOOP FOR EACH STABILITY                    PLB00860
C               |       |                                             PLB00870
C               |  ----| - LOOP FOR CONSTANT WIND SPEEDS WITH HEIGHT  PLB00880
C               |  |    |                                             PLB00890
C               |  |    | * * PH                                      PLB00900
C               |  |    |                                             PLB00910
C               |  |    | * * TPMX                                    PLB00920
C               |  |    |       |                                     PLB00930
C               |  |    |       * * PHX                               PLB00940
C               |  |    |       |                                     PLB00950
C               |  |    |       * * RCON                              PLB00960
C               |  |    |            |                                PLB00970
C               |  |    |            * * PSIG                         PLB00980
C               |  |    |                                             PLB00990
C               |  |    | * ADD CAUTIONARY LABELS                     PLB01000
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             C              |   |   |                                          PLB01010
             C              |   ----*                                          PLB01020
             C              |       |                                          PLB01030
             C              |   ----- - LOOP FOR WIND SPEEDS VARYING WITH HEIGHT PLB01040
             C              |   |   |                                          PLB01050
             C              |   |   | * * PH                                   PLB01060
             C              |   |   |                                          PLB01070
             C              |   |   | * * TPMX                                 PLB01080
             C              |   |   |         |                                PLB01090
             C              |   |   |         * * PHX                          PLB01100
             C              |   |   |         |                                PLB01110
             C              |   |   |         * * RCON                         PLB01120
             C              |   |   |              |                           PLB01130
             C              |   |   |              * * PSIG                    PLB01140
             C              |   |   |                                          PLB01150
             C              |   |   | * ADD CAUTIONARY LABELS                  PLB01160
             C              |   |   |                                          PLB01170
             C              |   ----*                                          PLB01180
             C              |       |                                          PLB01190
             C              --------*                                          PLB01200
             C                      |                                          PLB01210
             C                      * WRITE OUTPUT                             PLB01220
             C                      |                                          PLB01230
             C                     EXIT                                        PLB01240
             C                                                                 PLB01250
      1            COMMON /MS/ KST,X,SY,SZ                                     PLB01260
      2            COMMON /MH/ HP,VS,XFUN,DHU,ME,XFOUSE,DHUTE,DHAUE,DUTE,DHCAE,DHCAF,PLB01270
                  1MF,XFOUSF,DHUTF,DHAUF,DUTF,D                                PLB01280
      3            COMMON /ALL/ IOPT(3),U,HL,H,Z,Y,XF,DELH,HF,CMAX,XMAX,RC,PDHX,HPRM PLB01290
      4            DIMENSION ANOT(4), UA(14), CM(6,14), XM(6,14), HE(6,14), AD(6,14),PLB01300
                  1 AH(6,14), ALP(20), CM2(6,14), XM2(6,14), HE2(6,14), AD2    PLB01310
                  2(6,14), AH2(6,14), UZ(6,14), PL(6), WI(6)                   PLB01320
      5            DATA UA /.5,.8,1.,1.5,2.,2.5,3.,4.,5.,7.,10.,12.,15.,20./   PLB01330
      6            DATA ANOT /'    ','(1)','(2)','(3)'/                        PLB01340
      7            IRD=5                                                       PLB01350
      8            IWRI=6                                                      PLB01360
      9            WRITE(IWRI,5432)                                            PLB01370
     10     5432   FORMAT('1',21X,'PTPLU (VERSION 81036)'/22X,'AN IMPROVED POINT', PLB01380
                  .' SOURCE SCREENING MODEL'/22X,'MODIFIED BY: JOE CATALANO AND ', PLB01390
                  .'FRANK HALE'/22X,'AEROCOMP, INC. - COSTA MESA, CA      FOR THE'/ PLB01400
                  .22X,'ENVIRONMENTAL OPERATIONS BRANCH, EPA')                 PLB01410
             C        READ CARD TYPE 1, OPTIONS, TEMP, MX HT, AND RECEPTOR HT  PLB01420
     11            READ (IRD, * ) (IOPT(I),I=1,3),T,HL,Z                       PLB01430
             C        READ CARD TYPE 2, ANEMOMETER HT AND WIND SPEED EXPONENTS PLB01440
     12            READ (IRD, * ) HANE,(PL(I),I=1,6)                           PLB01450
             C        ENTRY POINT FOR CALCULATIONS OF ADDITIONAL SOURCES.      PLB01460
             C        READ CARD TYPE 3, OUTPUT HEADING                         PLB01470
     13     10     READ (IRD,430,END=400) ALP                                  PLB01480
             C        READ CARD TYPE 4, SOURCE INFORMATION                     PLB01490
     14            READ (IRD, * ,END=400) Q,HP,TS,VS,D                         PLB01500
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15       DO 20 K=1,6
16    20 WI(K)=(HP/HANE)**PL(K)
      C     WI WILL BE USED TO CALCULATE THE WIND AT STACK TOP
      C     THE FOLLOWING 3 STATEMENTS CHECK TO INSURE THE REASONABLENESS
      C     OF THE INPUT PARAMETERS.
17       IF (HL.LE.0.0) HL=5000.0
18       IF (Z.LE.0.0) Z=0.0
19       IF (Q.GT.0.) GO TO 530
      C     CHECK ON EMISSION VALUE
20       WRITE (IWRI,410) Q
21       STOP
      C     IF NO AMBIENT AIR TEMP IS INPUT  293 KELVIN IS ASSUMED.
22   530 IF (T.EQ.0.) T=293.
23       VF=0.785398*VS*D*D
      C     CALCULATE VOLUME FLOW  (VF)
      C     PRINT INITIAL INFORMATION
24       WRITE(IWRI,440)ALP
25       WRITE(IWRI,460)T,Q
26       WRITE(IWRI,461)HL,HP,IOPT(1),HANE,TS
27       WRITE(IWRI,462)IOPT(2),(PL(I),I=1,3),VS
28       WRITE(IWRI,463)IOPT(3),(PL(I),I=4,6),D,Z
29       DELT=TS-T
      C     DELT (TEMPERATURE DIFFERENCE)
30       F=3.1214*VF*DELT/TS
      C     CALCULATE F (BUOYANCY FLUX PARAMETER)
      C     WRITE CALCULATED PARAMETERS.
31       WRITE(IWRI,465)VF,F
32       WRITE (IWRI,470)ALP
33       PDHX=160.*F**0.33333
      C     PDHX = PARTIAL DELH(X)
      C     THIS EQUATION IS PART OF THAT IN BRIGGS(1969) P. 57
      C     CHECK TO SEE IF BUOYANT OR MOMENTUM FLOW;STABLE OR UNSTABLE
34       IF (TS.LT.T) GO TO 40
35       IF (F.GE.55.) GO TO 30
      C     DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER (F<55) FOUND
      C     BY EQUATING BRIGGS(1969) EQ 5.2,PAGE 59 WITH COMBINATION OF
      C     BRIGGS (1971) EQUATIONS 6 AND 7, PAGE 1031 FOR F<55.
36       DTMB=0.0297*TS*VS**0.33333/D**0.66667
37       IF (DELT.LT.DTMB) GO TO 40
      C     THE FOLLOWING VARIABLES HAVE BEEN NORMALIZED WITH RESPECT TO U
      C           E.G. XFUN = FINAL DISTANCE (X) AS A FNCN OF U.
      C     (0.049 IS 14*3.5/1000)BRIGGS(1971) EQUATION 7,F<55, AND
      C     FINAL DISTANCE AS A FUNCTION OF U IS 3.5*XSTAR
38       XFUN=0.049*F**0.625
      C     USED A COMBINATION OF BRIGGS(1971) EQNS. 6 AND 7, P. 1031 FOR
      C     F<55 - DHU IS AGAIN A FUNCTION OF WIND SPEED.
39       DHU=21.425*F**0.75
40       GO TO 50
      C     DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER (F>55)
      C     FOUND BY EQUATING BRIGGS(1969) EQ. 5.2, PAGE 59 WITH
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         C     COMBINATION OF BRIGGS(1971) EQNS. 6 AND 7, PAGE 1031 FOR F>55.
41       30   DTMB=0.00575*TS*VS**0.66667/D**0.33333
42            IF (DELT.LT.DTMB) GO TO 40
         C     DISTANCE TO FINAL BUOYANT RISE AS A FUNCTION OF U
         C       ( 0.119 = 34*3.5/100  )
         C     FROM BRIGGS(1971) EQN. 7, F>55, AND DISTANCE TO FINAL RISE IS
         C     3.5 XSTAR.
43            XFUN=0.119*F**0.4
         C     USING A COMBINATION OF BRIGGS (1971) EQNS. 6 AND 7, PAGE 1031
         C     FOR F > 55.
44            DHU=38.71*F**0.6
45            GO TO 50
         C     UNSTABLE-NEUTRAL MOMENTUM RISE FROM BRIGGS(1969) EQN.5.2, P.59
         C     NOTE: MOST ACCURATE WHEN VS/U>4  IT TENDS TO OVERESTIMATE RISE
         C     WHEN VS/U<4  (SEE BRIGGS(1975) PAGE 78, FIG. 4)
46       40   XFUN=0.
47            DHU=3.*VS*D
         C     PREPARE PLUME RISE CALCULATIONS FOR STABLE CONDITIONS
         C     SE- STABILITY E     SF- STABILITY F
         C     0.196123 = 9.80616 * 0.02
48       50   SE=0.196123/T
         C     1.75 = 0.035/0.02
49            SF=1.75*SE
         C     ME AND MF ARE INDICATORS FOR MOMENTUM PREDICTORS UNDER
         C     STABILITIES E AND F, RESPECTIVELY.
50            ME=0
51            MF=0
52            IF (TS.LT.T) GO TO 60
         C     DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER (STABLE)
         C     FOUND BY EQUATING BRIGGS(1975) EQ. 59, PAGE 96 FOR STABLE
         C     BUOYANT RISE WITH BRIGGS(1969) EQ. 4.25, PAGE 59 .
         C                   STABILITY E CALCULATIONS
53            DTMB=0.019582*T*VS*SQRT(SE)
54            IF (DELT.LT.DTMB) GO TO 60
         C     STABLE BUOYANT RISE  (DELTA-H WILL BE DETERMINED LATER IN THE
         C     PROGRAM AFTER THE WIND SPEED IS INPUT)(WIND WILL BE ALLOWED TO
         C     BE LOW ENOUGH TO REQUIRE STABLE RISE IN CALM CONDITIONS)
         C     BRIGGS(1975) EQ. 59,PAGE 96.
55            DHUTE=2.6*(F/SE)**0.33333
56            DHCAE=4.0*F**0.25/SE**0.375
         C    PLUME RISE UNDER CALM CONDITIONS, EQ 56 AND TOP P82 (BRIGGS 75)
         C    COMBINATION OF BRIGGS(1975) EQNS. 48 AND 59, DISTANCE TO FINAL
         C    RISE WILL BE DETERMINED AFTER THE WIND SPEED IS INTRODUCED.
57            XFOUSE=0.0020715/SQRT(SE)
58            GO TO 70
         C    STABLE MOMENTUM RISE FOR E STABILITY
59       60   ME=1
60            DHAUE=3.*VS*D
         C    THE FOLLOWING TWO EQNS. ARE TAKEN FROM BRIGGS EQNS. 4.28, P. 59-
         C    DUM IS A DUMMY EXPRESSION USED IN CALCULATING DELTA-H.
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 61          DUM=1.5*(VS*VS*D*D*T/(4.*TS))**0.33333                         PLB02510
 62          DUTE=DUM/SE**0.166667                                          PLB02520
       C         F STABILITY CASE                                           PLB02530
 63    70    DTMB=0.019582*T*VS*SQRT(SF)                                    PLB02540
       C        THE FOLLOWING EXPRESSIONS ARE SIMILAR TO THOSE USED IN THE  PLB02550
       C        E-STABILITY SECTION.                                        PLB02560
 64          IF (DELT.LT.DTMB) GO TO 80                                     PLB02570
 65          DHUTF=2.6*(F/SF)**0.33333                                      PLB02580
 66          DHCAF=4.0*F**0.25/SF**0.375                                    PLB02590
       C        PLUME RISE UNDER CALM CONDITIONS, EQ 56 AND TOP P82 (BRIGGS 75)PLB02600
 67          XFOUSF=0.0020715/SQRT(SF)                                      PLB02610
 68          GO TO 90                                                       PLB02620
 69    80    MF=1                                                           PLB02630
 70          DHAUF=3.*VS*D                                                  PLB02640
 71          IF (ME.EQ.0) DUM=1.5*(VS*VS*D*D*T/(4.*TS))**0.33333            PLB02650
 72          DUTF=DUM/SF**0.166667                                          PLB02660
 73    90    DO 330 KST=1,6                                                 PLB02670
 74          GO TO (100,110,120,130,140,150), KST                           PLB02680
       C        SET DO LOOP LIMITS AND TEST TIME (THOUSANDS OF SECONDS) AS A PLB02690
       C         FUNCTION OF STABILITY.                                     PLB02700
       C        IA AND IB ARE INDICIES WHICH RESTRICT THE WIND SPEEDS       PLB02710
       C        FOR EACH STABILITY CLASS. TM, THE TRAVEIL TIME OF THE PLUME, ISPLB02720
       C        THE MAXIMUM TIME A PLUME IS EXPECTED TO REMAIN AT A PARTICULAR PLB02730
       C        STABILITY. THE LIMITS FOR EACH STABILITY CLASS ARE          PLB02740
       C              A - 4 HOURS                                           PLB02750
       C              B - 6 HOURS                                           PLB02760
       C              C - 8 HOURS                                           PLB02770
       C              D - UNLIMITED                                         PLB02780
       C              E - 8 HOURS                                           PLB02790
       C              F - 8 HOURS                                           PLB02800
       C                                                                    PLB02810
 75   100    IA=1                                                           PLB02820
 76          IB=7                                                           PLB02830
 77          TM=14.4                                                        PLB02840
       C        14.4 IS EQUIVALENT TO 4 HOURS. (IN THOUSANDS OF SECONDS)    PLB02850
 78          GO TO 160                                                      PLB02860
       C        STABILITY B (60)                                            PLB02870
 79   110    IA=1                                                           PLB02880
 80          IB=9                                                           PLB02890
 81          TM=21.6                                                        PLB02900
       C        21.6 IS EQUIVALENT TO 6 HOURS.                              PLB02910
 82          GO TO 160                                                      PLB02920
       C        STABILITY C (70)                                            PLB02930
 83   120    IA=5                                                           PLB02940
 84          IB=13                                                          PLB02950
 85          TM=28.8                                                        PLB02960
       C        28.8 IS EQUIVALENT TO 8 HOURS.                              PLB02970
 86          GO TO 160                                                      PLB02980
       C        STABILITY D (80)                                            PLB02990
 87   130    IA=1                                                           PLB03000
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  88            IB=14
  89            TM=999.
          C        999. IS MORE THAN 24 HOURS SINCE THE MET CONDITIONS PRODUCING
          C        D-STABILITY CAN PERSIST FOR EXTENDED PERIODS OF TIME.
  90            GO TO 160
          C        STABILITY E (90)
  91      140   IA=5
  92            IB=9
  93            TM=28.8
          C        28.8 IS EQUIVALENT TO 8 HOURS.
  94            GO TO 160
          C        STABILITY F (100)
  95      150   IA=5
  96            IB=9
          C        TM IS STILL EQUAL TO 28.8 (8 HOURS).
          C        CALCULATE FOR EACH APPROPRIATE WIND SPEED.
  97      160   DO 240 I=IA,IB
  98            U=UA(I)
          C        DETERMINE  PLUME HEIGHT.
  99            CALL PH
 100            H=HF
          C        DETERMINE MAXIMUM CONCENTRATION FOR THIS EFFECTIVE HEIGHT.
 101            CALL TPMX
          C        DETERMINE IF CAUTIONARY NOTES ARE NEEDED.
 102            IF (CMAX.NE.9.999E+9) GO TO 170
 103            CM(KST,I)=CMAX
 104            GO TO 180
 105      170   CM(KST,I)=CMAX*Q
 106      180   XM(KST,I)=XMAX
 107            HE(KST,I)=H
          C        TI IS THE TRAVEL TIME FROM SOURCE TO DISTANCE OF MAX.
 108            TI=XMAX/U
          C        SECTION FOR CAUTIONARY MESSAGES.
          C        INITIALIZE CAUTIONARY FLAGS.
 109            AH(KST,I) = ANOT(1)
 110            AD(KST,I) = ANOT(1)
          C        TEST FOR EXCESSIVE TRAVEL TIME.
 111            IF(TI.GT.TM)AD(KST,I) = ANOT(2)
          C        CHECK FOR DIST TO MAX GREATER THAN 100 KM.
 112            IF(XMAX.LT.100.)GOTO200
 113            CM(KST,I)=9.999E+9
 114            XM(KST,I)=999.999
 115            AD(KST,I)=ANOT(4)
          C        TEST FOR EFFECTIVE HEIGHT MORE THAN 200 M.
 116      200   IF(H.GT.200.)AH(KST,I)=ANOT(3)
 117      240   CONTINUE
          C        END OF LOOP FOR EACH WIND SPEED.
          C
          C        DO-LOOP WITH WIND PROFILE EXPONENTS
          C
```

```
118          DO 320 I=IA,IB
119          U=UA(I)*WI(KST)
        C       CALCULATE THE EFFECTIVE STACK HEIGHT
        C       CALL THE PLUME RISE ROUTINE
120          CALL PH
121          H=HF
        C       CALCULATE MAXIMUM CNCENTRATION AND
        C       LOCATE THE DISTANCE TO MAX CONCENTRATION FOR THIS
        C       WIND SPEED AND STABILITY BY CALLING TPMX
122          CALL TPMX
123          IF (CMAX.NE.9.999E+9) GO TO 250
124          CM2(KST,I)=CMAX
125          GO TO 260
126     250  CM2(KST,I)=CMAX*Q
127     260  XM2(KST,I)=XMAX
128          HE2(KST,I)=H
129          UZ(KST,I)=U
130          TI=XMAX/U
        C       SECTION FOR CAUTIONARY MESSAGES.
        C       INITIALIZE CAUTIONARY FLAGS.
131          AH2(KST,I) = ANOT(1)
132          AD2(KST,I) = ANOT(1)
        C       TEST FOR EXCESSIVE TRAVEL TIME.
133          IF(TI.GT.TM)AD2(KST,I) = ANOT(2)
        C       CHECK FOR DIST TO MAX GREATER THAN 100 KM.
134          IF(XMAX.LT.100.)GOTO201
135          CM2(KST,I)=9.999E+9
136          XM2(KST,I)=999.999
137          AD2(KST,I)=ANOT(4)
        C       TEST FOR EFFECTIVE HEIGHT MORE THAN 200 M.
138     201  IF(H.GT.200.)AH2(KST,I)=ANOT(3)
139     320  CONTINUE
        C       END OF LOOP FOR EXTRAPOLATED WIND SPEEDS.
140     330  CONTINUE
        C       END OF LOOP FOR EACH STABILITY.
        C
        C       WRITE OUTPUT SUMMARY TABLE.
141          KST=1
142          WRITE (IWRI,480)HANE
143          WRITE(IWRI,482)
144          WRITE (IWRI,485)
145          DO 340 N=1,7
146          WRITE (IWRI,490) KST,UA(N),CM(KST,N),XM(KST,N),AD(KST,N),HE(KST,N)
            1,AH(KST,N),UZ(KST,N),CM2(KST,N),XM2(KST,N),AD2(KST,N),HE2(KST,N),A
            2H2(KST,N)
147     340  CONTINUE
148          KST=2
149          WRITE (IWRI,480)HANE
150          WRITE(IWRI,482)
151          WRITE (IWRI,485)
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```
152          DO 350 N=1,9
153          WRITE (IWRI,490) KST,UA(N),CM(KST,N),XM(KST,N),AD(KST,N),HE(KST,N)
            1,AH(KST,N),UZ(KST,N),CM2(KST,N),XM2(KST,N),AD2(KST,N),HE2(KST,N),A
            2H2(KST,N)
154    350   CONTINUE
155          KST=3
156          WRITE (IWRI,480)HANE
157          WRITE(IWRI,482)
158          WRITE (IWRI,485)
159          DO 360 N=5,13
160          WRITE (IWRI,490) KST,UA(N),CM(KST,N),XM(KST,N),AD(KST,N),HE(KST,N)
            1,AH(KST,N),UZ(KST,N),CM2(KST,N),XM2(KST,N),AD2(KST,N),HE2(KST,N),A
            2H2(KST,N)
161    360   CONTINUE
162          KST=4
163          WRITE (IWRI,480)HANE
164          WRITE(IWRI,482)
165          WRITE (IWRI,485)
166          DO 370 N=1,14
167          WRITE (IWRI,490) KST,UA(N),CM(KST,N),XM(KST,N),AD(KST,N),HE(KST,N)
            1,AH(KST,N),UZ(KST,N),CM2(KST,N),XM2(KST,N),AD2(KST,N),HE2(KST,N),A
            2H2(KST,N)
168    370   CONTINUE
169          KST=5
170          WRITE (IWRI,480)HANE
171          WRITE(IWRI,482)
172          WRITE (IWRI,485)
173          DO 380 N=5,9
174          WRITE (IWRI,490) KST,UA(N),CM(KST,N),XM(KST,N),AD(KST,N),HE(KST,N)
            1,AH(KST,N),UZ(KST,N),CM2(KST,N),XM2(KST,N),AD2(KST,N),HE2(KST,N),A
            2H2(KST,N)
175    380   CONTINUE
176          KST=6
177          WRITE (6,480)HANE
178          WRITE(IWRI,482)
179          WRITE (6,485)
180          DO 390 N=5,9
181          WRITE (IWRI,490) KST,UA(N),CM(KST,N),XM(KST,N),AD(KST,N),HE(KST,N)
            1,AH(KST,N),UZ(KST,N),CM2(KST,N),XM2(KST,N),AD2(KST,N),HE2(KST,N),A
            2H2(KST,N)
182    390   CONTINUE
183          WRITE (IWRI,500)
184          WRITE (IWRI,510)
185          WRITE (IWRI,520)
186          GO TO 10
187    400   STOP
       C
188    410   FORMAT (1X,' EMISSION OF ',F10.4,' G/SEC NOT ACCEPTABLE.'/' ***
            1EXECUTION TERMINATED - CHECK INPUT DATA *** ')
189    430   FORMAT (20A4)
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190        440 FORMAT(/49X,'>>>INPUT PARAMETERS<<<'/' *** TITLE***  ',20A4)      PLB04510
191        460 FORMAT(/1X,'***OPTIONS***',24X,                                   PLB04520
               1'***METEOROLOGY***',33X,'***SOURCE***'/1X,'IF = 1, USE OPTION',  PLB04530
               219X,'AMBIENT AIR TEMPERATURE =',F9.2,' (K)',12X,                 PLB04540
               3'EMISSION RATE =',F9.2,' (G/SEC)')                               PLB04550
192      461    FORMAT(1X,'IF = 0, IGNORE OPTION',16X,'MIXING HEIGHT',11X,       PLB04560
               5'=',F9.2,' (M)',12X,'STACK HEIGHT  =',F9.2,' (M)'/1X,            PLB04570
               6'IOPT(1) = ',I1,' (GRAD PLUME RISE)',8X,'ANEMOMETER HEIGHT',     PLB04580
               77X,'=',F9.2,' (M)',12X,'EXIT TEMP.   =',F9.2,' (K)')             PLB04590
193      462    FORMAT(1X,'IOPT(2) = ',I1,' (STACK DOWNWASH)',9X,                PLB04600
               9'WIND PROFILE EXPONENTS  = A:',F4.2,', B:',F4.2,', C:',          PLB04610
               .F4.2,2X,'EXIT VELOCITY =',F9.2,' (M/SEC)')                       PLB04620
194      463    FORMAT(1X,'IOPT(3) = ',I1,' (BUOY. INDUCED DISP.)',30X,          PLB04630
               .'D:',F4.2,', E:',F4.2,', F:',F4.2,2X,'STACK DIAM.   =',          PLB04640
               .F9.2,' (M)'/'0***RECEPTOR HEIGHT*** =',F9.2,' (M)')              PLB04650
195      465    FORMAT  (/47X,'>>>CALCULATED PARAMETERS<<<',/1X,'VOLUMETRIC FLO','PLB04660
               1W =',F9.2,' (M**3/SEC)',11X,'BUOYANCY FLUX PARAMETER =',F9.2,    PLB04670
               2' (M**4/SEC**3)')                                                PLB04680
196      470    FORMAT(//1X,20A4)                                                PLB04690
197      480    FORMAT (1H0,20X,'****WINDS CONSTANT WITH HEIGHT****',            PLB04700
               .9X,'****STACK TOP WINDS (EXTRAPOLATED FROM ',F5.1,' METERS)',    PLB04710
               .'****')                                                          PLB04720
198      482    FORMAT(' STABILITY',3X,'WIND SPEED',                             PLB04730
               13X,'MAX CONC',3X,'DIST OF MAX',3X,' PLUME HT ',7X,'WIND SPEED',  PLB04740
               23X,'MAX CONC',3X,'DIST OF MAX',3X,' PLUME HT')                   PLB04750
199      485    FORMAT(15X,'(M/SEC)     (G/CU M)',7X,4H(KM),10X,3H(M),12X,       PLB04760
               4'(M/SEC)     (G/CU M)',7X,4H(KM),10X,3H(M))                      PLB04770
200      490    FORMAT (4X,I1,10X,F6.2,3X,1PE10.4,4X,0PF8.3,A3,1X,F8.1,A3,9X,    PLB04780
               1F6.2,3X,1PE10.4,4X,0PF8.3,A3,1X,F8.1,A3)                         PLB04790
201      500    FORMAT (1H0,' (1) THE DISTANCE TO THE POINT OF MAXIMUM CONCENTRATIPLB04800
               1ON IS SO GREAT THAT THE SAME STABILITY IS NOT LIKELY'/1H ,       PLB04810
               2'         TO PERSIST LONG ENOUGH FOR THE PLUME TO TRAVEL THIS FAR.'PLB04820
               3)                                                                PLB04830
202      510    FORMAT ('0 (2) THE PLUME IS CALCULATED TO BE AT A HEIGHT WHERE CARPLB04840
               1E SHOULD BE USED IN INTERPRETING THE COMPUTATION.')              PLB04850
203      520    FORMAT (1H0,' (3) NO COMPUTATION WAS ATTEMPTED FOR THIS HEIGHT AS PLB04860
               1THE POINT OF MAXIMUM CONCENTRATION IS GREATER THAN 100 KILOMETERS'PLB04870
               2/1H ,'         FROM THE SOURCE.')                                PLB04880
         C                                                                       PLB04890
204             END                                                              PLB04900
         C                                                                       PLB04910
```

PTPLU VERSION 81036

SYMBOL		= = = = = = REFERENCES = = = = = =						
10	-	13*	186					
20	-	15	16*					
30	-	35	41*					
40	-	34	37	42	46*			
50	-	40	45	48*				
60	-	52	54	59*				
70	-	58	63*					
80	-	64	69*					
90	-	68	73*					
100	-	74	75*					
110	-	74	79*					
120	-	74	83*					
130	-	74	87*					
140	-	74	91*					
150	-	74	95*					
160	-	78	82	86	90	94	97*	
170	-	102	105*					
180	-	104	106*					
200	-	112	116*					
201	-	134	138*					
240	-	97	117*					
250	-	123	126*					
260	-	125	127*					
320	-	118	139*					
330	-	73	140*					
340	-	145	147*					
350	-	152	154*					
360	-	159	161*					
370	-	166	168*					
380	-	173	175*					
390	-	180	182*					
400	-	13RD	14RD	187*				
410	-	20WR	188*					
430	-	13RD	189*					
440	-	24WR	190*					
460	-	25WR	191*					
461	-	26WR	192*					
462	-	27WR	193*					
463	-	28WR	194*					
465	-	31WR	195*					
470	-	32WR	196*					
480	-	142WR	149WR	156WR	163WR	170WR	177WR	197*
482	-	143WR	150WR	157WR	164WR	171WR	178WR	198*
485	-	144WR	151WR	158WR	165WR	172WR	179WR	199*
490	-	146WR	153WR	160WR	167WR	174WR	181WR	200*
500	-	183WR	201*					
510	-	184WR	202*					
520	-	185WR	203*					

530	-	19	22*								
5432	-	9WR	10*								
AD	-	4DI	110=	111=	115=	146WR	153WR	160WR	167WR	174WR	181WR
AD2	-	4DI	132=	133=	137=	146WR	153WR	160WR	167WR	174WR	181WR
AH	-	4DI	109=	116=	146WR	153WR	160WR	167WR	174WR	181WR	
AH2	-	4DI	131=	138=	146WR	153WR	160WR	167WR	174WR	181WR	
ALL	-	3CO									
ALP	-	4DI	13RD	24WR	32WR						
ANOT	-	4DI	6DA	109	110	111	115	116	131	132	133
		137	138								
CM	-	4DI	103=	105=	113=	146WR	153WR	160WR	167WR	174WR	181WR
CM2	-	4DI	124=	126=	135=	146WR	153WR	160WR	167WR	174WR	181WR
CMAX	-	3CO	102	103	105	123	124	126			
D	-	2CO	14RD	23	23	28WR	36	41	47	60	61
		61	70	71	71						
DELH	-	3CO									
DELT	-	29=	30	37	42	54	64				
DHAUE	-	2CO	60=								
DHAUF	-	2CO	70=								
DHCAE	-	2CO	56=								
DHCAF	-	2CO	66=								
DHU	-	2CO	39=	44=	47=						
DHUTE	-	2CO	55=								
DHUTF	-	2CO	65=								
DTMB	-	36=	37	41=	42	53=	54	63=	64		
DUM	-	61=	62	71=	72						
DUTE	-	2CO	62=								
DUTF	-	2CO	72=								
F	-	30=	31WR	33	35	38	39	43	44	55	56
		65	66								
H	-	3CO	100=	107	116	121=	128	138			
HANE	-	12RD	16	26WR	142WR	149WR	156WR	163WR	170WR	177WR	
HE	-	4DI	107=	146WR	153WR	160WR	167WR	174WR	181WR		
HE2	-	4DI	128=	146WR	153WR	160WR	167WR	174WR	181WR		
HF	-	3CO	100	121							
HL	-	3CO	11RD	17	17=	26WR					
HP	-	2CO	14RD	16	26WR						
HPRM	-	3CO									
I	-	11RD	11RD	12RD	12RD	27WR	27WR	28WR	28WR	97	98
		103	105	106	107	109	110	111	113	114	115
		116	118	119	124	126	127	128	129	131	132
		133	135	136	137	138					
IA	-	75=	79=	83=	87=	91=	95=	97	118		
IB	-	76=	80=	84=	88=	92=	96=	97	118		
IOPT	-	3CO	11RD	26WR	27WR	28WR					
IRD	-	7=	11RD	12RD	13RD	14RD					
IWRI	-	8=	9WR	20WR	24WR	25WR	26WR	27WR	28WR	31WR	32WR
		142WR	143WR	144WR	146WR	149WR	150WR	151WR	153WR	156WR	157WR
		158WR	160WR	163WR	164WR	165WR	167WR	170WR	171WR	172WR	174WR
		178WR	181WR	183WR	184WR	185WR					

XFOUSF	-	2CO	67=							
XFUN	-	2CO	38=	43=	46=					
XM	-	4DI	106=	114=	146WR	153WR	160WR	167WR	174WR	181WR
XM2	-	4DI	127=	136=	146WR	153WR	160WR	167WR	174WR	181WR
XMAX	-	3CO	106	108	112	127	130	134		
Y	-	3CO								
Z	-	3CO	11RD	18	18=	28WR				

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SUBROUTINE RCON

```
      SUBROUTINE RCON                                                   PLB04920
C                                                                       PLB04930
C->->->->SECTION RCON.A - COMMON.                                        PLB04940
      COMMON /MS/KST,X,SY,SZ                                            PLB04950
      COMMON /ALL/IOPT(3),U,HL,H,Z,Y,XF,DELH,HF,CMAX,XMAX,RC,PDHX,HPRM  PLB04960
C                                                                       PLB04970
C                                                                       PLB04980
C->->->->SECTION RCON.B - EXPLANATIONS AND COMPUTATIONS                  PLB04990
C                         COMMON TO ALL CONDITIONS.                     PLB05000
C                                                                       PLB05010
C  RCON DETERMINES RELATIVE CONCENTRATIONS, CHI/Q, FROM POINT SOURCES.  PLB05020
C         RCON CALLS PSIG FOR THE DISPERSION COEFFICENTS.               PLB05030
C        THE INPUT VARIABLES ARE:                                       PLB05040
C         U  WIND SPEED (M/SEC)                                         PLB05050
C         Z    RECEPTOR HEIGHT (M)                                      PLB05060
C         H    EFFECTIVE STACK HEIGHT (M)                               PLB05070
C         HL   MIXING HEIGHT- TOP OF NEUTRAL OR UNSTABLE LAYER(M).      PLB05080
C         X    DISTANCE RECEPTOR IS DOWNWIND OF SOURCE (KM)             PLB05090
C         Y    DISTANCE RECEPTOR IS CROSSWIND FROM SOURCE (KM)          PLB05100
C         KST  STABILITY CLASS                                          PLB05110
C         DELH PLUME RISE(METERS)                                       PLB05120
C        THE OUTPUT VARIABLES ARE....                                   PLB05130
C         SY      HORIZONTAL DISPERSION PARAMETER                       PLB05140
C         SZ     VERTICAL DISPERSION PARAMETER                          PLB05150
C         RC   RELATIVE CONCENTRATION (SEC/M**3) ,CHI/Q                 PLB05160
C         IWRI      OUTPUT UNIT CONTROL                                 PLB05170
      IWRI=6                                                            PLB05180
C        THE FOLLOWING EQUATION IS SOLVED --                            PLB05190
C        RC = (1/(2*PI*U*SIGMA Y*SIGMA Z))* (EXP(-0.5*(Y/SIGMA Y)**2))  PLB05200
C           (EXP(-0.5*((Z-H)/SIGMA Z)**2) + EXP(-0.5*((Z+H)/SIGMA Z)**2)PLB05210
C             PLUS THE SUM OF THE FOLLOWING 4 TERMS K TIMES (N=1,K) --  PLB05220
C                  FOR NEUTRAL OR UNSTABLE CASES:                       PLB05230
C              TERM 1- EXP(-0.5*((Z-H-2NL)/SIGMA Z)**2)                 PLB05240
C              TERM 2- EXP(-0.5*((Z+H-2NL)/SIGMA Z)**2)                 PLB05250
C              TERM 3- EXP(-0.5*((Z-H+2NL)/SIGMA Z)**2)                 PLB05260
C              TERM 4- EXP(-0.5*((Z+H+2NL)/SIGMA Z)**2)                 PLB05270
C NOTE THAT MIXING HEIGHT- THE TOP OF THE NEUTRAL OR UNSTABLE LAYER-    PLB05280
C HAS A VALUE ONLY FOR STABILITIES 1-4, THAT IS, MIXING HEIGHT,         PLB05290
C THE HEIGHT OF THE NEUTRAL OR UNSTABLE LAYER, DOES NOT EXIST FOR STABLEPLB05300
C LAYERS AT THE GROUND SURFACE- STABILITY 5 OR 6.                       PLB05310
C        THE ABOVE EQUATION IS SIMILAR TO EQUATION (5.8) P 36 IN        PLB05320
C         WORKBOOK OF ATMOSPHERIC DISPERSION ESTIMATES WITH THE ADDITIONPLB05330
C         OF THE EXPONENTIAL INVOLVING Y.                               PLB05340
C       IF STABLE, SKIP CONSIDERATION OF MIXING HEIGHT.                 PLB05350
      IF (KST.GE.5) GO TO 50                                            PLB05360
C        IF THE SOURCE IS ABOVE THE LID, SET RC = 0., AND RETURN.       PLB05370
      IF (H.GT.HL) GO TO 20                                             PLB05380
      IF (Z-HL) 50,50,40                                                PLB05390
 20   IF (Z.LT.HL) GO TO 40                                             PLB05400
      WRITE (IWRI,470)                                                  PLB05410
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SUBROUTINE RCON

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00542*        10    40    RC=0.                                                            PLB05420
00543*        11          RETURN                                                           PLB05430
00544*              C        IF X IS LESS THAN 1 METER, SET RC=0. AND RETURN.  THIS AVOIDS PLB05440
00545*              C         PROBLEMS OF INCORRECT VALUES NEAR THE SOURCE.                 PLB05450
00546*        12    50    IF (X.LT.0.001) GO TO 40                                         PLB05460
00547*              C       CALL PSIG TO OBTAIN VALUES FOR SY AND SZ                         PLB05470
00548*        13          CALL PSIG                                                        PLB05480
00549*              C         SY = SIGMA Y, THE STANDARD DEVIATION OF CONCENTRATION IN THE  PLB05490
00550*              C         Y-DIRECTION (M)                                               PLB05500
00551*              C         SZ = SIGMA Z, THE STANDARD DEVIATION OF CONCENTRATION IN THE  PLB05510
00552*              C         Z-DIRECTION (M)                                               PLB05520
00553*              C     IF IOPT(3) = 1, CONSIDER BUOYANCY INDUCED DISPERSION               PLB05530
00554*        14          IF (IOPT(3).EQ.0) GO TO 70                                       PLB05540
00555*        15          DUM=DELH/3.5                                                     PLB05550
00556*        16          IF(IOPT(1).EQ.0. .AND. X.LT.XF)DUM=PDHX*X**0.666667/(3.5*U)      PLB05560
00557*        17          DUM=DUM*DUM                                                      PLB05570
00558*        18          SY=SQRT(SY*SY+DUM)                                               PLB05580
00559*        19          SZ=SQRT(SZ*SZ+DUM)                                               PLB05590
00560*        20    70    C1=1.                                                            PLB05600
00561*        21          IF (Y.EQ.0.0) GO TO 100                                          PLB05610
00562*        22          YD=1000.*Y                                                       PLB05620
00563*              C       YD IS CROSSWIND DISTANCE IN METERS.                            PLB05630
00564*        23          DUM=YD/SY                                                        PLB05640
00565*        24          TEMP=0.5*DUM*DUM                                                 PLB05650
00566*        25          IF (TEMP.GE.50.) GO TO 40                                        PLB05660
00567*        26          C1=EXP(TEMP)                                                     PLB05670
00568*        27    100   IF (KST.GT.4) GO TO 120                                          PLB05680
00569*        28          IF (HL.LT.5000.) GO TO 200                                       PLB05690
00570*              C       IF STABLE CONDITION OR UNLIMITED MIXING HEIGHT,                PLB05700
00571*              C        USE EQUATION 3.2 IF Z = 0, OR EQ 3.1 FOR NON-ZERO Z.          PLB05710
00572*              C        (EQUATION NUMBERS REFER TO WORKBOOK OF ATMOSPHERIC DISPERSION PLB05720
00573*              C        ESTIMATES.)                                                   PLB05730
00574*        29    120   C2=2.*SZ*SZ                                                      PLB05740
00575*        30          IF (Z) 40,130,150                                                PLB05750
00576*              C     NOTE: AN ERRONEOUS NEGATIVE Z WILL RESULT IN ZERO CONCENTRATIONSPLB05760
00577*              C                                                                      PLB05770
00578*              C->->->->SECTION RCON.C - STABLE OR UNLIMITED MIXING, Z IS ZERO.       PLB05780
00579*              C                                                                      PLB05790
00580*        31    130   C3=H*H/C2                                                        PLB05800
00581*        32          IF (C3.GE.50.) GO TO 40                                          PLB05810
00582*        33          A2=1./EXP(C3)                                                    PLB05820
00583*              C       WADE EQUATION 3.2.                                             PLB05830
00584*        34          RC=A2/(3.14159*U*SY*SZ*C1)                                       PLB05840
00585*        35          RETURN                                                           PLB05850
00586*              C                                                                      PLB05860
00587*              C->->->->SECTION RCON.D - STABLE OR UNLIMITED MIXING, Z IS NON-ZERO.   PLB05870
00588*              C                                                                      PLB05880
00589*        36    150   A2=0.                                                            PLB05890
00590*        37          A3=0.                                                            PLB05900
00591*        38          CA=Z-H                                                           PLB05910
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SUBROUTINE RCON

```
00592*          39          CB=Z+H                                                            PLB05920
00593*          40          C3=CA*CA/C2                                                       PLB05930
00594*          41          C4=CB*CB/C2                                                       PLB05940
00595*          42          IF (C3.GE.50.) GO TO 170                                          PLB05950
00596*          43          A2=1./EXP(C3)                                                     PLB05960
00597*          44     170  IF (C4.GE.50.) GO TO 190                                          PLB05970
00598*          45          A3=1./EXP(C4)                                                     PLB05980
00599*                 C       WADE EQUATION 3.1.                                             PLB05990
00600*          46     190  RC=(A2+A3)/(6.28318*U*SY*SZ*C1)                                   PLB06000
00601*          47          RETURN                                                            PLB06010
00602*                 C                                                                      PLB06020
00603*                 C->->->->SECTION RCON.E - UNSTABLE, ASSURED OF UNIFORM MIXING.         PLB06030
00604*                 C                                                                      PLB06040
00605*                 C       IF SIGMA-Z IS GREATER THAN 1.6 TIMES THE MIXING HEIGHT,        PLB06050
00606*                 C       THE DISTRIBUTION BELOW THE MIXING HEIGHT IS UNIFORM WITH       PLB06060
00607*                 C       HEIGHT REGARDLESS OF SOURCE HEIGHT OR RECEPTOR HEIGHT BECAUSE  PLB06070
00608*                 C       OF REPEATED EDDY REFLECTIONS FROM THE GROUND AND THE MIXING HT PLB06080
00609*          48     200  IF (SZ/HL.LE.1.6) GO TO 220                                       PLB06090
00610*                 C       WADE EQUATION 3.5.                                             PLB06100
00611*          49          RC=1./(2.5066*U*SY*HL*C1)                                         PLB06110
00612*          50          RETURN                                                            PLB06120
00613*                 C       INITIAL VALUE OF AN SET = 0.                                   PLB06130
00614*                 C        AN - THE NUMBER OF TIMES THE SUMMATION TERM IS EVALUATED      PLB06140
00615*                 C              AND ADDED IN.                                           PLB06150
00616*          51     220  AN=0.                                                             PLB06160
00617*          52          IF (Z) 40,380,230                                                 PLB06170
00618*                 C                                                                      PLB06180
00619*                 C->->->->SECTION RCON.F - UNSTABLE, CALCULATE MULTIPLE EDDY            PLB06190
00620*                 C                         REFLECTIONS, Z IS NON-ZERO.                  PLB06200
00621*                 C                                                                      PLB06210
00622*                 C      STATEMENTS 220-260 CALCULATE RC, THE RELATIVE CONCENTRATION,    PLB06220
00623*                 C        USING THE EQUATION DISCUSSED ABOVE.  SEVERAL INTERMEDIATE     PLB06230
00624*                 C        VARIABLES ARE USED TO AVOID REPEATING CALCULATIONS.           PLB06240
00625*                 C        CHECKS ARE MADE TO BE SURE THAT THE ARGUMENT OF THE           PLB06250
00626*                 C        EXPONENTIAL FUNCTION IS NEVER GREATER THAN 50 (OR LESS THAN   PLB06260
00627*                 C        -50).                                                         PLB06270
00628*                 C       CALCULATE MULTIPLE EDDY REFLECTIONS FOR RECEPTOR HEIGHT Z.     PLB06280
00629*          53     230  A1=1./(6.28318*U*SY*SZ*C1)                                        PLB06290
00630*          54          C2=2.*SZ*SZ                                                       PLB06300
00631*          55          A2=0.                                                             PLB06310
00632*          56          A3=0.                                                             PLB06320
00633*          57          CA=Z-H                                                            PLB06330
00634*          58          CB=Z+H                                                            PLB06340
00635*          59          C3=CA*CA/C2                                                       PLB06350
00636*          60          C4=CB*CB/C2                                                       PLB06360
00637*          61          IF (C3.GE.50.) GO TO 250                                          PLB06370
00638*          62          A2=1./EXP(C3)                                                     PLB06380
00639*          63     250  IF (C4.GE.50.) GO TO 270                                          PLB06390
00640*          64          A3=1./EXP(C4)                                                     PLB06400
00641*          65     270  SUM=0.                                                            PLB06410
```

SUBROUTINE RCON

```
      THL=2.*HL
  280 AN=AN+1.
      A4=0.
      A5=0.
      A6=0.
      A7=0.
      C5=AN*THL
      CC=CA-C5
      CD=CB-C5
      CE=CA+C5
      CF=CB+C5
      C6=CC*CC/C2
      C7=CD*CD/C2
      C8=CE*CE/C2
      C9=CF*CF/C2
      IF (C6.GE.50.) GO TO 300
      A4=1./EXP(C6)
  300 IF (C7.GE.50.) GO TO 320
      A5=1./EXP(C7)
  320 IF (C8.GE.50.) GO TO 340
      A6=1./EXP(C8)
  340 IF (C9.GE.50.) GO TO 360
      A7=1./EXP(C9)
  360 T=A4+A5+A6+A7
      SUM=SUM+T
      IF (T.GE.0.01) GO TO 280
      RC=A1*(A2+A3+SUM)
      RETURN
C
C->->->->SECTION RCON.G - UNSTABLE, CALCULATE MULTIPLE EDDY
C                             REFLECTIONS, Z IS ZERO.
C
C     CALCULATE MULTIPLE EDDY REFLECTIONS FOR GROUND LEVEL RECEPTOR
C     HEIGHT.
  380 A1=1./(6.28318*U*SY*SZ*C1)
      A2=0.
      C2=2.*SZ*SZ
      C3=H*H/C2
      IF (C3.GE.50.) GO TO 400
      A2=2./EXP(C3)
  400 SUM=0.
      THL=2.*HL
  410 AN=AN+1.
      A4=0.
      A6=0.
      C5=AN*THL
      CC=H-C5
      CE=H+C5
      C6=CC*CC/C2
      C8=CE*CE/C2
```

SUBROUTINE RCON

```
110            IF (C6.GE.50.) GO TO 430
111            A4=2./EXP(C6)
112       430  IF (C8.GE.50.) GO TO 450
113            A6=2./EXP(C8)
114       450  T=A4+A6
115            SUM=SUM+T
116            IF (T.GE.0.01) GO TO 410
117            RC=A1*(A2+SUM)
118            RETURN
          C
          C
          C***   SECTIONS OF SUBROUTINE RCON.
          C         SECTION RCON.A -  COMMON.
          C         SECTION RCON.B -  EXPLANATIONS AND COMPUTATIONS COMMON TO ALL
          C                           CONDITIONS.
          C         SECTION RCON.C -  STABLE OR UNLIMITED MIXING, Z IS ZERO.
          C         SECTION RCON.D -  STABLE OR UNLIMITED MIXING, Z IS NON-ZERO.
          C         SECTION RCON.E -  UNSTABLE, ASSURED OF UNIFORM MIXING.
          C         SECTION RCON.F -  UNSTABLE, CALCULATE MULTIPLE EDDY
          C                           REFLECTIONS; Z IS NON-ZERO.
          C         SECTION RCON.G -  UNSTABLE, CALCULATE MULTIPLE EDDY
          C                           REFLECTIONS; Z IS ZERO.
          C         SECTION RCON.H -  FORMAT.
          C
          C->->->->SECTION RCON.H - FORMAT
119       470  FORMAT (1HO,'BOTH H AND Z ARE ABOVE THE MIXING HEIGHT SO A RELIABL
              1E COMPUTATION CAN NOT BE MADE.')
          C
120             END
          C
```

SUBROUTINE RCON

SYMBOL		REFERENCES									
20	-	6	8*								
40	-	7	8	10*	12	25	30	32	52		
50	-	5	7	7	12*						
70	-	14	20*								
100	-	21	27*								
120	-	27	29*								
130	-	30	31*								
150	-	30	36*								
170	-	42	44*								
190	-	44	46*								
200	-	28	48*								
220	-	48	51*								
230	-	52	53*								
250	-	61	63*								
270	-	63	65*								
280	-	67*	91								
300	-	81	83*								
320	-	83	85*								
340	-	85	87*								
360	-	87	89*								
380	-	52	94*								
400	-	98	100*								
410	-	102*	116								
430	-	110	112*								
450	-	112	114*								
470	-	9WR	119*								
A1	-	53=	92	94=	117						
A2	-	33=	34	36=	43=	46	55=	62=	92	95=	99=
		117									
A3	-	37=	45=	46	56=	64=	92				
A4	-	68=	82=	89	103=	111=	114				
A5	-	69=	84=	89							
A6	-	70=	86=	89	104=	113=	114				
A7	-	71=	88=	89							
ALL	-	3CO									
AN	-	51=	67=	67	72	102=	102	105			
C1	-	20=	26=	34	46	49	53	94			
C2	-	29=	31	40	41	54=	59	60	77	78	79
		80	96=	97	108	109					
C3	-	31=	32	33	40=	42	43	59=	61	62	97=
		98	99								
C4	-	41=	44	45	60=	63	64				
C5	-	72=	73	74	75	76	105=	106	107		
C6	-	77=	81	82	108=	110	111				
C7	-	78=	83	84							
C8	-	79=	85	86	109=	112	113				
C9	-	80=	87	88							
CA	-	38=	40	40	57=	59	59	73	75		

SUBROUTINE RCON

-+

```
      SUBROUTINE TPMX
C        SUBROUTINE TPMX LOCATES THE DISTANCE TO MAX CONCENTRATION.
C        THE PROXIMITY OF THE MAXIMUM CONCENTRATION IS DETERMINED BY
C        SCREENING THE CALCULATED CONCENTRATIONS OF 16 PRESET DISTANCES.
C        THEN AN ITERATIVE PROCEDURE IS EMPLOYED TO PINPOINT THE
C        DISTANCE TO MAX CONCENTRATION TO WITHIN ONE METER.
      COMMON /MS/KST,X,SY,SZ
      COMMON /ALL/IOPT(3),U,HL,H,Z,Y,XF,DELH,HF,CMAX,XMAX,RC,PDHX,HPRM
      DIMENSION XV(16),DX1(16)
      DATA XV/.1,.3,.5,.7,1.,2.,3.,5.,7.,10.,15.,20.,30.,40.,50.,100./
      DATA DX1/4*-1.,5*-10.,6*-100.,100./
      DUM = DELH
      CMAX=0.
      RC=0.0
      Y=0.
      XMAX=0.0
C         DO LOOP DETERMINING THE DISTANCE OF MAX CONC AMONG THE
C         FIXED DISTANCES.
      DO 5 I =1,16
      X = XV(I)
C        OPTION 1 EMPLOYS THE GRADUAL RISE ROUTINE
      IF(IOPT(1).EQ.0)GOTO15
      DELH=DUM
      H=HF
      IF(X.GE.XF)GOTO15
      CALL PHX
   15 CALL RCON
      IF (.NOT.(H.GT.HL.AND.KST.LE.4)) GO TO 347
         CMAX = 0. `
         XMAX = 0.
         RETURN
  347 CONTINUE
      IF(RC.LT.CMAX)GOTO5
      CMAX=RC
      XMAX=X
      JB=I
    5 CONTINUE
C        CMAX IS THE HIGHEST OF THE 16 CONCENTRATIONS OCCURRING
C         AT DISTANCE XMAX. JB IS THE INDEX (1-16) FOR THE MAX.
      X=XMAX
C        SET X EQUAL TO XMAX FOUND FROM PRESET X'S
      CLST=CMAX
      XLST=XMAX
C        THE FOLLOWING INCREMENTS ARE USED:
C            0.1 KM FOR X LESS THAN 1 KM
C            1.0 KM FOR X 1 KM TO 10 KM
C            10. KM FOR X 10 KM TO 100 KM
      DX=DX1(JB)
    8 IF(ABS(DX).LE..001)RETURN
C         INCREMENT NOT ALLOWED TO BE LESS THAN 1 METER
```

SUBROUTINE TPMX

```
 35       DX=-0.1*DX                                                                  PLB07720
      C      REVERSE DIRECTIONS, REDUCE INCREMENT BY ONE-TENTH                        PLB07730
      C      THE ITERATIVE PROCESS CONTINUES IN THIS MANNER                           PLB07740
      C      WITH CALCULATIONS GOING BACKWARDS AND FORWARDS                           PLB07750
      C      IN SMALLER AND SMALLER INCREMENTS UNTIL A 1                              PLB07760
      C      METER INTERVAL IS REACHED.                                               PLB07770
 36   9   IF(X.GT.100.)RETURN                                                         PLB07780
      C      IF X REACHES 100 KM CEASE COMPUTATIONS FOR THIS WIND SPEED.              PLB07790
 37       X=X+DX                                                                      PLB07800
      C      OPTION 1 EMPLOYS GRADUAL PLUME RISE ROUTINE                              PLB07810
 38       IF(IOPT(1).EQ.0)GOTO7                                                       PLB07820
 39       DELH=DUM                                                                    PLB07830
 40       H=HF                                                                        PLB07840
 41       IF(X.GE.XF)GOTO7                                                            PLB07850
 42       CALL PHX                                                                    PLB07860
 43   7   CALL RCON                                                                   PLB07870
 44       IF(RC.LE.CLST)GOTO50                                                        PLB07880
      C      NEW CONCENTRATION IS HIGHER, KEEP GOING TO FIND MAX.                     PLB07890
 45       CLST=RC                                                                     PLB07900
 46       XLST=X                                                                      PLB07910
 47       GOTO9                                                                       PLB07920
 48   50  CMAX=CLST                                                                   PLB07930
      C      NEW CONCENTRATION IS LOWER, RETURN TO REVERSE DIRECTIONS                 PLB07940
 49       XMAX=XLST                                                                   PLB07950
 50       CLST=RC                                                                     PLB07960
 51       XLST=X                                                                      PLB07970
 52       GOTO8                                                                       PLB07980
 53       END                                                                         PLB07990
      C                                                                               PLB08000
```

SUBROUTINE TPMX

SYMBOL		= = = = = = = =	= = = = = = =	REFERENCES	= = = = = = = = =	= = = = = = = =					
5	-	12	25	29*							
7	-	38	41	43*							
8	-	34*	52								
9	-	36*	47								
15	-	14	17	19*							
50	-	44	48*								
347	-	20	24*								
ABS	-	34									
ALL	-	3CO									
CLST	-	31=	44	45=	48	50=					
CMAX	-	3CO	8=	21=	25	26=	31	48=			
DELH	-	3CO	7	15=	39=						
DUM	-	7=	15	39							
DX	-	33=	34	35=	35	37					
DX1	-	4DI	6DA	33							
H	-	3CO	16=	20	40=						
HF	-	3CO	16	40							
HL	-	3CO	20								
HPRM	-	3CO									
I	-	12	13	28							
IOPT	-	3CO	14	38							
JB	-	28=	33								
KST	-	2CO	20								
MS	-	2CO									
PDHX	-	3CO									
PHX	-	18	42								
RC	-	3CO	9=	25	26	44	45	50			
RCON	-	19	43								
SY	-	2CO									
SZ	-	2CO									
TPMX	-	1EY									
U	-	3CO									
X	-	2CO	13=	17	27	30=	36	37=	37	41	46
		51									
XF	-	3CO	17	41							
XLST	-	32=	46=	49	51=						
XMAX	-	3CO	11=	22=	27=	30	32	49=			
XV	-	4DI	5DA	13							
Y	-	3CO	10=								
Z	-	3CO									

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SUBROUTINE PH

```
  1            SUBROUTINE PH
          C       ROUTINE FOR DETERMINING PLUME RISE.
  2            COMMON /MS/ KST,X,SY,SZ
  3            COMMON /MH/ HP,VS,XFUN,DHU,ME,XFOUSE,DHUTE,DHAUE,DUTE,DHCAE,DHCAF,
              1MF,XFOUSF,DHUTF,DHAUF,DUTF,D
  4            COMMON /ALL/ IOPT(3),U,HL,H,Z,Y,XF,DELH,HF,CMAX,XMAX,RC,PDHX,HPRM
          C  THE FOLLOWING PARAMETERS ARE INPUT TO SUBROUTINE PH:
          C       DHAUE: DELTA-H*U  MOMENTUM RISE USING UNSTABLE RISE FOR E
          C       DHAUF:   "          "       "     "       "        "    "  F
          C       DHCAE: DELTA-H CALM BUOYANT RISE FOR E-STABILITY
          C       DHCAF:    "      "      "       "    "  F-STABILITY
          C       DHU: DELTA-H*U (UNSTABLE AND NEUTRAL)
          C       DHUTE: DELTA-H*U**.3333 STABLE BUOYANT RISE FOR E
          C       DHUTF:   "     "     "        "       "       "    "  F
          C       DUTE: DELTA-H*U**.3333 STABLE MOMENTUM RISE FOR E
          C       DUTF:   "    "   "         "        "       "   "  F
          C       HP: PHYSICAL STACK HEIGHT (FROM CARD INPUT)
          C       ME: MOMENTUM INDICATOR FOR E-STABILITY
          C       MF:    "          "       "  F-STABILITY
          C       VS: STACK GAS VELOCITY (FROM CARD INPUT)
          C       XFOUSE: DISTANCE TO STABLE BUOYANCY RISE/U FOR E
          C       XFOUSF:    "     "    "       "       "     "  F
          C       XFUN: DIST(KM) TO FINAL BUOYANT RISE (UNSTABLE AND NEUTRAL)
          C
          C    THE FOLLOWING PARAMETERS ARE OUTPUT FROM SUBROUTINE PH:
          C       XF: DISTANCE OF FINAL RISE
          C       DELH: FINAL PLUME RISE
          C       HF: FINAL EFFECTIVE HEIGHT
          C
  5            HPRM=HP
  6            IF (IOPT(2).EQ.0) GO TO 10
          C       OPTION FOR STACK DOWNWASH
  7            DUM=VS/U
  8            IF (DUM.LT.1.5) HPRM=HP+2.*D*(DUM-1.5)
  9            IF (HPRM.LT.0.) HPRM=0.
 10       10   GO TO (20,20,20,20,30,50), KST
          C       NEUTRAL OR UNSTABLE
 11       20   XF=XFUN
 12            DELH=DHU/U
 13            HF=HPRM+DELH
 14            RETURN
          C        E STABILITY
 15       30   IF (ME.EQ.1) GO TO 40
 16            XF=XFOUSE*U
 17            DELH=DHUTE/U**0.33333
 18            IF (DHCAE.LT.DELH) DELH=DHCAE
          C       COMPARE CALC PLUME RISE WITH CALM WIND PLUME RISE
 19            HF=HPRM+DELH
 20            RETURN
          C       MOMENTUM RISE FOR E STABILITY
```

```
21   40   XF=0.                                                      PLB08510
22        DHA=DHAUE/U                                                PLB08520
23        DELH=DUTE/U**0.33333                                       PLB08530
24        IF (DHA.LT.DELH) DELH=DHA                                  PLB08540
25        HF=HPRM+DELH                                               PLB08550
26        RETURN                                                     PLB08560
     C       F STABILITY                                             PLB08570
27   50   IF (MF.EQ.1) GO TO 60                                      PLB08580
28        XF=XFOUSF*U                                                PLB08590
29        DELH=DHUTF/U**0.33333                                      PLB08600
30        IF (DHCAF.LT.DELH) DELH=DHCAF                              PLB08610
     C       COMPARE CALC PLUME RISE FOR CALM WIND PLUME RISE        PLB08620
31        HF=HPRM+DELH                                               PLB08630
32        RETURN                                                     PLB08640
     C       MOMENTUM RISE FOR F STABILITY                           PLB08650
33   60   XF=0.                                                      PLB08660
34        DHA=DHAUF/U                                                PLB08670
35        DELH=DUTF/U**0.33333                                       PLB08680
36        IF (DHA.LT.DELH) DELH=DHA                                  PLB08690
37        HF=HPRM+DELH                                               PLB08700
38        RETURN                                                     PLB08710
     C                                                               PLB08720
39        END                                                        PLB08730
     C                                                               PLB08740
```

SUBROUTINE PH

SYMBOL		= = = = = = = = = REFERENCES = = = = = = = = =										
10	-	6	10*									
20	-	10	10	10	10	11*						
30	-	10	15*									
40	-	15	21*									
50	-	10	27*									
60	-	27	33*									
ALL	-	4CO										
CMAX	-	4CO										
D	-	3CO	8									
DELH	-	4CO	12=	13	17=	18	18=	19	23=	24	24=	
		25	29=	30	30=	31	35=	36	36=	37		
DHA	-	22=	24	24	34=	36	36					
DHAUE	-	3CO	22									
DHAUF	-	3CO	34									
DHCAE	-	3CO	18	18								
DHCAF	-	3CO	30	30								
DHU	-	3CO	12									
DHUTE	-	3CO	17									
DHUTF	-	3CO	29									
DUM	-	7=	8	8								
DUTE	-	3CO	23									
DUTF	-	3CO	35									
H	-	4CO										
HF	-	4CO	13=	19=	25=	31=	37=					
HL	-	4CO										
HP	-	3CO	5	8								
HPRM	-	4CO	5=	8=	9	9=	13	19	25	31	37	
IOPT	-	4CO	6									
KST	-	2CO	10									
ME	-	3CO	15									
MF	-	3CO	27									
MH	-	3CO										
MS	-	2CO										
PDHX	-	4CO										
PH	-	1EY										
RC	-	4CO										
SY	-	2CO										
SZ	-	2CO										
U	-	4CO	7	12	16	17	22	23	28	29	34	35
VS	-	3CO	7									
X	-	2CO										
XF	-	4CO	11=	16=	21=	28=	33=					
XFOUSE	-	3CO	16									
XFOUSF	-	3CO	28									
XFUN	-	3CO	11									
XMAX	-	4CO										
Y	-	4CO										
Z	-	4CO										

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SUBROUTINE PHX

```
00875*          1             SUBROUTINE PHX                                                        PLB08750
00876*                  C        THIS ROUTINE CALLED WHEN EMPLOYING THE GRADUAL RISE OPTION.        PLB08760
00877*          2             COMMON /MS/KST,X,SY,SZ                                                PLB08770
00878*          3             COMMON/ALL/IOPT(3),U,HL,H,Z,Y,XF,DELH,HF,CMAX,XMAX,RC,PDHX,HPRM       PLB08780
00879*                  C        PDHX IS 160.*F**0.3333                                             PLB08790
00880*          4             DELH = PDHX*X**0.6666667/U                                            PLB08800
00881*          5             HX =HPRM + DELH                                                       PLB08810
00882*          6             IF (HX .LT. HF) H = HX                                                PLB08820
00883*          7             RETURN                                                                PLB08830
00884*          8             END                                                                   PLB08840
00885*                  C                                                                           PLB08850
```


SUBROUTINE PHX

SYMBOL		= = = = = = = = = = = = = = = REFERENCES = = = = = = = = = = = = = = =		
ALL	-	3CO		
CMAX	-	3CO		
DELH	-	3CO	4=	5
H	-	3CO	6=	
HF	-	3CO	6	
HL	-	3CO		
HPRM	-	3CO	5	
HX	-	5=	6	6
IOPT	-	3CO		
KST	-	2CO		
MS	-	2CO		
PDHX	-	3CO	4	
PHX	-	1EY		
RC	-	3CO		
SY	-	2CO		
SZ	-	2CO		
U	-	3CO	4	
X	-	2CO	4	
XF	-	3CO		
XMAX	-	3CO		
Y	-	3CO		
Z	-	3CO		

-+

```
 1         SUBROUTINE PSIG                                                 PLB08860
      C       VERTICAL DISPERSION PARAMETER VALUE, SZ DETERMINED BY       PLB08870
      C        SZ = A * X ** B WHERE A AND B ARE FUNCTIONS OF BOTH STABILITY PLB08880
      C        AND RANGE OF X.                                             PLB08890
      C       HORIZONTAL DISPERSION PARAMETER VALUE, SY DETERMINED BY     PLB08900
      C        LOGARITHMIC INTERPOLATION OF PLUME HALF-ANGLE ACCORDING TO  PLB08910
      C        DISTANCE AND CALCULATION OF 1/2.15 TIMES HALF-ARC LENGTH.   PLB08920
 2         COMMON /MS/KST,X,SY,SZ                                          PLB08930
 3         DIMENSION XA(7), XB(2), XD(5), XE(8), XF(9), AA(8), BA(8), AB(3), PLB08940
          1BB(3), AD(6), BD(6), AE(9), BE(9), AF(10), BF(10)               PLB08950
 4         DATA XA /.5,.4,.3,.25,.2,.15,.1/                                PLB08960
 5         DATA XB /.4,.2/                                                 PLB08970
 6         DATA XD /30.,10.,3.,1.,.3/                                      PLB08980
 7         DATA XE /40.,20.,10.,4.,2.,1.,.3,.1/                            PLB08990
 8         DATA XF /60.,30.,15.,7.,3.,2.,1.,.7,.2/                         PLB09000
 9         DATA AA /453.85,346.75,258.89,217.41,179.52,170.22,158.08,122.8/ PLB09010
 10        DATA BA /2.1166,1.7283,1.4094,1.2644,1.1262,1.0932,1.0542,.9447/ PLB09020
 11        DATA AB /109.30,98.483,90.673/                                  PLB09030
 12        DATA BB /1.0971,0.98332,0.93198/                                PLB09040
 13        DATA AD /44.053,36.650,33.504,32.093,32.093,34.459/             PLB09050
 14        DATA BD /0.51179,0.56589,0.60486,0.64403,0.81066,0.86974/       PLB09060
 15        DATA AE /47.618,35.420,26.970,24.703,22.534,21.628,21.628,23.331,2PLB09070
          14.26/                                                           PLB09080
 16        DATA BE /0.29592,0.37615,0.46713,0.50527,0.57154,0.63077,0.75660,0PLB09090
          1.81956,0.8366/                                                  PLB09100
 17        DATA AF /34.219,27.074,22.651,17.836,16.187,14.823,13.953,13.953,1PLB09110
          14.457,15.209/                                                   PLB09120
 18        DATA BF /0.21716,0.27436,0.32681,0.41507,0.46490,0.54503,0.63227,0PLB09130
          1.68465,0.78407,0.81558/                                         PLB09140
 19        XY=X                                                            PLB09150
 20        GO TO (10,40,70,80,110,140), KST                                PLB09160
      C       STABILITY A (10)                                            PLB09170
 21   10   TH=(24.167-2.5334*ALOG(XY))/57.2958                             PLB09180
 22        IF (X.GT.3.11) GO TO 170                                        PLB09190
 23        DO 20 ID=1,7                                                    PLB09200
 24        IF (X.GE.XA(ID)) GO TO 30                                       PLB09210
 25   20   CONTINUE                                                        PLB09220
 26        ID=8                                                            PLB09230
 27   30   SZ=AA(ID)*X**BA(ID)                                             PLB09240
 28        GO TO 190                                                       PLB09250
      C       STABILITY B (20)                                            PLB09260
 29   40   TH=(18.333-1.8096*ALOG(XY))/57.2958                             PLB09270
 30        IF (X.GT.35.) GO TO 170                                         PLB09280
 31        DO 50 ID=1,2                                                    PLB09290
 32        IF (X.GE.XB(ID)) GO TO 60                                       PLB09300
 33   50   CONTINUE                                                        PLB09310
 34        ID=3                                                            PLB09320
 35   60   SZ=AB(ID)*X**BB(ID)                                             PLB09330
 36        GO TO 180                                                       PLB09340
      C       STABILITY C (30)                                            PLB09350
```

SUBROUTINE PSIG

```
37     70     TH=(12.5-1.0857*ALOG(XY))/57.2958                PLB09360
38            SZ=61.141*X**0.91465                             PLB09370
39            GO TO 180                                        PLB09380
       C         STABILITY D (40)                              PLB09390
40     80     TH=(8.3333-0.72382*ALOG(XY))/57.2958             PLB09400
41            DO 90 ID=1,5                                     PLB09410
42            IF (X.GE.XD(ID)) GO TO 100                       PLB09420
43     90     CONTINUE                                         PLB09430
44            ID=6                                             PLB09440
45     100    SZ=AD(ID)*X**BD(ID)                              PLB09450
46            GO TO 180                                        PLB09460
       C         STABILITY E (50)                              PLB09470
47     110    TH=(6.25-0.54287*ALOG(XY))/57.2958               PLB09480
48            DO 120 ID=1,8                                    PLB09490
49            IF (X.GE.XE(ID)) GO TO 130                       PLB09500
50     120    CONTINUE                                         PLB09510
51            ID=9                                             PLB09520
52     130    SZ=AE(ID)*X**BE(ID)                              PLB09530
53            GO TO 180                                        PLB09540
       C         STABILITY F (60)                              PLB09550
54     140    TH=(4.1667-0.36191*ALOG(XY))/57.2958             PLB09560
55            DO 150 ID=1,9                                    PLB09570
56            IF (X.GE.XF(ID)) GO TO 160                       PLB09580
57     150    CONTINUE                                         PLB09590
58            ID=10                                            PLB09600
59     160    SZ=AF(ID)*X**BF(ID)                              PLB09610
60            GO TO 180                                        PLB09620
61     170    SZ=5000.                                         PLB09630
62            GO TO 190                                        PLB09640
63     180    IF (SZ.GT.5000.) SZ=5000.                        PLB09650
64     190    SY=465.116*XY*SIN(TH)/COS(TH)                    PLB09660
       C         465.116 = 1000. (M/KM) / 2.15                 PLB09670
65            RETURN                                           PLB09680
       C                                                       PLB09690
66            END                                              PLB09700
```

SUBROUTINE PSIG

SYMBOL		= = = = = = = =	= = = = = = = =	REFERENCES				= = = = = = = =	= = = = = = = =		
10	-	20	21*								
20	-	23	25*								
30	-	24	27*								
40	-	20	29*								
50	-	31	33*								
60	-	32	35*								
70	-	20	37*								
80	-	20	40*								
90	-	41	43*								
100	-	42	45*								
110	-	20	47*								
120	-	48	50*								
130	-	49	52*								
140	-	20	54*								
150	-	55	57*								
160	-	56	59*								
170	-	22	30	61*							
180	-	36	39	46	53	60	63*				
190	-	28	62	64*							
AA	-	3DI	9DA	27							
AB	-	3DI	11DA	35							
AD	-	3DI	13DA	45							
AE	-	3DI	15DA	52							
AF	-	3DI	17DA	59							
ALOG	-	21	29	37	40	47	54				
BA	-	3DI	10DA	27							
BB	-	3DI	12DA	35							
BD	-	3DI	14DA	45							
BE	-	3DI	16DA	52							
BF	-	3DI	18DA	59							
COS	-	64									
ID	-	23	24	26=	27	27	31	32	34=	35	35
		41	42	44=	45	45	48	49	51=	52	52
		55	56	58=	59	59					
KST	-	2CO	20								
MS	-	2CO									
PSIG	-	1EY									
SIN	-	64									
SY	-	2CO	64=								
SZ	-	2CO	27=	35=	38=	45=	52=	59=	61=	63	63=
TH	-	21=	29=	37=	40=	47=	54=	64	64		
X	-	2CO	19	22	24	27	30	32	35	38	42
		45	49	52	56	59					
XA	-	3DI	4DA	24							
XB	-	3DI	5DA	32							
XD	-	3DI	6DA	42							
XE	-	3DI	7DA	49							
XF	-	3DI	8DA	56							
XY	-	19=	21	29	37	40	47	54	64		

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********** SUPER INDEX **********

SYMBOL	-	================== ROUTINES IN WHICH THE SYMBOL IS USED ==================			
A1	-	RCON			
A2	-	RCON			
A3	-	RCON			
A4	-	RCON			
A5	-	RCON			
A6	-	RCON			
A7	-	RCON			
AA	-	PSIG			
AB	-	PSIG			
ABS	-	TPMX			
AD	-	MAIN P	PSIG		
AD2	-	MAIN P			
AE	-	PSIG			
AF	-	PSIG			
AH	-	MAIN P			
AH2	-	MAIN P			
ALOG	-	PSIG			
ALP	-	MAIN P			
AN	-	RCON			
ANOT	-	MAIN P			
BA	-	PSIG			
BB	-	PSIG			
BD	-	PSIG			
BE	-	PSIG			
BF	-	PSIG			
C1	-	RCON			
C2	-	RCON			
C3	-	RCON			
C4	-	RCON			
C5	-	RCON			
C6	-	RCON			
C7	-	RCON			
C8	-	RCON			
C9	-	RCON			
CA	-	RCON			
CB	-	RCON			
CC	-	RCON			
CD	-	RCON			
CE	-	RCON			
CF	-	RCON			
CLST	-	TPMX			
CM	-	MAIN P			
CM2	-	MAIN P			
CMAX	-	MAIN P	TPMX		
COS	-	PSIG			
D	-	MAIN P	PH		
DELH	-	PH	PHX	RCON	TPMX
DELT	-	MAIN P			

********** SUPER INDEX **********

DHA	-	PH				
DHAUE	-	MAIN P	PH			
DHAUF	-	MAIN P	PH			
DHCAE	-	MAIN P	PH			
DHCAF	-	MAIN P	PH			
DHU	-	MAIN P	PH			
DHUTE	-	MAIN P	PH			
DHUTF	-	MAIN P	PH			
DTMB	-	MAIN P				
DUM	-	MAIN P	PH	RCON	TPMX	
DUTE	-	MAIN P	PH			
DUTF	-	MAIN P	PH			
DX	-	TPMX				
DX1	-	TPMX				
EXP	-	RCON				
F	-	MAIN P				
H	-	MAIN P	PHX	RCON	TPMX	
HANE	-	MAIN P				
HE	-	MAIN P				
HE2	-	MAIN P				
HF	-	MAIN P	PH	PHX	TPMX	
HL	-	MAIN P	RCON	TPMX		
HP	-	MAIN P	PH			
HPRM	-	PH	PHX			
HX	-	PHX				
I	-	MAIN P	TPMX			
IA	-	MAIN P				
IB	-	MAIN P				
ID	-	PSIG				
IOPT	-	MAIN P	PH	RCON	TPMX	
IRD	-	MAIN P				
IWRI	-	MAIN P	RCON			
JB	-	TPMX				
K	-	MAIN P				
KST	-	MAIN P	PH	PSIG	RCON	TPMX
ME	-	MAIN P	PH			
MF	-	MAIN P	PH			
N	-	MAIN P				
PDHX	-	MAIN P	PHX	RCON		
PH	-	MAIN P				
PHX	-	TPMX				
PL	-	MAIN P				
PSIG	-	RCON				
Q	-	MAIN P				
RC	-	RCON	TPMX			
RCON	-	TPMX				
SE	-	MAIN P				
SF	-	MAIN P				
SIN	-	PSIG				
SQRT	-	MAIN P	RCON			

********** SUPER INDEX **********

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I N D E X
END OF ANALYSIS
JPL FORTRAN V VERSION

APPENDIX C

SENSITIVITY ANALYSIS

This section presents a simple analysis designed to acquaint the user with the magnitude of changes expected in surface concentrations when certain model inputs are varied.

OPTIONS

PTPLU has three technical options: gradual plume rise, stack downwash, and buoyancy-induced dispersion. The effects of employing each of the options are discussed next, using as a base the calculation presented in Section 8.

Gradual Plume Rise

The gradual plume rise option alters the assumptions made about the height of the plume up to the distance of final rise. If the option is not employed, calculations are made as if the plume is always at the effective height. If the option is employed, the plume is assumed to rise gradually to the final height as the distance downwind increases. The effect of employing the option is to decrease the plume height between the point of release and the point of final rise, which results in higher ground-level concentrations.

In the example presented in Section 8, the maximum concentration occurs at a point beyond the distance of final rise (see Figure 7). Thus, the gradual plume rise option has no effect for stabilities B or D with a wind speed of 4 m/s. Despite the fact that the option has no effect on the maxima, it should be noted that in the process of searching for the maximum, the option affects calculations for locations between the source and the distance to final rise. Table C-1 shows the plume heights and concentrations with and without the option for some of the distances for which calculations were performed, for stability B with a wind speed of 4 m/s. It can be seen that beyond 0.6 km, which is the distance to final rise, the option has no effect. Also note in Figure 7 that the maximum concentration for stability A with a wind speed of 3.0 m/s is affected by the option, as this maximum occurs before final rise.

TABLE C-1. PLUME HEIGHTS AND CONCENTRATIONS WITH AND WITHOUT THE GRADUAL-RISE OPTION*

	With gradual rise		Without gradual rise	
Distance (km)	Height (m)	Conc. ($\mu g/m^3$)	Height (m)	Conc. ($\mu g/m^3$)
0.1	73.3	0	150.0	0
0.3	109.2	11	150.0	0
0.5	137.2	77	150.0	38
0.7	150.0	190	150.0	190

* For stability B and wind speed of 4 m/s.

Stack Downwash

The stack downwash option simulates lowering of the plume just after it leaves the stack, as a result of low pressures on the leeward side of the stack. The model carries out this simulation by using a modified value for the physical height, which lowers the effective height of the plume. Again, decreased plume height results in higher ground-level concentrations.

The stack downwash option is important if the exit velocity of the effluent is less than 1.5 times the wind speed. In the example considered here, the wind speed is only 4 m/s, while the stack gas velocity is 20 m/s; therefore stack downwash should have a minimal effect. As can be seen in Table C-2, this is the case. However, if the wind speed in this example was 15 m/s or greater, the option becomes important and should be implemented.

TABLE C-2. MAXIMUM CONCENTRATIONS WITH AND WITHOUT STACK DOWNWASH, FOR STABILITY CLASS D

With stack downwash		Without stack downwash	
Conc. ($\mu g/m^3$)	Distance to max. conc. (km)	Conc. ($\mu g/m^3$)	Distance to max. conc. (km)
204	1.64	198	1.67

Buoyancy-Induced Dispersion (BID)

Buoyancy-induced dispersion is estimated by an increase in the dispersion parameters proportional to the plume rise under the assumption that the more buoyant a plume, the more the buoyancy contributes to dispersion. In the two cases considered, this increase in the dispersion parameters results in an increase in the maximum ground-level concentrations. However, use of this option will not always produce higher concentrations. For stability A with a wind speed of 0.5 m/s, concentration is reduced 23%. In general, the effect of buoyancy-induced dispersion on concentration is negligible, except when the stack height is small compared with the plume rise (as in this example). It should be noted that multiple concentration peaks are possible when this option is used along with the gradual plume rise option.

TABLE C-3. MAXIMUM CONCENTRATIONS WITH AND WITHOUT BID

Stability class	With BID Conc. (μg/m³)	With BID Distance to max. conc. (km)	Without BID Conc. (μg/m³)	Without BID Distance to max. conc. (km)
B	282	0.97	278	1.02
D	122	4.79	112	5.63

PLUME-RISE-RELATED PARAMETERS

Of several parameters that can influence plume rise, two are varied here. The results of these variations are discussed next.

Stack Gas Temperature

Sensitivity to variations in stack gas temperature was studied using the program's built-in sample test as a base. Figure C-1 shows the percent change in maximum concentration and the percent change in distance to maximum concentration resulting from decreases in stack gas temperature under three wind and stability conditions. These results are also presented in Tables C-4 and C-5 with an additional wind and stability condition analyzed.

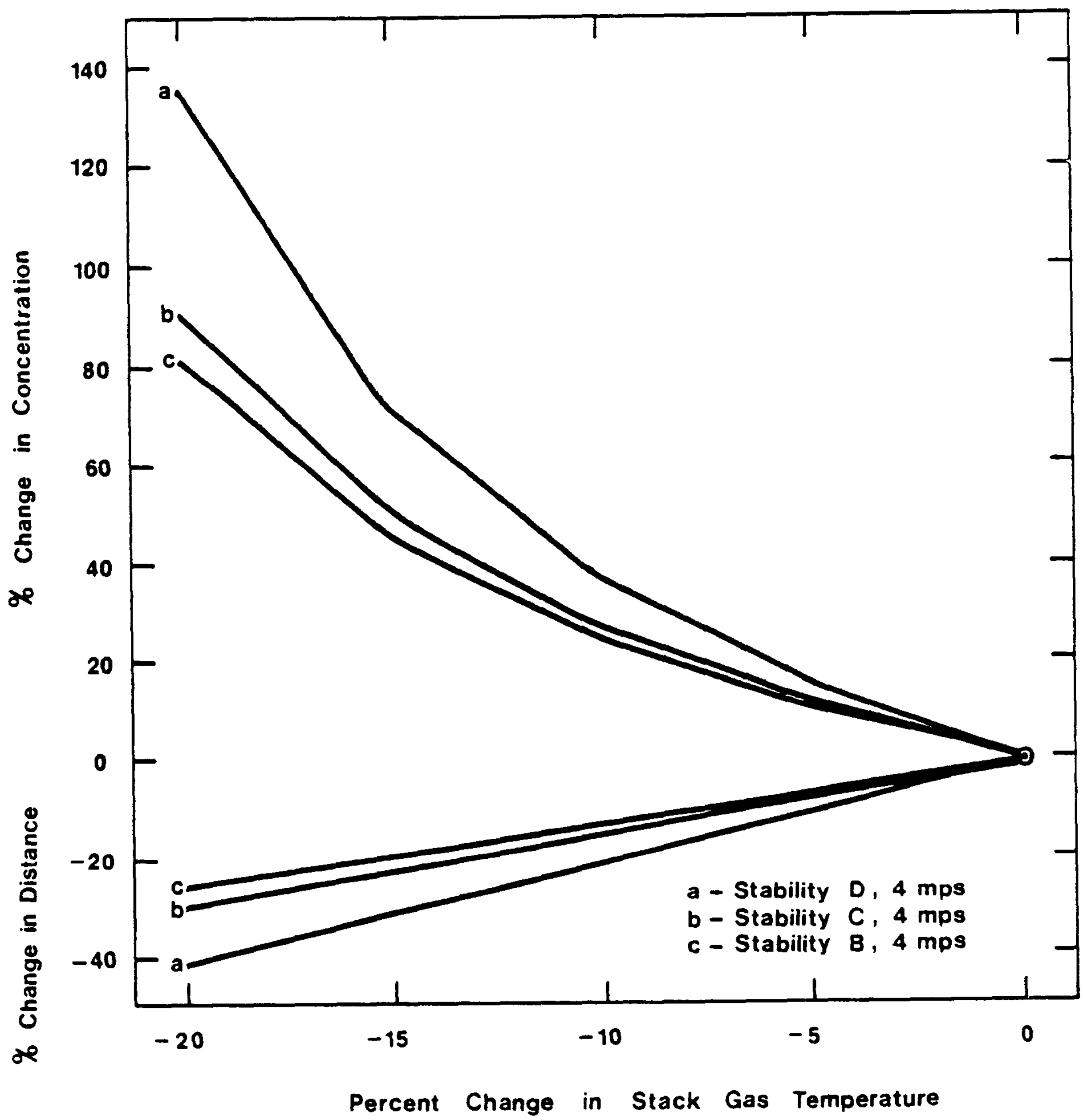

Figure C-1. Sensitivity of maximum concentration and distance-to-maximum to changes in stack gas temperature.

TABLE C-4. PERCENT INCREASE IN MAXIMUM CONCENTRATION WITH DECREASING STACK GAS TEMPERATURE

Stability class	Wind (m/s)	Decrease in stack gas temperature			
		5%	10%	15%	20%
B	4.0	10.26	24.57	45.95	81.70
C	4.0	11.08	26.66	50.21	90.22
C	2.0	12.91	31.69	61.35	115.04
D	4.0	15.01	36.97	71.93	135.35

TABLE C-5. PERCENT DECREASE IN DISTANCE TO MAXIMUM CONCENTRATION WITH DECREASING STACK GAS TEMPERATURE

Stability class	Wind (m/s)	Decrease in stack gas temperature			
		5%	10%	15%	20%
B	4.0	-4.70	-10.17	-16.83	-25.23
C	4.0	-5.47	-11.88	-19.52	-29.02
C	2.0	-6.47	-14.30	-23.22	-34.22
D	4.0	-9.13	-19.37	-30.85	-41.94

From Tables C-4 and C-5, it is apparent that decreased stack gas temperature, which makes the plume less buoyant, generally results in a higher maximum closer to the source. The specific changes, however, also depend on the stability and wind speed.

Stack Gas Velocity

Sensitivity to variation in stack gas velocity was studied using the built-in sample test as a base. Tables C-6 and C-7 show the percent change in maximum concentration and the percent change in distance to maximum concentration resulting from decreases in stack gas velocity under four wind and stability conditions. Figure C-2 graphically depicts some of these changes. It is apparent from Tables C-6 and C-7 and Figure C-2 that decreased stack gas velocity, which decreases plume rise, generally results in higher maximum concentrations closer to the source. However, the specific change in the results depends on the stability and wind speed as well. In general, for a given stability, higher wind speed counters the effect of increasing the stack gas velocity.

TABLE C-6. PERCENT INCREASE IN MAXIMUM CONCENTRATION WITH DECREASING STACK GAS VELOCITY

Stability class	Wind (m/s)	Decrease in stack gas velocity			
		5%	10%	15%	20%
B	4.0	4.14	8.66	13.59	19.00
C	4.0	4.46	9.33	14.68	25.58
C	2.0	5.15	10.85	17.19	24.28
D	4.0	5.98	12.62	20.00	28.30

TABLE C-7. PERCENT DECREASE IN DISTANCE TO MAXIMUM CONCENTRATION WITH DECREASING STACK GAS VELOCITY

Stability class	Wind (m/s)	Decrease in stack gas velocity			
		5%	10%	15%	20%
B	4.0	-1.94	-3.99	-6.04	-8.15
C	4.0	-2.30	-4.65	-7.05	-9.55
C	2.0	-2.68	-5.78	-8.64	-11.52
D	4.0	-3.95	-7.88	-11.85	-15.68

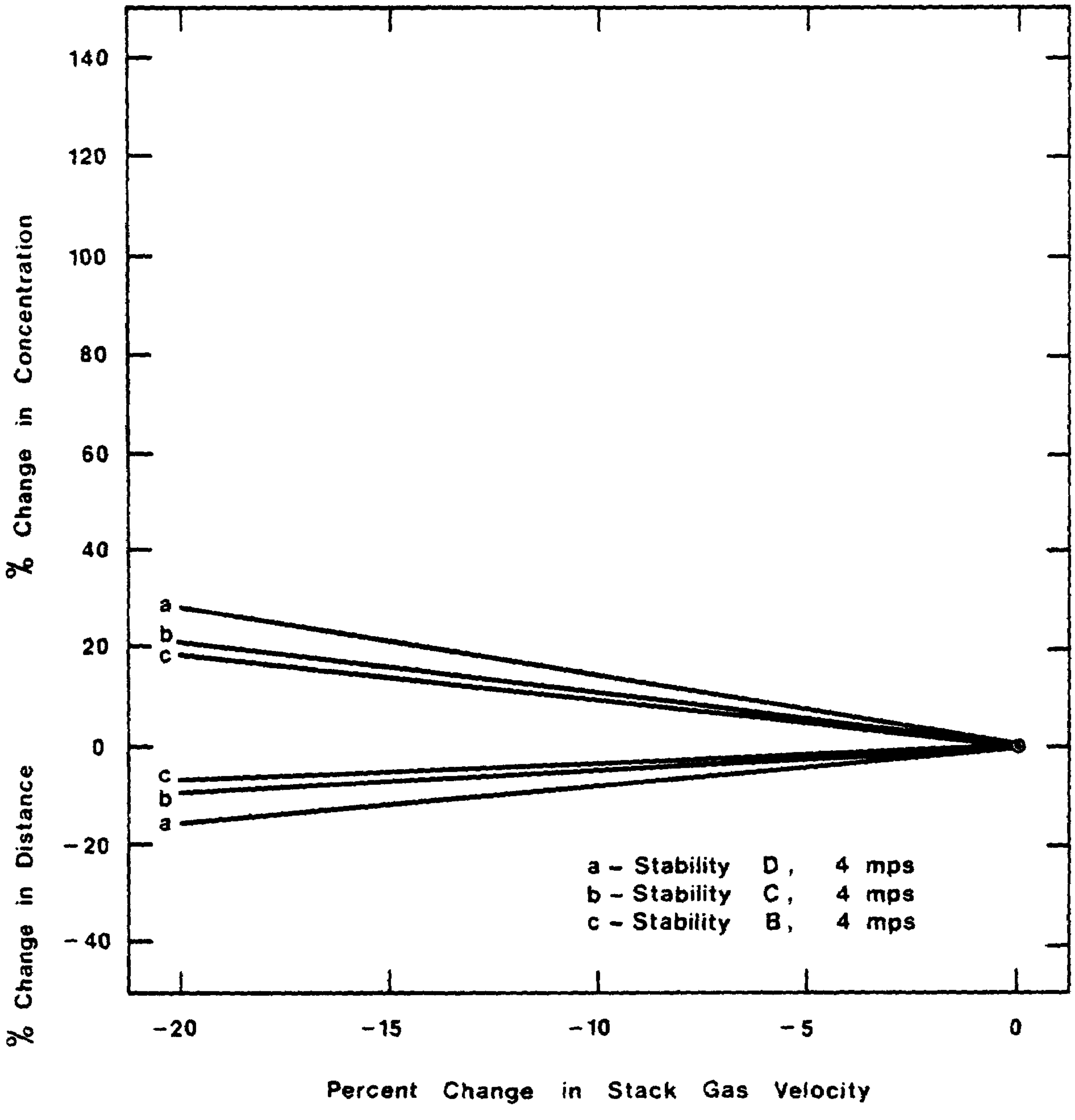

Figure C-2. Sensitivity of maximum concentration and distance-to-maximum to changes in stack gas velocity.

GLOSSARY

Some of the following definitions are taken from "Glossary of Meteorology," Ralph E. Huschke, editor. American Meteorological Society, Boston. 1959. 638 pp.

ADIABATIC PROCESS--A thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system. In an adiabatic process, compression always results in warming, expansion in cooling.

ADVECTION--The process of transport of an atmospheric property solely by the mass motion (velocity field) of the atmosphere. Refers to predominantly horizontal large-scale motions of the atmosphere.

AIR MASS--A widespread body of air that is approximately homogeneous in its horizontal and vertical properties, particularly with reference to temperature and moisture distribution.

ATMOSPHERIC STABILITY--State of the atmosphere with respect to vertical motions. Atmospheric conditions may be classified as stable, neutral, or unstable. In stable conditions, the potential temperature increases with height, and vertical motions are inhibited. Under these conditions, pollutants emitted at the ground tend to accumulate, while effluents from elevated sources normally remain aloft for long distances. In unstable conditions, the potential temperature decreases with height, and vertical motions are enhanced. Low-level emissions are dispersed rapidly upward, and high-level emissions are dispersed rapidly in the vertical. Elevated sources frequently make their maximum contribution to short-term ambient pollutant concentrations under unstable conditions. Between stable and unstable conditions is the situation in which the vertical temperature profile decreases nearly adiabatically. This condition, called "neutral stability," is quite frequent in most locations. For sources with tall stacks, the high wind speed neutral condition suppresses plume rise, and high ground-level concentrations are often observed. For ground-level emissions, near-neutral conditions usually result in concentrations between those for stable and unstable conditions.

BUOYANCY FLUX--A parameter related to the buoyant vertical motions of a released volume of effluent due to its excess of temperature over the surrounding air.

CONING--Spreading to produce a cone-shaped plume with its apex at the source. This usually occurs under windy conditions, and when the vertical temperature is near dry adiabatic or somewhat subadiabatic.

DOWNWASH--Rapid mixing downward of a plume by strong winds; usually observed in the lee of buildings and stacks.

DRY ADIABATIC LAPSE RATE--The rate of decrease of temperature with height of a parcel of dry air lifted adiabatically to lower pressures; 9.8°C/km.

EFFECTIVE STACK HEIGHT--The physical stack height plus plume rise. The point above the ground at which the gaseous effluent becomes essentially level.

ELEVATED INVERSION--An inversion layer above the ground surface that inhibits the dispersion of buoyant plumes. Elevated inversions are initiated by subsiding air from upper atmospheric levels or are the transitional zones between dissimilar air masses. Elevated inversions can also result from radiation inversions (which start at the surface) that are partially eliminated from below, due to surface heating.

FANNING--Spreading of a plume to give the appearance of a fan spread horizontally. This occurs under stable conditions when the vertical dispersion is greatly suppressed due to the vertical thermal structure but does not impede horizontal direction variations.

FUMIGATION--The rapid mixing downward to the ground of material previously emitted into a stable layer. Commonly occurs when the nocturnal temperature inversion is rapidly dissipated by solar heating of the surface; also occurs in sea breeze circulations during late morning or early afternoon.

INSOLATION--Incoming solar radiation received at the earth's surface.

INVERSION--A layer of air in which temperature increases with altitude; that is, inverted with respect to the more usual decrease of temperature with altitude.

LAPSE RATE--Adiabatic lapse rate is the rate of temperature change with height of a parcel displaced vertically in the atmosphere adiabatically. The parcel becomes cooler with lifting as it expands upon encountering less pressure;

conversely, the parcel becomes warmer with descent as it is compressed due to higher pressures. The adiabatic lapse rate is a decrease of about 1°C/100 m rise. When the temperature structure of the atmosphere (the environmental lapse rate) is subadiabatic (i.e., cooling is less rapid with height than the adiabatic rate), the atmosphere damps out vertical motion. When the temperature structure is superadiabatic, (i.e., cooling with height is more rapid than the adiabatic rate), rising parcels continue to accelerate upward. When the environmental lapse rate is near the dry adiabatic rate, vertical motions are neither damped out nor enhanced.

LOFTING--Upward spreading of the plume in the vertical above the plume centerline, but minimum spreading downward, because the plume is unable to penetrate an inversion below the plume centerline.

LOOPING--Plume spreading with the instantaneous appearance of large loops; the emitted plume is caught in thermals and rises, and a few seconds later, the newly emitted plume is caught in descending air and moves downward from the point of emission. Occurs in strongly unstable air; usually, the vertical thermal structure is superadiabatic near the ground.

MIXING HEIGHT--Height of the unstable or neutral layer that is well-mixed. Usually the height of the first significant inversion above the surface delimits the depth available for vertical dispersion of pollutants.

NOCTURNAL INVERSION--Surface-based inversion induced by radiational cooling.

PHYSICAL STACK HEIGHT--Actual height (above ground) of a stack or effluent source.

PLUME RISE--The height of a plume centerline above the point of release at a distance downwind from a source due to buoyancy and momentum effects. (The height above the point of release where the plume becomes level is the final plume rise.)

SUBSIDENCE INVERSION--A temperature inversion produced by the adiabatic warming of a layer of descending air. Results in a limited mixing volume below the subsiding layer.

SURFACE-BASED INVERSION--An inversion layer of stable air close to the ground, usually a radiation inversion. Inhibits dispersion of low-level releases of fugitive dust and other pollutants.

SURFACE BOUNDARY LAYER--The thin layer of air immediately above the earth's surface. (In this layer, shearing stresses are nearly constant.)

SURFACE ROUGHNESS--Irregularities in or on the earth's surface that increase mechanical turbulence and enhance pollutant dispersion.

TRAPPING--Plume spreading is moderate to rapid near the point of emission, but is impeded vertically (trapped) by an elevated stable layer. Usually, thermal conditions in the lower layer are adiabatic or subadiabatic.

Date____________________

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