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**User's Manual for
DWNWND—An Interactive
Gaussian Plume Atmospheric
Transport Model with Eight
Dispersion Parameter Options**

David E. Fields
Charles W. Miller

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USER'S MANUAL FOR DWNWIND — AN INTERACTIVE GAUSSIAN
PLUME ATMOSPHERIC TRANSPORT MODEL WITH EIGHT
DISPERSION PARAMETER OPTIONS

David E. Fields
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and

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ABSTRACT

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The most commonly used approach for estimating the atmospheric concentration and deposition of material downwind from its point of release is the Gaussian plume atmospheric dispersion model. Two of the critical parameters in this model are σ_y and σ_z , the horizontal and vertical dispersion parameters, respectively. A number of different sets of values for σ_y and σ_z have been determined empirically for different release heights and meteorological and terrain conditions.

The computer code DWNWND, described in this report, is an interactive implementation of the Gaussian plume model. This code allows the user to specify any one of eight different sets of the empirically determined dispersion parameters. The sets available in DWNWND are Pasquill-Gifford, Briggs-Smith, Briggs, Klug, Brookhaven, St. Louis, Jülich (50-m release height), and Jülich (100-m release height). Using the selected dispersion parameters, ground-level normalized exposure estimates are made at any specified downwind distance for the plume centerline and for the 22.5° sector average. Computed values may be corrected for plume depletion due to deposition and for plume settling due to gravitational fall.

With this interactive code, the user chooses values for ten parameters which define the source, the dispersion and deposition process, and the sampling point. DWNWND is written in FORTRAN for timesharing execution on a Digital Equipment Corporation PDP-10 computer. It contains 445 lines of code and executes rapidly, requiring less than one second of central processor unit time for each simulation. A listing of the code and a representative printout from the code's execution are included in this report.

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1. INTRODUCTION

The most common approach to computation of an atmospheric concentration E of an aerosol at distances of up to 50 km from the release point is based upon an equation of the form (Slade, 1968)

$$E = \frac{Q}{2\pi u \sigma_y \sigma_z} \left\{ \exp \left[-\left(\frac{y^2}{2\sigma_y^2} \right) \right] \right\} \left\{ \exp \left[-1/2 \left(\frac{z - H}{\sigma_z} \right)^2 \right] + \exp \left[-1/2 \left(\frac{z + H}{\sigma_z} \right)^2 \right] \right\}. \quad (1)$$

This equation describes a distribution of bell-shaped (Gaussian) profile, where Q represents the source strength and H the corrected source release height as discussed later. Dispersion parameters σ_y and σ_z are the standard deviations of the plume concentration in the horizontal and vertical directions, respectively. The aerosol is assumed transported at a height-independent wind speed u to a sampling position located at surface elevation z and horizontal distance y from the plume center. Mass conservation within the plume is insured by assuming perfect reflection at the ground surface. This is accomplished by the use of an image source at an elevation $-H$, which leads to the presence of two terms within the braces, and to the factor $1/2$. Equation (1) may be obtained from any of several reasonable conceptual transport/dispersion models. Despite the wide use of this Gaussian plume model, there are many atmospheric release conditions, such as low wind speeds, complex terrain, and others, for which this model may not be applicable (Gifford, 1976). Any potential user of Eq. (1) should be sure that this model is appropriate for the release being considered.

Crucial to successful use of Eq. (1) is knowledge of appropriate values of σ_y and σ_z . These dispersion parameters are functions of x , the downwind source to receptor distance, atmospheric stability class, release height, and terrain conditions. Calculation of σ_y and σ_z values from first principles has proven infeasible, but several investigators have developed empirical values for these parameters. Each of these sets of parameters has in some measure been based on the meteorology prevailing at a particular experimental site and thus is most suited to certain atmospheric stability classes and terrains.

We have implemented a special-purpose Gaussian plume transport model which allows the user to choose between different sets of values for σ_y and σ_z . This model is specifically intended to compute normalized estimates of the time integrated air concentration of the aerosol at a given reception point. From Eq. (1), this normalized exposure is given by

$$\frac{Eu}{Q} = \frac{1}{2\pi\sigma_y\sigma_z} \left\{ \exp \left[-\left(\frac{y^2}{2\sigma_y^2} \right) \right] \right\} \left\{ \exp \left[-1/2 \left(\frac{z-H}{\sigma_z} \right)^2 \right] + \exp \left[-1/2 \left(\frac{z+H}{\sigma_z} \right)^2 \right] \right\}. \quad (2)$$

The computer code, called DWNWND, provides ground-level Eu/Q values for points on the plume centerline and an average value across a 22.5° downwind sector. Computed values may be corrected for plume depletion due to deposition and for plume settling due to gravitational fall as described in the next chapter. The code is interactive and allows the user to specify any one of eight sets of dispersion parameters, and to further choose any of the defined stability classes corresponding to this particular parameterization. The user also chooses values for eight other parameters which further define the source, the deposition process, and the sampling point. DWNWND is written in FORTRAN for timesharing execution on a Digital Equipment Corporation PDP-10 computer. It contains 445 lines of code and executes rapidly, requiring less than one second of central processor unit time for each simulation.

2. CONSIDERATIONS INVOLVED IN CALCULATING Eu/Q

Implicit in Eqs. (1) and (2) is the assumption that the plume centerline height is that of the release height H . In practice, the plume typically emerges from a vertical stack with a net upward momentum and at a temperature higher than the surrounding air. The effluent may be partially composed of entrained particulates, which probably have a greater density than the accompanying gases. The plume thus has an effective stack height H_{eff} , at which the plume becomes nearly horizontal, greater than the physical stack height. This effective value should be used instead of the actual stack height as the starting point for Gaussian

plume calculations. If the particulates in the effluent have an average gravitational fall velocity v_g , the plume centerline will tilt downward with an angle from the horizontal, the tangent of which is v_g/u . The elevation of the plume centerline a distance x downwind is then

$$H = H_{\text{eff}} - xv_g/u; H \geq 0, \quad (3)$$

and it is this corrected value that is used to compute the aerosol concentration at a distant point.

Two other corrections of the computed concentration may be significant — one of these due to modification of the Gaussian profile at high altitude and the other near ground level. We must consider these corrections. Upward dispersion of the plume subsequent to release is eventually restricted when the plume encounters an elevated stable air layer or lid at some height H_{lid} . Pasquill (1976) has summarized some reasonable approximations to the modified vertical concentration profile for various ranges downwind, and his remarks have influenced our approach. We compute a limiting value of σ_z defined as

$$\sigma_z(\text{limit}) = 2(H_{\text{lid}} - H)/2.15. \quad (4)$$

In this equation, we have modified the plume release height for plume tilt and have subtracted the result from the lid altitude to obtain the Gaussian half-width. The factor of 2 appears since we wish the value of $\sigma_z(\text{limit})$ to be used beyond a point twice as far downwind as when the plume first reaches the boundary layer, while the factor 2.15, estimated from field measurements (Pasquill, 1961), implies that the effective spread of a Gaussian plume is $2.15 \sigma_z$. For shorter downwind distances where the vertical dispersion coefficient $\sigma_z < \sigma_z(\text{limit})$, the value of σ_z is used as computed. For greater downwind distances, where $\sigma_z \geq \sigma_z(\text{limit})$, the value of $\sigma_z(\text{limit})$ given in Eq. (4) is used instead of σ_z .

The plume is depleted at ground level during travel as the aerosol is deposited. Both fallout and electrochemical deposition may be important considerations, and ground cover characteristics are of major importance. (Under certain obvious conditions, washout is also of great importance, but those conditions are not within the scope of this model.) Fallout

is partially quantified in the v_g term defined earlier. Near ground level the deposition process is often characterized by a deposition velocity v_d (Gifford and Pack, 1962; Murphy 1976a, b). The deposition rate W is defined by

$$W = v_d E .$$

We may compute the magnitude of plume depletion within the downwind sector by integrating across the plume. Using Eq. (1) and setting $z = 0$, we have

$$\begin{aligned} \frac{dQ}{dx} &= - \int_{-\infty}^{\infty} v_d E \, dy \\ &= - \int_{-\infty}^{\infty} \frac{v_d}{u} \frac{Q}{\pi \sigma_y \sigma_z} \exp \left\{ - \frac{y^2}{2\sigma_z^2} - \frac{H^2}{2\sigma_z^2} \right\} dy . \end{aligned} \quad (5)$$

By performing the indicated quadrature across the plume and further integrating along the longitudinal direction to express the loss of release agent as a multiplicative factor, it can be shown (Miller et al, 1978) that the ratio of the air concentration considering deposition processes E_d to the air concentration without considering deposition is

$$F = \frac{E_d}{E} = \exp \left\{ - \sqrt{\frac{2}{\pi}} \frac{v_d}{u} \int_0^X \frac{\exp \left(- \frac{H^2}{2\sigma_z^2} \right) dx}{\sigma_z} \right\} . \quad (6)$$

Since σ_z is a complicated empirical function of x , Eq. (6) must be evaluated numerically.

The average value of Eu/Q across a 22.5° downwind sector is sometimes the desired quantity. In this case, the factor $\frac{1}{\sigma_y}$ in Eq. (2) is replaced by 2.032 (Culkowski and Patterson, 1976).

In summary, if a point source releases a quantity of material under conditions such that the resulting agent distribution is that of a Gaussian plume, we may compute the quantity Eu/Q at ground level at the downwind plume centerline, by

$$\frac{Eu}{Q} = \frac{F}{\pi\sigma_y\sigma_z} \exp\left(-\frac{H^2}{2\sigma_z^2}\right), \quad (7)$$

and the average value of Eu/Q for the 22.5° downwind sector by

$$\frac{Eu}{Q} = \frac{2.032F}{\pi\sigma_z} \exp\left(-\frac{H^2}{2\sigma_z^2}\right). \quad (8)$$

The value H in Eqs. (7) and (8) must be corrected for effective stack height and for plume tilt as in Eq. (3) and the preceding discussion. The plume depletion factor F must be computed numerically using Eq. (6), and the tabulated or calculated value of σ_z must be, when appropriate, replaced by the limiting value $\sigma_z(\text{limit})$ defined in Eq. (4). The user of our numerical model must enter the effective stack height; the model makes the other computations.

3. COMMONLY USED PARAMETERIZATIONS OF ATMOSPHERIC DISPERSION

The set of empirically determined atmospheric dispersion values that will yield a predicted value of Eu/Q in closest agreement with measured values will vary for differing meteorological, topographical, and release conditions. A common challenge is that of choosing the dispersion parameterization that most closely suits a given, poorly characterized, emission site.

3.1 Pasquill-Gifford Dispersion Parameters

Pasquill (1961, 1974) considered ground-level emission tracer studies and wind-direction fluctuation data to arrive at a dispersion parameterization for six atmospheric stability classes ranging from A, most unstable, through F, most stable (Table 1). Pasquill's values are approximate for ground-level emissions of low surface roughness (Vogt, 1977). These values were devised for small source distances (<1 km).

Table 1. Definition of the Pasquill atmospheric stability categories (Pasquill, 1961)

Surface Wind Speed (at 10 m), m sec ⁻¹	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or ≥4/8 Low Cloud	≤3/8 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 so-called Pasquill-Gifford form of this parameterization (Hilsmeier and Gifford, 1962) has been tabulated by Culkowski and Patterson (1976), and we have used their approach in our model. Pasquill-Gifford values are computed if the program parameter IT is chosen to be 1.

3.2 Briggs Dispersion Parameters

Briggs' values for horizontal and vertical dispersion coefficients (Gifford 1976) have been used in our model in two forms. For each of these forms, the horizontal dispersion coefficient σ_y is computed from the formulas contained in Moore (1977). These values were represented as a different function for each stability class corresponding to the six classes defined by Pasquill (1961). If IT is chosen 2, Hosker's (1974) formulation of Briggs' values for vertical dispersion, as used by Culkowski and Patterson (1976), is used for the σ_z computation. This approach uses Lagrangian interpolation to arrive at appropriate equation coefficients. The surface roughness is a necessary site-specific input value. It is expected that this parameterization is more appropriate than the Pasquill values for distances between 1 and 50 km. If IT is chosen 3, Briggs' values for σ_z are computed by a simpler method using the formulas found in Moore (1977). Table 2 summarizes values for parameters used in this computation of dispersion coefficients. The horizontal dispersion coefficient is calculated for the downwind distance x using the formula

Table 2. Parameters used for computing dispersion coefficients

Pasquill stability class	A	B	C	D	E	F	(IT=1)
Tabulated values used (see text)							
Briggs/Smith; Hosker's formulation	A	B	C	D	E	F	(IT=2)
Lagrangian interpolation used (see text)							
Briggs parameterization class	A	B	C	D	E	F	(IT=3)
α	0.22	0.16	0.11	0.08	0.06	0.04	
p	0.20	0.12	0.08	0.06	0.03	0.016	
q	0.00	0.00	0.0002	0.0015	0.0003	0.0003	
r	1.00	1.00	-0.50	-0.50	-1.00	-1.00	
Klug parameterization class	V	IV	III ₂	III ₁	II	I	(IT=4)
p	0.469	0.306	0.230	0.210	0.237	0.273	
q	0.903	0.885	0.855	0.764	0.691	0.594	
r	0.017	0.072	0.076	0.140	0.217	0.262	
s	1.380	1.021	0.879	0.727	0.610	0.500	
Brookhaven gustiness class		B ₂	B ₁	C		D	(IT=5)
p		0.400	0.360	0.320		0.310	
q		0.910	0.860	0.780		0.710	
r		0.411	0.326	0.223		0.062	
s		0.907	0.859	0.776		0.709	
St. Louis parameterization class		B	C	D	E		(IT=6)
p		1.700	1.440	0.910	1.020		
q		0.717	0.710	0.729	0.648		
r		0.079	0.131	0.910	1.930		
s		1.200	1.046	0.702	0.465		
Jülich parameterization class	A	B	C	D	E	F	(IT=7)
(50 meter)							
p	0.66	0.66	0.63	0.53	0.41	7.56	
q	0.83	0.83	0.80	0.80	0.87	0.52	
r	0.14	0.14	0.21	0.26	0.13	0.56	
s	1.09	1.09	0.98	0.89	0.83	0.55	
(100 meter)							
p	0.34	0.37	0.40	0.43	0.46	7.56	(IT=8)
q	1.00	0.94	0.88	0.82	0.76	0.52	
r	0.037	0.076	0.16	0.32	0.66	1.37	
s	1.28	1.12	0.96	0.88	0.63	0.47	

$$\sigma_y = \alpha \times (1 + 0.0001x)^{-1/2} , \quad (9)$$

where values of α are defined in Table 2. For $IT = 3$, the vertical dispersion coefficient is found by

$$\sigma_z = p \times (1 + qx)^r , \quad (10)$$

with values of p , q , and r defined in Table 2.

3.3 Klug Dispersion Parameters

The Klug (1969) dispersion parameterization, intended primarily for short-term ground-level releases over terrain having low surface roughness, is invoked for a choice of $IT = 4$. Klug dispersion coefficients are normally determined from assessments of several observables, such as insolation and sun altitude angle, wind velocity, and, of course, site-specific equation coefficients. Vogt (1977) infers a correspondence between Klug and Pasquill stability classes, and defines parameters used in the dispersion coefficients functions

$$\sigma_y = px^q , \text{ and} \quad (11)$$

$$\sigma_z = rx^s . \quad (12)$$

We have summarized these results in Table 2.

3.4 Brookhaven Dispersion Parameters

The "Brookhaven" dispersion parameterization as formulated by Singer and Smith (1966) was derived from experiments made using a 108-m stack height, one-hour emission period, and over terrain of "medium" roughness. Vogt fitted these values to Eqs. (11) and (12) with the coefficients shown in Table 2. Also shown here are his correspondences between the Brookhaven "gustiness classes" and the Pasquill dispersion categories. The Brookhaven parameterization is evoked by choosing $IT = 5$.

3.5 St. Louis Dispersion Parameters

Choosing $IT = 6$ results in the St. Louis dispersion coefficients (McElroy and Pooler, 1968) being computed. Experimental conditions for which these urban parameterizations were compiled included one-hour emission duration, source near ground level, and relatively flat terrain of high surface roughness. We use Vogt's correspondences between McElroy and Pooler's and Pasquill's dispersion classes, and compute the St. Louis dispersion parameterization using Eqs. (11) and (12) with Vogt's parameters listed in Table 2.

3.6 Jülich Dispersion Parameters

Experiments performed near the Jülich Nuclear Research Center with emission heights of 50 and 100 m have been evaluated by Geiss et al (1979). They considered wind velocity, sun angle and insolation, and the vertical temperature gradient and derived two dispersion classifications which correspond closely to the Pasquill categories. Jülich parameterizations are expected to be appropriate for "medium to higher" surface roughness. This scheme uses equations of the form of Eqs. (11) and (2) with parameters as given in Table 2 to compute the dispersion coefficients. In the DWNWND code the user chooses the 50 m parameterization for $IT = 7$ and the 100 m parameterization for $IT = 8$.

4. CODE STRUCTURE

Figure 1 shows the subprogram structure of code DWNWND. A FORTRAN listing of the code is included in Appendix A.

The main program shares functions of user prompting and input of control information with subroutine INPUT. Default simulation parameters are initialized in MAIN — the values chosen are "reasonable" values so that a naive user may easily make an initial test simulation. Parameter definitions are printed from MAIN. In addition to invoking most other major subroutines, MAIN contains algorithms to account for plume tilt and to compute the normalized exposure value E_u/Q as defined in Eqs. (7) and

Fig. 1. Subprogram structure of code DWNWIND.

(8). The value of the plume depletion correction term defined in Eq. (6) and computed in subroutine DPLT is used in MAIN.

Subroutine INPUT, if invoked from MAIN, prompts the users to alter simulation parameter values. These values are referenced by name, and INPUT prints error messages if invalid parameter names are input or if an invalid combination of dispersion parameterization and stability class is chosen.

Subroutine SIGMAY computes the value of the horizontal dispersion coefficient σ_y necessary for solving Eq. (7). This value depends on the dispersion parameterization and stability class, which are user-chosen as discussed in the next chapter. SIGMAY tests the value of off-centerline distance chosen to ensure it is not outside the downwind sector [thus invalidating assumptions made in the derivation of Eq. (6)].

The BLOCK DATA subprogram initializes labeled COMMON/C/. This common area is accessed by subroutine SIGMAY, SIGMAZ, and DPLT, and contains parameters for computing the dispersion coefficients σ_y and σ_z for the particular dispersion parameterization and atmospheric stability class chosen by the code user. COMMON/C/ also stores tabulated values of distance-from-source used in the plume depletion calculation.

Subroutine SIGMAZ computes the value of σ_z , the vertical dispersion coefficient used in solving Eqs. (5), (6), (7), and (8), for a given dispersion parameterization and atmospheric stability class. If the user has chosen Hosker's formulation of the Briggs-Smith dispersion parameterization, SIGMAZ invokes subroutine YLAG. This approach was used in the model by Culkowski and Patterson (1976). SIGMAZ also contains algorithms for modifying the computed value of σ_z as the plume edge reaches the stable upper atmosphere layer at altitude H_{lid} , as discussed in the derivation of Eq. (4).

Subroutine YLAG is called by SIGMAZ, as described above. YLAG (Brooks and Long, 1970) performs Lagrangian interpolation on a set of equation coefficients to determine appropriate equation coefficients for a user-specified value of surface roughness.

Subroutine DPLT determines the depletion correction factor F defined in Eq. (5). DPLT calls subroutine SIGMAZ and SIMPUN.

Subroutine SIMPUN (Barish, 1970) is called by DPLT, and performs a Simpson's rule integration along the ground-level centerline path of the plume to allow computation of the depletion coefficient.

5. DISCUSSION OF CODE USAGE

Appendix B contains printout from a representative run of the DWNWND code. Table 3 lists DWNWND messages and their interpretations.

The user may specify values for ten simulation parameters defined in Table 4. Not all combinations of dispersion parameterization type (IT) and atmospheric stability (IS) are defined. Valid sets are enumerated in Table 5, where the implied correspondence between stability classes is based on the review paper by Vogt (1977). For a discussion of how to choose values of IT, the user should refer to Sect. 3.

The depletion factor calculations (Eq. 5) are not performed if the user specifies zero values for both the gravitational fall velocity (v_g) and the deposition velocity (v_d). Even when this calculation is performed, the resulting multiplicative correction term (which lies between 0.0 and 1.0) is not printed unless the value is less than 0.999.

Table 3. DWNWND messages

MESSAGE	COMMENTS
"PRINT PARAMETER DEFINITIONS?"	Input "YES" or "Y" if parameter names and definitions are desired, followed by a carriage return. Enter carriage return for no definitions.
"PARAMETER CHANGE MODE?"	An affirmative input (see above) caused Subroutine INPUT to be called, and the user will be prompted to new parameter values.
"END DWNWND SIMULATION"	Simulation completed but program execution continues. Parameter values used in the run being completed are saved for possible use in next run.
The following messages are printed by Subroutine Input:	
"ALTER WHICH PARAMETER? (E=EXIT)"	The user enters the parameter name, as defined after the "PRINT PARAMETER DEFINITIONS?" message. An "E" input terminates program execution.
"INVALID PARAMETER SPECIFIED. PARM WAS XXXX."	The name entered by the user was XXXX, which is not one of the parameters for which the user may specify a value.
"WHAT VALUE?"	The user may input the chosen parameter value within the first 12 spaces of the line. A decimal point should be included if the number is not right justified.
"INVALID COMBINATION OF IT=M and IS=N"	The user's choice of dispersion parameterization type (M) and atmospheric stability class (N) is not an allowable combination. See Table 4.

Table 4. Model parameters set by user input

NAME	DEFINITION
H	Effective Source Height, meters
VG	Gravitational Fall velocity, meters/sec
U	Wind Velocity, meters/sec
IT	Dispersion Parameterization, 1 for Pasquill/Gifford 2 for Briggs/Smith (Hosker's formulation) 3 for Briggs 4 for Klug 5 for Brookhaven 6 for St. Louis 7 for Jülich (50 meters) 8 for Jülich (100 meters)
IS	Stability Class
VD	Deposition Velocity, meters/sec
XG	Downwind Distance, meters
YG	Crosswind Distance, meters
HLID	Lid Height, meters
ROUGH	Surface Roughness (meters — used only for IT=2)

Table 5. Valid combinations of dispersion parameterization (IT) and stability class (IS). Class numbers used as column headings are equivalent to the class types listed below.

IS	1	2	3	4	5	6
Pasquill/Gifford IT = 1	A	B	C	D	E	F
Briggs/Smith IT = 2	A	B	C	D	E	F
Briggs IT = 3	A	B	C	D	E	F
Klug IT = 4	V	VI	III ₂	III ₁	II	I
Brookhaven IT = 5	-	B ₂	B ₁	C	-	D
St. Louis IT = 6	-	B	C	D	E	-
Jülich (50 meters) IT = 7	A	B	C	D	E	F
Jülich (100 meters) IT = 8	A	B	C	D	E	F

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APPENDIX A

A FORTRAN LISTING OF THE CODE DWNWND

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C      CODE DWNWND
C      D.E. FIELDS AND C.W. MILLER
C      7/78.
C      COMPUTES EXPOSURE VALUES AT POINTS DOWNWIND FROM
C      RELEASE SITE. ALSO AVERAGES OVER 22.5 DEG. SECTOR
C      RECEPTOR ASSUMED AT GROUND LEVEL
C
C      EXPN      =NORMALIZED EXPOSURE = EU/Q, S/M**2,
C                WHERE  E=EXPOSURE,GM S/M**3
C                Q=RELEASE RATE, GM/S
C      H         =SOURCE HGT, M
C      HLID      =LID HEIGHT
C      IPLU      =1 IMPLIES TRANSVERSE PLUME CALCULATION REQUIRED
C      ISEC      =1 IMPLIES SECTOR AVERAGE REQUIRED
C      IS        =STABILITY CLASS
C      IT        =TYPE OF STABILITY FORMULATION,
C                =1 FOR PG
C                =2 FOR BRIGGS-SMITH
C      ROUGH     =HOSKER ROUGHNESS PARAMETER, M, ABOUT
C                .01*PHYSICAL ROUGHNESS
C      U         =VELOCITY, WIND, M/S
C      VD        =VELOCITY, DEPOSITION, M/S
C      VG        =VELOCITY, GRAVITATIONAL FALL
C      XG        =GAUGE DISTANCE FROM SOURCE BASE, M
C      YG        =GAUGE TRANSVERSE COORDINATE, M
C
C      DATA Y/'Y'/
C      SELECT COMPUTER
C      COMP=10.
C      INITIALIZE PARAMETERS
C      IPLU=1
C      ISEC=1
C      ROUGH=.01
C      H=10.
C      PI=3.141593
C      HLID=0.
C      IS=4
C      IT=5
C      XG=500.
C      YG=0.
C      VD=.01
C      VG=.1
C      U=2.
C      IF (COMP.NE.10.) GOTO 12
C      WRITE(6,90)
90      FORMAT(2X,/,2X,'PRINT PARAMETER DEFINITIONS?')
C      READ(6,91)A
91      FORMAT(A1)
C      IF(A.EQ.Y)WRITE(6,92)
92      FORMAT(2X,'H      =SOURCE HGT, M',/,2X,'VG      =GRAV. FALL',
& ' VEL., M/S',/,2X,'U      =WIND VEL., M/S',/,2X,'IT      =',
& ' DISPERSION PARAMETERIZATION',
& ' ',/,15X,'= 1 FOR PG',/,15X,'= 2 FOR BRIGGS',/,
& ' SMITH',/,15X,'= 3 FOR BRIGGS',/,15X,'= 4 FOR KLUG')
C      IF(A.EQ.Y)WRITE(6,95)
95      FORMAT(15X,
& '= 5 FOR BROOKHAVEN',/,15X,'= 6 FOR ST. LOUIS',/,15X,'= ',
& '7 FOR JULICH',
& ' (50)',
& ',/,15X,'= 8 FOR JULICH(100)',/,2X,'IS      =STABILITY CLASS'
& ',/,2X,'VD      =DEPOSITION VEL., M/S',/,2X,'XG      =DWNWND DIST., M'
& ',/,2X,'YG      =CROSSWIND DIS., M',/,2X,'HLID      =LID HGT'
& ',/, M',/,2X,'ROUGH =SURFACE ROUGHNESS')

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2      WRITE(6,4)
4      FORMAT(2X,/,2X,'PARAMETER CHANGE MODE?')
      READ(6,6)A
6      FORMAT(A1)
      IF(A.NE.Y)GOTO12
      CALL INPUT(H,VG,U,IT,IS,VD,XG,YG,HLID,ROUGH)
12     CONTINUE
      WRITE(6,20)
20     FORMAT('      H      VG      U      IT      IS      VD      XG      YG      HLID',
& ' ROUGH')
      IF(HLID.EQ.0.)HLID=12000.
      LID=HLID
      IXG=XG
      IYG=YG
      WRITE(6,30)H,VG,U,IT,IS,VD,IXG,IYG,LID,ROUGH
30     FORMAT(2X,F5.0,F5.2,F6.1,2(13,2X),F5.3,1X,2I6,1X,I6,F5.2)
C     ACCOUNT FOR PLUME TILT
      HH=H-VG*XG/U
      IF(HH.LT.0.)HH=0.0
C     COMPUTE PLUME WIDTH FACTORS AT DISTANCE XG
      CALL SIGMAY(XG,YG,IT,IS,SIGY)
      CALL SIGMAZ(XG,IT,IS,ROUGH,SIGZ, IKPM,HLID,VG,U,HH)
      WRITE(6,15)SIGY,SIGZ
15     FORMAT(2X,'SIGY =',F8.2,' AND SIGZ =',F8.2)
C     RESTRICT HLID TO TROPOPAUSE IF INPUT SPEC. =0.0
C     COMPUTE CORRECTION FACTOR FOR PLUME DEPLETION
C
      COR=1.
      IF(VG.EQ.0..AND.VD.EQ.0.)GOTO45
      CALL DPLT(PI,HH,VD,U,IT,IS,XG,ROUGH,HLID,COR,VG,H)
C
      IF(COR.LT..999)WRITE(6,40) COR
40     FORMAT(2X,'DEPLETION CORRECTION FACTOR =',F8.4)
45     EXPQ=EXP(-HH*HH/2./SIGZ/SIGZ)
      IF(1+PLU.NE.1)GOTO60
C     COMPUTE NORMALIZED EXPOSURE EU/Q
C     NOTE THAT WE DO NOT HERE SPREAD PLUME OVER SECTOR.
      EXPN=COR*EXPQ/SIGY/SIGZ/PI
      WRITE(6,50)EXPN
50     FORMAT(2X,'TRANSVERSE VALUE OF EU/Q =',1PE14.5)
60     IF(1+SEC.NE.1)GOTO80
C     COMPUTE SECTOR AVERAGE
      EXPN=COR*2.092*EXPQ/SIGZ/XG
      WRITE(6,70)EXPN
70     FORMAT(2X,'TRANSVERSE SECTOR AVERAGE OF EU/Q =',1PE14.5)
80     CONTINUE
      WRITE(6,100)
100    FORMAT(2X,'END DWNWND SIMULATION',/)
1000   CONTINUE
      IF(COMP.EQ.10)GOTO2
      STOP
      END

```

```

      BLOCK DATA
C      D.E. FIELDS AND C.W. MILLER
      COMMON/C/RY(6),BZ1(6),BZ2(6),BZ3(6),A1(6),A2(6),B1(6),B2(6),
& B3(6),PY(6,5),PZ(6,5),QY(6,5),QZ(6,5),XM(50)

```

```

C      FOR BRIGGS
      DATA BY/.22,.16,.11,.08,.06,.04/,
8 BZ1/.2,.12,.08,.06,.03,.016/,
8 BZ2/0.,0.,.0002,.0015,.0003,.0003/,
8 BZ3/1.,1.,-.5,-.5,-1.,-1./
C      FOR PG
      DATA A1/-.0234,-.0147,-.0117,-.0059,-.0059,-.0029/,
8 A2/.35,.248,.175,.108,.088,.054/,
8 B1/.88,-.985,-1.186,-1.35,-2.88,-3.8/,
8 B2/-.152,.82,.85,.793,1.255,1.419/,
8 B3/.1475,.0168,.0045,.0022,-.042,-.055/
C      FOR KLUG, ET. AL. TYPES OF DISPERSION...
      DATA PY/.469,.306,.23,.219,.237,.273,0.,.4,.36,.32,.0,.31,
8 .0,1.7,1.44,.91,1.02,.0,.66,.66,.63,.53,.41,7.56,
8 .34,.37,.40,.43,.46,7.56/
      DATA QY/.903,.885,.855,.764,.691,.594,0.,.91,.86,.78,.0,.71,
8 0.,.717,.71,.729,.648,.0,.83,.83,.80,.80,.87,.52,
8 1.00,.94,.88,.82,.76,.52/
      DATA PZ/.017,.072,.076,.14,.217,.262,.0,.411,.326,.223,.0,
8 .062,.0,.079,.131,.91,1.93,.0,.14,.14,.21,.26,.13,.56,
8 .037,.076,.16,.32,.66,1.37/
      DATA QZ/1.38,1.021,.879,.727,.61,.5,.0,.907,.859,.776,.0,.709,
8 .0,1.2,1.046,.702,.465,.0,1.09,1.09,.98,.89,.83,.55,1.28,
8 1.12,.96,.88,.63,.47/
      DATA XM/
8 1.000E+00,2.000E+00,3.000E+00,4.000E+00,5.000E+00,
8 1.000E+01,1.500E+01,2.000E+01,2.500E+01,3.000E+01,
8 3.500E+01,4.000E+01,4.500E+01,5.000E+01,1.500E+02,
8 2.000E+02,3.000E+02,4.000E+02,5.000E+02,6.000E+02,
8 7.000E+02,8.000E+02,9.000E+02,1.000E+03,1.100E+03,
8 1.200E+03,1.300E+03,1.400E+03,1.600E+03,1.800E+03,
8 2.000E+03,2.500E+03,3.000E+03,3.500E+03,4.000E+03,
8 4.500E+03,5.000E+03,6.000E+03,7.000E+03,8.000E+03,
8 1.000E+04,1.500E+04,2.000E+04,3.000E+04,4.000E+04,
8 5.000E+04,6.000E+04,7.000E+04,8.000E+04,1.000E+05/
      END

```

```

      SUBROUTINE DPLT(PI,HH,VD,U,IT,IS,XG,ROUGH,HLID,COR,VG,H)
      COMPUTES PLUME DEPLETION CORRECTION
      DIMENSION XX(50),FX(50),AX(50)
      COMMON/C/BY(6),BZ1(6),BZ2(6),BZ3(6),A1(6),A2(6),B1(6),B2(6),
8 B3(6),PY(6,5),PZ(6,5),QY(6,5),QZ(6,5),XM(50)
      IF(IS.GT.6)IS=6
      IKPM=1
      IDUM=1
      CALL SIGMAZ(XG,IT,IS,ROUGH,SIGZ,IKPM,HLID,VG,U,HH)
C      IKPM HAS BEEN RECOMPUTED
      IKP=IKPM+1
      SQRTPI=.79785
      FX(IKPM)=EXP(-.5*(HH/SIGZ)**2)/SIGZ
      XX(IKPM)=XG
      DO 20 I=1,IKPM
      XX(I)=XM(I)
      CALL SIGMAZ(XX(I),IT,IS,ROUGH,SIGZ,IDUM,HLID,VG,U,HH)
      FX(I)=EXP(-.5*(HH/SIGZ)**2)/SIGZ
20  CONTINUE
      L=1

```



```

CALL SIMPUN(XX,FX,IKP,L,AX)
COR=EXP(-SQRTPI*VD/U*AX( IKP))
RETURN
END

```

```

SUBROUTINE INPUT(H,VG,U,IT,IS,VD,XG,YG,HLID,ROUGH)
C   D. E. FIELDS AND C. MILLER
C   INTERACTIVE SUBROUTINE FOR VARYING SIMULATION PARAMETER SET
DIMENSION PARM(11)
DATA PARM/'H','VG','U','IT','IS','VD',
& 'XG','YG','HLID','ROUGH',' '/
2   WRITE(6,4)
4   FORMAT(2X,'ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)')
READ(6,10)A
10  FORMAT(A4)
IF(A.EQ.'E')GOTO40
C   ACCOUNT FOR INVALID PARAMETER CHOICE
IPAR=12
DO12 I=1,11
IF(PARM(I).NE.A)GOTO12
IPAR=I
12  CONTINUE
IF(IPAR.LE.11)GOTO8
WRITE(6,6)A
6   FORMAT(2X,'INVALID PARAMETER SPECIFIED. PARM WAS ',A4,'.')
GOTO2
8   CONTINUE
IF(IPAR.EQ.11)RETURN
WRITE(6,9)
9   FORMAT(2X,'WHAT VALUE?')
READ(6,11)V
11  FORMAT(F12.0)
GOTO(14,16,18,20,22,24,26,28,30,32),IPAR
14  H=V
GOTO36
16  VG=V
GOTO36
18  U=V
GOTO36
20  IT=V
GOTO36
22  IS=V
GOTO36
24  VD=V
GOTO36
26  XG=V
GOTO36
28  YG=V
GOTO36
30  HLID=V
GOTO36
32  ROUGH=V
36  IF(IS.LT.1.OR.IS.GT.6)WRITE(6,38)IT,IS
IF(IT.EQ.5.AND.(IS.EQ.1.OR.IS.EQ.5))WRITE(6,38)IT,IS
IF(IT.EQ.6.AND.(IS.EQ.1.OR.IS.EQ.6))WRITE(6,38)IT,IS
38  FORMAT(2X,'INVALID COMBINATION OF IT=',I2,'AND IS=',I2)
GOTO2

```

```

40      STOP
      END

```

```

      SUBROUTINE SIGMAY(XG,YG,IT,IS,SIGY)
      COMPUTES HORIZONTAL TRANSVERSE DISPERSION COEFF.
      C      D.E. FIELDS AND C.W.MILLER
      DIMENSION C3(7)
      COMMON/C/RY(6),BZ1(6),BZ2(6),BZ3(6),A1(6),A2(6),B1(6),B2(6),
      & B3(6),PY(6,5),PZ(6,5),QY(6,5),QZ(6,5),XM(50)
      DATA C3/.22,.16,.11,.08,.06,.04,.04/
      CHOOSE DISPERSION COMPUTATION
      IPOINT=IT
      IF(IT.GT.3)IPOINT=4
      GOTO(10,20,20,40),IPOINT
      C      PG VALUES, FROM VOGT
      10      SIGY=XG*(A1(IS)*ALOG(XG)+A2(IS))
      GOTO50
      C      BRIGGS AND BRIGGS-SMITH FORMULATION
      20      SIGY=XG*C3(IS)/SQRT(1+.0001*XG)
      GOTO50
      C      DISPERSION VALUES AFTER KLUG, ETC
      40      J=IT-3
      C          =1 FOR KLUG
      C          =2 FOR BROOKHAVEN
      C          =3 FOR ST. LOUIS
      C          =4 FOR JULICH(50M)
      C          =5 FOR JULICH(100M)
      SIGY=PY(IS,J)*XG**QY(IS,J)
      C      WRITE(6,500)PY
      50      B=YG-XG*.1989
      IF(B.GT.0.)WRITE(6,200)
      200      FORMAT(2X,'GAUGE LIES OUTSIDE DOWNWIND SECTOR')
      300      FORMAT(2X,'PY: ',F8.3)
      RETURN
      END

```

```

      SUBROUTINE SIGMAZ(XG,IT,IS,ROUGH,SIGZ,IKPM,HLID,VG,U,HH)
      COMPUTES VERTICAL DISPERSION COEFFICIENT
      C      D.E. FIELDS AND C.W. MILLER
      COMMON/C/RY(6),BZ1(6),BZ2(6),BZ3(6),A1(6),A2(6),B1(6),B2(6),
      & B3(6),PY(6,5),PZ(6,5),QY(6,5),QZ(6,5),XM(50)
      DIMENSION AONE(6),BONE(6),ATWO(6),BTWO(6),CONE(6),DONE(6),
      & CTWO(6),DTWO(6),RGH(6)
      DATA AONE/0.112,0.130,0.112,0.098,0.0609,0.0638/
      DATA BONE/1.06,0.950,0.920,0.889,0.895,0.783/
      DATA ATWO/5.38E-4,6.52E-4,9.05E-4,1.35E-3,1.96E-3,1.36E-3/
      DATA BTWO/0.815,0.750,0.718,0.688,0.684,0.672/
      DATA CONE/1.56,2.02,2.72,5.16,7.37,11.7/
      DATA DONE/0.0480,0.0269,0.,-0.060,-0.0957,-0.128/
      DATA CTWO/6.25E-4,7.76E-4,0.,186.,4.29E+3,4.59E+4/
      DATA DTWO/0.45,0.37,0.,-0.225,-0.60,-0.78/

```

```

DATA RGH/0.01,0.04,0.10,0.40,1.0,4.0/
P=0.0
DO 8 I=1,50
  IKP=I
  IF(XM(I).GE.XG)GOTO9
8  CONTINUE
9  IF(IKP.LT.2)IKP=2
  IKPM=IKP-1
CHOOSE TYPE OF COMPUTATION
  IPOINT=IT
  IF(IT.GT.3)IPOINT=4
  GOTO(10,20,30,40),IPOINT
C  PASQUILL-GIFFORD DISPERSION VALUES, FROM VOGT
10  ALX=ALOG(XG)
  SIGZ=(EXP(B1(IS)+(B2(IS)+B3(IS)*ALX)*ALX))/2.15
  GOTO99
C  MOSKERS FORM. OF BRIGGS-SMITH DISPERSION VALUES, FROM ATM
20 ABS=ROUGH
  C1=YLAG(ABS,RGH,DONE,0,3,6,0)
  D1=YLAG(ABS,RGH,DONE,0,2,6,0)
  C2=YLAG(ABS,RGH,CTWO,0,3,6,0)
  D2=YLAG(ABS,RGH,DTWO,0,2,6,0)
  G=ADONE(IS)*XG**ADONE(IS)/(1.0+ATWO(IS)*XG**BTWO(IS))
  F=C1*(XG**D1)
  F=ALOG(F)
  IF(ROUGH.LE.0.10) GO TO 26
  F=F+ALOG(1.+1./(C2*XG**D2))
  GO TO 27
26 F=F-ALOG(1.+C2*XG**D2)
27 SIGZ=G*F
  IF(SIGZ.LT.1.0) SIGZ=1.0
  GOTO99
C  BRIGGS DISPERSION VALUES, FROM AIRPONS II
30  SIGZ=BZ1(IS)*XG*(1+BZ2(IS)*XG)**BZ3(IS)
  GOTO99
C  DISPERSION VALUES AFTER KLUG, AND OTHERS
40  J=IT 5
C      =1 FOR KLUG
C      =2 FOR BROOKHAVEN
C      =3 FOR ST. LOUIS
C      =4 FOR JULICH(50M)
C      =5 FOR JULICH(100M)
  SIGZ=PZ(IS,J)*XG**QZ(IS,J)
99  SIGCAL=2.*(HLID-HH)/2.15
  IF(SIGZ.LT.SIGCAL) GO TO 1000
  SIGZ=SIGCAL
1000 RETURN
END

```

```

SUBROUTINE SIMPUN(XX,FX,NX,I,AX)
C  PROGRAM AUTHOR      J. BARISH,
C  COMPUTING TECHNOLOGY CENTER, UNION CARBIDE CORP., NUCLEAR DIV.,
C  OAK RIDGE, TENN.
C
  DIMENSION XX(2),FX(2),AX(2)
  IF (I.LT.0) GO TO 30
  AX(1)=0.0

```

```

      DO 10 IX=2,NX,2
        D1=XX(IX)-XX(IX-1)
        AX(IX)=AX(IX-1)+D1/2.0*(FX(IX)+FX(IX-1))
        IF (NX.EQ.IX) GO TO 20
        D2=XX(IX+1)-XX(IX-1)
        D3=D2/D1
        A2=D3/6.0*D2**2/(XX(IX+1)-XX(IX))
        A3=D2/2.0-A2/D3
10     AX(IX+1)=AX(IX-1)+(D2-A2-A3)*FX(IX-1)+A2*FX(IX)+A3*FX(IX+1)
20  RETURN
50  AX(NX)=0.0
      DO 40 IX=2,NX,2
        IC=NX+1-IX
        D1=XX(IC+1)-XX(IC)
        AX(IC)=AX(IC+1)+D1/2.0*(FX(IC+1)+FX(IC))
        IF (NX.EQ.IC) GO TO 20
        D2=XX(IC+1)-XX(IC-1)
        D3=D2/(XX(IC)-XX(IC-1))
        A2=D3/6.0*D2**2/D1
        A3=D2/2.0-A2/D3
40     AX(IC-1)=AX(IC+1)+(D2-A2-A3)*FX(IC-1)+A2*FX(IC)+A3*FX(IC+1)
      RETURN
      END

```

```

      FUNCTION YLAG(XI,X,Y,IND1,N1,IMAX, IEX)
C     PROGRAM AUTHORS  A. A. BROOKS AND E.C. LONG,
C     COMPUTING TECHNOLOGY CENTER, UNION CARBIDE CORP., NUCLEAR DIV.,
C     OAK RIDGE, TENN.
C
C     LAGRANGIAN INTERPOLATION
C     XI IS INTERPOLATED ENTRY INTO X-ARRAY
C     N IS THE ORDER OF LAGRANGIAN INTERPOLATION
C     Y IS ARRAY FROM WHICH YLAG IS OBTAINED BY INTERPOLATION
C     IND IS THE MIN-I FOR X(I).GT.XI
C     IF IND=0,X-ARRAY WILL BE SEARCHED
C     IMAX IS MAX INDEX OF X-AND Y-ARRAYS
C     EXTRAPOLATION CAN OCCUR,IEX=-1 OR +1
C
C

```

```

      DIMENSION X(1),Y(1)
      IND=IND1
      N=N1
      IEX=0
      IF (N.LE.IMAX) GO TO 10
      N=IMAX
      IEX=N
10  IF (IND.GT.0) GO TO 40
      DO 20 J = 1,IMAX
        IF (XI-X(J)) 30,130,20
20  CONTINUE
      IEX=1
      GO TO 70
30  IND=J
40  IF (IND.GT.1) GO TO 50
      IEX=-1

```

```

50 INL=IND-(N+1)/2
   IF (INL.GT.0) GO TO 60
   INL=1
60 INU=INL+N-1
   IF (INU.LE.IMAX) GO TO 80
70 INL=IMAX-N+1
   INU=IMAX
80 S=0.
   P=1.
   DO 110 J=INL,INU
     P=P*(XI-X(J))
     D=1.
     DO 100 I=INL,INU
       IF (I.NE.J) GO TO 90
       XD=XI
       GO TO 100
90     XD=X(J)
100    D=D*(XD-X(I))
110    S=S+Y(J)/D
       YLAG=S*P
120 RETURN
130 YLAG=Y(J)
     GO TO 120
   END

```

APPENDIX B

REPRESENTATIVE PRINTOUT FROM AN EXECUTION OF DWNWND

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WAS INTENTIONALLY
LEFT BLANK

.ASS TTY 6
TTY11 ASSIGNED

.EX @DWN SUB
LINK: LOADING
CLNKXCT DWNWND EXECUTION]

PRINT PARAMETER DEFINITIONS?
YES

H =SOURCE HGT, M
UG =GRAV. FALL VEL., M/S
U =WIND VEL., M/S
IT = DISPERSION PARAMETERIZATION,
 = 1 FOR PG
 = 2 FOR BRIGGS/SMITH
 = 3 FOR BRIGGS
 = 4 FOR KLUG
 = 5 FOR BROOKHAVEN
 = 6 FOR ST. LOUIS
 = 7 FOR JULICH(50)
 = 8 FOR JULICH(100)
IS =STABILITY CLASS
UD =DEPOSITION VEL., M/S
XG =DWNWND DIST., M
YG =CROSSWIND DIS., M
HLID =LID HGT, M
ROUGH =SURFACE ROUGHNESS

PARAMETER CHANGE MODE?
NO

H	UG	U	IT	IS	UD	XG	YG	HLID	ROUGH
10.	0.10	2.0	5	4	.010	500	0	12000	0.01

SIGY = 40.77 AND SIGZ = 27.71
 DEPLETION CORRECTION FACTOR = 0.7914
 TRANSVERSE VALUE OF EU/Q = 2.22940E-04
 TRANSVERSE SECTOR AVERAGE OF EU/Q = 1.16048E-04
 END DWNWNO SIMULATION

PARAMETER CHANGE MODE?
YES

ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)
XG

WHAT VALUE?
1250.

ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)

H	UG	U	IT	IS	UD	XG	YG	HLID	ROUGH
10.	0.10	2.0	5	4	.010	1250	0	12000	0.01

SIGY = 83.32 AND SIGZ = 56.43
 DEPLETION CORRECTION FACTOR = 0.7355
 TRANSVERSE VALUE OF EU/Q = 4.97967E-05
 TRANSVERSE SECTOR AVERAGE OF EU/Q = 2.11887E-05
 END DWNWNO SIMULATION

PARAMETER CHANGE MODE?
YES

ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)
UG

WHAT VALUE?
.25

ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)

H	UG	U	IT	IS	UD	XG	YG	HLID	ROUGH
10.	0.25	2.0	5	4	.010	1250	0	12000	0.01

SIGY = 83.32 AND SIGZ = 56.43
 DEPLETION CORRECTION FACTOR = 0.7355
 TRANSVERSE VALUE OF EU/Q = 4.97967E-05
 TRANSVERSE SECTOR AVERAGE OF EU/Q = 2.11887E-05
 END DWNWIND SIMULATION

PARAMETER CHANGE MODE?
YES

ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)
U

WHAT VALUE?
10.

ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)

H	UG	U	IT	IS	VD	XG	YG	HLID	ROUGH
10.	0.25	10.0	5	4	.010	1250	0	12000	0.01

SIGY = 83.32 AND SIGZ = 56.43
 DEPLETION CORRECTION FACTOR = 0.9404
 TRANSVERSE VALUE OF EU/Q = 6.36682E-05
 TRANSVERSE SECTOR AVERAGE OF EU/Q = 2.70911E-05
 END DWNWNO SIMULATION

PARAMETER CHANGE MODE?

YES

ALTER WHICH PARAMETER? (E=EXIT, SPACE=RUN)

E

STOP

END OF EXECUTION

CPU TIME: 0.29 ELAPSED TIME: 4:8.30

EXIT

ORNL/TM-6874
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