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ORNL-5913

Dist. Categories UC-11,41

Contract No. DE-AC05-84OR21400

Health and Safety Research Division

ORNL--5913

DE87 002986

ANEMOS: A Computer Code to Estimate Air Concentrations and Ground Deposition Rates for Atmospheric Nuclides Emitted from Multiple Operating Sources

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Date Completed: September 1986

Date Published: November 1986

Research sponsored by the Office of Radiation Programs,
U.S. Environmental Protection Agency under Interagency Agreement
AD-89-F-2-A106 (formerly EPA-78-D-X0394)

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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ACKNOWLEDGMENTS

We wish to express our deepest gratitude to Mr. C. B. Nelson, Office of Radiation Programs, U.S. Environmental Protection Agency, for his ideas, support, discussion, and assistance in this work. R. J. Raridon, D. M. Hetrick, and C. C. Gilmore provided helpful reviews of the draft of this document. A special thanks is extended to U. F. Strong and S. A. White for typing the multiple drafts required for this document to reach final publication form.

HIGHLIGHTS

The purpose of the ANEMOS code is to estimate concentrations in air and ground deposition rates for Atmospheric Nuclides Emitted from Multiple Operating Sources. ANEMOS is one component of an integrated Computerized Radiological Risk Investigation System (CRRIS) developed for the U.S. Environmental Protection Agency (EPA) for use in performing radiological assessments and in developing radiation standards. The concentrations and deposition rates calculated by ANEMOS are used in subsequent portions of the CRRIS for estimating doses and risks to man.

The calculations made in ANEMOS are based on the use of a straight-line Gaussian plume atmospheric dispersion model with both dry and wet deposition parameter options. The code will accommodate a ground-level or elevated point and area source or windblown source. Adjustments may be made during the calculations for surface roughness, building wake effects, terrain height, wind speed at the height of release, the variation in plume rise as a function of downwind distance, and the in-growth and decay of daughter products in the plume as it travels downwind. ANEMOS can also accommodate multiple particle sizes and clearance classes, and it may be used to calculate the dose from a finite plume of gamma-ray-emitting radionuclides passing overhead.

The output of this code is presented for 16 sectors of a circular grid. ANEMOS can calculate both the sector-average concentrations and deposition rates at a given set of downwind distances in each sector and the average of these quantities over an area within each sector bounded by two successive downwind distances. ANEMOS is designed to be used primarily for continuous, long-term radionuclide releases.

This report describes the models used in the code, their computer implementation, the uncertainty associated with their use, and the use of ANEMOS in conjunction with other codes in the CRRIS. A listing of the code is included in Appendix C.

To obtain a copy of the computer outputs, please contact the following: Radiation Shielding Information Center (RSIC)
(615) 574-6176.

1. INTRODUCTION

The funding for this research was provided by the U.S. Environmental Protection Agency (EPA); which, upon assuming regulatory authority of nuclear effluents covered by the Clean Air Act of 1977, launched an extensive review and revision of models that simulate transport of radionuclides through environmental pathways to man and calculate resulting health impacts. The results of the first phase of this work undertaken by the Health and Safety Research Division (HASRD) of the Oak Ridge National Laboratory (ORNL) are published in two reports: AIRDOS-EPA (Moore et al., 1979) and DARTAB (Begovich et al., 1981). While the AIRDOS-EPA and DARTAB computer codes have provided EPA with an interim methodology for performing nuclear assessments, work has continued at ORNL on an integrated set of computer codes and data bases that serves as a state-of-the-art radiological risk assessment methodology. This Computerized Radiological Risk Investigation System, or CRRIS (Baes et al., 1985), is based on a review and evaluation of the AIRDOS-EPA/DARTAB system. This report documents one code of the CRRIS--ANEMOS, a computer code to estimate air concentrations and ground deposition rates for Atmospheric Nuclides Emitted from Multiple Operating Sources (Miller and Hermann, 1981).

The relationship of ANEMOS to the other codes of the CRRIS is shown in Fig. 1. PRIMUS (Hermann et al., 1984) accesses a data base of decay data (Kocher, 1981a) and determines all the radionuclides in a decay chain which must be considered in transport, dose, and risk calculations by other codes of the CRRIS. RETADD-II (Murphy, Ohr, and Begovich, 1984) is a long-range trajectory atmospheric dispersion code that calculates radionuclide air concentrations and ground deposition rates on a square grid on a regional or continental scale. Multiple runs of ANEMOS within a relatively small area may be summed on a master grid by the SUMIT code (Begovich et al., 1984). SUMIT may also be used simply to transform the results from an ANEMOS calculational grid to another grid configuration that is more convenient for assessment purposes. TERRA (Baes et al., 1984a; 1984b) is used to calculate concentrations of radionuclide chains in four produce categories, four cattle feed categories, irrigated and non-irrigated soils, beef, and milk. MLSOIL

Fig. 1. The computer codes that comprise the CRRIS.

and DFSOIL (Sjoreen et al., 1984) compute an effective soil concentration to be used in the calculation of external dose. MLSOIL implements a five-layer soil model rather than the single-layer model used in TERRA. DFSOIL computes the dose-rate factors used in MLSOIL. ANDROS (Begovich et al., in press) receives environmental radionuclide concentrations and combines them with population estimates, food and air consumption rates, and dose and risk factors to calculate population and average individual doses and risks from the source term supplied to ANEMOS or RETADD-II.

As indicated by Fig. 1, various combinations of the CKRIS codes may be used to tailor the assessment to the user's needs. For example, if only inhalation and air immersion doses and risks are to be calculated, then the user may wish to eliminate TERRA and MLSOIL from the assessment strategy. If ground deposition rates or air concentrations are known for a given location, then the user may wish to make the assessment by using only PRIMUS, TERRA, MLSOIL, and ANDROS.

A schematic representation of the ANEMOS code is shown in Fig. 2. The calculations made in ANEMOS are based on the use of a straight-line Gaussian plume atmospheric dispersion model with both dry and wet deposition parameter options (Gifford, 1968). The code will accommodate a ground-level or elevated point and area source. Adjustments may be made during the calculations for surface roughness, building wake effects, terrain height, wind speed at the height of release, the variation in plume rise as a function of downwind distance, the build-up and decay of daughter products, and the effective air concentration that can be used to calculate the dose from a finite plume of gamma-ray emitters passing overhead.

The output of this code is presented for a 16-sector polar grid with nuclide-specific and particle size specific air concentrations and ground deposition rates. While ANEMOS is most appropriate for continuous, routine, radionuclide releases, in accordance with EPA's expressed needs, this basic methodology has been applied to longer-term, acute releases as well (Miller et al., 1980).

The following sections present a discussion of the models used in the ANEMOS code, followed by instructions for using the code. A sample problem is also included to illustrate the use of ANEMOS. The sample

Fig. 2. Schematic representation of the ANEMOS code.

job control language (JCL) and input data are included in Appendix A. The output of the sample problem is included in Appendix B. The ANEMOS code is listed in Appendix C.

2. AIR CONCENTRATION CALCULATIONS

2.1 THE GAUSSIAN PLUME MODEL

2.1.1 Basic Formulation

The most frequently used dispersion model in estimating the dose to man from radionuclides released to the atmosphere is the Gaussian plume model (Hoffman et al., 1977). This model is widely used because (Hanna, Briggs, and Hosker, 1982): (1) it produces results similar to those produced by other models when comparisons are made to experimental data, (2) it is easy to perform the necessary mathematical operations, (3) it is appealing conceptually, (4) it is consistent with the random nature of turbulence, (5) it is a solution to the Fickian diffusion equation for constant diffusion and wind speed, (6) other so-called theoretical formulas contain large amounts of empiricism in their final stages, and (7) it is the model most often referred to in government guidebooks, such as U.S. Nuclear Regulatory Commission Regulatory Guide 1.111 (USNRC, 1977b). The Gaussian model is often applied when purely theoretical considerations call its use into question. This practice has been accepted when predicted impacts are so small as to diminish the importance of potential errors (Rohwer, Hoffman, and Miller, 1981).

The Gaussian model is based primarily on the work of Sutton (1932), Pasquill (1961 and 1974), and Gifford (1961 and 1968). The model assumes that the dispersion of material released to the atmosphere can be described by a Gaussian distribution in the horizontal and vertical directions. The basic equation of the Gaussian model is given by

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

where

- C = air concentration at position (x, y, z) (Bq/m^3 or Ci/m^3);
 Q = release rate (Bq/s or Ci/s);
 u = wind speed (m/s);
 σ_y, σ_z = standard deviation of the material in the plume (m) at downwind distance x in the horizontal, y , and vertical, z , directions, respectively;
 h_p = effective height of plume (m).

It is assumed in deriving Eq. (1) that diffusion in the downwind distance, x , is negligible compared to the transport by the mean wind.

When material is released by an elevated source, the plume will spread in the vertical direction until it eventually encounters the ground. It is then assumed that the plume is reflected and dispersed back up into the air as shown in Fig. 3. This reflection is equivalent to a virtual source at a distance h_p below the ground so that Eq. (1) becomes

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

$$\left\{ \exp \left[-1/2 \left(\frac{z - h_p}{\sigma_z} \right)^2 \right] + \exp \left[-1/2 \left(\frac{z + h_p}{\sigma_z} \right)^2 \right] \right\}.$$

Inversion conditions (i.e., positive potential temperature gradients in the lower levels of the atmosphere) may occur at varying heights in the atmosphere. When dispersing material encounters such an inversion, the material is assumed not to penetrate but to be reflected from this boundary, which serves effectively as the top of the tropospheric mixing layer (see Fig. 3). The result of assuming multiple reflections of the plume from both the ground and the top of the mixing layer is that the air concentration at any point downwind is calculated by summing the contributions from many virtual sources. Thus Eq. (2) becomes

Fig. 3. Schematic drawing of the reference system used in the calculational model for the air concentration under a capping inversion.

$$C = \frac{Q}{\sqrt{2\pi u \sigma_y}} \exp \left[-1/2 \left(\frac{y}{\sigma_y} \right)^2 \right] G, \quad (3)$$

where

$$\begin{aligned} G = & \frac{1}{\sqrt{2\pi \sigma_z}} \sum_{m=0}^{\infty} \exp \left[-1/2 \left(\frac{2mh_L + h_p - z}{\sigma_z} \right)^2 \right] \\ & + \exp \left[-1/2 \left(\frac{2mh_L + h_p + z}{\sigma_z} \right)^2 \right] \\ & + \exp \left\{ -1/2 \left(\frac{2(m+1)h_L - h_p - z}{\sigma_z} \right)^2 \right\} \\ & + \exp \left\{ -1/2 \left(\frac{2(m+1)h_L - h_p + z}{\sigma_z} \right)^2 \right\}, \end{aligned}$$

where

h_L = depth of the mixing layer (m).

The arbitrary index $m = 0$ is used for the first two ground reflections (i.e., points a and a', b and b' in Fig. 3); the value $m = 1$ is used for the next two reflections and so forth (Healy and Baker, 1968). The path lengths can be described in general terms as shown in Table 1. For example, the vertical distance traveled by the bottom of the plume to reach a is $h_p - z$. To reach a', the distance traveled is $h_p + z$. Likewise, to reach b the top of the plume must travel a distance $(h_L - h_p) + h_L - z = 2h_L - h_p - z$. At the present time, ANEMOS uses a maximum value of $m = 10$.

Equation (3) assumes, of course, that $z \leq h_p \leq h_L$. There are times, however, when this is not the case. For example, under very stable conditions, the top of the mixing layer may be at or very near to ground level so that $h_L \leq z$ and $h_L \leq h_p$. As a result, there is only a lower reflection of the plume and G becomes

Table 1. Path lengths associated with multiple reflections of a plume under a capping inversion (adapted from Healy and Baker, 1968)

Reference points in Fig. 3	Distances
Lower Reflections	
(a, c, e, . . . m)	$2mh_L + h_p - z$
(a', c', e', . . . m')	$2mh_L + h_p + z$
Upper Reflections	
(b, d, f, . . . n)	$2(m + 1)h_L - h_p - z$
(b', d', f', . . . n')	$2(m + 1)h_L - h_p + z$

$$G = \frac{1}{2\pi\sigma_z} \left\{ \exp \left[-1/2 \left(\frac{h_p - z}{\sigma_z} \right)^2 \right] + \exp \left[-1/2 \left(\frac{-2h_L + h_p + z}{\sigma_z} \right)^2 \right] \right\}.$$

There are also times when $z < h_L < h_p$ or $h_p < h_L < z$. Under these conditions, $G = 0$.

When the value of $\sigma_z(p, x)$, the vertical dispersion parameter for stability category p and downwind distance x (m), becomes greater than some factor multiplied by the depth of the tropospheric boundary layer, the radionuclide can be assumed to be effectively distributed uniformly in the vertical throughout the mixing layer. Under these circumstances, G becomes

$$G = \frac{1}{h_L(p)}$$

where

$h_L(p)$ = the mixing height associated with stability class p .

The multiplication factor to be used in ANEMOS for this test is an input parameter. A default value of 2 is currently used in the code.

2.1.2 Average Concentrations

Equations (1) through (3) refer to the situation where the duration of the release is such that the resulting distribution of the radionuclides may be considered to be in the form of a plume (Clarke, 1979). However, the purpose of ANEMOS is to calculate the average concentration around a source for releases that occur over an extended period of time, such as a year. As a result, Eq. (3) is modified to eliminate its σ_y dependence.

The modification of Eq. (3) is based on the type of long-term meteorological data available for most U.S. sites. These data are usually expressed in terms of a joint frequency distribution of wind direction, wind speed class, and atmospheric stability class. The average distribution of material across the sectors defined by the available wind directions is calculated. In the United States, 16 wind directions are normally available; hence, a 22.5°-sector average air concentration is calculated.

The crosswind integrated concentration from a continuous source can be obtained by integrating Eq. (3) over the variable y from $-\infty$ to $+\infty$. An estimate of the average concentration over a period that is very long compared with the time period over which the mean wind is determined can be calculated by multiplying the crosswind integrated concentration by the frequency with which the wind blows toward a given sector and dividing by the width of that sector at the downwind distance of interest (Gifford, 1968). The resulting long-term air concentration is given by

$$C_{is}(x) = \sum_{p=1}^{N_p} \sum_{r=1}^{N_r} \frac{N_s Q'_{iprs}(x)}{2\pi x u_r} G(p, x) \quad (4)$$

where

- $C_{is}(x)$ = ground-level air concentration of radionuclide i in wind direction s at downwind distance x (Bq/m^3 or Ci/m^3);
- N_p = number of atmospheric stability classes (unitless);
- N_r = number of wind speed classes (unitless);
- N_s = number of wind directions in a standard data set = 16 (unitless);
- $Q'_{iprs}(x)$ = effective activity flux for radionuclide i in stability class p , wind speed class r , and wind direction s at downwind distance x (Bq/s or Ci/s);
- u_r = mean wind speed associated with wind speed category r (m/s).

It should be noted that Eq. (4) is no longer truly a Gaussian plume equation. Furthermore, one problem implicit in the use of Eq. (4) is

that there is no consideration of wind velocity and stability class persistence (i.e., for each stability class the wind does not actually blow steadily in one direction with a given speed for a long period of time as is assumed here). Hence, uniform vertical mixing will not be obtained under all conditions even at very large distances, and concentrations at very large distances will be unduly influenced by stable classes with low wind speeds. However, empirical evidence supports the use of this equation to calculate long-term average ground-level air concentrations out to distances of 100 to 150 km from a point source [e.g., Fields, Miller, and Cotter (1981a)] (see Table 9).

In addition to calculating air concentrations and ground deposition rates for use in dose and risk estimation, ANEMOS also calculates the activity flux at each downwind distance. This is given by

$$Q'_{is}(x) = \sum_{p=1}^{N_p} \sum_{r=1}^{N_r} Q'_{iprs}(x) , \quad (5)$$

where $Q'_{is}(x)$ is the effective flux of pollutant i across the downwind sector direction s and through the vertical plane at downwind distance x (Ci/s or Bq/s). This calculation allows the user to monitor the downwind movement of the pollutant.

2.2 PARAMETERS

2.2.1 Wind Direction

Wind direction is an implicit rather than explicit parameter in the Gaussian formulation. The frequency of occurrence of each wind direction is an input variable in ANEMOS. Spatial and temporal variability of the wind direction throughout the assessment area is not accounted for in the straight-line model used in ANEMOS.

In standard meteorological nomenclature, the wind is reported in terms of the direction from which it is blowing. What is required in dispersion analyses, however, is the direction toward which the wind is blowing. Since standard meteorological data are assumed as input to

ANEMOS, the code automatically adjusts all input wind directions by 180°. The user may need to reorganize the input data if nonstandard meteorological information is used.

2.2.2 Wind Speed

Wind speed is entered to ANEMOS in terms of the frequency of occurrence of wind speed classes. Up to eight wind speed classes may be used. The mean wind speed for each class is used in the dispersion and deposition calculations. These values are also input parameters in the code.

The wind speed used in the ANEMOS calculations should be the wind speed at the source height (Clarke, 1979). However, meteorological data are seldom available at every source height of interest. Within the boundary layer, the wind speed tends to increase with increasing height above the ground. An initial rapid increase in speed with height diminishes to a much slower increase with height as the effect of the frictional forces at the surface of the earth decreases. This effect is often more pronounced at night than in the daytime (Fig. 4).

It is convenient to express the variation of wind speed with height in terms of a wind profile power law

$$u_2 = u_1 \left(\frac{z_2}{z_1} \right)^q, \quad (6)$$

where

u_2 = wind speed at height z_2 above ground;
 u_1 = wind speed at height z_1 above ground;
 q = power-law exponent.

Irwin (1979) has published values of q as a function of atmospheric stability and surface roughness. These values (shown in Table 2) have been incorporated into ANEMOS for each stability category and selected values of surface roughness length, z_0 (see Sect. 2.4). Irwin (1979)

Fig. 4. Schematic representation of the diurnal variations of wind speed with height over average terrain.

Table 2. Variations of the power-law exponent, q , and the inverse Monin-Obukhov length, L^{-1} , as a function of atmospheric stability class and surface roughness length, z_0 (Irwin, 1979)

Stability	$z_0 = 0.01 \text{ m}$		$z_0 = 0.10 \text{ m}$		$z_0 = 1.00 \text{ m}$		$z_0 = 3.00 \text{ m}$	
	$L^{-1} \text{ (m}^{-1}\text{)}$	q	$L^{-1} \text{ (m}^{-1}\text{)}$	q	$L^{-1} \text{ (m}^{-1}\text{)}$	q	$L^{-1} \text{ (m}^{-1}\text{)}$	q
A	-0.1405	0.05	-0.1109	0.08	-0.0875	0.17	-0.0781	0.27
B	-0.0848	0.06	-0.0571	0.09	-0.0385	0.17	-0.0319	0.28
C	-0.0329	0.06	-0.0163	0.11	-0.0081	0.20	-0.0058	0.31
D	0.0000	0.12	0.0000	0.16	0.0000	0.27	0.0000	0.37
E	0.0329	0.34	0.0163	0.32	0.0081	0.38	0.0058	0.47
F	0.0848	0.53	0.0571	0.54	0.0385	0.61	0.0319	0.69

does not include values of q for stability category G; therefore, ANEMOS uses the values of q shown for stability category F for stability category G, too (Raridon et al., 1984). Values of q are determined for values of z_0 not listed in Table 2 by interpolating between the given points using a linear interpolation. Because of the inherent limitations of this procedure, however, the user should not enter a value of z_0 less than 0.01 m or greater than 3.00 m.

Values of z_0 may be estimated from vertical wind profiles. However, this information may not be available for all sites of interest. Presented in Table 3 are some representative values of z_0 for various types of surfaces, which can be used in lieu of more precise site-specific information (Clarke, 1979).

In ANEMOS, the wind speed values for each wind speed class are automatically adjusted from the height at which they are measured (z_1), an input value, to the calculated plume height (z_2). It will be noticed from Eq. (6), however, that, as z_2 approaches ground level, u_2 potentially becomes unrealistically small. As a result, ANEMOS includes as an input parameter the minimum value of z_2 that will be used in the extrapolation. A value of 10 m may be appropriate for this minimum (Clarke, 1979). However, if z_1 is less than 10 m, then z_1 should be used for this minimum.

2.2.3 Downwind Distance

ANEMOS calculations are based on a circular grid (Fig. 5), with each sector centered on one of the 16 cardinal wind directions (Table 4). The air concentration and ground deposition rates may be calculated at each successive annular distance in a given sector, or the average air concentration and ground deposition rate between any two successive annular distances may be determined. The latter calculations are useful when population dose and health effects are being calculated. The method used is to assume that the air concentration or ground deposition follows an interpolating function $f(x) = ax^b$. We can use the two end points to determine this function, with

Table 3. Representative values of z_0 for natural surfaces under neutral stability (Clarke, 1979)

Terrain	z_0 (m)
Sea	0.0001
Sandy desert	0.001
Short grass	0.005
Open grassland	0.02
Root crops	0.1
Agricultural areas	0.2
	0.3
Parkland, open suburbia	0.5
Cities, woodlands	1.0

ORNL-DWG 85-16529

Fig. 5. Circular grid system upon which ANEMOS calculations are based.

Table 4. Wind-direction sectors

Sector	Direction	Range of angle (in degrees)	
		From	To
1	N	348.75	11.25
2	NNE	11.25	33.75
3	NE	33.75	56.25
4	ENE	56.25	78.75
5	E	78.75	101.25
6	ESE	101.25	123.75
7	SE	123.75	146.25
8	SSE	146.25	168.75
9	S	168.75	191.25
10	SSW	191.25	213.75
11	SW	213.75	236.25
12	WSW	236.25	258.75
13	W	258.75	281.25
14	WNW	281.25	303.75
15	NW	303.75	326.25
16	NNW	326.25	348.75

$$C_L = ax_L^b \quad \text{and} \quad C_U = ax_U^b, \quad (7)$$

where

C_L = concentration or deposition at the lower of two consecutive distances, x_L ;

C_U = concentration or deposition at the upper distance, x_U .

Solving these, we get

$$b = \frac{\ln(C_L/C_U)}{\ln(x_L/x_U)},$$

$$a = C_L/x_L^b.$$

Since the incremental area is proportional to x , the average concentration (or deposition rate) over the area between x_L and x_U is then computed as

$$\frac{\int_{x_L}^{x_U} ax^{(b+1)} dx}{\int_{x_L}^{x_U} x dx}.$$

The user may enter the number of annular rings and enter the specific distances to each ring or may choose to have ANEMOS calculate the distances. In the latter case, the user must first specify the maximum downwind distance desired and the total number of distances to be considered. The user must then choose one of three calculational grid options which are used by ANEMOS to automatically set the relationship between any two successive downwind distances. These relationships are shown in Table 5.

**Table 5. Specification of the three standard calculational
grid options available in ANEMOS**

Grid	Ratio of two successive downwind distances	Default number of downwind distances
Coarse	2	10
Medium	2.5	20
Fine	2.25	40

2.2.4 Vertical Dispersion Parameter

2.2.4.1 Basic Parameter

As might be expected from examining Eq. (4), changes in $\sigma_z(p, x)$ have been shown to affect greatly the resulting air concentration (Pasquill, 1974; Weber, 1976). Empirically determined graphs of $\sigma_z(p, x)$ have been developed by a number of authors (Gifford, 1976). Smith (1972) has developed a set of $\sigma_z(p, x)$ values designed to include downwind distances up to 100 km and a variety of surface roughnesses. Smith based his results on numerical solutions to the basic atmospheric diffusion equation using wind-speed and diffusivity profiles gained from experience over a range of stability categories. Hosker (1974) used a form of Smith's results to estimate the effect of surface roughness on downwind air concentrations. The increased mechanical turbulence generated by rough surfaces enhances plume diffusion and thus reduces air concentrations. Miller (1978) compared values of $\sigma_z(p, x)$ observed at two rough terrain sites with values predicted by the Smith-Hosker formulation and found the respective values to be in reasonably good agreement.

An important consideration when selecting a set of dispersion parameters for an application is the height of release for which they are applicable. Smith's values of $\sigma_z(p, x)$ are based on data from low-level releases. It has been suggested that the height of release is an important parameter in determining the rate at which the plume dispersion occurs, especially in the vertical (see Gifford, 1976). Pasquill (1976) argues, however, that for a sampling time >10 min the Smith values of $\sigma_z(p, x)$ should be equally applicable for ground-level or elevated releases.

The Smith-Hosker values of $\sigma_z(p, x)$ have been selected for use in ANEMOS. The analytical formula for these values is

$$\sigma_z(p, x) = \frac{ax^b}{1 + cx^d} F(z_0, x), \quad (8)$$

where

$F(z_0, x)$ - the roughness correction factor.

The stability-dependent coefficients used to calculate $\sigma_z(p, x)$ in ANEMOS are presented in Table 6. The coefficient values given in this table for stability category G were derived from data presented by Clarke (1979). All other coefficients are based on Hosker (1974).

A correction factor is calculated by ANEMOS to adjust the dispersion parameters given by Eq. (8) for variations in surface roughness. The procedure used here is the same as that used by Raridon et al. (1984). Data from Fig. 6 (Smith, 1972) were fit using a bicubic spline expression (NAG, 1981). The parameters from this fit are used to calculate the correction factor as a function of roughness length, z_0 , and the distance between the source and the receptor, x .

2.2.4.2 Building Wake Effects

The dispersion parameters defined in Eq. (8) are for an ideal point source. When the release point is on or near a building or complex of physical structures, however, building wake effects can enhance the initial growth of stack plumes. Plumes that are affected in this manner can result in ground-level concentrations that are significantly different from those found in the absence of such effects (Huber, 1979).

To account for building wake effects, ANEMOS uses a technique for estimating an enhanced dispersion parameter, $\sigma_z'(p, x)$, suggested by Huber and Snyder (1976) and Huber (1977) and incorporated into the Industrial Source Complex (ISC) computer code (Bowers, Bjorklund, and Cheney, 1979). This technique is based on a wind-tunnel study and a literature review and evaluation (Huber, 1979). It is estimated by

$$\sigma_z'(p, x) = \begin{cases} 0.7H_b; & x_w \leq 3H_b \\ 0.7H_b + 0.067(x_w - 3H_b); & 3H_b < x_w < 10H_b \\ \sigma_z(x_w + S_z); & x_w \geq 10H_b \end{cases} \quad (9)$$

Table 6. Coefficients used to derive the values of $\sigma_z(p, x)$ for various stability categories

Stability category	a	b	c	d
A	0.112	1.06	5.38×10^{-4}	0.815
B	0.130	0.950	6.52×10^{-4}	0.750
C	0.112	0.920	9.05×10^{-4}	0.718
D	0.098	0.889	1.35×10^{-3}	0.688
E	0.0609	0.895	1.96×10^{-3}	0.684
F	0.0638	0.783	1.36×10^{-3}	0.672
G	0.0366	0.767	5.44×10^{-4}	0.7427

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Fig. 6. Isopleths of $\sigma_z(z_o)/\sigma_z(z_o = 10 \text{ cm})$, virtually independent of heat flux (Smith, 1972).

where

- H_b = height of highest influential building (m);
- x_w = downwind distance from the building edge = $x - H_w/2$ (m);
- H_w = width of the region of influential buildings normal to the wind (m);
- σ_z = the value of the appropriate vertical dispersion parameter, $\sigma_z(p, x)$, in the absence of building influences;
- S_z = the virtual source distance such that $\sigma_z'(10H_b) = 1.2H_b$ (m).

Equation (9) should be applied for sources located within $2H_b$ of a building and lower than $2.5H_b$ or, in cases where $H_w < H_b$, a height of $(H_b + 1.5 H_w)$ (Huber, 1979). When $H_w < H_b$, H_b should be replaced by H_w in Eq. (9) because the width scale H_w is likely to be more significant. If the unmodified values of $\sigma_z(p, x)$ are greater than $\sigma_z'(p, x)$ at $x_w \leq 10 H_b$ downwind, then no modification is made to $\sigma_z(p, x)$. This is often the case for very unstable (A or B category) conditions (Huber, 1977). Comparisons of air concentration predictions made using this technique with field observations support the use of Eq. (9) in assessment calculations (Huber, 1979; Miller, 1981).

2.2.5 Effective Stack Height

The physical height of the release location above plant grade is an input parameter for ANEMOS calculations. However, the actual effective stack height will often be different from the physical stack height because of the nature of the plume. ANEMOS contains procedures that may be used to adjust the stack height. These procedures are discussed in the following sections. It should be noted, however, that the ANEMOS user has an option of ignoring all these adjustments and keeping the effective stack height equal to the physical stack height, which is entered.

2.2.5.1 Momentum and Buoyancy

When a plume possesses momentum and/or thermal buoyancy, it will tend to rise above the physical stack. To account for this process, ANEMOS uses Briggs' (1971, 1975) plume-rise equations. This is also the

methodology incorporated into the ISC code (Bowers, Bjorkland, and Cheney, 1979). The parameters used in this model have been defined as follows:

$$F_m = \left(T_a/T_s \right) V_s^2 d_s^2 / 4 \quad (10)$$

$$F = \begin{cases} F' - \frac{g V_s d_s^2}{4} \left(1 - T_a/T_s \right); & F' > F_c \\ 0; & F' \leq F_c \end{cases} \quad (11)$$

$$F_c = \begin{cases} 0.072 (V_s d_s)^{4/3}; & F' \leq 55 \text{ m}^4/\text{s}^3 \\ 0.014 (V_s d_s)^{5/3}; & F' > 55 \text{ m}^4/\text{s}^3 \end{cases} \quad (11a)$$

$$\beta_j = \left[1/3 + \frac{\bar{u}(H)}{V_s} \right], \quad (12)$$

where

- F_m - momentum flux;
- T_a - ambient air temperature (K);
- T_s - stack exit temperature (K), input as zero for a pure momentum source;
- V_s - stack exit velocity (m/s), input as zero if no plume rise is to be calculated;
- d_s - stack exit diameter (m);
- F - buoyancy flux;
- g - acceleration due to gravity (9.8 m/s^2);
- F_c - buoyancy flux below which plume rise is due to momentum only;
- β_j - jet entrainment coefficient;
- $\bar{u}(H)$ - mean wind speed (m/s) at emission height H .

During stability categories A, B, C, and D, plume rise Δh_n due to buoyancy and/or momentum at downwind distance x is estimated by

$$\Delta h_n(x) = \left[\frac{3F_m x'}{\beta_j^2 \bar{u}(H)^2} + \frac{3F x'^2}{2\beta_1^2 \bar{u}(H)^3} \right]^{1/3} \quad (13)$$

$$x' = \begin{cases} x; & x < 3.5x^* \text{ and } F > 0 \\ x; & x < \frac{4d \left[v_s + 3\bar{u}(H) \right]^2}{v_s \bar{u}(H)} \text{ and } F = 0 \\ 3.5x^*; & x \geq 3.5x^* \text{ and } F > 0 \\ \frac{4d \left[v_s + 3\bar{u}(H) \right]^2}{v_s \bar{u}(H)}; & x \geq \frac{4d \left[v_s + 3\bar{u}(H) \right]^2}{v_s \bar{u}(H)} \text{ and } F = 0 \end{cases} \quad (14)$$

$$x^* = \begin{cases} 14F^{5/8}; & F \leq 55 \text{ m}^4/\text{s}^3 \\ 34F^{2/5}; & F > 55 \text{ m}^4/\text{s}^3 \end{cases} \quad (15)$$

For stability categories E, F, and G, plume rise Δh_s at downwind distance x is given by

$$\Delta h_s(x)^3 = \frac{3F_m}{\beta_j^2 \bar{u}(H) S^{1/2}} \sin \left[S^{1/2} x' / \bar{u}(H) \right] + \frac{3F}{\beta_2^2 \bar{u}(H) S} \left\{ 1 - \cos \left[S^{1/2} x' / \bar{u}(H) \right] \right\} \quad (16)$$

$$x' = \begin{cases} x; & x < \pi \bar{u}(H) S^{-1/2} \quad \text{and } F > 0 \\ x; & x < \frac{\pi}{2} \bar{u}(H) S^{-1/2} \quad \text{and } F = 0 \\ \pi \bar{u}(H) S^{-1/2}; & x \geq \pi \bar{u}(H) S^{-1/2} \quad \text{and } F > 0 \\ \frac{\pi}{2} \bar{u}(H) S^{-1/2}; & x \geq \frac{\pi}{2} \bar{u}(H) S^{-1/2} \quad \text{and } F = 0 \end{cases} \quad (17)$$

$$S = \frac{g}{T_a} \frac{\partial \theta}{\partial z} \quad (17a)$$

where

S = stability parameter (s^{-2});
 $\frac{\partial \theta}{\partial z}$ = vertical potential temperature gradient (the default value is 0.020 K/m for E stability, 0.035 K/m for F stability, and 0.042 K/m for G stability).

Both β_1 and β_2 have a default value of 0.6 (Briggs, 1975). Like ISC, if $F = 0$ and $\Delta h_s(x) > 3V_s d/\bar{u}(H)$, ANEMOS sets $\Delta h_s(x) = 3V_s d/\bar{u}(H)$. Also, it should be noted that Eq. (16) is a theoretical formulation with partial experimental validation; however, for nonbuoyant plumes there are no appropriate data available for validation (Bowers, Bjorklund, and Cheney, 1979). Equation (6) is used to extrapolate the wind speed from the height of measurement to the height of release H .

It should be noted that the calculation of plume rise as a function of downwind distance is an option in ANEMOS. It should always be used when building wake effects (Sect. 2.2.4.2) are calculated (Bowers, Bjorklund, and Cheney, 1979). It should also be considered when calculations of the gamma-ray dose from a plume passing overhead are made. There may be other times when a distance-dependent plume rise is calculated, but it should be kept in mind that this calculation can be time consuming and, hence, expensive.

When ANEMOS is not directed to calculate distance-dependent plume rise, it will assume that the final plume rise is to be used at all downwind distances. The final plume rise for neutral or unstable

conditions is found from Eq. (13) using the maximum value of x' allowed by Eq. (14). Likewise, for stable conditions the final plume rise is given by Eq. (16) with x' equal to the maximum value allowed by Eq. (17).

2.2.5.2 Downwash

Another option in ANEMOS is that the user may request calculation of stack-tip downwash using a model after Briggs (1973). If $V_s \geq 1.5\bar{u}(H)$, no downwash occurs. If $V_s < 1.5\bar{u}(H)$, however, a factor Δh_d is added to the stack height, where

$$\Delta h_d = 2[V_s/\bar{u}(H) - 1.5]d_s. \quad (18)$$

The user should note that Eq. (18) is based on wind tunnel data that might not be entirely appropriate for environmental stack releases (Bowers, Bjorkland, and Cheney, 1979). Also, Eq. (18) should not be used when the building effects option (Sect. 2.2.4.2) is used because downwash is already implicitly included in the building wake-effects calculation (Bowers, Bjorkland, and Cheney, 1979).

2.2.5.3 Determining Effective Stack Height

The effective stack height due to momentum, buoyancy, and downwash is calculated by modifying the input value of the physical stack height, h_s . One option in ANEMOS is to make this modification in a simple linear fashion, that is,

$$h_e = h_s + \Delta h_d + \Delta h(x), \quad (19)$$

where $\Delta h(x)$ is $\Delta h_n(x)$ or $\Delta h_s(x)$ depending upon the atmospheric stability category. Briggs (1981) has suggested, however, that it may be more realistic to use the nonlinear ANEMOS option whereby

$$h_e = h_s + \left[\left(\Delta h_m + \Delta h_d \right)^3 + \Delta h_b^3 \right]^{1/3}, \quad (20)$$

where Δh_m and Δh_b are, respectively, the momentum and buoyancy terms of Eq. (13) or (16). Equation (19) will likely result in higher population dose estimates than will Eq. (20) (Briggs, 1981), the default in ANEMOS.

2.2.6 Effective Plume Height

Equation (4) requires the use of the effective plume height to calculate air concentrations and ground deposition rates. Further modification of h_e may be needed because of the nature of the material in the plume and/or the surrounding terrain. The ANEMOS procedures for doing this are discussed below.

2.2.6.1 Gravitational Effects

Particles with a diameter of 10 μm or more may have significant gravitational settling speeds, V_g , in the atmosphere. For particle diameters greater than 100 μm , it is doubtful that Eq. (4) can be applied because the particles are falling so fast that diffusion is no longer significant (Van der Hoven, 1968). For particles $\leq 100 \mu\text{m}$, however, the Gaussian plume model may still be used by incorporating the "tilted plume model" (Fig. 7). This is accomplished by subtracting xV_g/u from the previously calculated plume-rise enhanced stack height, h_g , Eq. (19) or (20). If $h_e - xV_g/u$ is calculated to be less than zero, it is set equal to zero by ANEMOS. Values of V_g for each particle may be entered by the user, or they may be calculated in the code (see Sect. 2.6.1).

2.2.6.2 Terrain Effects

ANEMOS can adjust the height of the plume for the height of the surrounding terrain by subtracting from h_e one-half the maximum terrain height above the stack base between the release point and the location

$\Rightarrow U$

Fig. 7. Tilted plume model.

for which the calculation is being made, h_t (Egan, 1975). Note that $h_t \geq 0$; that is, valleys do not increase the effective height of the plume, while hills may reduce it. Also, ANEMOS requires that $h_e - h_t \geq 0$. If the terrain effects option is selected, the user must enter the height of the stack base and the appropriate terrain height for each sector and downwind distance.

2.2.7 Mixing Heights

In ANEMOS, the height of the top of the tropospheric mixing layer above ground is considered to be a function of stability class. The user has the option of entering a specific mixing height value for each of up to eight stability categories that are allowed in ANEMOS [A, B, C, D (day), D (night), E, F, and G]. Another option, however, is to enter only the average morning (h_M) and afternoon (h_A) mixing heights for the time period of interest and to allow the code to calculate the stability-class-dependent mixing height values according to the algorithm adapted from the CDM computer code (Busse and Zimmerman, 1973; USEPA, 1978) and given in Table 7. Annual average values of h_A and h_M for the contiguous 48 states of the United States have been published by Holzworth (1972) (see Figs. 8 and 9). As part of the CRRIS, these mixing height values have been interpolated to grid cells 0.5° latitude $\times$ 0.5° longitude in size to facilitate their use for site-specific calculations in codes such as ANEMOS (Baes et al., 1984b). However, ANEMOS does not access these data directly; values of h_A and h_M must be entered by the user.

2.3 AREA SOURCE CALCULATIONS

At the option of the user, the emission source for an ANEMOS calculation can be a finite area with the computational grid centered on the centroid of the assumed circular area. The area of this source, A (m^2), is an input parameter in ANEMOS, with a value of zero indicating a point source. Radionuclides are assumed to be released uniformly throughout the area. The method used in ANEMOS to calculate resulting

Table 7. Algorithm used to calculate the mixing height associated with each stability class as a function of the average morning (h_M) and afternoon (h_A) mixing heights

Stability class	Mixing height, h_L (m)
A	$1.5h_A$
B	h_A
C	h_A
D (day)	h_A
D (night)	$(h_A + h_M)/2$
E	h_M
F	0
G	0

Fig. 8. Annual average morning mixing heights ($m \times 10^2$) for the contiguous United States (Holzworth, 1972).

Fig. 9. Annual average afternoon mixing heights ($m \times 10^2$) for the contiguous United States (Holzworth, 1972).

air concentrations and ground deposition rates was adapted from the method described by Mills and Reeves (1973) in ATM-TOX (Raridon et al., 1984).

Basically, air concentration and ground deposition for an area source are calculated by interchanging the source and receptor points and approximating the effect of a point source (receptor) on a sector (area source). For small downwind distances, the transformed source will be approximated by a circular sector centered at the point source; for large downwind distances, the transformed source becomes a point.

The transformation from the original source into a sector source of the same area is illustrated in Fig. 10. When the distance from the centroid of the source to the receptor, R (m), is greater than eight times the square root of the area of the source, A , the area source is treated as a point source. When $\frac{\sqrt{A}}{2} < R \leq 8\sqrt{A}$ [Fig. 10(a)], the transformed source is described by

$$\begin{aligned} R_1 &= R - \frac{\sqrt{A}}{2}, \\ R_2 &= R + \frac{\sqrt{A}}{2}, \text{ and} \\ \Delta\theta &= \frac{\sqrt{A}}{R}, \end{aligned}$$

where

R_1 = inner radius of transformed source;
 R_2 = outer radius of transformed source; and
 $\Delta\theta$ = angle subtended by transformed source.

If $\frac{\sqrt{A/\pi}}{2} < R \leq \frac{\sqrt{A}}{2}$ [Fig. 10(b)], then

$$\begin{aligned} R_1 &= 0 \\ R_2 &= 2R; \text{ and} \\ \Delta\theta &= \frac{A}{2R^2} \end{aligned}$$

Finally, if $R \leq \frac{\sqrt{A/\pi}}{2}$ [Fig. 10(c)], the transformation is given by

$$R_1 = 0;$$

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(a)

(b)

(c)

Fig. 10. Initial and transformed area sources.

$$R_2 = \sqrt{A/\pi} ; \text{ and} \\ \Delta\theta = 2\pi .$$

The distance between the receptor and the transformed area source is based on an application of the mean value theorem. If we assume that $C_{is}(x)/Q'_{iprs}(x)$ is proportional to $r^{-1.5}$, then

$$x^{-1.5} = \frac{\int_{R_1}^{R_2} R^{-1.5} r dr}{\int_{R_1}^{R_2} r dr} = \frac{4}{(R_2 + R_1)(\sqrt{R_2} + \sqrt{R_1})} .$$

For transformation (a),

$$x = \left[\frac{R(\sqrt{R_2} + \sqrt{R_1})}{2} \right]^{2/3} . \quad (22)$$

For transformation (b),

$$x = \frac{R}{2^{1/3}} . \quad (23)$$

Finally, for transformation (c),

$$x = \frac{\sqrt{A/\pi/2}}{2^{1/3}} . \quad (24)$$

The area source calculations now proceed analogously to the point source calculation discussed previously using the effective distance calculated using Eq. (22), (23), or (24). However, the frequency of the wind velocity must be adjusted to account for the contribution from each direction which would be included in the transformed source. Using the width of the sector of the transformed source, the frequencies of surrounding sectors are used in the air concentration and ground

deposition rate calculations for the original sector. Given $\Delta\theta$ as the angle of the transformed source, those sectors within $\Delta\theta/2$ of the receptor sectors are used to calculate the weighted sum of frequencies of winds that blow from the source to the receptor.

2.4 WINDBLOWN SOURCES

In some places, including those in the United States where uranium mining and milling take place, previously deposited radionuclides may be reentrained into the atmosphere under dry and windy weather conditions. The source strength of this type of radionuclide release depends on the wind speed and the physical properties of the source itself. ANEMOS uses a model developed by Mills, Dahlman, and Olson (1975) and implemented by Culkowski and Patterson (1976) to estimate this source strength.

Central to the discussion of this model is the relationship between z_0 and the friction velocity, u_* . Values of z_0 and u_* are usually found empirically from the vertical wind speed profile above a relatively smooth ground surface for near-neutral atmospheric stability conditions using the relationship (Sehmel and Hodgson, 1980; Businger et al., 1971)

$$u = \frac{u_*}{k} \ln \left(\frac{z + z_0}{z_0} \right), \quad (25)$$

where

- u = measured wind speed (m/s),
- z = height above ground at which u is measured (m),
- z_0 = surface roughness length (m),
- k = von Karman's constant (0.4).

Because z_0 is only the result of an empirical data fit, it cannot be physically measured (Sehmel and Hodgson, 1980). However, z_0 has been found to be about 0.1 times the height of various structures on the ground, for example, crops, trees, and buildings (Briggs, 1975). As noted earlier, representative values of z_0 for various land surfaces are

listed in Table 3. Relations similar to Eq. (25) for stability categories A through G have been derived for use in ANEMOS.

Assuming that the forces of wind and gravity on a particle are equal, the friction velocity at which wind erosion begins, u_{*t} , is given by (Bagnold, 1941):

$$u_{*t} = A_f \left[\frac{g d_a (\rho_s - \rho_a)}{\rho_a} \right]^{1/2}, \quad (26)$$

where

- A_f - an empirical constant (0.1),
- d_a - actual grain diameter (m),
- ρ_s - density of sand grains (g/m^3),
- ρ_a - density of air (g/m^3), and
- g - gravitational acceleration (m/s^2).

Bagnold (1941) expressed the saltation rate j ($\text{g/m}\cdot\text{s}$) in terms of u'_* , the effective friction velocity during wind erosion, as

$$j = K \left(\frac{d_a}{d_g} \right)^4 \frac{\rho_a}{g} (u'_*)^3, \quad (27)$$

where

- K - constant depending upon particle size distribution (nearly uniform sand, $K = 1.5$; naturally graded sand, $K = 1.8$; wide range of grain size, $K = 2.8$);

- d_g - standard grain diameter (m).

Mills, Dahlman, and Olson (1975) assume that

$$u'_* = u_* - u_{*t}. \quad (28)$$

Therefore,

$$j = K \left(\frac{d_a}{d_g} \right)^4 \frac{\rho_a}{g} \left(u_* - u_{*t} \right)^3, \quad (29)$$

where u_{*t} can be calculated using Eq. (26).

The fluid threshold velocity u_t is the wind speed required to begin particle movement by the wind. Assuming that $z_0 \ll z$, the relationship between u_t and u_{*t} for neutral stability is given by (Bagnold, 1941):

$$u_t = \frac{1}{k} u_{*t} \ln \left(\frac{z}{z_0} \right). \quad (30)$$

Solving Eq. (25) for u_* , assuming $z_0 \ll z$, and substituting this result and Eq. (30) into Eq. (29) results in

$$j = K \left(\frac{d_a}{d_g} \right)^4 \frac{\rho_a}{g} \left[\frac{k(u - u_t)}{\ln(z/z_0)} \right]^3. \quad (31)$$

Equation (31) is used in ANEMOS to calculate the saltation rate, j , for windblown sources under neutral stability conditions. Similar equations are used for other stability categories.

Impaction occurs when the larger sand grains return to earth and dislodge other sand grains. As a first approximation, the suspension rate, Q_w , and hence the windblown radionuclide release rate, is assumed to be proportional to saltation rate j ,

$$Q_w = R_f j \quad (32)$$

R_f , which has units of inverse length, is an empirical factor relating the suspension rate ($\text{g/m}^2 \cdot \text{s}$) of respirable particles to the saltation rate ($\text{g/m} \cdot \text{s}$). R_f is an input parameter in ANEMOS. Culkowski and Patterson (1976) used a value of 10^{-5} m^{-1} , but they strongly suggest that site-specific measurements of R_f be made whenever possible. Gillette (1976) indicates that the range of R_f is approximately three orders of magnitude with 10^{-5} m^{-1} near the midpoint of that range. It has been suggested that this model provides estimates of the saltation rate for respirable particles only (Smith, Whicker, and Meyer, 1982).

It should be noted that this method of calculating suspension is not the same as that used in TERRA (Baes et al., 1984a) to calculate resuspension of previously deposited material. Rather than use a local-scale approach like that in ANEMOS, TERRA uses a large-scale, mass-loading type of calculation. This simpler approach is acceptable because resuspension is a secondary source in TERRA rather than a primary source as it is in ANEMOS.

2.5 SOURCE TERM SPECIFICATIONS

ANEMOS allows the user to enter a one-line title that may be used to identify the particular run being made. The user must also specify the latitude and longitude of the source to be associated with a particular run. If a given run is one of multiple ANEMOS runs that will be combined using SUMIT (Begovich et al., 1984), the location of the release point with respect to the center of the grid that will be used in SUMIT may also need to be specified. This may be done in terms of either an (x, y) or (r, θ) coordinate system. The latitude and longitude information is used by other codes in the CRRIS for accessing the data bases of location-dependent model parameters (Baes et al., 1984b).

For a point or area source, the radiological source term is specified in terms of the name of each radionuclide and its rate of release (activity/s). For a windblown source, the activity density (activity/g) and the fraction of time that the windblown source remains dry are input instead of a release rate for each radionuclide to be considered. Equations (31) and (32) are then used to calculate the actual radionuclide release rates. The ANEMOS user must also input the units of activity being used, either Bq or Ci. In ANEMOS, these radionuclide release rates are assumed to be uniform throughout the assessment period.

Associated with each radionuclide in the source term is a physical size. In ANEMOS this information is supplied in the form of up to five particle size classes. The particle diameter associated with each size class and the fraction of the release in each size class are input into

the code. If desired, each radionuclide released may have a unique set of particle size class characteristics. If the particle size is set equal to zero, the radionuclide is assumed to be released in the form of a gas.

As some radionuclides (parents) travel downwind, they form one or more new radionuclides (daughters) as a result of radiological decay processes. The default in ANEMOS is that the particle size distribution associated with the daughter products is the same as that associated with the parent radionuclide. This is especially appropriate for particulate parents because it assumes that the daughters, either gases or particulates, are physically trapped in the material matrix of the parent. In some cases, however, such as when the parent is a gas and one or more of the daughters are particulates, this default may not be appropriate. If desired, the user may override the default assumption by entering the identification of the daughter radionuclide to be specified, the desired particle size information, and a release rate of zero. However, all members of a chain must have the same number of particle size classes.

For the assessment of inhalation doses of radionuclides, one is more interested in the activity median aerodynamic diameter (AMAD) than the physical size of a particle. The aerodynamic diameter of a particle is the diameter of an equivalent unit density sphere with the same settling velocity as the particle itself (Morrow et al., 1966). The AMAD of an aerosol is the median of the distribution of activity against aerodynamic diameter. A default value of 1 g/cm^3 is used for the particle density input parameter in ANEMOS. Therefore, the user may directly specify the particle diameter associated with each particle size class in terms of AMADs without changing the default value of particle density. If the particle density is not equal to one, an AMAD is calculated by multiplying the input particle diameter by the square root of the particle density. Because the inhalation dose conversion factors used in the CRRIS are specified in terms of AMAD, these diameters will be given in the ANEMOS output file designed to be used eventually by ANDROS (Begovich et al., in press). However, the actual physical particle diameter will be used in the calculation of any deposition effects (see Sect. 2.6.1).

Another important aerosol characteristic utilized in inhalation dose assessments is the clearance class. This parameter is an indication of the relative length of time it takes for aerosols deposited in the lung to be cleared from the lung and into the lymphatic system, the blood stream, or the gastrointestinal tract. Three different clearance classifications are used (Morrow et al., 1966):

- D - clearance half-times of less than one day;
- W - clearance half-times of a few days to a few months;
- Y - clearance half-times of 6 months to several years.

A fourth clearance class, *, is used in ANEMOS to indicate those nonreactive gases which are assumed not to deposit on or react with lung tissue if inhaled (e.g., Kr) or which are handled in a special manner for dose calculational purposes (e.g., CO₂).

The clearance class that is most appropriately associated with a given radionuclide depends on the physiochemical form of the radionuclide (Morrow et al., 1966). Shown in Table 8 are the default clearance class values used in ANEMOS. When the reference indicated the possibility of more than one clearance class for a given element depending upon its chemical form, the oxide and/or hydroxide form was assumed. Please note that these default values do not necessarily maximize the dose from any particular radionuclide to a given organ or the risk of any possible individual health effect. As with other variables in ANEMOS, these default values may be overridden for any particular radionuclide by entering the fraction of the release that is associated with a given clearance class. These values may also be reassigned in ANDROS.

2.6 SOURCE TERM MODIFICATIONS

As previously indicated, released radionuclides will be changed as they travel downwind because of radiological decay processes which may even result in the formation of new radionuclides in the plume. In addition, both parent and daughter radionuclides may be removed from the plume during transport by dry and wet deposition processes. ANEMOS

Table 8. Default values of clearance class used in ANEMOS

Clearance class	Element	Reference
D	At, Br, Cl, F, S	Morrow et al., 1966
	Cs, I, P, Sr	ICRP, 1979
	Ba, K, Na, Pb, Rb	ICRP, 1980
	Fr, Pt, Tl, W	ICRP, 1981
W	Am, Cm, Mn, Ra, Te, Zr	ICRP, 1979
	Bi, Ca, Fe, Hg, In, Np, Re, Tc	ICRP, 1980
	Al, As, Bk, Dy, Er, Es, Eu, Fm, Ga, Gd, Ge, Hf, Ho, La, Mg, Ni, Sb, Se, Si, Sm, Sn, Tb, Ti, Tm, V	ICRP, 1981
Y	Ce, Cf, Co, Mo, Nb, Pu, Th	ICRP, 1979
	Ag, Au, Cd, Cr, Cu, Ir, Os, Rh, Ru, Y, Zn	ICRP, 1980
	Ac, Be, Lu, Nd, Pa, Pd, Pm, Pr, Sc, U, Yb	
*	Ar, C, H, Kr, N, O, Rn, Xe	Killough et al., 1978 Sullivan et al., 1981

accounts for removal of a released radionuclide by using a modified source term in the calculation of radionuclide air concentrations and ground deposition rates. This revised source term is given by

$$Q'_{iprs}(x) = Q_i f_{prs} \exp \left[- \int_0^x \frac{\lambda_{ipr}^e(x')}{u_r} dx' \right], \quad (33)$$

where

- $Q'_{iprs}(x)$ - effective flux for radionuclide i in stability class p , wind speed class r , and wind direction s at downwind distance x (Bq/s or Ci/s);
- Q_i - initial emission rate from the source for radionuclide i (Bq/s or Ci/s);
- f_{prs} - frequency with which the wind blows towards direction s in stability class p and wind speed class r ;
- $\lambda_{ipr}^e(x')$ - effective decay constant for radionuclide i in stability class p and wind speed class r at downwind distance x (s^{-1}),
  - $= \lambda_i^n + \lambda_{ipr}^d(x) + \lambda_{ip}^w$;
- λ_i^n - radiological decay constant for radionuclide i (s^{-1});
- $\lambda_{ipr}^d(x)$ - effective decay constant due to dry deposition processes for radionuclide i in stability class p and wind speed class r at downwind distance x (s^{-1});
- λ_{ip}^w - effective decay constant due to wet deposition processes for radionuclide i in stability class p (s^{-1});
- x' - dummy variable of integration.

Note that $Q'_{iprs}(x)$ is required for Eqs. (4) and (5) but that the user enters Q_i to ANEMOS. Also, note again that the code expects the user to enter the frequency with which the wind blows from direction s in stability class p and wind speed class r . ANEMOS then automatically computes f_{prs} by rotating the input wind directions 180° .

2.6.1 Source Depletion Due to Dry Deposition

In the absence of precipitation, particles and reactive gases may deposit on various surfaces via impingement, electrostatic interactions, chemical reactions, and other processes. In ANEMOS, these dry deposition processes are parameterized in terms of a dry deposition velocity, V_d (m/s). This parameter is defined as the ratio between the rate at which material is deposited on the surface of the earth and the air concentration measured at some reference height, usually 1 m, above the depositing surface. It must be stressed that V_d is merely a proportionality constant even though it has the units of velocity.

A value of V_d may be provided to ANEMOS for each particle size and reactive gas considered in a run. Care should be taken when selecting values of V_d to be sure that the values chosen represent the total deposited radionuclide per unit of ground area and not just the quantity deposited on vegetation, which is often the one reported in the literature (Hoffman, 1977; Miller, Hoffman, and Shaeffer, 1978). Also, the ANEMOS user should make sure that $V_d \geq V_g$.

Values of V_d are expected to be a function of numerous meteorological variables and characteristics of both the depositing material and the deposition surface (Sehmel, 1980). A review of field measurements of V_d (McMahon and Dennison, 1979; Sehmel, 1980), however, shows such a scatter and sparsity of data that a rigorous analysis of the relationship between V_d and various controlling parameters is impossible at this time (Hanna, Briggs, and Hosker, 1982). Sehmel (1980) includes graphs of predicted values of V_d for particles based primarily on theoretical considerations and wind tunnel studies rather than actual field data. Hanna, Briggs, and Hosker (1982) have suggested that, when calculations are made with codes such as ANEMOS, a range (often orders of magnitude) of possible V_d values should be used instead of a single estimate. Such calculations will place upper and lower bounds on the computed results, which may be all the accuracy one can expect with the present state of the art (Hanna, Briggs, and Hosker, 1982). It should be noted, however, that the applicable range in V_d is likely to be less for long-term releases than it is for short-term releases.

Shown in Fig. 11 is one set of curves from Sehmel (1980) showing predicted values of V_d for particles under stable atmospheric conditions as a function of particle size and density for a friction velocity, u_* , of 50 cm/s. This value of u_* is representative of short (10 cm) thick grass or tall (50 cm) thin grass (Sutton, 1953). The user may want to use this figure as a guide in selecting values of V_d for use in various assessment activities.

ANEMOS allows input of V_d and V_g for each particle size. However, these variables may be computed within ANEMOS. The computations are done assuming a reference height of 1 m for particles using the model which generated the curves shown in Fig. 11 (Sehmel and Hodgson, 1975; 1980). These calculations are performed using algorithms developed by Nelson (1982). Note that the value of the input variable, CUTOFF, sets a minimum for the value of V_g that will be used in subsequent calculations both for deposition and effective plume height (see Sect. 2.2.6.1). If V_g is less than CUTOFF, V_g is set to zero. The default value of CUTOFF is 0.001 m/s.

These calculations require the parameters of physical diameter, particle density, atmospheric stability class, u_* , and z_0 . The relationship between z_0 and u_* is discussed in Sect. 2.4. The value of z_0 used in the calculation of V_d is the same as that used for the calculation of wind speed at the height of release [Eq. (6)] and σ_z [Eq. (8)]. It must be noted that values of V_d should be calculated only for small surface roughness values at present (Sehmel and Hodgson, 1980).

In ANEMOS, a value of V_d is computed for each radionuclide i , stability class p , and wind speed class r ; that is, $V_d = V_{dipr}$. The friction velocity u_* is calculated using Eq. (25) and the value of u appropriate for each wind speed class r . The value used for von Karman's constant is 0.4. The value of z may be entered by the user. The default value is 10 m. The stability class p enters into the calculation through the inverse Monin-Obukhov length, L^{-1} (m^{-1}) (Irwin, 1979). Values of L^{-1} as a function of z_0 and stability class are shown in Table 2. Values of L^{-1} for any z_0 not listed in Table 2 are calculated by interpolating between the given points using a linear interpolation. Again, however, because of the inherent limitations of this procedure, users should not enter a value of z_0 less than 0.01 m or

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Fig. 11. Predicted deposition velocities at 1 m for $u_* = 50$ cm/s and particle densities of 1, 4, and 11.5 g/cm^3 .

greater than 3 m.

Values of V_d for gases have been suggested for use in AIRDOS-EPA (Moore et al., 1979):

1. 3.5 cm/s for reactive gases (e.g., molecular iodine);
2. 0.018 cm/s for relatively unreactive gases (e.g., CH_3I);
3. 0.0 cm/s for nonreactive gases (e.g., Ar).

These values may still be appropriate for use in radiological assessments (Hanna, Briggs, and Hosker, 1982). ANEMOS assumes $V_d = 0$ for gases unless the user enters a different value.

Calculation in ANEMOS of plume depletion due to dry deposition is based on the assumption that as material is deposited on the ground it is replenished from above at such a rate that the Gaussian profile in the vertical is maintained; that is, depletion occurs uniformly throughout the plume. Other models have been proposed in which the vertical concentration profile is not necessarily maintained [e.g., Horst, (1977a)]. Such a "surface depletion" model is generally more difficult to use, however, than the common source depletion approach used in ANEMOS. The greatest differences between these two models are expected to occur for stable atmospheric conditions (Horst, 1977b). However, Jensen (1981) suggests that even this may not be a serious limitation under realistic meteorological and deposition conditions. Until model validation studies become available that indicate to the contrary, Miller and Hoffman (1979) have recommended that the source depletion model be utilized for radiological assessment purposes.

For the Gaussian plume model as expressed by Eq. (4), the model for source depletion because of dry deposition of a radionuclide may be expressed by Van der Hoven (1968):

$$Q'_{i\text{pr}s} = Q_{i\text{fpr}s} \exp \left[- \int_0^x \frac{V_{d\text{pr}}}{u_r} G(p, x) dx' \right]. \quad (34)$$

It follows directly from Eqs. (33) and (34) that

$$\lambda_{ipr}^d(x) = V_{dipr} G(p, x) \quad (35)$$

As noted previously, the form of $G(p, x)$ used in Eqs. (34) and (35) depends upon the relationship between stack height, mixing height, and receptor height.

2.6.2 Source Depletion Due to Wet Deposition

In the presence of precipitation, radionuclides may be removed from a plume primarily by being incorporated into the precipitation as it is formed (rainout) or by being swept out of the air by the precipitation as it falls (Engelmann, 1968). In ANEMOS, these processes are parameterized in terms of washout rate, or scavenging rate, for radionuclide i , λ_{ip}^w , in which it is assumed that the scavenging process is irreversible.

Values of λ_{ip}^w should theoretically be a function of the precipitation-droplet size spectrum, the precipitation rate, and the physical and chemical characteristics of the particle or gas (Hanna, Briggs, and Hosker, 1982). McMahon and Dennison (1979) reviewed field measurements of λ_{ip}^w , and found a great deal of scatter in these data. Hanna, Briggs, and Hosker (1982) suggest that the use of values of λ_{ip}^w for wet removal modeling may be at best an order-of-magnitude estimate of the amount of material removed by wet deposition processes. However, this is a more serious problem for short-term releases than it is for long-term releases.

The values of λ_{ip}^w used in ANEMOS are based on the use of washout ratios, W_{ri} . If K_{oi} and C_{oi} represent the concentration of the radionuclide (measured in units of mass per unit volume) in the precipitation and in the air, respectively, then (Hanna, Briggs, and Hosker, 1982),

$$W_{ri} = \frac{K_{oi}}{C_{oi}} \quad (36)$$

It should be noted that other definitions of W_{ri} are used in the literature (e.g., McMahon and Dennison, 1979; Slinn, 1978; Slinn et al., 1978). As a result, reported values of W_{ri} for various particles and gases may vary several orders of magnitude because of variations in the way W_{ri} is defined.

Hosker (in press) has shown that, to a reasonable approximation,

$$\lambda_i^w = \frac{W_{ri} J_o}{Z_w} \quad (37)$$

where

J_o = equivalent rainfall rate (m/s),

Z_w = depth of the plume layer through which the precipitation falls (m).

The user of ANEMOS may enter values of W_{ri} , J_o , and Z_w . It must be noted, however, that, while values of W_{ri} are reported in the literature, the accompanying values of Z_w are generally not reported. ANEMOS assumes the default value of Z_w is the depth of the mixed layer. Three values of W_{ri} have been suggested (Slinn et al., 1978; Slinn, 1978):

1. 1×10^6 for small particles;
2. 1×10^3 for reactive gases and vapors; and
3. 0 for nonreactive gases.

Default values of 1×10^6 for particles and 0 for gases are used in ANEMOS. ANEMOS presumes that rainfall occurs only during stability categories C and D. The value of J_o used in ANEMOS is given by

$$J_o = \frac{RR}{(f_3 + f_4)(3.16 \times 10^7)} \quad (38)$$

where

RR = annual rainfall (m),

f_3 - frequency of stability category C,

f_4 - frequency of stability category D,

3.16×10^7 - number of seconds in one year.

Note that through Eq. (38) ANEMOS assumes that it rains all the time during stability categories C and D. The value of λ_{pi}^w used to calculate λ_{ipr}^e for Eq. (33) is then equal to λ_i^w from Eq. (38) multiplied by the appropriate value of f_3 or f_4 . Values of λ_i^w may also be entered directly into ANEMOS by the user.

2.6.3 Radiological Decay and Total Depletion

Based on the radionuclides in the source term supplied as input by the user, ANEMOS sets up matrices of radiological decay constants, λ_i^n , and branching ratios for the calculation of parent decay and daughter ingrowth and decay by accessing a radionuclide decay data base (Kocher, 1981a). ANEMOS then creates arrays of released radionuclides and their associated daughter products for use in solving matrix equations similar in form to the scalar equation represented by Eq. (33). Note that, if dry and/or wet deposition effects are to be included, these last arrays contain λ_{ipr}^e , not just λ_i^n . The calculational model used to solve these equations in the ORIGEN-S code (Hermann and Westfall, 1981) has been incorporated into ANEMOS as well as other codes in the CRRIS. A complete description of this methodology may be found in the PRIMUS report (Hermann et al., 1984).

It should be noted that air concentrations and ground deposition rates are output in terms of the exposure radionuclides, that is, those radionuclides that actually result in an external exposure or intake to humans. Exposure radionuclides may be either released radionuclides or daughter products that are created in the plume during downwind transport. Also, a given radionuclide may appear more than once in the list of exposure radionuclides. This might happen, for example, if a released radionuclide is also a member of the decay chain associated with another released radionuclide. Each time a radionuclide appears in the list of exposure radionuclides, it will have a unique set of air

concentration and ground deposition rate values associated with it, calculated on the basis of its individual point and method of origin, that is, whether it was a released radionuclide or a progeny formed during the decay of one or more parent radionuclides. The effects on man due to the total exposure from a given radionuclide from all sources of origin may be obtained from the ANDROS code. ANDROS can provide (at the option of the user) an assessment based on either released or exposure radionuclides. In the first case, the assessment includes all decay product doses and risks associated with the released radionuclides. In the second, the contributions from all the released radionuclides are considered for each exposure radionuclide.

2.7 INTEGRATION OPTIONS

From Eq. (34), the dry deposition depletion integral, I_{dipr} , can be defined as

$$I_{dipr} = \int_0^x \frac{V_{dipr}}{u_r} G(p, x') dx' \quad (39)$$

One option in ANEMOS for solving this integral is to evaluate it using a Simpson's rule subroutine for numerical integration. While this is a reasonably accurate way of determining I_{dipr} , it is also relatively slow and expensive. As a result, ANEMOS includes an option for using a slightly less accurate but much faster method of solution.

In this second option, $G(p, x)$ is presumed to vary as a power function of x between successive grid points, that is,

$$G(p, x) = G(p, x_i)(x/x_i)^b \quad (40)$$

for

$$x_{i-1} \leq x \leq x_i ,$$

where

$$b = \frac{\ln \left[G(p, x_i) / G(p, x_{i-1}) \right]}{\ln(x_i / x_{i-1})} \quad (41)$$

In this case, the dry deposition depletion integral for the range x_{i-1} to x is given by

$$\begin{aligned} I_{\text{dipr}} &= \frac{v_{\text{dipr}}}{u_r} \int_{x_{i-1}}^{x_i} G(p, x) dx \\ &= \frac{v_{\text{dipr}}}{u_r(b+1)} G(p, x_i)x_i - G(p, x_{i-1})x_{i-1} \end{aligned} \quad (42)$$

For the range 0 to x , we can approximate $G(p, x)$ as $G(p, x_1)$ and the depletion integral becomes

$$I_{\text{dipr}} = \frac{v_{\text{dipr}}}{u_r} G(p, x_1) x_1 \quad (43)$$

3. GROUND DEPOSITION RATE CALCULATIONS

In addition to the calculation of air concentration, ANEMOS calculates the rate at which radionuclide i is deposited on the ground at location (x) , $W_{is}^t(x)$ (Bq/m²-year or Ci/m²-year) because of both dry and wet deposition processes; that is,

$$W_{is}^t(x) = W_{is}^d(x) + W_{is}^w(x) , \quad (44)$$

where

$W_{is}^d(x)$ - the ground deposition rate because of dry deposition;

$W_{is}^w(x)$ - the ground deposition rate because of wet deposition.

Values of $W_{is}^t(x)$ are used in other codes in the CRRIS as input for the calculation of terrestrial food-chain transport and for the calculation of direct dose to man as a result of ground deposition. The calculation of $W_{is}^d(x)$ and $W_{is}^w(x)$ in ANEMOS is discussed below.

3.1 DRY DEPOSITION

After the air concentration at a given location has been calculated, ANEMOS calculates $W_{is}^d(x)$ using the basic definition of the deposition velocity; that is,

$$W_{is}^d(x) = \sum_{p,r} V_{dipr} C_{is}(x) . \quad (45)$$

Whenever $V_{dipr} > 0$, values of $W_{is}^d(x)$ are calculated in ANEMOS for all time periods.

3.2 WET DEPOSITION

The rate of deposition onto ground surface from wet deposition processes is given by (Hanna, Briggs, and Hosker, 1982):

$$W_{is}^w(x) = \int_0^{Z_w} \lambda_{ip}^w C_{is}(z') dz', \quad (46)$$

where

$C_{is}(z')$ = air concentration within the vertical layer through which the rain is falling (Bq/m^3 or Ci/m^3).

Substituting Eq. (4) into Eq. (46) and integrating,

$$W_{is}^w(x) = \sum_{p=3}^4 \sum_{r=1}^{N_r} \frac{N_r Q'_{s iprs}(x)}{2\pi x u_r} \lambda_{ip}^w, \quad (47)$$

Equation (47) is used to calculate $W_{is}^w(x)$ in ANEMOS. Note again that wet deposition is calculated only under stability categories C and D; that is, $p = 3$ or 4 .

4. DOSES FROM FINITE GAMMA PLUMES

In the CRRIS, the dose to man as a result of an exposure to radionuclide i from one or more pathways is estimated in the ANDROS computer code (Begovich et al., in press). In ANDROS, the external dose at location (x) resulting from immersion in air contaminated by a gamma- or x-ray-emitting radionuclide, $D_{igs}(x)$ (Sv/year or rem/year), is given by

$$D_{igs}(x) = C_{is}(x)DRF_{ig} , \quad (48)$$

where

DRF_{ig} = the gamma or x-ray dose-equivalent rate per unit concentration of radionuclide i (Sv/year per Bq/m³ or rem/year per Ci/m³).

Values of DRF_{ig} derived assuming a semi-infinite cloud of photon emitters have been tabulated by Kocher (1981b), and these values are used in the ANDROS code. There are times, however, especially near the release point for elevated sources, when the assumption of a semi-infinite cloud at ground level is not met. Instead, the user must calculate the photon dose from a finite cloud passing over the ground. Failure to account for this overhead plume dose can lead to an underestimate of the near-in dose for an elevated release (Lahti, Hubner, and Golden, 1981).

If desired, a user of the CRRIS codes may calculate a finite cloud dose by exercising an option in ANEMOS. This calculation is made on the basis of the methodology presented by Healy and Baker (1968) and incorporated into U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 (USNRC, 1977a) for use with noble gas releases from stacks greater than 80 m in height. The computation performed by ANEMOS is adapted from the CRRIS code DFSOIL (Sjoreen et al., 1984). If D_{iprs}^g is the photon (γ) dose rate in air for radionuclide i , stability class p , wind speed class r , and wind direction s with units of Gy/s per Bq/m², it

follows from Eq. (4) that

$$D_{iprs}^G = \frac{P}{2} \frac{N_s Q'_{iprs}(x)}{2\pi x u_r} \sum_b E_b A_{bi} \left[\frac{\mu_{en}}{\rho} \right]_b \left[I_0 + \left[\frac{C_b}{1 - D_b} \right] I_1 \right], \quad (49)$$

$$I_0 = \int_0^\infty G(z) E_b(\mu_b z) dz, \quad (50)$$

$$I_1 = \int_0^\infty G(z) \exp \left[- (1 - D_b) \mu_b z \right] dz, \quad (51)$$

where

P - a constant which is the product of 1.6×10^{-10} g-Gy/MeV and 10^{-4} cm²/m²;

E_b - energy of photon energy group b (MeV/photon);

A_{bi} - photon yield in energy group b of radionuclide i (photons/disintegration);

$\left[\frac{\mu_{en}}{\rho} \right]_b$ - mass energy-absorption coefficient in air for energy E_b (cm²/g);

μ_b - linear attenuation coefficient in air for energy E_b (cm⁻¹);

C_b and D_b - coefficients in the Berger form of the energy-absorption buildup factor in air for energy E_b (B_{en}^a) given by Trubey (1966);

$B_{en}^a = 1 + C_b \mu_b z \exp(D_b \mu_b z)$;

z - distance between source (plume) and receptor (ground) (m).

Note that, if desired by the user, h_e may also be a function of downwind

distance, x . In ANEMOS, Eqs. (50) and (51) are solved using a subroutine developed by Hamawi (1976) and presented in Regulatory Guide 1.109 (USNRC, 1977a).

Once Eq. (49) has been solved, $D_{fs}(x)$ for the finite plume can be derived. This value is then divided by the appropriate DRF_{fig} to get an "effective" air concentration, $C_{ies}(x)$, that is, the air concentration one must have to get the same dose using a dose conversion factor based on the semi-infinite cloud model. It is this "effective" air concentration which is passed to ANDROS for subsequent calculations of dose and health risk due to submersion in contaminated air. Also, after each calculation, $C_{ies}(x)$ is compared to $C_{is}(x)$ at the same location. For an elevated release, $C_{ies}(x) > C_{is}(x)$ for quite some distance downwind of the release point. For a very low level release, $C_{ies}(x) < C_{is}(x)$ until quite some distance from the release. When the relationship $C_{ies}(x) \approx C_{is}(x)$ is satisfied for two successive downwind distances, ANEMOS automatically ceases calculating $C_{ies}(x)$ for that wind direction sector. This is important because evaluating Eqs. (49) through (51) is a very computer-intensive calculation and thus one does not want to make it any longer than absolutely necessary. One should also keep this fact in mind when deciding if it is necessary to select the option of calculating a finite plume dose for a given assessment problem.

To run the finite plume option in ANEMOS, the user must provide a file from which the data necessary to make the calculation can be read. These data include the identification of radionuclide i , values of A_{bi} , E_b , $\mu_b(E_b)$, and $(\mu_{en}/\rho)_b$ for each energy group b , and the value of DRF_{fig} . A file of these data for 462 nuclides will be provided with the source code.

5. EXPECTED ACCURACY OF THE ANEMOS CALCULATIONS

An important consideration when ANEMOS or any other assessment methodology is used is the question of what is the accuracy of the resulting concentrations. ANEMOS itself remains to be extensively tested to determine the accuracy of this particular combination of algorithms. However, Miller and Little (1982) have reviewed the uncertainty associated with the models used in ANEMOS. The following discussion is adapted from their report.

5.1 AIR CONCENTRATIONS

The best way to determine the overall uncertainty associated with atmospheric dispersion models such as the Gaussian plume model is to compare their predictions with environmental measurements taken under release conditions similar to those assumed by the model. Such studies need to be conducted under a variety of terrain, release height, and meteorological conditions. Unfortunately, not enough model validation studies have been performed or are likely to be performed to allow for a reliable statistical analysis of the uncertainty associated with the Gaussian plume model (Crawford, 1978; Faberick, Sklarew, and Wilson, 1977; Hilst, 1978; Koch et al., 1977). However, a number of validation studies were reviewed by Miller and Little (1982), and a summary of their results is presented in Table 9 (Miller and Little, 1983).

It can readily be seen from Table 9 that the uncertainty associated with Gaussian plume model predictions is highly dependent on the site and release conditions being considered. For routine release conditions considered over long time periods and over flat terrain, the uncertainties are relatively small. As the release time becomes shorter and/or the terrain becomes more complex, however, it can be seen that the uncertainty increases. The uncertainty also increases when releases occur under complex site or meteorological conditions, such as building influences or sea breeze regimes. This increase in uncertainty is not unexpected in view of the fact that spatial and temporal changes in air flow induced by such release conditions are not accounted for in the

Table 9. Estimates of the ratio of predicted to observed air concentration associated with predictions by the Gaussian plume atmospheric dispersion model under various release conditions (Miller and Little, 1983)

Conditions	Range	Variance of log-transformed data ^a
Non-complex terrain and meteorology		
Annual average concentrations		
0 - 10 km downwind	0.5 - 2	0.16
10 - 150 km downwind	0.25 - 4	0.64
Short-term, elevated releases		
Without building wake effects	0.1 - 10	1.8
With building wake effects	0.01 - 100	7.1
Short-term, surface-level releases		
With building wake effects	0.7 - 100	1.8 - 2.1
Without building wake effects	0.3 - 100	1.0 - 1.8
Complex terrain or meteorology (e.g., sea breeze regimes)		
Annual average concentrations	0.1 - 10	1.8
Short-term releases	0.01 - 100	7.1

^aCalculated by assuming that the given range in each case represents the extremes of a log-uniform probability distribution of predicted to observed ratios (Netter, Wasserman, and Whitmore, 1979).

normal straight-line Gaussian model, as discussed previously in Sect. 2.1.2.

5.2 DEPOSITION

A number of different measurements of dry deposition processes have been made (McMahon and Dennison, 1979; Sehmel, 1980). Also, a number of different models for estimating plume depletion have been proposed (Hosker, in press). However, Miller and Little (1982) report finding no data that are adequate for validating plume depletion processes. For example, calculations have been performed in which inclusion of depositional processes in the model predictions improved agreement with the observed air concentrations of fluorescein particles (Fields, Miller, and Cotter, 1981b; Little, Miller, and Cotter, 1982; Piepho, 1981). However, no deposition measurements were taken during the field studies considered in these comparisons. Good agreement has also been reported between three observed and predicted values of ^{131}I concentration on grass, but because of the input data used in the calculation, the authors do not consider their methods to constitute a validation study (Hubschmann and Miller, 1980). Until such data sets become available, Miller and Little (1983) suggest that one cannot specify the accuracy associated with a calculation of concentration on ground or with an air concentration involving significant plume depletion.

6. HOW TO RUN ANEMOS

ANEMOS requires several input files and user option selection via NAMELIST input. A large amount of data is in the input files, and their format is nontrivial. It is assumed that the user will be given these files along with the source code. Figure 12 diagrams the input and output for ANEMOS. A sample JCL and NAMELIST input file are included in Appendix A. The function of each file and the NAMELIST variables are presented below.

6.1 INPUT FILES

ANEMOS requires one to three files. First is the file of decay data. This file is used to determine the full decay chain of each released nuclide and to determine the decay matrices. This file is written by PRIMUS, which reads the standard decay data base and reformats it for ANEMOS. Second, if overhead gamma plume calculations are to be performed, then a file of data is required for those calculations. The file contains the number of photon energies used, the photon energies, the attenuation coefficient in air for each energy, and the linear energy-absorption coefficient in air for each energy. For each nuclide there are the nuclide name, the photon yield for each energy, and the dose factor for dose to air. The binned photon yields and dose factors were computed from a file of specific photon energies and intensities. Third, the wind frequency data may be entered either with the NAMELIST input or as a separate file. If these data are entered in a separate file, the file format is entered in the NAMELIST data. Also, ANEMOS requires a scratch file for intermediate calculations, and both the point value and average value output files are used as scratch files by ANEMOS.

Fig. 12. Diagram of ANEMOS input and output files, including unit numbers.

6.2 USER INPUT

The input options are read using NAMELIST input. The default value for each variable is given in parentheses.

6.2.1 NAMELIST/NAMRUN/TI

TI   - Title, 80 characters

6.2.2 NAMELIST/IOUNIT/KOUT,NR,NTEMP,NREAD,IOUT,NSTAR,FMT

KOUT   - Output unit number (6)
 NR   - Unit number of PRIMUS decay-chain library (2)
 NTEMP   - Unit number of temporary library (12)
 NREAD   - Unit number of problem decay library (3)
 IOUT   - Unit number of output file for TERRA/ANDROS (21)
           Unit IOUT+1 will be used for averaged grid cell values
 NSTAR   - Unit number for STAR data base if used; if 0 data entered in
           NAMELIST format (0)
 FMT   - Format for STAR data if used

6.2.3 NAMELIST/GRIDAT/ALAT,ALONG,SRUNIT,DI

ALAT   - Latitude of reference grid (decimal degrees)
 ALONG   - Longitude of reference grid (decimal degrees)
 SRUNIT   - Units of source, either 'BQ' or 'CI' ('CI')
 DI   - Alphanumeric names of the directions (default: clockwise
           directions)

6.2.4 NAMELIST/OPTS/TERHT, LINEAR, HTMAX, CWAKE, DNWASH, DSKIP, MAKEDS,
MAKEDA, FASDEP, OVPCAL, SROUGH, CONSHT, AVGG, CLAMDA, CUTOFF

- TERHT - Include terrain height calculations if TRUE (FALSE)
- LINEAR - Use linear option of effective height calculations if
TRUE (FALSE)
- HTMAX - Use maximum plume rise option if TRUE (TRUE)
- CWAKE - Include wake effects option if TRUE (FALSE)
- DNWASH - Include downwash effect if TRUE (FALSE)
- DSKIP - Fraction is input for only one D stability category (TRUE)
- MAKEDS - Output file for CRRIS with concentration/deposition
rates for each distance if TRUE; sets IOPT to TRUE (TRUE)
- MAKEDA - Output file for CRRIS with average concentration/deposition
rates for cell if TRUE; sets IOAVGG to TRUE (TRUE)
- FASDEP - Use exponential approximation for estimating dry plume deple-
tion instead of integrating if TRUE (TRUE)
- OVPCAL - Do overhead plume concentrations if TRUE (FALSE)
- SROUGH - Use Smith's F-factor adjustment to σ_z for roughness length if
TRUE (TRUE)
- CONSHT - The plume height will remain constant if TRUE (FALSE)
- AVGG - Calculations will be done for an average over two sequential
distances if TRUE (TRUE)
- CLAMDA - Dry deposition removal rates will be calculated if TRUE (TRUE)
- CUTOFF - Minimum V_g used; V_g is set to zero if less than CUTOFF (0.01)

6.2.5 NAMELIST/IOOPT/IOTIM, IOHGT, IOQPR, IOWSP, IOSGZ, IOCPQ, IODRY, IOPT,
IOAVGG, IOPART

- IOTIM - Output table of travel time from release (sec) if TRUE (TRUE)
- IOHGT - Output table of plume height if TRUE (TRUE)
- IOQPR - Output table of Q' if TRUE (TRUE)
- IOWSP - Output table of wind speeds if TRUE (TRUE)
- IOSGZ - Output table of σ_z if TRUE (TRUE)
- IOCPQ - Output table of C/Q if TRUE (TRUE)
- IODRY - Output table of average dry deposition λ 's if TRUE (TRUE)

- IOPT - Output summary tables for concentration and deposition at each distance if TRUE (TRUE)
- IOAVGG - Output summary tables for concentration and deposition averaged over consecutive distances if TRUE (TRUE)
- IOPART - Output summary tables for each particle size if TRUE (TRUE)

6.2.6 NAMELIST/OVPLUM/NUCOVP,NUMOVP,IOVP

- NUCOVP - Nuclide names for which the overhead plume gamma dose will be calculated
- NUMOVP - Number of nuclides for which gamma air dose from overhead plume will be calculated (≤ 5) (0)
- IOVP - Unit number of overhead plume data

6.2.7 NAMELIST/LOC DAT/NAMESR,RLOC,THLOC,XDIFF,YDIFF,AREA,HSTACK,DIAMS,VELS,TEMPS,TEMAIR,ZZERO,TERHTO,WBLD,HBLD,WMINHT,DELTLM,NUMX,X,MESHTY,NTHETA,NWIND,MINSTA,MAXSTA,XMAX,RHOAIR,WNDBLS,TTRAIN

- NAMESR - Source name ('TESTCASE')
- RLOC - Distance (m) source is from master grid reference point (0.)
- THLOC - Angular distance clockwise from north that the source is from the master grid reference point (0.)
- XDIFF - East-west distance (m) source is from master grid reference point (0.)
- YDIFF - North-south distance (m) source is from master grid reference point (0.)
- AREA - Area of the source (m^2) (0 for stack, 1. for windblown)
- HSTACK - Height of stack (m) or height of windblown source (100. for stack, 0 for windblown)
- DIAMS - Stack inner diameter (m) (0.)
- VELS - Stack exit velocity (m/s) (0.001)
- TEMPS - Stack exit temperature in $^{\circ}\text{C}$ (15.)
- TEMAIR - Ambient air temperature in $^{\circ}\text{C}$ (15.)
- ZZERO - Terrain surface roughness length (m) (0.1)

- TERHTO - Terrain elevation at stack base (m) (0.)
- WBLD - Width of most influential building (m) (0.)
- HBLD - Height of most influential building (m) (0.)
- WMINHT - Minimum height (m) of wind velocity correction of height (10.)
- DELTLM - If the average deviation from an average dry deposition is less than DELTLM, the average dry deposition is used in the decay calculations (0.02)
- NUMX - Number of distances in grid (1)
- X - User-defined downwind distances (m) (100.)
- MESHTY - Mesh size to use (1)
  - 1, coarse grid $x_i = x_{i+1}/2$
  - 2, medium grid $x_i = x_{i+1}/2^{0.5}$
  - 3, fine grid $x_i = x_{i+1}/2^{0.25}$
- NTHETA - Number of radial directions in grid (16)
- NWIND - Number of wind speed classes to use (6)
- MINSTA - Minimum stability class (1)
- MAXSTA - Maximum stability class (7)
- XMAX - Largest x direction (m), used with MESHTY only (0.)
- RHOAIR - Density of air (g/cm³) (1.317E-3)
- WNBLS - The source is a windblown source if TRUE (FALSE)
- TERAIN - Terrain heights (m); TERAIN (I,J) is terrain height for direction I, distance J (0.)

6.2.8 NAMELIST/METDAT/ UIN, ZIN, OPTLID, HLID, OPTRN, RAINAV, RAIN, FRACW

- UIN - Wind speeds of wind classes (m/s) (1., 3.2, 4., 7.2, 9.3, 13.)
- ZIN - Height of UIN (m) (10.)
- OPTLID - Compute mixing layer dependent on morning and afternoon mixing heights if TRUE or input for stability class if FALSE (TRUE)
- HLID - Lid heights (m) of mixing layers for 8 stability class or morning then afternoon mixing height (m) depending on OPTLID (8*2000.)
- OPTRN - Calculate average rainfall from period of release and total

if TRUE, read in an average rainfall if FALSE (FALSE)

RAINAV - Average rainfall rate (mm/hr) when it is raining; calculated if OPTRN is TRUE, by $\text{RAINAV} = \text{RAINAM}(m) / [\text{TREL}(\text{days}) * \text{fraction of C and D stabilities} * 24 \text{ hr/day}]$ (0.)

RAIN - annual rainfall (mm) (0.)

FRACW - Wind frequency (I,K,J): Ith wind speed class, Kth direction, Jth stability class ($6*16*8*0.$)

6.2.9 NAMELIST/NSIZES/NDAT,NNUC,NCAT

NDAT - Number of nuclide data tables (1)

NNUC - Number of released radionuclides (1)

NCAT - Number of particle distribution data tables (1)

6.2.10 NAMELIST/NUCDAT/INDEX,SYMBOL,RELSR,RSYM,CLEARF(3)

Enter one NUCDAT NAMELIST for each released nuclide.

INDEX - Index table for nuclide particle distribution (0)

SYMBOL - Alphanumeric name of nuclide (U-238)

RELSR - Source term--release rate (Ci/s or Bq/s) or activity concentration for windblown source (Ci/g or Bq/g)(0)

RSYM - Symbol of released nuclide (' ')

CLEARF - Clearance class fractions--fraction in D, W, and Y (0.,0.,0)

6.2.11 NAMELIST/PARTAB/PDIAM,PFRAC,PRHO,DEPVEL,INDEX,NPAR,PWR,PZW,PJO

Enter one PARTAB namelist and one WNDBLD NAMELIST for each particle category defined

PDIAM - Nuclide particle diameter in μm (0 for gas) (0.3,1.0,3,10,30)

PFRAC - Fraction of nuclide with values of PDIAM, PRHO, etc. (0,1,0,0,0)

PRHO - Nuclide particle density (g/cm^3) (1)

- DEPVEL - Deposition velocity (V_d) of nuclide particle (m/s)
(0.01, 0 for gas)
- INDEX - Particle size category number, a maximum of 40 (position in
input list)
- NPAR - Number of particle size types in this particle size category,
a maximum of 4 (3)
- PWR - Washout ratio (1E-6 for particles, 0 for gases)
- PZW - Depth of plume layer (m) (lid height)
- PJO - Equivalent rainfall rate (m/s) (computed from annual rate)

6.2.12 NAMELIST/WNDBLD/ITYPE,RF

Include NAMELIST WNDBLD only if WNDLBS = TRUE

- ITYPE - 1 for nearly uniform sand
2 for naturally graded sand
3 for wide range of grain sizes (3)
- RF - proportion factor (1/m) required to estimate the suspension
rate from the saltation rate (1.E-5)

6.3 OUTPUT

ANEMOS can write an extensive output listing. The user can include or exclude parts of this listing using the NAMELIST options described above. A sample output listing is presented in Appendix B. One to three output files may be written by ANEMOS. A problem-specific decay file, like that written by PRIMUS, can be constructed by ANEMOS. Air concentrations and ground deposition rates can be written to output files two ways, either as point values or as cell averaged values. If both are requested, then two separate files are written. These files are in the proper format to be read by the codes which follow ANEMOS in the CRRIS. These are unformatted files with variable record lengths. All data are scalars unless otherwise noted. All arrays are dimensioned 40 unless otherwise noted. For each variable written, the variable type

and a definition are given. The data contained in this file are as follows:

line 1

TITLE	R4	dimensioned 20; 80 character title
GRDOPT	I4	grid option
IPTOGR	I4	point or averaged deposition option
ALAT	R8	source latitude
ALONG	R8	source longitude
RLOC	R8	input data used to relate source to grid
THLOC	R8	input data used to relate source to grid
DIFFX	R8	input data used to relate source to grid
DIFFY	R8	input data used to relate source to grid
UNIT	R4	'CI' or 'BQ'
NLOC	I4	number of locations included

line 2

ICODE	I4	designates which CRRIS codes produced this file
OPTS	I4	dimensioned 13 options used in running ANEMOS: TERHT, LINEAR, HTMAX, CWAKE, DNWASH, CLAMDA, SUMIT, FASDEP, OVPCAL SROUGH, CONSHT, SAREA, SUMIT

line 3

NRNUCS	I4	number of released nuclides
(ZASRN(I),		
I=1,NRNUCS)	I4	ZAS numbers of released nuclides
NPACK	I4	number of exposure nuclides
(ZAS(I),		
I=1,NPACK)	I4	ZAS numbers of exposure nuclides

The following lines are repeated for each NLOC location:

line A

XMIN   R4   minimum radius of circular grid
 XMAX   R4   maximum radius of circular grid
 YMIN   R4   minimum angle of circular grid
 YMAX   R4   maximum angle of circular grid
 NIND   I4   number of lines to follow for each location,
                  excluding lines C

Lines B, C, and D are repeated for each particle size category.

line B

1   I4   indicates air concentration
 NPACK   I4   number of values written
 (CPACK(I),I=1,NPACK)   R4   data values

line C

(PSIZE(N),N=1,NPACK)   R4   particle size
 ((CLCLS(I,N),I=1,4),
 N=1,NPACK)   R4   clearance class

Line D, written only if overhead gamma calculations were performed.

2   I4   indicates effective air concentration
 NPACK   I4   number of values written
 (CPACK(I),I=1,NPACK)   R4   data values

line E

10   I4   indicates deposition rates
 NPACK   I4   number of values written
 (CPACK(I),I=1,NPACK)   R4   data values

7. THE COMPUTER PROGRAM

7.1 PROGRAM FLOW

The basic programming flow of ANEMOS is outlined below. The subroutines which are involved in the steps are indicated in parentheses.

1. Input data using NAMELIST statements (MAIN, RDNUC, WBREL, OVPDAT).
2. Set the decay parameters for released nuclides and their daughters (SETDEC, ISERCH, REDUCE, ID, LIBMAK, RELESE).
3. Determine the deposition velocity, settling velocity, and wet and dry deposition lambda for every particle size category (SETDEP, SETVD).
4. Adjust the wind speed to stack height (WIND).
5. Calculate effective stack heights (HTEFF); output if requested (OUTHG1).
6. Compute corrections if necessary for area source model (AREASR).
7. Adjust the wind speed to effective stack height and calculate travel times (WIND); output if requested (OUTWSP, OUTTIM).
8. Calculate dispersion coefficients σ_z (SIG, FFAC, WAKE); output if requested (OUTSGZ).
9. Begin loop over particle sizes, wind speed, and stability class (GCONC).
10. Calculate depletion fraction (DPRATE, DPFINE).
11. Deplete the plume; that is, calculate Q' (DPLETE, DECAY, QPRIME); output if requested (OUTQPR).
12. Begin loop over nuclide category, that is, nuclides with same gravitational velocity and fraction in each particle size (GCONC).
13. Begin loop over distance (GCONC).
14. If terrain height is considered, begin loop over direction (GCONC).

15. Calculate G (GCONC,V).
16. Begin loop over direction if terrain height was not considered (GCONC).
17. If necessary, correct factors for area source calculation (GCONC).
18. Calculate C/Q (GCONC).
19. Begin loop over nuclides (GCONC).
20. Calculate air concentration, total deposition, and dry deposition (GCONC).
21. Calculate overhead gamma shine (GCONC, DOSINT).
22. End loops over nuclide, direction, distance, wind speed, and stability class (GCONC).
23. Output to temporary file air concentration, dry deposition, and total deposition for each particle size (GCONC).
24. Average over consecutive distances, if required (AVERI, INTEQA).
25. Write C/Q (OUTCPQ) and flux (OUTFLX) if requested.
26. End loop over particle size (GCONC).
27. Write average dry deposition lambda (OUTDRY); write average plume height if requested (OUTHG2).
28. Print final results (PRINTR).
29. Output to the CRRIS system file (FILEIO).

Table 10 lists all ANEMOS routines, their calls, and their COMMONs.

7.2 MODEL FEATURES

As noted in the previous sections of this report, ANEMOS is basically a Gaussian plume model for the atmospheric transport of radionuclides. The specific features incorporated in the code can be grouped in the areas of:

1. source calculations,
2. dispersion calculations,
3. plume height calculations,
4. plume depletion calculations,

Table 10. ANEMOS routines, their calls, and their COMMONs

Routine	Called from	Calls	COMMONs
MAIN		CLEARC RDNUC DPHEAD SETDEC FILEIO SETDEP GCONC SZ LIBMAK XCALS OVPDAT ZS PRINTR ZD	BIGMAT LMAXCM CASE MATRX CH MISDB CHK NUCDAT CLFLAG NUCSTO DEPDAT OPT DEPSTO OUTDS DIR OVPLGS HT PARM HUT PL IO SIZE SC IONUMB STABIN IOOUT
AREASR	GCONC		
AVERI	GCONC	INTEQA	
CLEARC	MAIN		IONUMB LABEL
DECAY	DPLETE	DECDC	DECP
DECDC	DECAY		
DECEX	DECAY		
DECEP	DECAY		
DOSINT	GCONC		
DPFINE	DPRATE	HTEFF NPOWER SIG SIMPUN V	OPT PARM
DPHEAD	MAIN		IONUMB NUCDAT
DPLETE	GCONC	DECAY DRYARG QPRIME	DEPDAT IONUMB NUCDAT
DPRATE	GCONC	DPFINE SIMPUN V	CASE IONUMB CLFLAG NUCDAT DEPDAT STABIN
DRYARG	DPLETE		
E02CBF	FFAC		
FFAC	SIG	E02CBF	
FILEIO	MAIN		CASE NUCDAT DEPDAT OPT DIR OUTDS IONUMB OVPLGS IOOUT SIZE SC

Table 10. (Continued)

Routine	Called from	Calls		COMMONs	
GCONC	MAIN	AREASR	OUTHG1	CASE	IONUMB
		AVERI	OUTHG2	DEPDAT	IOOUT
		DOSINT	OUTQPR	DIR	NUCDAT
		DPLETE	OUTSGZ	EXTRA	OPT
		DPRATE	OUTTIM	HT	OUTDS
		HTEFF	OUTWSP	IO	OVPLGS
		NPOWER	SIG	PARM	
		OUTCPQ	V	STABIN	
		OUTDRY	WIND		
		OUTFLX	ZS		
HTEFF	DPFINE GCONC			HT PARM	OPT
ID	LIBMAK OVPDAT RDNUC RELESE SETDEC			IONUMB LABEL	
INTEQA	AVERI				
ISERCH	SETDEC				
BLOCK DATA				LABEL	
LIBMAK	MAIN	ID RELESE		IONUMB NUCDAT	
NPOWER	DPFINE GCONC WBREL WIND				
OUTCPQ	GCONC			CASE IONUMB	DIR
OUTDRY	GCONC			CASE	IONUMB

Table 10. (Continued)

Routine	Called from	Calls		COMMONs	
OUTFLX	GCONC			CASE IONUMB	DIR OUTDS
OUTHG1	GCONC			CASE	IONUMB
OUTHG2	GCONC			CASE	IONUMB
OUTQPR	GCONC			CASE OUTDS	IONUM
OUTSGZ	GCONC			CASE	IONUMB
OUTTIM	GCONC			CASE	IONUMB
OUTWSP	GCONC			CASE	IONUMB
OVPDAT	MAIN	ID		IONUMB	OVPLGS
PRINTR	MAIN	ZS		CASE DEPDAT DIR IO	IONUMB OUTDS OVPLGS SIZEsc
QPRIME	DPLETE				
RDNuc	MAIN	ID WBREL	SZ	NUCSTO	
REDUCE	SETDEC			IONUMB	
RELESE	LIBMAK	ID		IONUMB	
SETDEC	MAIN	ID ISERCH	REDUCE	IONUMB OUTDS	NUCDAT
SETDEP	MAIN	SETVD		DEPDAT	IONUMB
SETVD	SETDEP			PARM	
SIG	DPFINE GCONC	FFAC WAKE		HT OPT	PARM

Table 10. (Continued)

Routine	Called from	Calls	COMMONs
SIMFUN	DPRATE DPFINE		
SZ	MAIN RDNVC		CHK IONUMB
V	DPFINE DPRATE GCONC		
WAKE	SIC		IONUMB
WBREL	RDNUC	NPOWER	IONUMB PARM
WIND	GCONC	NPOWER	PARM
XCALC	MAIN		
ZD	MAIN		
ZS	GCONC MAIN PRINTER		

4. plume depletion calculations,
5. overhead gamma shine calculations, and
6. output files.

The following sections describe where these calculations are located within the code.

7.2.1 Source Calculations

The main data for a source are read in subroutine RDNUC. If the area of the source is greater than 0, the area source calculations are done. If the input indicates a windblown source (WNDBLS = true), then the source is assumed to be an area source.

The area source calculations are performed in AREASR and GCONC. Subroutine AREASR calculates the effective source-to-receptor distance and the number and fraction of each adjoining sector to use in summary of the multiple effects of the area source (Sect. 2.3). The information is stored and passed to GCONC, where the main C/Q calculations are performed using the effective distance between the source and the receptor [Eqs. (23) and (24)]. An estimate of the concentration in a sector due to the area source is then derived by using the fraction of the frequencies of the adjoining sectors.

For the windblown source, the threshold velocity for each particle size is computed in WBREL [Eq. (30)]. The amount of contaminant reentering the air is approximated [Eq. (31)] for every stability and wind speed class and is averaged using the frequency from the meteorological data. The average release rate for each particle size of the windblown source is then returned to subroutine RDNUC.

7.2.2 Dispersion Calculations

The general procedure used for calculating C/Q is given in Eq. (4). This calculation is done primarily in subroutine GCONC, with separate calls for determining many of the parameters as described below. The mean wind speed at downwind distance x , height z_2 , and stability class p

is calculated in WIND using the power law [Eq. (6)].

The σ_z values are computed using the method given by Hosker in subroutine SIG. If the option (SROUGH) is specified, Smith's (1972) F factor is calculated as a function of roughness length and distance using a bicubic spline fit to Smith's curve. Subroutine FFAC calls NAG routine E02CBF (NAG, 1981) for these calculations. The σ_z values may also be adjusted for building wake effects (see Sect. 2.2.4.2).

The infinite sum in Eq. (4), that is, the multiple reflection term, is summed in GCONC until the nth term is less than 10^{-6} of the sum up to that point. The multiple reflection term accounts for the gradual filling up of the mixing layer until $\sigma_z = 2h_L$. Once $\sigma_z > 2h_L$, $G = 1/h_L$ is used.

7.2.3 Plume Height Calculations

The plume height calculations include options for calculating buoyancy plume rise, momentum plume rise, stack downwash, and building wake effects. The user may specify an option to allow the height to remain constant (CONSHT), to use the maximum plume height (HTMAX) as a function of stability and wind speed, or to compute the plume height as a function of distance also. Option LINEAR determines whether the physical stack height is modified linearly [Eq. (19)] or by cubes [Eq. (20)]. The effective height calculations are performed in subroutine HTEFF and can be output in a table by subroutines OUTHG1 or OUTHG2. The plume rise and downwash correction is calculated in HTEFF using the formulation described in Sect. 2.2.5.

7.2.4 Plume Depletion Calculations

One of the unique features of ANEMOS is the capability of computing radionuclide decay and daughter buildup along with wet and dry deposition plus settling. The basic flow of the computation includes the determination of chain daughters and half-lives from a standard library, the calculation of depletion rates, and then the final calculation of the decayed and depleted source term for each nuclide and

distance. The routines (LIBMAK, SETDEC, RELESE), which set up the decay library, are from the code PRIMUS, described in a companion report (Hermann et al., 1984).

The wet deposition lambda calculations are performed in subroutine WASH (Sect. 2.6.2). The calculation for λ_d (Sect. 2.6.1) is done in subroutine DPRATE. The calculation is performed for each nuclide, particle size, wind speed class, stability class, and distance.

To avoid time-consuming numerical integration at each step, two options are available in the code for calculating plume depletion caused by dry deposition. The first option is to assume that the deposition process can be approximated by a succession of simple exponential removals so the value of λ_d is calculated only at the endpoints of the interval. In the second option, numerical integration is performed with the integration done by Simpson's rule (SIMPUN) using only each distance as a grid point. Using the results of that integration, I, the λ_d is calculated using:

1. I or the value assuming that the integrand is constant, whichever is greater, if $I < .001$;
2. I, if $.001 < I < .02$; or
3. The interval between x_i and x_{i+1} is subdivided into 10 grid points and a new approximation for the integral is obtained if $I > .02$.

The depletion and decay calculations are then combined in subroutine DPLETE. The routine DECAY, which computes the nuclide chain decay and build-up plus the source depletion, is accessed from DPLETE. The equations for the DECAY subroutine are described in Sect. 2.6.3. Again, an option has been added to possibly save computing time. To avoid calling DECAY for every distance, if the deviation of λ_d for one distance is less than an input fraction (DELTLM) of the average λ_d over distances within the same geometric progression and if the adjustment factor to account for using the average λ_d is less than .095, DECAY is called only once for the distances within that geometric progression. After the call to DECAY, subroutine QPRIME calculates the depleted source for each nuclide at each distance.

7.2.5 Overhead Gamma Plume Calculations

The overhead gamma plume calculation is described in Sect. 4. The photon energy groups and the linear attenuation coefficient plus the air energy absorption coefficient related to each energy group are input in a separate file (see Appendix A). This file also contains the photon yield for gamma-ray photons in each energy group and the total-body dose conversion factor for air immersion for each radionuclide. These values are read and printed in subroutine OVPDAT. As the air concentration calculations are being done in CCONC, subroutine DOSINT is called to perform the numerical integration of Eq. (49), and the annual gamma air dose is calculated. The dose is then divided by the whole-body dose conversion factor for air immersion to give an effective air concentration. When the overhead plume effective air concentration and the actual air concentration become approximately equal for two consecutive downwind distances, ANEMOS automatically ceases calculating the effective air concentration for that wind direction sector. The effective air concentrations are stored in a separate array and printed out separately.

7.3 SUBROUTINE DESCRIPTIONS

MAIN

The MAIN routine sets defaults, reads input data using NAMELIST, and prints input data. It then calls the primary routines for the calculations to be performed and finally calls the I/O routines.

AREASR

This subroutine transforms the area source into a circular sector.

AVERI

This routine calculates an average concentration value over a circular sector using the methods described in Sect. 2.2.3.

CLEARC

CLEARC sets the default clearance classes (Table 8) for each nuclide.

DECAY, DECDC, DECEX, DECP

These routines calculate the decay and ingrowth of a single nuclide chain using the method described in Sect. 2.6.3.

DOSINT

This subroutine was written by Dr. John Hamawi to calculate the dose integral for overhead plume gamma shine (USNRC, 1977a).

DPFINE

This routine is called from DPRATE and divides a distance into smaller grid spaces to get a more accurate solution using Simpson integration to determine the dry deposition lambda.

DPHEAD

This subroutine reads the header records for the temporary file storing the problem decay library.

DPLETE

This routine prepares the decay matrices for each nuclide chain. It calculates the coefficient matrix for decay plus depletion and calls DECAY.

DPRATE

This routine calculates the depletion fraction for wet and dry deposition. The dry deposition lambda is calculated as described in Sect. 2.6.1.

DRYARG

This routine calculates the maximum adjustment factor to dry deposition necessary if the average dry deposition is used to avoid the calling to the DECAY routines for each distance.

FFAC

This routine from ATM-TOX (Raridon et al., 1984) is used to interpolate over roughness, length, and distance to get Smith's (1972) F-factor.

FILEIO

This routine writes the files for use by other codes in the CRRIS.

GCONC

This routine controls the primary calculations of the air concentration and deposition rates. Equation (4) is determined after the various parameters are calculated by calls to separate routines. If the source is an area source, the necessary summary over sectors is done. If overhead plume gamma shine calculations are requested, they are also controlled here. The air concentrations for each particle size and deposition rate are then written to a temporary file for later use.

HTEFF

This routine calculates the effective stack height due to plume rise, stack downwash, and wake effects depending on the requested options.

ID

This function converts an alphanumeric nuclide name to its ZAS number.

INTEQA

This routine calculates the parameters used to calculate an integral average used by routine AVERI.

ISERCH

ISERCH searches the master decay library for nuclide chains. It is called from SETDEC.

LIBMAK

This routine collects information for and writes the header of the problem decay library.

NPOWER

This routine computes the wind profile exponent.

OUTCPQ

This routine writes a table for C/Q.

OUTDRY

This routine writes the average dry deposition lambda.

OUTFLX

This routine writes the calculated flux for each distance and direction.

OUTHG1

This routine writes the effective stack height for stability class, wind speed class, and distance.

OUTHG2

This routine writes the effective stack height for distance, averaged over stability class and wind speed.

OUTQPR

This routine writes a table of effective source strength.

OUTSGZ

This routine writes the σ_z dispersion parameter.

OUTTIM

This routine writes a table of travel time to each downwind distance for each direction.

OUTWSP

Wind speeds are written by this routine.

OVPDAT

This routine reads the data file for overhead plume calculations.

PRINTR

This routine prints tables of air concentrations and ground deposition rates.

QPRIME

This routine calculates effective source strength resulting from decay and depletion.

RDNUC

This routine reads the nuclide-dependent data and the particle size category data.

REDUCE

This routine removes short half-life daughters from the calculations.

RELESE

This routine sets pointers for the released nuclides.

SETDEC

SETDEC determines the nuclide chains that result from the released nuclides.

SETDEP

This routine determines the arrays for gravitational fall velocity, deposition velocity, and wet deposition lambda. The particle size category for each nuclide is also set.

SETVD

This routine computes the gravitational fall velocity and the stability-dependent dry deposition lambda.

SIG

This routine calculates the σ_z and adjusts it for wake effects if necessary. SIG calls WAKE to compute S_z .

SIMPUN

This routine written by Barish (Westley and Watts, 1970) performs numerical integration using Simpson's rule.

SZ

This routine checks input parameters to determine if any array capacities are exceeded.

V

This function computes G.

WAKE

This routine determines the distance to add to σ_z to account for building wake effects using Newton's method.

WBREL

WBREL calculates the average release rate for a windblown source.

WIND

This routine adjusts the wind speed to effective stack heights.

XCALC

XCALC determines the x distances for the grid.

ZD,ZS

These routines initialize arrays to 0.

A complete listing of the ANEMOS computer code may be found in Appendix C.

8. DISCUSSION

ANEMOS is the short-range air transport model of the CRRIS. It directly replaces the AIRDOS-EPA model, except for the food-chain calculations, which are in TERRA, and the dose calculations, which are in ANDROS. ANEMOS is a much more complex model than AIRDOS-EPA and includes many more user options. An advantage to using ANEMOS is that default values are included for all options so that very little input is needed when the defaults are acceptable. ANEMOS incorporates several computations that were not available in AIRDOS-EPA, including the overhead gamma plume computation. Although ANEMOS allows the entry of data for only one source, the code SUMIT can sum and scale several ANEMOS runs. It is possible to run ANEMOS once for a unit release and then use SUMIT to scale and translate that one output file many times to simulate a complex multiple-source release.

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APPENDIX A

**Printout of the Data File
Used in ANEMOS to Calculate
Doses from Finite Gamma Plumes**

APPENDIX B

Sample Problem

An example run of ANEMOS has been made assuming a unit release of three radionuclides (^3H , ^{14}C , and ^{222}Rn) from a point source 43 m in physical height. Annual average meteorological data for Evansville, Indiana, were used for the calculations.

The input data used and the calculational options selected for this run are given on the following pages. Note that since the released radionuclide ^{222}Rn is a gas, a nuclide data table was input for its first particulate daughter product, ^{218}Po . All subsequent particulate daughters of ^{222}Rn (^{214}Pb , ^{214}Bi , ^{210}Pb , ^{210}Bi , and ^{210}Po) are defaulted to have the same particle size and clearance class distributions as that input for ^{218}Po .

A complete set of output tables generated by this sample run can be found on the microfiche attached to the back cover page of this report. The Job Control Language file and the NAMELIST file that were used to run this sample problem at Oak Ridge National Laboratory are also included on this microfiche.

APPENDIX C

The ANEMOS Code

SAMPLE RUN TO TEST ANEMOS

```
UNIT NUMBER: 5
INPUT DATA: 6231
PRINT DATA: 1231
TEMP FILE: 1231
OUTPUT FILE: 21
```

UNITS OF RELEASE
REFERENCE LONGTYPE
INFORMATION:
LAYTYPE
35-500
35-500
C1

.....

NUMBER OF RELEASES RADIATIONCLIDES= 5
NUMBER OF HUGL OF DATA TABLES= 5
NUMBER OF PARTICLE DISTRIBUTION TABLES= 2

```

THE SOURCE NAME IS TEST
THE DISTANCE (M) FROM THE REFERENCE GRID IS 0.00E+00
THE ANGLE (DEG) FROM THE REFERENCE GRID IS 0.00E+00
THE ANGLE OF DISTANCE FROM THE REFERENCE GRID IS 0.00E+00
THE AREA OF THE SOURCE IS 0.00E+00 M=2

```

[illegible]

AM OUTPUT FILE (POINT) FOR TERRA/ANDROS WILL BE WRITTEN.
AM OUTPUT FILE (AVERAGE) FOR TERRA/ANDROS WILL BE WRITTEN.

THE MAXIMUM PLUMBER RISE OPTION WILL BE USED. CATEGORICAL
COST OPPOSITION REMOVAL RATE IS 15% IN CATEGORY A. RATE
ONLY ONE D STABILITY CATEGORY IS INPUT IN CATEGORY A.

THE MIXING LAYER HEIGHT WILL BE AVERAGE OVER THE ENTIRE FACTOR WILL BE 1.50. INC.

WG WILL BE SET TO ZERO IF LESS THAN 1.0E-02
HREFS FOR THE COMPUTATION IS 1.00E+00
20-301.0E-02

[illegible][illegible]

TERRAIN ROUGHNESS (M) = 1.0E-01
 TERRAIN ELEVATION (M) AT STATION BUILDING = 3.00E+00
 WIND DIRECTION (M) OF MOST INFLUENTIAL BUILDING = 1.0E+00
 WIND VELOCITY CORRECTION (M) = 1.0E+00
 WIND VELOCITY CORRECTION IS 1.0E+00
 ALLOWABLE DEVIATION FROM AVERAGE LAMCDA IS 2.0E-02


```

11 0.000000 0.000000 0.000000 0.020219 0.000000 0.000000 0.000000
12 0.000000 0.000000 0.000000 0.004260 0.000000 0.000000 0.000000
13 0.000000 0.000000 0.000000 0.001170 0.000000 0.000000 0.000000
14 0.000000 0.000000 0.000000 0.000719 0.000000 0.000000 0.000000
15 0.000000 0.000000 0.000000 0.000150 0.000000 0.000000 0.000000
16 0.000000 0.000000 0.000000 0.000480 0.000000 0.000000 0.000000
1 0.000000 0.000000 0.000000 0.000769 0.000000 0.000000 0.000000
2 0.000000 0.000000 0.000000 0.003249 0.000000 0.000000 0.000000
3 0.000000 0.000000 0.000000 0.004493 0.000000 0.000000 0.000000
4 0.000000 0.000000 0.000000 0.001510 0.000000 0.000000 0.000000
5 0.000000 0.000000 0.000000 0.000308 0.000000 0.000000 0.000000
6 0.000000 0.000000 0.000000 0.000460 0.000000 0.000000 0.000000
7 0.000000 0.000000 0.000000 0.001610 0.000000 0.000000 0.000000
8 0.000000 0.000000 0.000000 0.001017 0.000000 0.000000 0.000000
9 0.000000 0.000000 0.000000 0.002269 0.000000 0.000000 0.000000
10 0.000000 0.000000 0.000000 0.001412 0.000000 0.000000 0.000000
11 0.000000 0.000000 0.000000 0.000347 0.000000 0.000000 0.000000
12 0.000000 0.000000 0.000000 0.000630 0.000000 0.000000 0.000000
13 0.000000 0.000000 0.000000 0.000020 0.000000 0.000000 0.000000
14 0.000000 0.000000 0.000000 0.000080 0.000000 0.000000 0.000000
15 0.000000 0.000000 0.000000 0.000070 0.000000 0.000000 0.000000
16 0.000000 0.000000 0.000000 0.000460 0.000000 0.000000 0.000000
1 0.000000 0.000000 0.000000 0.000120 0.000000 0.000000 0.000000
2 0.000000 0.000000 0.000000 0.000180 0.000000 0.000000 0.000000
3 0.000000 0.000000 0.000000 0.000380 0.000000 0.000000 0.000000
4 0.000000 0.000000 0.000000 0.000070 0.000000 0.000000 0.000000
5 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
6 0.000000 0.000000 0.000000 0.000030 0.000000 0.000000 0.000000
7 0.000000 0.000000 0.000000 0.000180 0.000000 0.000000 0.000000
8 0.000000 0.000000 0.000000 0.002950 0.000000 0.000000 0.000000
9 0.000000 0.000000 0.000000 0.000900 0.000000 0.000000 0.000000
10 0.000000 0.000000 0.000000 0.002350 0.000000 0.000000 0.000000
11 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
12 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
13 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
14 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
15 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
16 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000

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NET DATA SUMMARY
WIND DIRECTIONS
FRACTION TOWARD N 0.025% NNE 0.0041 NE 0.0948 ENE 0.1010 E 0.0216 ESE 0.0154 SE 0.0218 SSE 0.0793 S 0.1304 SSW 0.1712 SW 0.1192 WSW 0.0364 W 0.0133 WNW 0.0287 NNW 0.0227 VNW 0.0314

NET DATA SUMMARY
STABILITY CLASSES
FRACTION OF EACH 1 0.0207 2 0.2343 3 0.1745 4 0.2021 5 0.0000 6 0.1718 7 0.1165

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SW7J CLASS
NO SPECIFIC
DISTANCE: STABILITY

93.00 200.20 453.00

[illegible][illegible][illegible][illegible]

[illegible]

NUCLEON	DISTANCE FROM SOURCE IN:	FUNCTIONS										SVI	J	AV
		US	3M	PS	NSP	2	35J	35	35J	35	35J			
90-210	0.0005+00	1.0	7.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	5.252-36
90-210	0.0005+00	2.0	7.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.012-03
91-210	0.0005+00	8.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.582-08
90-210	0.0005+00	8.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.372-54
90-220	0.0005+00	8.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.802-07
90-210	0.0005+00	1.0	5.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.852-04
90-210	0.0005+00	2.0	5.0	5.0	4.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.252-09
91-210	0.0005+00	4.0	5.0	5.0	9.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.752-11
90-210	0.0005+00	4.0	5.0	5.0	9.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.722-11
90-210	0.0005+00	1.0	5.0	5.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.822-19
91-210	0.0005+00	7.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.312-23
90-210	0.0005+00	1.1	5.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	5.372-29
90-220	0.0005+00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.312+00
90-216	0.0005+00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.312+00
90-212	0.0005+00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.372-03
91-212	0.0005+00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.072-05
90-212	0.0005+00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.072-05
71-208	0.0005+00	5.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.172-06
90-230	0.0005+00	8.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.802-07
91-230	0.0005+00	2.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.372-17
91-220	0.0005+00	3.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.002-26
90-220	0.0005+00	5.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.362-30
90-210	0.0005+00	1.0	5.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.002-31
90-210	0.0005+00	1.0	5.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.332-32
91-210	0.0005+00	1.0	5.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.122-34
90-210	0.0005+00	1.0	5.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.122-34
91-210	0.0005+00	7.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.332-41
90-210	0.0005+00	5.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.102-43
90-210	0.0005+00	1.0	5.0	5.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.122-51
90-220	0.0005+00	8.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.022-07
90-210	0.0005+00	8.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.362-07
90-210	0.0005+00	9.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	5.742-09
91-210	0.0005+00	9.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.742-10
90-210	0.0005+00	9.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.742-10
90-210	0.0005+00	3.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.192-17

DISTANCE FROM SOURCE IN:

FUNCTIONS

NUCLEON

DISTANCE (M): 90.000
DIRECTOR: P-312T
ADJUTANT: 0
CLEARANCE CLASS.

PSIZE	GROUPS	REP	PAT	CI/M=2/SEC	AIH CONC	EFF AIH CONC
PRACF	STY	RT		(CI/M=3)	(CI/M=3)	(CI/M=3)
				TOTAL		

DISTANCE(MI)	98300
DIRECTION FROM	SOURCE
RADIOMODE	P.SIZE
(MICROVS)	CLEARANCE
	Y CLASS.
	P.SIZE
	GROUND DEF RATT(CI/MO-2/ARC)
	3NY TOTAL
	AIR CONC
	(CI/MO-3)
	EFF AIR CONC
	(CI/MO-3)

[illegible]

[illegible]

SOMEONE LEFT A NOTE ON THE WALL

SAMPLE RUN TO TEST ANALYSIS
AIR CONCENTRATION (PPM) SIZES
SUMMED OVER ALL PARTICLES
DISTANCE (M) FROM THE SOURCE
DIRECTIONS FROM SOURCE : N -

90.000- 200.000 VNE

ADDITIONAL INFORMATION

U-234

TW-230

RA-226

WM-222

00-318

013-01
V16-00

MIJ-64

91-214

P0-214

012-04

01-210

PO-210

MM-222

PO-218

PD-214

01-210

PD-219

PA-210

015-10
015-10

013-19

012-04

RN-220

P0-216

00-313
00-313

GROUND DEPOSITION RATE (GDR) IN SEC
 SUMMED OVER ALL PARTICLES
 IN THE SOURCE
 DIRECTIONS FROM SOURCE

RADIONUCLIDE

	90.000	100.000	200.000	VE	ENE	E	ENE	SE	SSE	AV3
U-234	6.202	1.122	1.122	6.202	7.620	1.122	1.122	2.000	1.000	9.232-20
Th-230	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-226	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Ac-222	4.000	1.122	1.122	4.000	4.000	1.122	1.122	2.000	1.000	2.000-30
Pa-218	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-214	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-214	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-222	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-218	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-214	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-214	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-210	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-220	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-216	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-212	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Pa-212	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30
Th-208	3.000	1.122	1.122	3.000	3.000	1.122	1.122	2.000	1.000	2.000-30

[illegible]

CHINESE IN NUME(200)*DEVEL(200)*DRY(4000)*FMT(10)*KEIP(15)*
GCHONY(24000)*7(15)

DATA WUNE DEPTL /200+1.200+0.0/


```

K=9 - K1
DO 40 J=1,16
DO 40 I=1,NWIND
40 FRACW(I,J,K)=FRACW(I,J,K-1)
DO 50 J=1,16
DO 50 I=1,NWIND
50 FRACW(I,J,K)=0
IF(MNSTA=10.5) MNSTA=5
IF(MNSTA=2.5) MNSTA=6
IS=MNSTA
DO 60 K=6,MNSTA
MLID(IS)=MLID(IS-1)
IS=IS-1
60 CONTINUE
70 CONTINUE

C
FSUM=0.0
DO 80 K=1,9
DO 80 J=1,16
DO 80 I=1,6
80 FSUM=FSUM+FRACW(I,J,K)
RENORMALIZE TO 1.0 USING FSUM
ALSO CHANGE FROM DIRECTION TO DIRECTION FROM
DO 90 K=1,9
DO 90 J=1,16
DO 90 I=1,6
TFMHP=FRACW(I,J+8,K)/FSUM
FRACW(I,J+8,K)=FRACW(I,J,K)/FSUM
90 FRACW(I,J,K)=TFMHP
IF (.NOT. OPTLID) GO TO 110
HTMORN=MLID(1)
HTAFT=MLID(2)
MLID(1)=1.5*HTAFT
DO 100 J=1,16
MLID(J+1)=HTAFT
100 MLID(5)=.5*(HTMORN+HTAFT)
MLID(6)=HTMORN
MLID(7)=.5*
MLID(8)=1.5*
110 IF (.NOT. OPTRN) GO TO 130
DO 120 J=1,16
DO 120 I=1,NWIND
FRRD=FRRD+FRACW(I,J,4)
IF (.NOT. DSKIP) FRRD=FRRD+FRACW(I,J,5)
120 FRRD=FRRD+FRACW(I,J,3)
IF (FRRD-FRRD.NE.0) RAINAV=RAIN/(FRRD-FRRD)
RAINAV=RAIN*1.44E-3*1.44E-3
130 CONTINUE

C
N2DRR=4000/NUMX
CALDRY=CLAND
KTRUNC=0
READ(IN,NSIZES)
WRITE(KOUT,10200)IV,KOUT,NR,NTEMP,NREAD,IOUT
WRITE(KOUT,10300)ALAT,ALONG,SRUVIT
WRITE(KOUT,10400)NNJC,NDAY,NCAT
WRITE(KOUT,12000)NAME,R,RLAC,THLOC,AREA
IF(10714) WRITE(KOUT,1010)
IF(10867) WRITE(KOUT,1030)
IF(10868) WRITE(KOUT,1050)
IF(10869) WRITE(KOUT,1060)
IF(10870) WRITE(KOUT,1070)
IF(10871) WRITE(KOUT,1080)
IF(10872) WRITE(KOUT,1090)
IF(10873) WRITE(KOUT,1100)
IF(10874) WRITE(KOUT,1110)
WRITE(KOUT,1180)
IF (MAKEOS) WRITE(KOUT,11300)
IF (MAKEOA) WRITE(KOUT,11400)
WRITE(KOUT,1180)
IF (TE44Y) WRITE(KOUT,10500)
IF (LINEAR) WRITE(KOUT,10600)
IF (MYMAX) WRITE(KOUT,10700)
IF (CMAXE) WRITE(KOUT,10800)
IF (CMVASH) WRITE(KOUT,10900)
IF (CLAND) WRITE(KOUT,11000)
IF (DSKIP) WRITE(KOUT,11100)
IF (PASSCP) WRITE(KOUT,11200)
IF (OVPICAL) WRITE(KOUT,11600)IOVP,NUMOVP,(NUCOVP(I),I=1,NUMOVP)
IF (CONSH) WRITE(KOUT,11700)
IF (SRDUSH) WRITE(KOUT,11900)
IF (AVGS) WRITE(KOUT,11800)
IF (OPTLID) WRITE(KOUT,1120)

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10700 FORMAT(' THE MAXIMUM PLUME RISE OPTION WILL BE USED.')
10800 FORMAT(' WAKE EFFECTS WILL BE INCLUDED.')
10900 FORMAT(' DOWNWASH EFFECTS WILL BE INCLUDED.')
11000 FORMAT(' DRY DEPOSITION REMOVAL RATES WILL BE CALCULATED.')
11100 FORMAT(' ONLY ONE STABILITY CATEGORY IS INPUT IN PLACE.')
11200 FORMAT(' AN OUTPUT FILE (POINT) FOR TERRA.')
11300 > 'ANDROS WILL BE WRITTEN.')
11400 FORMAT(' AN OUTPUT FILE (AVERAGE) FOR TERRA.')
11500 > 'ANDROS WILL BE WRITTEN.')
11500 FORMAT(' DRY DEPOSITION FACT OPTION WILL BE USED.')
11600 FORMAT(' OVERHEAD PLUME GAMMA SHINE CALCULATIONS WILL ')
> 'BE DONE.')
> 'OVERHEAD DOSE DATA READ FROM UNIT ',I2,
> ' IS.')
11700 FORMAT(' PLUME HEIGHT WILL REMAIN CONSTANT AT STACK HEIGHT.')
11800 FORMAT(' THE OUTPUT VALUES WILL BE AVERAGED OVER THE ')
> 'SRID SPACES.')
11900 FORMAT(' THE CORRECTION TO SIGMAZ USING SMITHS F FACTOR.')
> ' WILL BE DONE.')
11950 FORMAT(' VS WILL BE SET TO ZERO IF LESS THAN ',IPE7,1)
12000 FORMAT(' THE SOURCE NAME IS ',A4,
> ' THE DISTANCE (M) FROM THE REFERENCE GRID IS ',IPE8,2/
> ' THE ANGULAR DISTANCE FROM NORTH ON THE REFERENCE GRID IS ',
> IPE8,2/
> ' THE AREA OF THE SOURCE IS ',IPE8,2,' M**2/')
12100 FORMAT(' RELEASE INFORMATION: ', ' THE STACK HEIGHT (M) IS ',
- IPE8,2/ ' THE STACK INNER DIAMETER (M) IS ',IPE8,2/
- ' THE STACK EXIT VELOCITY (M/SEC) IS ',IPE8,2/
- ' THE EXIT TEMPERATURE (DEG K) IS ',IPE8,2/
- ' THE AMBIENT AIR TEMPERATURE (DEG K) IS ',IPE8,2)
12200 FORMAT(' TERRAIN ROUGHNESS (M) = ',IPE8,2/
> ' TERRAIN ELEVATION (M) AT STACK BASE ',IPE8,2/
> ' WIDTH (M) OF MOST INFLUENTIAL BUILDINGS IS ',IPE8,2/
> ' HEIGHT (M) OF MOST INFLUENTIAL BUILDING IS ',IPE8,2)
12300 FORMAT(' MIN. AT. (M) OF WIND VELOCITY CORRECTION IS ',IPE8,2/
> ' ALLOWABLE DEVIATION FROM AVERAGE LAMDA IS ',IPE8,2/
12400 FORMAT(' GRID INFORMATION: ', ' NUMBER OF DIRECTIONS = ',I2/
> ' WIND SIZE = ',I2/ ' NUMBER OF DIRECTIONS = ',I2/
> ' NUMBER OF WIND SPEEDS = ',I2/ ' MINIMUM STABILITY CLASS = ',I2/
> ' MAXIMUM STABILITY CLASS = ',I2/
> ' MAXIMUM DISTANCE FROM THE STACK = ',IPE8,2)
12500 FORMAT(' DISTANCES FOR THE GRID (M) = ',(I0X,I0F12,3))
12600 FORMAT(' DIRECTIONS FOR THE GRID = ',(I4,I4,I4))
12700 FORMAT(' TERRAIN HEIGHTS (METERS) /
> ' DIST. DIRECTIONS / 16(I4))
12800 FORMAT(' 13,16(F8,3))
12900 FORMAT(' WIND SPEED CLASSES: ',(I8))
13000 FORMAT(' WIND SPEED (M/SEC): ',(F8,2))
13100 FORMAT(' HEIGHT (M) OF WEAS: ',(F8,2))
13200 FORMAT(' AVERAGE RAINFALL (M/S): ',IPE10,4/))
13300 FORMAT(' LTD HEIGHT (M) ',(F10,1))
13400 FORMAT(' 0.25X, FRACTION OF WIND TOWARD ', ' WIND SPEED DIRECTION')
> ' CLASS')
13500 FORMAT(' STABILITY CLASS: ',(I6,X))
13600 FORMAT(' 3X,14,67,14,8F10,6)
13700 FORMAT(' ONET DATA SUMMARY: ', ' WIND DIRECTIONS ',(I4,I4,3))
13800 FORMAT(' FRACTION TOWARD: ',(F7,4))
13900 FORMAT(' ONET DATA SUMMARY: ', ' STABILITY CLASSES: ',(I4,3))
14000 FORMAT(' FRACTION OF EACH ',(F7,4))
14100 FORMAT(' THE DIMENSION OF ARRAY A NEEDS TO BE AT LEAST ',I10)
14100 FORMAT(' TRAVEL TIME WILL BE PRINTED BY DISTANCE AND DIRECTION')
14200 FORMAT(' EFFECTIVE STACK HEIGHT WILL BE PRINTED BY WIND SPEED,
- ' AND STABILITY')
14300 FORMAT(' OPRIE WILL BE PRINTED BY DISTANCE AND STABILITY')
- ' FLUX WILL BE PRINTED BY DISTANCE AND DIRECTION')
14400 FORMAT(' WIND SPEED WILL BE PRINTED BY DISTANCE AND DIRECTION')
14500 FORMAT(' SIGMA-Z WILL BE PRINTED BY DISTANCE AND STABILITY')
14600 FORMAT(' CH/3 WILL BE PRINTED BY DISTANCE AND DIRECTION')
14700 FORMAT(' DRY LAMBDAS WILL BE PRINTED BY STABILITY AND ')
- ' ARTICLE SIZE')
14800 FORMAT(' MREC FOR THE S COMPUTATION IS ',IPE8,2)
14900 FORMAT(' S.LT. UNIT=AC * MXMGT1 UNIFAC= ',IPE8,2)
15000 FORMAT(' AIR DENSITY (G/C**3) IS ',IPE8,2)
15100 > ' THE MIXING LAYER HEIGHT WILL BE COMPUTED BASED',
- ' ON MORNING AND AFTERNOON MIXING HEIGHTS')
15200 FORMAT(' THE NUMBER OF DAYS THAT IT RAINS IS ',IPE8,2)
15300 FORMAT(' THE AMOUNT (M) OF RAIN DURING THAT TIME IS ',IPE8,2)
15400 FORMAT(' THE FRACTION OF THE TIME THAT IT RAINS DURING ')
- ' STABILITY CLASS IS ',IPE8,2)
15500 FORMAT(' THE FRACTION OF THE TIME THAT IT RAINS DURING ')
- ' STABILITY CLASS IS ',IPE8,2)
15600 FORMAT(' STABILITY CLASS IS ',IPE8,2)
15700 FORMAT(' STAR DATA WILL BE READ ON UNIT ',I2,' USING FORMAT')
- ' (20A4)')
15800 FORMAT(' ')
END

```

```

SUBROUTINE AREASR(AREA,X,XO,NUMX,NI,SRA)
DIMENSION X(NUMX),XO(NUMX),MI(NUMX),SRA(NUMX),ABC(4)
DATA PI/3.141593/,PI2/1.570796/,PI4/0.785398/,PI8/0.3926991/
DATA C1/0.6666667/,C2/2.519842/,C3/1.259921/,ARC/0.785398/,C*
C** C1 IS 2/3 C2 IS 4*(2/3) C3 IS C2/2
H=SQR(AREA)
H2=H**2
H0=SQR(AREA/PI)
WRITE(6,10000)AREA
DO 70 I=1,NUMX
XI=X(I)
IF (XI.LE.16.*H2) GO TO 10
C*** AT DISTANCES GREATER THAN 16*H2,TREAT THE SOURCE
C*** AS A POINT SOURCE
FN=ABC(1)
XO(I)=XI
MI(I)=0
GO TO 20
10 IF (XI.LE.H2) GO TO 40
C*** USE TRANSFORMATION(A),R1=XI-H2,R2=XI+H2,THETA=H/XI
XO(I)=(XI+4*SQR(XI+H2)+SQR(XI-H2))*0.5**C1
MI(I)=INT(H/XI/PI4**5)
IF (MI(I).GT.0) GO TO 30
20 SRA(I)=1.
GO TO 60
30 SRA(I)=PI8*XI/H
GO TO 60
40 IF (XI.LE.H0**0.5) GO TO 50
C*** USE TRANSFORMATION(B),R1=0,R2=2.*XI,THETA=A/(2+R**2)
XO(I)=XI/C3
MI(I)=INT(AREA/XI**2/PI2*0.5)
SRA(I)=PI4*XI**2/AREA
GO TO 60
C*** USE TRANSFORMATION(C),R1=0,R2=R0,THETA=2*PI
50 XO(I)=R0/C2
FN=ABC(4)
MI(I)=8
SRA(I)=0.0625
60 CONTINUE
WRITE(6,10100)X(I),XO(I),MI(I),SRA(I),FN
70 CONTINUE
DO 80 I=1,NUMX
HOLD=X(I)
XI=XO(I)
XO(I)=HOLD
80 CONTINUE
WRITE(6,10200)
10200 FORMAT(0,-----'/' TRANSFORMATION USED:/'
- ' (BLANK) NO TRANSFORMATION/'
- ' A R1=XI-H2, R2=XI+H2, THETA=H/XI/'
- ' B R1=0, R2=2*XI, THETA=A/(2+R**2)/'
- ' C R1=0, R2=R0, THETA=2*PI/'
RETURN
10000 FORMAT('1 AREA SOURCE CALCULATIONS/' '0 AREA OF SOURCE='/'12.2'
> ' (M**2) '/' '0 ORIGINAL TRANSFORMED NUM. OF FRACTIONS/'
> ' DISTANCE DISTANCE ADD. OF/'
> ' FROM SOURCE FROM SOURCE SECT. EACH SECT. TRANSFORMATION')
10100 FORMAT('1,2F10.2,19,F12.5,11X,A1)
END
SUBROUTINE AVERI(GCONP9,GDEP,GDRY,GCONDV,DVPCAL,X,NI,THETA,NUMX,
> NUCOUT,NUMDVP)
LOGICAL DVPCAL
DIMENSION GCONP9(NTHTA,NUMX,NUCOUT),GDEP(NTHTA,NUMX,NUCOUT),
> GDRY(NTHTA,NUMX,NUCOUT),GCONDV(NTHTA,NUMX,NUCOUT),X(NUMX)
SUBROUTINE TC CALCULATE AN AVERAGE CONCENTRATION VALUE OVER THE
GRID CELL IF FINIS 4 AND 8 SUCH THAT C(I)=A*(I)**9
AND C(2)=A*(I)**8 WHERE 1 AND 2 INDICATE TWO ADJACENT
DISTANCES. IT THEN SETS THE AVERAGE CONCENTRATION
FOR R(1) TO R(2) EQUAL TO THE INTEGRAL FROM R(1) TO R(2) OF
1/R**3 WHICH IS THEN DIVIDED BY (R(2)-R(1)).
R1=ALOG(X(I))
DO 50 IX=2,NUMX
DEL R=1./(X(IX)*X(IX)-X(IX-1)*X(IX-1))
R2=ALOG(X(IX))
DIV=1./(R2-R1)
DO 20 IY=1,NUCOUT
DO 10 IZ=1,NTHTA
C2=6C0*PQ(17,IY,IZ)

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-----WRITTEN FOR AVENOS CODE BY D. W. MEYMAN, 10/22/80.
  *CALLED FROM DPLEY*
  PURPOSE: IF IT CALL DECAY TYPE SUBS, PREPARING SINGLING C-MATRIX AND
  AND FINAL PHS TO REPERSENT TRANSITION FROM ZERO TIME...
  APPLIES TO EITHER SINGLE(NX=1), OR MULTIPLE(NX > 1) RESULTS....
  DOUBLE PRECISION Y(C(L,L)),M(L,L),D(L,L),E(L,L),F(L,L), FF(L,L),
  > A(L,L),FACT
  DIMENSION N(1),NXX(1)
  DO 10 I=1,N
  DO 10 J=1,N
  10 CALL DECAY(C(L,L),M(L,L),D(L,L),E(L,L),F(L,L),FF(L,L),
  CALL DECCDC(NP,N,E,F,M,A,C,FF(C(L,L),X),VPL,N,VSPTS)
  SUBR. DECCDC COMPUTES WELL-BEHAVED M-MATRIX FROM C/2--NP AFTER
  DETERMINING NP SUCH THAT THE NORM-NDNM < 0.25
  IF (NP-52-NX) GO TO 30
  NP MUST BE LARGE ENOUGH TO MAKE ALL OF MULTIPLE CASE...
  NP=NP+X-1
  FACT=C(2,000) ** NP
  DO 20 I=1,N
  DO 20 J=1,N
  20 M(J,I)=C(J,I)/FACT
  30 NTR=1-2-NP+5
  ASSURES AT LEAST 5 TERMS IN EXPANSION...
  IF (NTR-1) NTR=3
  AND AT LEAST 3 TERMS IN EXP EXPANSION
  CALL DECCDC(NTR,N,D,E,M,A)
  SUBR. DECCDC COMPUTES D-MATRIX=EXP(M-MATRIX)...
  NP1=NP - NX+1
  M=1
  VSPTS=VSPTS
  CALL DECCDC(NP,N,E,F,M,A,C,FF(C(L,L),X),VPL,N,VSPTS)
  * SUBR DECCDC COMPUTES D(C) FROM D(M) AND M, IN RECURSION RELATIONSHIP.
  NX=JX - NGRORS
  DO 150 N=1,NX
  XX=XX+VSPTS
  JY=JX-1
  DO 60 I=1,N
  IF (FF(C(L,L),MXX,ST,0,000)) CALL EXPR
  IF (C(L,000+FF(C(L,L),KX),LT,1,000-1)) GO TO 50
  FF(C(L,L),KX)=FF(C(L,L),KX)+1.000
  50 C(000)=0
  C(000)=0.05(C(L,I))
  EXP=EXPON(LI,172.0) EXP=EXP(-EXPON)
  FF(C(L,L),KX)=EXP
  * NEED TO AVOID A DIFF. IN 12 AND FF THAT IS LESS THAN 10**(-11)
  THEN REPLACE FF WITH SIMPLY THE SMALL ELEMENTED Y(C(L,I))
  THIS AVOIDS >100X ERRORS IN REMAINING FRACTIONS WHICH < 10**(-15).
  60 CONTINUE
  MULT. FF(JX) BY FF(JX-1), IF JX .ST. 1.
  IF (XX-1) GO TO 130
  DO 70 I=1,N
  DO 70 J=1,N
  IF (FF(C(L,L),MXX,ST,0,000)) GO TO 70
  IF (C(L,000+FF(C(L,L),KX),LT,1,000-1)) GO TO 70
  70 FF(C(L,L),KX)=FF(C(L,L),KX)+1.000
  FF(C(L,L),KX)=0.000
  DO 80 I=1,N
  DO 80 J=1,N
  IF (0.000+FF(C(L,L),KX),LT,ALJ,KX) GO TO 80
  IF (C(L,000+FF(C(L,L),KX),LT,1,000-1)) GO TO 80
  80 CONTINUE
  IF (XX-5) GO TO 110

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NOTE: NO ADJUSTMENT NEEDED IF SINGLE RESULT COMPUTED...
20 100 J=1:L
30 100 J=1:L
100 F(0,J)=F(J,1)
110 CONTINUE
20 100 J=1:L
30 100 J=1:L
100 F(0,J)=F(J,1)
110 CONTINUE
120 F(0,J)=F(J,1)+DRY(KX,J)-DRY(KX,1)
130 IF (KX-1) 100, 110, 120
140 IF (KX-1) 100, 110, 120
150 IF (KX-1) 100, 110, 120
160 IF (KX-1) 100, 110, 120
170 IF (KX-1) 100, 110, 120
180 IF (KX-1) 100, 110, 120
190 IF (KX-1) 100, 110, 120
200 IF (KX-1) 100, 110, 120
210 IF (KX-1) 100, 110, 120
220 IF (KX-1) 100, 110, 120
230 IF (KX-1) 100, 110, 120
240 IF (KX-1) 100, 110, 120
250 IF (KX-1) 100, 110, 120
260 IF (KX-1) 100, 110, 120
270 IF (KX-1) 100, 110, 120
280 IF (KX-1) 100, 110, 120
290 IF (KX-1) 100, 110, 120
300 IF (KX-1) 100, 110, 120
310 IF (KX-1) 100, 110, 120
320 IF (KX-1) 100, 110, 120
330 IF (KX-1) 100, 110, 120
340 IF (KX-1) 100, 110, 120
350 IF (KX-1) 100, 110, 120
360 IF (KX-1) 100, 110, 120
370 IF (KX-1) 100, 110, 120
380 IF (KX-1) 100, 110, 120
390 IF (KX-1) 100, 110, 120
400 IF (KX-1) 100, 110, 120
410 IF (KX-1) 100, 110, 120
420 IF (KX-1) 100, 110, 120
430 IF (KX-1) 100, 110, 120
440 IF (KX-1) 100, 110, 120
450 IF (KX-1) 100, 110, 120
460 IF (KX-1) 100, 110, 120
470 IF (KX-1) 100, 110, 120
480 IF (KX-1) 100, 110, 120
490 IF (KX-1) 100, 110, 120
500 IF (KX-1) 100, 110, 120
510 IF (KX-1) 100, 110, 120
520 IF (KX-1) 100, 110, 120
530 IF (KX-1) 100, 110, 120
540 IF (KX-1) 100, 110, 120
550 IF (KX-1) 100, 110, 120
560 IF (KX-1) 100, 110, 120
570 IF (KX-1) 100, 110, 120
580 IF (KX-1) 100, 110, 120
590 IF (KX-1) 100, 110, 120
600 IF (KX-1) 100, 110, 120
610 IF (KX-1) 100, 110, 120
620 IF (KX-1) 100, 110, 120
630 IF (KX-1) 100, 110, 120
640 IF (KX-1) 100, 110, 120
650 IF (KX-1) 100, 110, 120
660 IF (KX-1) 100, 110, 120
670 IF (KX-1) 100, 110, 120
680 IF (KX-1) 100, 110, 120
690 IF (KX-1) 100, 110, 120
700 IF (KX-1) 100, 110, 120
710 IF (KX-1) 100, 110, 120
720 IF (KX-1) 100, 110, 120
730 IF (KX-1) 100, 110, 120
740 IF (KX-1) 100, 110, 120
750 IF (KX-1) 100, 110, 120
760 IF (KX-1) 100, 110, 120
770 IF (KX-1) 100, 110, 120
780 IF (KX-1) 100, 110, 120
790 IF (KX-1) 100, 110, 120
800 IF (KX-1) 100, 110, 120
810 IF (KX-1) 100, 110, 120
820 IF (KX-1) 100, 110, 120
830 IF (KX-1) 100, 110, 120
840 IF (KX-1) 100, 110, 120
850 IF (KX-1) 100, 110, 120
860 IF (KX-1) 100, 110, 120
870 IF (KX-1) 100, 110, 120
880 IF (KX-1) 100, 110, 120
890 IF (KX-1) 100, 110, 120
900 IF (KX-1) 100, 110, 120
910 IF (KX-1) 100, 110, 120
920 IF (KX-1) 100, 110, 120
930 IF (KX-1) 100, 110, 120
940 IF (KX-1) 100, 110, 120
950 IF (KX-1) 100, 110, 120
960 IF (KX-1) 100, 110, 120
970 IF (KX-1) 100, 110, 120
980 IF (KX-1) 100, 110, 120
990 IF (KX-1) 100, 110, 120
1000 IF (KX-1) 100, 110, 120

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50 F(I,J)=0.000
60 CONTINUE
RETURN
END
SUBROUTINE DECP(L,NP,KOUT,C,M)
-----WRITTEN FOR ANEMOS CODE BY D. W. HERMANN, 7/7/81.
** CALLED FROM SUBR. DECAV **
.. FINOS P IN REDUCTION EQ FOR M=2+((-P)*C
REAL*8 C(L,L),M(L,L),SUM,M1,MJ,MIM,MJM,FACT
..NOTE LEFT-HAND INDEX OF MATRICES DENOTES THE COLUMN OF MATRIX...
SUM=0.000
DO 10 I=1,L
DO 10 J=1,I
IF (C(I,J).EQ.0.0) GO TO 10
SUM=SUM+(J,I)-C(I,J)
10 CONTINUE
S=SUM
IF (S.LE.0.0) GO TO 40
S=SQRT(S)
P=ALOG(S)/0.693147*2.0
20 CONTINUE
NP=NP+1
IF (P.LT.0.0) NP=0
FACT=1.000
NP=MAX0(NP,1)
IF ..LAST CARD MAKES SUB. DECODE DO AT LEAST 1 RECURSION. DWH 7/7/91
DO 30 I=1,L
DO 30 J=1,I
30 M(I,J)=C(I,J)/FACT
40 MIM=0.000
MJM=0.000
MNORME=0.0
DO 60 I=1,L
MI=0.000
MJ=0.000
DO 50 J=1,I
IF (M(I,J).NE.0.0) MNORME=MNORME+M(I,I)*M(J,I)
..FOR CALC OF THE EUCLIDEAN NORM OF M(THEN SQRT,BELOD)4/28/90
MI=MI+ABS(M(I,I))
50 MJ=MJ+ABS(M(I,J))
MIM=DMAX(MIM,MI)
60 MJM=DMAX(MJM,MJ)
MNORME=DMIN(MI,MJM)
MNORME=SQRT(MNORME)
IF (KOUT.EQ.40) WRITE (KOUT,10000)NP,MNORME,MNORM
MNORM=MAX1(MNORM,MNORME)
..NORM SATISFIES EITHER DEFINITION BY LEE OR LAPICUS AND LUUS.
IF (S.GE.0.0.AND.MNORM.LT.0.25) RETURN
RN=MNORM/0.25
P=NP+ALOG(RN)/0.693147
GO TO 20
10000 FORMAT(3H NP =,I4,13H EUCLIDEAN-NORM= ,E15.4,
> 17H MIN-MAX-NORM = ,E16.4)
END
SUBROUTINE DOSINT(MU,DK,ZK,H,SIGZ,DI,L,HREC,P,ZN1,UNIFAC)
REAL MU
C**
DOSE INTEGRAL ROUTINE WRITTEN BY
DR. JOHN W. MANAU
YANKEE ATOMIC ELECTRIC COMPANY
NUCLEAR SERVICES DIVISION
20 TURNPIKE ROAD
WESTBOROUGH, MASSACHUSETTS 01581
YAEC REPORT NO. 1105
COMMON INFO
MU-MASS ATTENUATION COEFFICIENT(1/METERS)
ZK-BUILDUP FACTOR(MU-DA)QA
SIGZ-STANDARD DEVIATION OF PLUME(METERS)
DI-DOSE INTEGRAL-1 TOTAL
L- DETERMINES NUMBER OF INTERVALS USED IN INTEGRATION

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[illegible]

[illegible]


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80 CONTINUE
  ID=17
99 THETA2=90+DI(IID)
  ALWAYS TOTAL SECTOR ANGLE FOR NEXT DIRECTION
  START TOWARD NORTH DIRECTION
  DO 169 JX=1,NUMW
    NLOCX=NLOCV+1
    X2=X(1)
    IF (JX.LT.NUMX) X2=X(JX+1)
    WRITE(L) X(JX),X2,T1,T2,THETA2,NIND
  EACH RECORD TYPE 3 WRITTEN
  DO 150 NP=1,NPART
    READ(NTEMP)C
    READ(NTEMP)D
    READ(NTEMP)D
    IF (OVPCAL) READ(NTEMP)CC
    IF (NP.EQ.NPART) READ(NTEMP)D
  DO 108 K=1,NUCOUT
    I1=NUCPAR(KX)
    PSIZE(K)=DIAM(I1,NP)*SQRT(RHO(NP))
    WRITE(L)IND1,NPACK,C(N,JX,I),I=1,NPACK)
    WRITE(L)(PSIZE(NU),NU=1,NPACK), ((XCLEAR(I,NU),I=1,4),NU=1,NPACK)
    IF (.NOT.OVPCAL) GO TO 140
    DO 138 I=1,NPACK
    DO 119 IN=1,NUMOVP
    IF (IDEXP(IC(I)).EQ.IDNUC(IN)) GO TO 120
  110 CONTINUE
    GO TO 138
  120 IF (JX.LT.KEEPN(IN)) C(N,JX,I)=CC(N,JX,I)
  130 CONTINUE
    WRITE(L)IND2,NPACK,C(N,JX,I),I=1,NPACK)
  140 IF (NP.EQ.NPART) WRITE(L)IND18,NPACK,C(N,JX,I),I=1,NPACK)
  EACH RECORD TYPE 4 WRITTEN FOR CONC. & DEPOSITION RATES.
  150 CONTINUE
  REWIND NTEMP
  160 CONTINUE
  THETA1=THETA2
  170 CONTINUE
  199 CONTINUE
  WRITE(KOUT,10100)L
  RETURN
10000 FORMAT(1H1, '*** REQUESTED THE SAVING OF COMPUTED RESULTS ***')
10100 FORMAT(1H0, 'DATA SET ON UNIT NUMBER',I3, ' COMPLETED.')
  END
  SUBROUTINE GCONC(GCONPO,GCONOV,IDEXP,IC,JC,FRACH,K,XO,NT,SRA,
> UTIME,SIGZK,HEFF,C,QTOT,ZIN,WIN,UNSTAK,HEFF1,TERAIN,JUAKE,
> HTEFF1,DRYL,NUCPAR,GDEP,SDRY,QIN,SPR,C,H,D,E,F,PR,ITRAN,4,S,
> DRY,UT,TIME,VFLAG,V6,DV,FR,HLHDA,EXPSYN,ARE4,TEMP1,TEMP2,
> HLID,NUMX,NUMSTA,NUMIN,NTHETA,NUCOUT,NCAT,NUMOVP,AVGG,
> RELSYN,FLUX,KEEPN)
  -----WRITTEN FOR ANEMOS CODE BY O. W. HERMANN,7/8/81
  DIMENSION GCONPO(NTHETA,NUMX,NUCOUT),EXPSYN(1),GCONOV(NTHETA,
> NUMX,NUCOUT),IDEXP(1),IC(1),JC(1),GDEP(NTHETA,NUMX,NUCOUT),
> CQRY(NTHETA,NUMX,NUCOUT),NUCPAR(NUCOUT),V6(1),VFLAG(NCAT,1),
> HLHDA(1),DV(8,1),R(1),CPQTOT(NTHETA,NUMX),HTEFFA(NUMX,1),
> DRYL(NUMX,1),WININD(NUMX,NUIND,NUMSTA),TIME(NUMX,NUIND,NUMSTA),
> FRACH(6,16,8),K(NUMX),KO(NUMX),RI(NUMX),SRA(NUMX),TEMP1(1),
> UNSTAK(NUMSTA,NUIND),WIN(NUIND),TEMP2(1),HEFF1(NUMSTA,NUIND),
> ZIN(NUIND),HEFF(NUMSTA,NUIND,NUMX),TERAIN(16,1),JUAKE(NUIND,
> NUMSTA),SPR(NUCOUT,NUMX),ITRAN(2,1),QIN(1),C(1),H(1),D(1),E(1),
> F(1),FF(1),4(1),S(1),DRY(NUMX,1),UT(1),1J(12),SIGZK(NUMSTA,
> NUMX,NUIND,HLID,NUMSTA),KEEP(15),KEEPN(15),RELSYN(1),
> FLUX(NUCOUT,NUMX),VF(40)
  COMMON /CASE / TI(20)
  COMMON /DIR /DIRR(16),DIRSUM(16)
  COMMON /CLDTS / ALAT,ALONG,RLC,THLOC,DIFFX,DIFFY,NUMSR,
  1 ISRDOP,UNITSR
  COMMON /DPDAT / NPSIZE,NPART,NP,RAINAV,FRR,C,FRRD
  COMMON /DVLGS / IDNUC(15),EK(15),AK(20,15),DOSE(15),CA(15),DA(15),

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C RAINWT USED IN ONLY THE STAB. CLASSES IN WHICH RAIN IS ASSUMED.

NCATMX=NCAT
NTOT=NUCOUT+NI*ETA+NUMX
NTOTP=NUMOVP+NTHETA+NUMX
CALL ZS(SCONPQ,NTOT)
CALL ZS(GDEP,NTOT)
CALL ZS(GDRY,NTOT)
CALL ZS(GCONOV,NTOT)

***** OUTER LOOP BY PARTICLE SIZE TYPE...
THEN BY WIND SPEEDS, THEN STABILITY, THEN X, THEN THETAS....

DO 400 NP=1,NPART
CALL ZS(FLUX,NUCOUT+NUMX)
DO 450 JR=1,NJWIND
IF (IOPR) WRITE(KOUT,10000)TI,UNITSR,JR
DO 440 JSTAB=MINSTA,MAXSTA
IF (IJ(JSTAB).EQ.0) RAINF=0.0
IF (IJ(JSTAB).NE.0) RAINF=1.0
IF (CALDRY) CALL DPXTE(WUMX,NCAT,JSTAB,NUCOUT,NUMSTA,
> HLD(JSTAB),TIME(1,JR,JSTAB),HEFF,VG,ZIN(JR),UIN(JR), WLMDA,
> SIGZX(1,1,JR),X,DV,FR,NUCAP,NFLAG,DRY,MET, S,C,H,QIN,ITRAN,D,E,
> F,UWIND(1,JR,JSTAB),NWIND(JR)
REWIND NREAD
CALL DPLETE(UWIND(1,JR,JSTAB),X,QIN,QPR,DRY,MET, TIME(1,JR,JSTAB),
> C,H,D,E,F,FF,A,S, ITRAN,NUCOUT,NUMX,JR,AREA)
> IF (IOPR) CALL OUTSPR(QPR,JR,JSTAB,NUCOUT, X,NUMX,EXPSYM,IC,JC,
> NCAT,N,NUCAP,NFLAG,VG,NLSY)
DO 15 IX=1,NUMX
DO 15 IN=1,NUCOUT
DO 15 ITH=1,NTHETA
IF (DIRSUM(ITH).GT.0.0) FLUX(IN,IX) = FLUX(IN,IX) +
FRAC(JR,ITH,JSTAB)*QPR(IN,IX)/DIRSUM(ITH)
CONTINUE

DPLETE CALCS THE REMAINING FRACS. OF QIN AFTER DEPLETION OF NUCL BY
RADIOACTIVE DECAY AND GENERATION, WET DEPLETION AND DRY DEPLETION.
WITH RESULTS FOR ALL OUTPUT NUCL REQUESTED STORED IN QPR.....

CALL NPOWER(ZZERO,JSTAB,PN)
DO 430 NUC=1,NCATMX
IF (NFLAG(NUC,NP).EQ.0) GO TO 430
I=NFLAG(NUC,NP)
VGRAY=UC(I)
IF (.NOT. VGRAY) GO TO 30
DO 20 IVP=1,NUOVP
KEEP(IVP)=.TRUE.
30 IF (.NOT. TERHT) GO TO 230
DO 220 JX=1,NUMX
HT1=HEFF(JSTAB,JR,JX)
HT2=HT1 - VGRAY*TIME(JX,JR,JSTAB)
IF (HT2.LT.0.0) HT2=0.0
HT2C= MAX1(WMINHT,HT2)
HT1=MAX1(WMINHT,HT1)
HEFFX=HT2
UWINDX=UWIND(JX,JR,JSTAB)*(HT2C/ HT1)** PN
DO 200 JTH=1,NTHETA
ZNI=HEFFX
ZNI=AMIX(ZNI - TERAIN(JTHET,JX)/2.*TERHTO,ZNI)
ZNI=AMAX1(ZNI,0.0)
ZNI=AMIN1(HLD(JSTAB),ZNI)
EX = V(NRECP,ZNI,HLD(JSTAB),SIGZX(JSTAB,JX,JR),UNIFAC)

EX IS COMPUTED FOR EACH SET OF JX,JSTAB,JR.

NUM,CALC. GROUND CONCENTRATION PER Q(X)...

XXJX=X(JX)
IF (JWAKE(JR,JSTAB)) XXJX=AMAX1(3.0*HBLD,XXJX)
TE=FRAC(U(JR,JTHET,JSTAB) / (XXJX +UWINDX)
TI=1/(XXJX+UWINDX)
CONCAD=TE*EX+C2XL
C1=1-EX+C2XL
C...CORRECT TE AND CONCAD FOR AREA SOURCE
IF (AREA.EQ.0.0) GO TO 120
M=NT(JR)
IF (M.EQ.0) GO TO 120
FT=SRAT(JX)
FN=(1.-(2*M-1)*FT)*.5

[illegible]

[illegible]

[illegible]


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WRITE(KOUT,10100)X
WRITE(KOUT,10200)
DO 10 IP=1,NPART
DO 10 IC=1,NCAT
  NFLAG=IC*IP
  IF (I.LE.0) GO TO 10
  WRITE(KOUT,10300)IC,IP,V6(I),FR(I),(HTCFFA(J,I),J=1,NUMX)
10 CONTINUE
RETURN
10000 FORMAT('1',10X,20A4/ 11X,'MEAN PLUME HEIGHT(M)',
  - ' FOR EACH PARTICLE CATEGORY')
10100 FORMAT('1',10X,'DISTANCE(M):',7X,10F10.2,1H / (20X,10F10.2,1X))
10200 FORMAT('1',10X,'GRAV VEL FRACTION',/ CAT. NUM. (M/SEC)')
10300 FORMAT('1X,13,14,3X,12(1PE10.3),1H / (31X,10(1PE10.3),1X))
END
SUBROUTINE OUTQPR(QPR,JR,JSTAB,NUCOUT,X,NUMX,EXPSYM,IC,JC,NCAT,
  > NP,NUCPAR,NFLAG,V6,RELSYM)
COMMON/OUTQS/ALAT,ALONG,RLQC,THLOC,DIFFX,DIFFY,NUMSR,
  > IERDOP,UNITSR
COMMON/CASE/TI(20)
COMMON/IONUMB/NR,NREAD,IN,KOUT,NTEMP
COMMON /STABIN/ MINSTA,MAXSTA,NRECP,UNIFAC,DSKIP
COMMON/STABS/STAB(8),D
LOGICAL DSKIP
DOUBLE PRECISION EXPSYM,RELSYM,ALAT,ALONG,
  > RLQC,THLOC,DIFFX,DIFFY
DIMENSION QPR(NUCOUT,NUMX),EXPSYM(1),X(NUMX),IC(1),JC(1),
  > NFLAG(NCAT,1),NUCPAR(1),V6(1),RELSYM(1)
IF(DSKIP.AND.JSTAB.EQ.5) RETURN
OUT=STAB(JSTAB)
IF(DSKIP.AND.JSTAB.EQ.4) OUT=0
WRITE(KOUT,10100)OUT
WRITE(KOUT,10000)X
WRITE(KOUT,10200)
  JLAST=JC(1)
DO 10 NUC=1,NUCOUT
  ICAT=NUCPAR(NUC)
  IP=NFLAG(ICAT,NP)
  IF (IP.LE.0) GO TO 10
  IF(JC(NUC).EQ.JLAST) GO TO 8
  JLAST=JC(NUC)
  WRITE(KOUT,10050)
  CONTINUE
  WRITE(KOUT,10300)EXPSYM(IC(NUC)),V6(IP), (QPR(NUC,
  > J),J=1,NUMX)
10 CONTINUE
RETURN
10000 FORMAT('1',10X,10F10.2,/(26X,10F10.2))
10050 FORMAT('0')
10100 FORMAT('0STABILITY CLASS=',1X,A4)
10200 FORMAT(2X,'NUCLIDE',3X,'GRAV VEL',/ 13X,'(M/SEC)')
10300 FORMAT(3X,48,2X,11(1PE10.2), / (23X,10(1PE10.2)))
END
SUBROUTINE OUTSGZ(SIGZX,X,NUMX,NWIND,NUMSTA,AVG,FRACW)
DIMENSION SIGZX(NUMSTA,NUMX,NWIND),X(NUMX),
  > AVG(1),FRACW(6,16,9)
COMMON/CASE/TI(20)
COMMON/IONUMB/NR,NREAD,IN,KOUT,NTEMP
COMMON /STABIN/ MINSTA,MAXSTA,NRECP,UNIFAC,DSKIP
COMMON/STABS/ STAB(9),D
LOGICAL DSKIP
WRITE(KOUT,10050)TI
WRITE(KOUT,10100)X
WRITE(KOUT,10200)
DO 5 N=1,NUMX
  AVG(N)=0.0
5 DO 10 I=1,NWIND
DO 10 J=MINSTA,MAXSTA
  IF(DSKIP.AND.J.EQ.5) GO TO 10
  OUT=STAB(J)
  IF(DSKIP.AND.J.EQ.4) OUT=0
  WRITE(KOUT,10300)KOUT, (SIGZX(J,I,N),I=1,NUMX)
DO 10 I=1,16
DO 10 N=1,NUMX
  AVG(N)=AVG(N)+SIGZX(J,N,N)*FRACW(K,I,J)
10 CONTINUE
  WRITE(KOUT,10350) (AVG(N),N=1,NUMX)
  RETURN
10000 FORMAT('1',10X,20A4/ 11X,'SIGMAZ')
10100 FORMAT('1',10X,10F10.2,1H / (20X,10F10.2,1X))

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READ(NTEMP)GDRY
IF (OVPICAL) READ(NTEMP)GCONOV
DO 50 IX=1,NUNU
WRITE(KOUT,10000)TI
IF (AVS3) WRITE(KOUT,10100)
DO 50 IT=1,NTHETA
IF (.NOT. AVS5) WRITE(KOUT,10200)X(IX),DI(1T),UNITSR,UNITSR,UNITSR
IF (AVS6) WRITE(KOUT,10250) X(IX),X(IX+1),DI(1T),UNITSR,UNITSR.
> UNITSR
JLAST=JC(1)
DO 40 NUC=1,NUCOUT
IE=IC(NUC)
IF (JC(NUC).EQ. JLAST) GO TO 41
WRITE(KOUT,10255)
JLAST=JC(NUC)
CONTINUE
41 K=NUCPA(NUC)
I=VFLAG(K,MP)
IF (I.LE.0) GO TO 40
PS=D:AM(MP,K)
SWET=GDEP(1T,IX,NUC)-GDRY(1T,IX,NUC)
IF (.NOT. OVPICAL) GO TO 20
DO 10 IX=1,NUNUVP
IF (IDNUC(IX).NE. IDK(PE)) GO TO 10
FFF=GCONOV(1T,IX,NUC)
GO TO 30
10 CONTINUE
20 WRITE(KOUT,10300)EXP(SYN(IE),PS, (XCLEAR(IX,IE),IX=1,4),
> FR(1),GDRY(1T,IX,NUC),GDET,GDEP(1T,IX,NUC),GCONPO(1T,IX,NUC)
GO TO 40
30 WRITE(KOUT,10300)EXP(SYN(IE),PS, (XCLEAR(IX,IE),IX=1,4),
> FR(1),SDRY(1T,IX,NUC),GDET,GDEP(1T,IX,NUC), GCONPO(1T,IX,NUC).
> FFF
40 CONTINUE
50 CONTINUE
60 CONTINUE
70 CONTINUE
REWIND NTEMP
CALL ZS(GDEP,NUCOUT,NTHETA,NUNU)
CALL ZS(GCONPO,NUCOUT,NTHETA,NUNU)
DO 100 MP=1,NMART
READ(NTEMP)GDRY
DO 80 IX=1,NUCOUT
DO 80 IT=1,NUNU
DO 80 IT=1,NTHETA
SCONPO(1T,IX,IN)=GCONPO(1T,IX,IN)+GDRY(1T,IX,IN)
50 CONTINUE
READ(NTEMP)GDRY
DO 90 IX=1,NUCOUT
DO 90 IT=1,NUNU
DO 90 IT=1,NTHETA
SDEP(1T,IX,IN)=GDEP(1T,IX,IN)+GDRY(1T,IX,IN)
90 CONTINUE
READ(NTEMP)GDRY
IF (OVPICAL) READ(NTEMP)GCONOV
CONTINUE
100 WRITE(NTEMP)SDEP
DO 130 IX=1,NUNU
IF (.NOT. AVS6) WRITE(KOUT,10400)TI,UNITSR,X(IX),
> (DI(1T),IT=1,NTHETA),AVS
IF (AVS6) WRITE(KOUT,10450) TI,UNITSR,X(IX),X(IX+1),
> (DI(1T),IT=1,NTHETA),AVS
WRITE(KOUT,10600)
JLAST=JC(1)
DO 110 NUC=1,NUCOUT
IE=IC(NUC)
IF (JC(NUC).EQ. JLAST) GO TO 111
WRITE(KOUT,10255)
JLAST=JC(NUC)
CONTINUE
111 DAYS = 0.0
DO 200 IT=1,NTHETA
DAYS = DAYS + SCONPO(1T,IX,NUC)
200 CONTINUE
DAYS = DAYS / FLJAT(NTHETA)
WRITE(KOUT,10700)EXP(SYN(IE), (SCONPO(1T,IX,NUC),IT=1,
> NTHETA),DAYS
110 CONTINUE
IF (.NOT. AVS6) WRITE(KOUT,10500)UNITSR,X(IX), (DI(1T),IT=1,NTHETA)
IF (AVS6) WRITE(KOUT,10550)UNITSR,X(IX),X(IX+1),

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      < (DI(I),IT=1,NTHETA),AVG
      WRITE(ROUT,10400)
      JLAST=JC(1)
      DO 120 NUC=1,NUCOUT
      IE=IC(NUC)
      IF(JC(NUC).EQ.JLAST) GO TO 121
      WRITE(6,10255)
      JLAST=JC(NUC)
121    CONTINUE
      DAVS = 0.0
      DO 250 IT=1,NTHETA
      DAVG = DAVS + SDEP(IT,IX,NUC)
250    CONTINUE
      DAVG = DAVG / FLOAT(NTHETA)
      WRITE(ROUT,10700)EX=SYN(IE), (SDEP(IT,IX,NUC),IT=1,NTHETA),DAVG
120    CONTINUE
130    CONTINUE
      RETURN
10000  FORMAT('1',10X,20A4)
10100  FORMAT('0..... THE VALUES OUTPUT ARE FOR THE AVERAGE',
      > ' OVER THE GRID CELL'// ' EXTENDING FROM THE DISTANCE GIVEN',
      > ' TO THE NEXT LARGER DISTANCE.....')
10200  FORMAT('0 DISTANCE(M):',F10.3,' DIRECTION FROM SOURCE:',A4/
      > ' RADIONUCLIDE P.SIZE CLEARANCE CLASS ',3X,
      > ' P.SIZE GROUND DEP RATE(',F4.2,'/4=27SEC)',2X,
      > ' AIR CONC EFF AIR CONC / 13X,(MICRONS) ',
      > ' D Y FRACT DRY WET TOTAL',
      > ' 5X,',F4.2,'/4=3)',(F4.2,'/4=3)')
10250  FORMAT('0DISTANCE(M):',F10.3,'-F10.3,
      > ' DIRECTION FROM SOURCE:',A4/
      > ' RADIONUCLIDE P.SIZE CLEARANCE CLASS ',3X,
      > ' P.SIZE GROUND DEP RATE(',F4.2,'/4=27SEC)',2X,
      > ' AIR CONC EFF AIR CONC / 13X,(MICRONS) ',
      > ' D Y FRACT DRY WET TOTAL',
      > ' 5X,',F4.2,'/4=3)',(F4.2,'/4=3)')
10255  FORMAT('0')
10300  FORMAT(3X,A8,3X,1PE8.2,(OPF5.2),F6.2,3(1PE10.3),2(1PE12.4))
10400  FORMAT('1',10X,20A4,' AIR CONCENTRATION(',F4.2,'/4=3)')
      > ' SUMMED OVER ALL PARTICLES SIZES'//
      > ' DISTANCE(M)FROM THE SOURCE :',F15.2/
      > ' DIRECTIONS FROM SOURCE :',8(A4,9X)/(27X,7(A4,9X),A4,3X,A4))
10450  FORMAT('1',10X,20A4,' AIR CONCENTRATION(',F4.2,'/4=3)')
      > ' SUMMED OVER ALL PARTICLES SIZES'//
      > ' DISTANCE(M)FROM THE SOURCE :',F10.3,'-F10.3/
      > ' DIRECTIONS FROM SOURCE :',8(A4,9X)/(27X,7(A4,9X),A4,3X,A4))
10500  FORMAT('//00GROUND DEPOSITION RATE(',F4.2,'/SEC)')
      > ' SUMMED OVER ALL PARTICLES SIZES'//
      > ' DISTANCE(M)FROM THE SOURCE :',F15.2/
      > ' DIRECTIONS FROM SOURCE :',8(A4,9X)/(27X,7(A4,9X),A4,3X,A4))
10550  FORMAT('//00GROUND DEPOSITION RATE(',F4.2,'/SEC)')
      > ' SUMMED OVER ALL PARTICLES SIZES'//
      > ' DISTANCE(M)FROM THE SOURCE :',F10.3,'-F10.3/
      > ' DIRECTIONS FROM SOURCE :',8(A4,9X)/(27X,7(A4,9X),A4,3X,A4))
10600  FORMAT(' RADIONUCLIDE ')
10700  FORMAT(3X,A8,11X,8(1PE8.2,3X) /
      > ' (24X,7(1PE8.2,3X),1PE8.2,1X,1PE8.2))
      END
      SUBROUTINE QPRIME(NUC,NUCOUT,L,ROUT,NUMX,ITRAN,QIN,QPR,FF)
      -----WRITTEN FOR ANEMOS CODE BY O. J. HERMANN,10/6/80.
      *CALLED FROM CPLETE *
      COMPUTES QPR, THE FRACTION OF INITIAL '0', FOR A GIVEN CHAIN,
      FROM QIN AND THE FF-MATRIX FINAL TRANSITIONS - AS REQUESTED
      FROM ITRAY(1 & 2,NUC)...
      DIMENSION ITRAN(2,1),QIN(1),QPR(NUCOUT,1)
      DOUBLE PRECISION FF(L,L,1)
      DO 30 N=1,LOUT
      I=ITRAY(1,N)
      IF (I.EQ.0) GO TO 33
      NUC=NUC+1
      J=ITRAY(2,N)
      DO 20 JX=1,NUMX
      QPR(NUC,JX)=FF(J,I,JX)*QIN(J)
      ABOVE IS CONTRIBUTION TO 1 FROM ANCESTOR J.

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20 CONTINUE
25 CONTINUE
RETURN
END
SUBROUTINE RDNUCEN(DAT,NUC,CLAMDA,NUCDAT, NPART,NCAT,IN,KOUT,
> NUNK,NDDR,DOR,RHODAT,WIN,ZIN,HSTACK,FRACH,WIND,NTHETA,MNSTA,
> MAXSTA,NUMSTA,AREA,UL,RAINAV,MLID,UNITSR)

** CALLED FROM MAIN **
WRITTEN FOR ANFMS - ON HERMANN 6/23/81...
READS NUCLIDE SOURCE,DAT & NET REMOVAL LAMCDS,B PARTICLE SIZE DISTR..

COMMON /NUCSTD/ EXPSYM(200),RELSYM(200),FRAC(15,40),DIAM(5,40),
> B=0(AC),VR(200),VDEP(15,40),MLNDAT(200),NFLAB(200),NPART(40),
> CARRAY(200),FCLEAR(14,200),NUCPAR(1000),IPART(200),WTR(200),
> WTT(200),DVAR(40),IDR(200),JNUM(200),IDR(200),
> XCLEAR(4,200),PSIZE(1000)

REAL*8 SYMOL,RELSYM,U238,BL,EXPSYM,RSYM,UNPACK
LOGICAL CLAMDA,ANYMB
DIMENSION PDIAN(5),PFRAC(5),PSLIP(5),CLEARF(3),DEFDI(5),
> DRR(NUNK,1),DEPVEL(5),UINC(1),ZINC(1),UREL(40),FRACH(1),WIND,
> NTHETA,NUMSTA,PLAMDA(5),PWR(5),PZW(5),PJDI(5),WL(5,40)
LOGICAL WNDCLS,WND(40)

DATA DEFDI /0.3,1.0,3.0,10.0,100./, ANYMB/,FALSE./
DATA U238/86U-238 /,140,15,1200 /40,5,200/,9L/9H
- ,SEC/7/SEC/7, 6/7/6/

NAMELIST /NUCDAT/ INDEX,SYMBOL,RELSR,RSYM,CLEARF,WNDCLS
NAMELIST /WNDCLS/ ITYPE,RE
NAMELIST /PARTAR/ PDIAN,PFRAC,PRHO,DEPVEL,INDEX,PWR,PZW,PJD,NPAR
WRITE(KOUT,10000)
DO 20 I=1,140
  NPARX(I)=0
  RHO(I)=0
  DO 10 J=1,15
    IF (J.LE.3) FCLEAR(I,J)=0.0
    FRAC(I,J)=0.0
    DIAM(I,J)=0.0
    WL(I,J)=0.0
10 CONTINUE
DO 30 I=1,1200
  FCLEAR(I,1)=0.0
  FCLEAR(I,2)=0.0
  FCLEAR(I,3)=0.0
  WTT(I)=0.0
30 IPART(I)=0
DO 40 I=1,NUNK
  DRR(I,1)=0.
40 DRR(I,1)=0.

II=NVUC
DO 100 V=1,NDAT
  SYMBOL=U238
  WNDCLS=.FALSE.
  RELSR=BL
  INDEX=1
  DO 60 J=1,140
    CLEARF(1)=0.0
    CLEARF(2)=0.0
    CLEARF(3)=0.0
60 CONTINUE

...READ NUCLIDE DATA TABLE

READ(IN,NUCDAT)
OUT=SEC
IF(WNDCLS) OUT=6
WRITE(KOUT,10100)N,SYMBOL,RELSR,UNITSR,OUT,RSYM,INDEX,CLEARF
IF(WNDCLS) WRITE(KOUT,10400)
FORN=1 THE ABOVE NUCLIDE IS WINDFLOWN
IF(WNDCLS) ANYMB=.TRUE.
IPART(N)=INDEX
WND(N)=WNDCLS

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C      NOW, SCOOT ROWS BACK, NOT COLUMNS FOR IJ COLUMNS...
DO 100 J=1,IJ
C      NOW, SCOOT DOWN FOR REMAINING ELEMENTS....
DO 110 I=1,K,L
100 C(I,J,I-1)=C(I,J,I)
110 CONTINUE
DO 130 I=1,K,L
IF (KSHORT.EQ.0) NUCID(I-1)=NUCID(I)
130 C(I,J,I-1)=IND(I)
IF (KSHORT.EQ.0) GO TO 30
L=L-1
C      ALWAYS DECREASE AFTER USED AT TOP OF DO LOOP
140 CONTINUE
DCUT=17.329
L3=MINO(KSHORT,JSHORT)
IF (LS.ST.0) GO TO 190
IF (L.C.1) GO TO 150
IJ=0
DO 170 I=2,L
ASC=ARS(C(I,I))
IF (ASC.LT.DCUT) GO TO 170
JJ=0
KK=1-1
DO 150 J=1,KK
IF (C(J,I).EQ.0.0) GO TO 150
JJ=JJ+1/C(J,J).LT.2000.0) GO TO 170
IF (JJ.ST.1) IJ=0
IF (JJ.ST.1) GO TO 170
BFJTOI=-C(J,I)/C(I,I)
LJ=J
IJ=I-1
150 CONTINUE
IF (IJ.EQ.0) GO TO 170
HALF-LIFE < 8.04 SEC, LAMDA RATIO > 2000 AND NO BRANCHING IS THE
CRITERIA THAT HAS BEEN SET - DELETE NUC FROM MATRIX, BUT NEED TO
PRESERVE TRANSITION TO DAUGHTER.....
IST=I+1
DO 160 K=IST,L
IF (C(I,K).EQ.0.0) GO TO 160
WHEN ELEMENT IN SHORT-LIVED NUC COLUMN IS FOUND, ADD IT TO THE
ELEMENT IN LONG-LIVED PARENT COLUMN OF SAME ROW TO MAKE TRANSITION
FROM LONG-LIVED NUC DIRECTLY TO DAUGHTER OF THE SHORT-LIVED DAUGHTER
BEING REMOVED.....
C(LJ,K)=C(LJ,K)+C(I,K)+BFJTOI
160 CONTINUE
GO TO 180
170 CONTINUE
GO TO 190
C      WHEN IT FALLS THRU GO, NO MORE SHORT-LIVED NUCS TO BE REMOVED.
180 CONTINUE
IF (KSHORT.ST.0) JSHORT=KK
IF (KSHORT.ST.0) LJ=IND(KK+1)
IF (KSHORT.ST.0) KJ=IND(KK+1)
IF (KSHORT.EQ.0) KSHORT=KK
GO TO 70
190 CONTINUE
C      NOW, MOVE C-ARRAY INTO A COMPACT M-ARRAY OF SIZE L*L...
K=0
DO 210 I=1,L
DO 200 J=1,L
K=K+1
200 M(K)=C(I,J)
210 CONTINUE
RETURN
END
SUBROUTINE RELESE(NRELL,NREL,NC,MX,QSHORT,IDE,SYMBOL, JNUM,
> KSHORT)
C      ** CALLED FROM LIRNKK **

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-----WRITTEN FOR AENOS CODE BY O. W. HERMANN,12/30/80.
-----WRITTEN FOR PRIMUS CODE BY O. W. HERMANN,12/30/80.

PURPOSE TO SETUP JRMN POINTERS TO RELEASED NUCLS READ IN SET NREL.

INTEGER IOSH(20),IDF(1),NUMM(1)
DOUBLE PRECISION SYMOL(1),ZSHORT(1)
COMMON/JOYMS/VR,MR,SD,IN,KOUT,NTMP
IF (VMSVOT(50,0) 50 TO 20
DO 10 M=1,NVSHORT
IOSH(M)=IOSSHORT(M)
20 CONTINUE
K=0
DO 70 I=1,NE
DO 50 J=1,NRELIN
IDM=IOSYMOL(I,J)
CAN IDM BE RELEASED.R IS IT NEXT IN ORDER...
IF (IDC(I),NE,IDM) 50 TO 50
IF (IDSHORT(50,0) 60 TO 40
DO 30 M=1,NVSHORT
IF (IDSH(M),SD,IDM) 60 TO 60
30 CONTINUE
40 K=K+1
JNUMBER=J
50 CONTINUE
60 WRITE(ROUT,1000)IOSSHORT(M)
70 CONTINUE
RETURN
1000 FORMAT(10A8,' IS A VERY SHORT-LIVED NUCLIDE MODEL EXCLUDES IT
FROM DELAY DATA AND SETS EQUAL TO ZERO. ACTIVITY %I, A RELCA
>SET IS INCLUDED AS AN EXPOSURE NUCLIDE BUT WAS DELETED AS A RELCA
>NUCLIDE.
END
SUBROUTINE SETDEC(NTOT,NTOT1,MAYMX,MAX2,MUCDRT,MNUC,MNUM,NUCOUT,
>SUC,AVC,MN,CARRY,SNM,INNM,NDONE,DLAT,ITRAN,JTRAN,ZIV,INZ,
>MUCIDONETORY,VR,MR,SD,CHAIN,R,INDEXP,INDEXP,SSHORT,IC,UC,MNM,
>EXPSYM,NRELSYM,JJJ)
SUBROUTINE WAS WRITTEN FIRST FOR THE AENOS CODE. IT IS COMPLETELY
ORDERED TO SUPPLEMENTARY PART OF PRIMUS. THIS PART COULD BE COMPLY
COPIED AND MADE A PART OF PRIMUS. THE EXPOSURE AND SAVED FOR A RELCA
WITHOUT DUPLICATE. THE EXPOSURE AND SAVED FOR A RELCA. THE
PROGRAMMER. THEY ARE MEANINGLESS TO PRIMUS. FOR AENOS HAVE BEEN
DETERMINED. ALTHOUGH THEY ARE MEANINGLESS TO PRIMUS. PLEASE IGNORE THEM
INCLUDE: SET,DRY,VR,SD,ITRAN AND JTRAN. PLEASE IGNORE THEM
WHEN READING OR USING THE SUBROUTINE FOR PRIMUS.
-----
** CALLED FROM PRIMUS CODE MAIN **
-----WRITTEN FOR AENOS CODE BY O. W. HERMANN,12/30/80.
-----WRITTEN FOR PRIMUS CODE BY O. W. HERMANN,12/30/80.

NOTE...
THIS SUBROUTINE WAS WRITTEN FIRST FOR THE AENOS CODE. IT IS COMPLETELY
ORDERED TO SUPPLEMENTARY PART OF PRIMUS. THIS PART COULD BE COMPLY
COPIED AND MADE A PART OF PRIMUS. THE EXPOSURE AND SAVED FOR A RELCA
WITHOUT DUPLICATE. THE EXPOSURE AND SAVED FOR A RELCA. THE
PROGRAMMER. THEY ARE MEANINGLESS TO PRIMUS. FOR AENOS HAVE BEEN
DETERMINED. ALTHOUGH THEY ARE MEANINGLESS TO PRIMUS. PLEASE IGNORE THEM
INCLUDE: SET,DRY,VR,SD,ITRAN AND JTRAN. PLEASE IGNORE THEM
WHEN READING OR USING THE SUBROUTINE FOR PRIMUS.
-----
DOUBLE PRECISION QNM(MNUC),QNC(NTOT),QVC(NTOT),ZSHORT(1),BLANK,
>EXPSYM(1),NRELSYM(1),MNUC,THLOC,DIFFX,DIFFY,ALAT,ALONG,SYN,
>DIMENSION NMTOT(1),MNUC,MNUC,INNM,MNUC,INNM,MNUC,INNM,MNUC,INNM,
>ITRANZ,ITRANZ(1),SNM,MNUC,INNM,MNUC,INNM,MNUC,INNM,MNUC,INNM,
>ZIV,INZ,CHAIN,MNUC,INNM,MNUC,INNM,MNUC,INNM,MNUC,INNM,MNUC,INNM,
>MUCIDONETORY,VR,MR,SD,CHAIN,R,INDEXP,INDEXP,SSHORT,IC,UC,MNM,
>EXPSYM,NRELSYM,JJJ)
COMMON/JOYMS/VR,MR,SD,IN,KOUT,NTMP
COMMON/JOYMS/ALAT,ALONG,RLOC,THLOC,DIFFX,DIFFY,MUMSR,
>ISDOP,UNITSR
COMMON/NUCDATA/ MUMCA,MRP,DELT,M6PROG,CALDRY ,NEXT,KTRUNC,LMX,
>SHORT,MREL,MREL
DATA BLANK
MUCOUT=0

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[illegible]

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NUCPAR(K) IS PART. CATEGORY NUMBER OF EXP. NUC OR LAST EXP. NUC...
III=1
J=NUCPAR(1)
IF (NUCOUT.EQ.1) GO TO 130
DO 120 K=2,NUCOUT
IF (JC(K).EQ.JC(K-1)) GO TO 100
J=NUCPAR(K)
NPAR=NPAR(J)
III=K
GO TO 120
100 L=NUCPAR(K)
IF (NPARX(L).NE.NPAR) WRITE(KOUT,10300)IDEXP(K),IDEXP(III)
IF (NPARX(L).NE.NPAR) CALL ERROR
SHOULD BE SAME NO. OF PART. SIZE TYPES FOR ALL NUCS. IN CHAIN
DO 110 N=1,NPAR
II=NFLAS(J,N)
I2=NFLAS(L,N)
CODE SETS SAME FRACTION DISTRIBUTION FOR ALL OF CHAIN...
110 FR(I2)=FR(II)
120 CONTINUE
130 CONTINUE
RETURN
10000 FORMAT(1H1,15,' PARTICLE SIZES IN SET',I2,1X,
>' EXCLUDED INPUT SPECIFIED,NPAR=',I4)
10100 FORMAT(1P PARTICLE PARTICLE FRACTION SETTLING %,
>' NET DEPOSITION',
>' SIZE NUMBER VELOCITY',
>' LAMBDA VELOCITY', CATEGORY',2X,'(M/SEC)',5X,'(M/SEC)',
>' ST',(M/SEC))
10200 FORMAT(3X,14,6X,14,3X,F10.3,1P3E12,3/,(54X,1P12,3))
10300 FORMAT(1H0,'NUCLIDE',I7,1X,'HAS DIFFERENT NUMBER OF PARTICLE',
>' SIZE TYPES THAN RELEASED NUCLIDE',I7)
END
SUBROUTINE SETVO(VD,VT,DIN,RHO,L,US,COMP)
THIS ROUTINE USES SEMMEL AND HODGSON, 1980 TO CALCULATE DEPOSITIONAL
VELOCITY (M/S), TERMINAL (GRAVITATIONAL) VELOCITY (M/S), FOR A
PARTICLE OF DIAMETER D (M), DENSITY RHO (G/CC), AT VELOCITY
WINDSPEED US (M/S), ROUGHNESS LENGTH L (M), AND INVERSE MONIN-
OBUKOV LENGTH L (1/M). ATMOSPHERIC CONSTANTS ARE IC40 STANDARD
SEA LEVEL VALUES.
A (M) PARTICLE RADIUS
D (M) PARTICLE DIAMETER
DB (M**2/S) BROWNIAN DIFFUSIVITY
S (M/S**2) GRAVITATIONAL ACCELERATION
INT TOTAL RESISTANCE INTEGRAL
INTS LOWER BOUND OF INTS
INT12 RESISTANCE INTEGRAL FROM IN TO .01M
INT3 RESISTANCE INTEGRAL FROM .01M TO SURFACE
K VON-KARMAN CONSTANT
KB (J/KG) SOLID CORRELATION FACTOR
KS SLIP CORRELATION FACTOR
LI (1/M) INVERSE MONIN-OBUKOV LENGTH
MU (KG/M-S) COEFFICIENT OF VISCOSITY
NU (M**2/S) KINEMATIC VISCOSITY
P (N/M2) ATMOSPHERIC PRESSURE
RHO (G/CC) PARTICLE DENSITY; TAU CALCULATED WITH RHO=1.5E31
VT CALCULATED WITH RHO SCALED TO KB/M**3
SC SCHMIDT NUMBER
T (K) TEMPERATURE
TAU SCALED DIMENSIONLESS RELAXATION TIME
US (M/S) FRICTION VELOCITY
VD (M/S) DEPOSITIONAL VELOCITY
VT (M/S) TERMINAL SETTLING VELOCITY (V6 IN AIRDOS-EPA)
ZZERO (M) SURFACE ROUGHNESS LENGTH
COMMON/PAIR/PI,CONST,STACK,ZZERO,VGRAV,TERMO,UMINHT
LOGICAL COMP
REAL VD(4),L0,L1,K,KB,KS,MU,NU,INT12,INT3,INTS,INT
DIMENSION P(4),L0(4),L1(4),PPS(12)
DATA X1/-.69314718/,XU/.49546511/,
P70/.76/,K70/.33/,KB/.380662E-23/,T288.15/,
MU/1.7894285E-5/,NU/1.4607413E-5/,S/9.80665/
DATA Z0/.01/,L1.1,/,
DATA C0/-.1405, -.1109, -.0875, -.0701,
-.0848, -.0771, -.0385, -.0319,
-.0329, -.0163, -.0081, -.0050,
-.0329, -.0163, -.0081, -.0050,
-.0848, -.0371, -.0385, -.0319/

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C DIMENSION SIGZK(NUMSTA,NUMK,MWIND),X(MUXK),JWAKE(MWIND,NUMSTA),
> AA(8),BB(8),CC(8),DD(8),ZF(6),ZG(6),ZH(6),ZJ(6)
LOGICAL L1,JWAKE
COMMON /PARR/ PI,CONST,HSTACK,ZZERO,VBRAY,TERHTO,WRINHT
COMMON /OPT/ TERHT,HTMAX,CWAKE,DNUASH,DDWAKE,LINEAR,MAXM,SROUSH,
> CONST,OVPCAL
LOGICAL TERHT,HTMAX,CWAKE,DNUASH,DDWAKE,LINEAR,SROUSH,CONST,
> OVPCAL
COMMON /MT/ GRAY,BETA1,BETA2,TEMPAIR,TEMPS,VPLS,DIAM,HBLD,VBLO

C DATA AA /8.112,130.,112,2.0,8.898,8.609,8.638,8.366 /
DATA BB /1.86,3.98,3.20,2.0,8.889,8.893,8.83,7.74 /
DATA CC /3.38E-4,6.52E-4,9.85E-4,2.1,3.5E-3,1.96E-3,1.56E-3,5.44E-
> 4 /
DATA DD /8.815,758.,718,2.0,6.88,6.84,6.72,7.427 /
DATA ZF /1.56,7.02,7.72,3.16,7.37,11.7 /
DATA ZG /8.8480,8.8269,8.80,8.80,8.80,8.80,8.80,8.80 /
DATA ZH /6.23E-4,7.6E-4,8.0,8.6,8.2,8.5,8.5,8.4 /
DATA ZJ /8.45,8.37,8.0,8.22,8.0,8.60,8.78 /

C I=6
GBLD=ARJN1(HBLD,VBLO)
IF (ZG(I).GT.1.0) I=5
IF (ZG(I).GT.1.0) I=5
IF (ZG(I).GT.1.0) I=5
IF (ZG(I).GT.1.0) I=5
IF (ZG(I).GT.1.0) I=5
IF (ZG(I).GT.1.0) I=5
IF (ZG(I).GT.1.0) I=5
IF (ZG(I).GT.1.0) I=5
ROUGHNESS INDEX I,IS RT.
DO 100 JSTAB=1,NUMSTA
DO 100 JR=1,NUM7NO
S=0.0
Z=0.0
IF (.NOT.DOWAKE) GO TO 10
IF (.NOT.JWAKE(JR,JSTAB)) GO TO 10
C X-R IS THE DOWNWIND DISTANCE FROM THE EDGE OF THE BUILDING
R=VBLO*8.5
CALL WAKE(S,I,JSTAB,GBLD,AA(JSTAB),BB(JSTAB),CC(JSTAB),DD(JSTAB),
> ,ZF(I),ZG(I),ZH(I),ZJ(I))

C SUB WAKE ADJUSTS SIGMA-2 FOR BUILDING WAKE FOR X>10*GBLD
10 CONTINUE
DO 98 JR=1,NUMK
SIGBLD=-5.79
XADJS=X(JR)
IF (.NOT.DOWAKE) GO TO 30
IF (.NOT.JWAKE(JR,JSTAB)) GO TO 30
XADJS=XADJS-R
IF (XADJS.GT.3.0*GBLD) GO TO 20
SIGBLD=8.7*GBLD
GO TO 30
20 IF (XADJS.GE.10.0*GBLD) GO TO 25
SIGBLD=8.7*GBLD*8.057*(XADJSR-3.0*GBLD)
GO TO 30
25 XADJS=XADJS+S
30 IF (SROUSH) GO TO 70
FZX=1.8
IF (I.EQ.3) GO TO 60
MXJ=ZM(I)*XADJS**J(I)
IF (I.EQ.3) GO TO 40
FAC=1.0+1.0/MXJ
GO TO 50
40 FAC=1.0/(1.0+MXJ)
50 ARG=FAC*ZF(I)*XADJS**ZG(I)
FZX=ALOG(ARG)
60 CONTINUE
GO TO 80
70 CALL FFAC(ZZERO,XADJS,FZX)
80 DEN=1.0-CC(JSTAB)*XADJS**DD(JSTAB)
SM=FZX*AA(JSTAB)*XADJS**BB(JSTAB)
SIGZK(JSTAB,JR,JR)=SM/DEN
IF (JWAKE(JR,JSTAB).AND.SIGBLD.GT.SIGZK(JSTAB,JR,JR)) SIGZK(JSTAB,
> JR,JR)=SIGBLD
98 CONTINUE
100 CONTINUE
RETURN
END
SUBROUTINE SIMPUN(XR,FX,MY,I,AXI)
PROGRAM AUTHOI JS MARISH,
COMPUTING TECHNOLOGY CENTER,UNION CARBIDE CORP.,NUCLEAR DIV.,
344 RIDGE, TENN.

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    DIMENSION UMSTAK(NUMSTA,NUMIND),UMINDENUMX,NUMIND,NUMSTA,
    > TIME(NUMX,NUMIND,NUMSTA),X(NUMX)
    DIMENSION UIN(NUMIND),ZIN(NUMIND),HEFF(NUMSTA,NUMIND,NUMX),
    > HFFF(NUMSTA,NUMIND)

    COMMON /PARM/ PI,CONST,HSTACK,ZZERO,VGRAY,TEGHTD,JNINHT
    IF (UMINHT.EQ.0.0) JNINHT=10.
    DO 80 JSTAB=1,NUMSTA

    WIND SPEED ADJ. DIFFERS BY STAB. CLASS AND ZZERO
    CALL NPOWER(ZZERO,JSTAB,FN)

    SUBR NPOWER CALCS. FN FOR JSTAB,ZZERO

    NOW ADJ. EACH WIND SPEED(STACK HT. OR EFF. STACK HT.)
    DO 70 JR=1,NUMIND
    UI=UIN(JR)
    ZI=ZIN(JR)
    IF (ZI.LE.0.0) CALL ERROR
    T=0.0
    IF (INTYP.EQ.3.OR.INTYP.LE.0) CALL ERROR
    DO 70 (10,20,30),INTYP
10  MTWIND=AMAX1(HSTACK,UMINHT)
    UMSTAK(JSTAB,JR)=UI*(MTWIND/ZI)** FN
    GO TO 70
20  DO 40 JK=1,NUMX
    MTWIND=AMAX1(HEFF(JSTAB,JR,JK),UMINHT)
    UMIND(JK,JR,JSTAB)=UI*(MTWIND/ZI)** FN
    XI=0.0
    IF (JK.EQ.1) XI=X(JK-1)
    UI=UMSTAK(JSTAB,JR)
    IF (JK.EQ.1) UI=UMIND(JK-1,JR,JSTAB)
    T=(XI*JK)-XI-2.0/(UMIND(JK,JR,JSTAB)+UI)
40  TIME(JK,JR,JSTAB)=T
    GO TO 70
50  MTWIND=AMAX1(HEFF(JSTAB,JR),UMINHT)
    UI=UI*(MTWIND/ZI)** FN
    DO 60 JK=1,NUMX
    TIME(JK,JR,JSTAB)=X(JK)/UI
60  UMIND(JK,JR,JSTAB)=JU

70 CONTINUE
80 CONTINUE
    RETURN
    END
    SUBROUTINE XCALC(NUMX,N,X,VGR06,XMAX)
    WRITTEN FOR ANEMOS BY OM HERMANN -- 7/1/81
    CALLED FROM MAIN FOR CALC. OF X-DISTANCES FROM MESH FINENESS..
    DIMENSION Y(1)
    S02=SQRT(2.0)
    S04=SQRT(S02)
    VGR06=X
    X(NUMX)=XMAX
    IF (NUMX.EQ.1) GO TO 90
    IF (N.EQ.1) GO TO 25
    N1=NUMX-1
    DO 10 I=1,N1
    N=NUMX-I
10  X(I)=X(N+1)/2.0
    GO TO 40
20  IF (N.EQ.2) GO TO 35
    N=2
    N1=(NUMX-1)/2
    IF (NUMX.EQ.2) GO TO 40
    DO 30 I=1,N1
    N=NUMX-I-1
30  X(I)=X(N+2)/2.0
    IF (N.EQ.2) X(1)=X(2)/S02
    GO TO 90
50  VGR06=X
    N1=(NUMX-1)/4
    N=NUMX

```



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      ERROR = 2
      IF (YMIN-GE.YMAX .OR. Y.LT.YMIN .OR. Y.GT.YMAX) GO TO 80
      D = XMAX - XMIN
      CHECK THAT THE X RANGE IS REASONABLE AND THAT NONE OF
      THE GIVEN VALUES OF X IS OUTSIDE IT
      IF (D.LE.0.0E+22) GO TO 80
      DO 20 FIRST PASS
      IF (ICR).LT.YMIN .OR. X(R).GT.XMAX) GO TO 80
20 CONTINUE
      CALCULATE YCAP, THE NORMALIZED VALUE OF Y
      YCAP = ((Y-YMIN)-(YMAX-Y))/(YMAX-YMIN)
      ERROR = 1
      R = -1
      EVALUATE THE COEFFICIENTS OF THE POLYNOMIAL FOR THE GIVEN Y
      DO 40 121(KP)
      R = 2
      CALL SUBROUTINE POL1 (A(1), YCAP, WORK(1), ERROR)
      IF (ERROR.NE.1) GO TO 80
40 CONTINUE
      EVALUATE THE POLYNOMIAL AT THE GIVEN X VALUES
      DO 60 121(KP)
      YCAP = ((Y-YMIN)-(YMAX-Y))/(YMAX-YMIN)/D
      CALL SUBROUTINE POL2 (WORK, YCAP, F(1), ERROR)
      IF (ERROR.NE.1) GO TO 80
60 CONTINUE
      IF (FAIL) GO TO 80
      RETURN
      SUBROUTINE POL2(INPULS, A, YCAP, P, IFAIL)
      HAS LIBRARY SUBROUTINE POL2DEF
      POL2DEF EVALUATES A POLYNOMIAL FROM ITS CHEBYSHEV-
      SERIES REPRESENTATION.
      CLENSHAW METHOD WITH MODIFICATIONS DUE TO REINSCH
      AND GENTLEMAN.
      USES TWO LIBRARY ROUTINES POL1AP AND XCAPAP.
      USES INTRINSIC FUNCTION ABS.
      STARTED - 1973.
      COMPLETED - 1976.
      AUTHOR - MRC AND J64.
      HAS COPYRIGHT 1975
      COLLECTED BY JOYCE FOR THE OXFORD OFS NUCLEAR PHYSICS 05TH NOV 1976
      MARK 3 RELEASE 198-148 (DEC 1978)
      INTERFERED BY POL1AP, POL2AP, ERROR, X, KREV, N, MPLUS2
      DONALD BRADSHAW, SRA, MRC
      REAL INPULS, A(1), XCAP, X, XCAPAP, ABS, BK, BKPL, BKPL2, OK,
      .277, FACTOR
      DATA SYTIME /8H 0024EF /
      ERROR = 0
      EVA = XCAPAP(CTA)
      INSERT CALL TO XCAPAP
      CTA IS THE SMALLEST POSITIVE NUMBER SUCH THAT
      THE COMPUTED VALUE OF 1.0 + CTA EXCEEDS UNITY.
      IF (.MPLUS1-GE.1) GO TO 10

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EDITED BY JOYCE CLARK, OXFORD OEG NUCLEAR PHYSICS 05TH NOV 1976
FORTRAN MICRO VERSION P01A26.TEC
IF I = 0 SETS NERR TO CURRENT ERROR MESSAGE UNIT NUMBER
(STORED IN NERR1).
IF I = 1 CHANGES CURRENT ERROR MESSAGE UNIT NUMBER TO
VALUE SPECIFIED BY NERR.
*** NOTE *** ASSUMES THAT THE VALUE OF NERR1 IS SAVED
FROM THE SOME IMPLEMENTATIONS MAY BE
DIFFERENT TO THE ONE IN THIS.
BLOCK /X0800/ TO AVOID THIS.
** SCALAR ARGUMENTS **
INTEGER I, NERR
** LOCAL SCALARS **
INTEGER NERR1
DATA NERR1 / -1/
IF (I = 0) NERR = NERR1
RETURN
** FUNCTION P01A26 (FAIL, ERROR, SRNAME)
**
** REVISIONS:
** 1. REVISED (DEC 1978) - (APR 1979)
** 2. REVISED (DEC 1978) - (APR 1979)
** 3. REVISED (DEC 1978) - (APR 1979)
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** 100. REVISED (DEC 1978) - (APR 1979)

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APPENDIX D

List of Symbols Used in This Report

- A_{bi} - photon yield in energy group, b, of radionuclide, i (photons/disintegration)
- A_f - an empirical constant for wind erosion calculations (0.1)
- C - air concentration at position (x,y,z) (Bq/m^3 or Ci/m^3)
- C_b - coefficient in the Berger form of the energy-absorption buildup factor in air for energy E_b (B_{en}^a) given by Trubey (1966)
- $C_{ies}(x)$ - effective air concentration; the dose from overhead gamma plume divided by the dose conversion factor for a semi-infinite cloud
- $C_{is}(x)$ - ground-level air concentration of radionuclide, i, in wind direction, s, at downwind distance, x (Bq/m^3 or Ci/m^3)
- $C_{is}(z')$ - air concentration within the vertical layer through which the rain is falling (Bq/m^3 or Ci/m^3)
- C_L - concentration or deposition at the lower of two consecutive distances, x_1
- C_{oi} - concentration of radionuclides, i, in the air
- C_u - concentration or deposition at the upper distance, x_u
- d_a - actual grain diameter (m)
- d_s - stack exit diameter (m)
- d_g - standard grain diameter (m)
- D_b - coefficient in the Berger form of the energy-absorption buildup factor in air for energy E_b (B_{en}^a) given by Trubey (1966)
- $D_{igs}(x)$ - external dose at location, x, due to immersion in air contaminated by a gamma- or x-ray-emitting radionuclide, i (Sv/year or rem/year)
- D_{iprs}^g - photon dose rate in air for radionuclide, i, stability class, p, wind speed class, r, and wind direction, s (Gy/s per Bq/m^2)
- DRF_{ig} - gamma or x-ray dose equivalent rate per unit concentration of radionuclide, i (Sv/year per Bq/m^3 or rem/year per Ci/m^3)
- E_b - energy of photon energy group, b (MeV/photon)
- f_3 - frequency of stability category C
- f_4 - frequency of stability category D

- f_{prs} - frequency with which the wind blow towards direction, s , in stability category, p , and wind speed class, r
- F - buoyancy flux
- F_c - buoyancy flux below which plume rise is due to momentum only
- F_m - momentum flux
- g - acceleration due to gravity (9.8 m/s^2)
- G - mathematical expression for vertical dispersion of Gaussian plume model
- h_A - afternoon mixing height (m)
- h_e - effective stack height due to momentum, buoyancy, and downwash (m)
- h_L - depth of the mixing layer (m)
- $h_L(p)$ - mixing height associated with stability category, p
- h_M - morning mixing height (m)
- h_p - effective height of plume (m)
- h_s - physical stack height (m)
- h_t - terrain height above stack base (m)
- H - height of release of emissions (m)
- H_b - height of highest influential building (m)
- H_w - width of the region of influential buildings normal to the wind (m)
- $I_{di pr}$ - dry deposition depletion integral for radionuclide i in stability class p and wind speed class r
- j - saltation rate (g/m s)
- J_o - equivalent rainfall rate (m/s)
- k - von Karman's constant
- K - constant depending on particle size distribution
- K_{oi} - concentration of radionuclide, i , in the precipitation
- L^{-1} - inverse Monin-Obukhov length
- m - arbitrary index which refers to successive pairs of reflections
- N_p - number of atmospheric stability classes (unitless)

- N_r - number of wind speed classes (unitless)
 N_s - number of wind directions in a standard data set - 16 (unitless)
 P - constant which is the product of 1.6×10^{-10} g-Gy/MeV and 10^{-4} cm²/m²
 q - power-law exponent for adjusting wind speed for variations in height of measurement
 Q - release rate (Bq/s or Ci/s)
 Q_i - initial emission rate from the source for radionuclide, i , (Bq/s or Ci/s)
 Q_w - windblown radionuclide release rate resulting from saltation and impaction (g/m²s)
 $Q'_{iprs}(x)$ - effective emission rate for pollutant, i , in stability class, p , wind speed class, r , and wind direction, s , at downwind distance, x (Bq/s or Ci/s)
 $Q'_{is}(x)$ - the effective flux of pollutant, i , in wind direction, s , through the vertical plane at downwind distance, x , (Bq/s or Ci/s)
 RR - annual rainfall rate (m/year)
 R - radius of an assumed-circular area source (m)
 R_f - proportionality constant (1/m) required to estimate the suspension rate from the saltation rate
 S - stability parameter (s⁻²)
 S_z - virtual source distance such that $\sigma'_z(10H_b) = 1.2H_b$ (m)
 T_a - ambient air temperature (K)
 T_s - stack exit temperature (K)
 u - wind speed (m/s)
 u_t - fluid threshold velocity
 u_* - friction velocity (m/s)
 u'_* - friction velocity at which wind erosion begins
 u_1 - wind speed at height z_1 above ground
 u_2 - wind speed at height z_2 above ground
 $u(H)$ - mean wind speed (m/s) at emission height, H

- u_r - mean wind speed associated with wind speed category, r (m/s)
- V_{dipr} - dry deposition velocity (m/s) for each radionuclide, i , stability class, p , and wind speed class, r
- V_d - dry deposition velocity (m/s)
- V_g - gravitational settling velocity (m/s)
- V_s - stack exit velocity (m/s)
- $W_{is}^d(x)$ - ground deposition rate due to dry deposition (Bq/m²-year or Ci/m²-year)
- $W_{is}^t(x)$ - total ground deposition rate from both dry and wet deposition processes (Bq/m²-year or Ci/m²-year)
- $W_{is}^w(x)$ - ground deposition rate due to wet deposition (Bq/m²-year or Ci/m²-year)
- W_{ri} - washout ratio of radionuclide, i
- x - downwind distance from source of release (m)
- x_0 - distance from the centroid of an area source to the receptor (m)
- x_l - lower of two consecutive distances
- x_u - upper of two consecutive distances
- x_w - downwind distance from the building edge = $x - H_w/2$ (m)
- x' - dummy variable of integration
- y - horizontal distance perpendicular to the downwind distance, x , denoting crosswind location where air concentration is calculated
- z - vertical distance perpendicular to the downwind distance, x , denoting vertical location where air concentration is calculated
- z_0 - surface roughness length
- z_1 - height at which wind speed is measured
- z_2 - height for which wind speed is calculated using wind profile power law
- Z_w - depth of the plume layer through which the precipitation falls (m)
- ρ_a - density of air (g/m³)

- ρ_s - density of sand grains (g/m^3)
- β_j - jet entrainment coefficient
- Δh_b - plume rise due to buoyancy
- Δh_d - effective stack height due to downwash
- Δh_m - plume rise due to momentum
- Δh_N - plume rise due to buoyancy and/or momentum for stabilities A, B, C, and D
- Δh_s - plume rise due to buoyancy and/or momentum for stabilities E, F, and G
- $\Delta h(x)$ - $\Delta h_N(x)$ or $\Delta h_s(x)$ depending on the atmospheric stability category.
- λ_i^n - radiological decay constant for radionuclide, i (s^{-1})
- λ_{ip}^w - effective decay constant due to wet deposition processes for radionuclide, i, in stability class, p (s^{-1})
- $\lambda_{ipr}^d(x)$ - effective decay constant due to dry deposition processes for radionuclide, i, in stability class, p, and wind speed class, r, at downwind distance, x (s^{-1})
- $\lambda_{ipr}^e(x)$ - effective decay constant for radionuclide, i, in stability class, p, and wind speed class, r, at downwind distance, x (s^{-1})
- σ_y - standard deviation of the material in the plume (m) at downwind distance, x, in the horizontal direction, y
- σ_z - standard deviation of the material in the plume (m) at downwind distance, x, in the vertical direction, z
- $\sigma_z(p, x)$ - vertical dispersion parameter enhanced by building wake effects
- $\sigma_z(p, x)$ - vertical dispersion parameter for stability class, p, and downwind distance, x (m)
- $\mu_b(E_b)$ - linear attenuation coefficient in air for photon energy group, E_b (cm^{-1})
- $\frac{\mu_{en}}{\rho}_b$ - mass energy-absorption coefficient in air for energy, E_b (cm^2/g)

$\frac{\delta \theta}{\delta z}$ - vertical potential temperature gradient (k/m)

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