Technical Note
ORP-EAD-76-6

Area Source Radiological Emission Analysis Code (AREAC)

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

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(AREAC)

by
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October 1976

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FOREWORD

The Office of Radiation Programs carries out a National Program designed to evaluate the exposure of man to ionizing and nonionizing radiation and to promote development of controls necessary to protect the public health and safety and assure environmental quality.

In order to supplement our field measurement capabilities, we rely on computer models to estimate doses to man from releases of radioactive materials. Existing air pathway models estimate doses from point source releases of atmospheric radioactivity, i.e., where the size of the emitting source is small and does not perturb the resultant calculations. However, these models are not accurate at estimating doses at close-in distances when the area of the source is large as in the case of a uranium mill tailings pile, for example. Therefore, this model has been designed to more accurately assess close-in doses from large area sources.

Comments on this analysis would be appreciated. These should be sent to the Director, Environmental Analysis Division, of the Office of Radiation Programs.

Floyd L. Galpin
Director
Environmental Analysis Division

ABSTRACT

A computer code designed to calculate potential radiological impact of atmospheric releases of radionuclides from area sources is presented and discussed. The code is written in FORTRAN IV, requires 48 K storage, and runs about 12 seconds on an IBM 370 system. The code can calculate radionuclide concentrations and individual inhalation doses at up to six specific receptor locations and at up to 192 general locations around an area source. Population doses can also be calculated.

The code accounts for area source shape, cloud diffusion, ground and inversion-lid reflections, and radionuclide decay by time of flight. It is dose model independent and requires a dose conversion factor as part of input data to calculate doses proportional to radionuclide concentrations.

The code is extensively annotated and simply written, hopefully facilitating its use, and an effort was made to provide the user with a high degree of flexibility in the utilization of this code.

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Area Source Radiological Emissions Analysis Code (AREAC)

1. Introduction

The Office of Radiation Programs in the Environmental Protection Agency is developing a comprehensive dose computational system (CDCS) for the analysis of emissions and effluents from the nuclear fuel cycle. To assess the potential radiological effects of airborne radionuclide releases from point sources, a computer code AIREM has been developed by the Office of Radiation Programs in the past (1). The code described in this program manual has been based to a large extent on the AIREM code and represents an initial attempt at developing a quantitative model for analyzing the potential radiological impact of airborne constant, continuous releases of gaseous radionuclides from area sources; principally inactive uranium tailings piles.

As presently written, the code consists of two main parts. In the first part, a sector-averaged Gaussian diffusion equation is utilized to calculate radionuclide dispersion coefficients ($\chi/\dot{Q}$'s), radionuclide concentrations, and resultant inhalation yearly doses at up to six specific receptor locations in the vicinity of an area source. These, in practice, would correspond to the maximally exposed individuals identified to be living near the pile. In the second part, the same diffusion equation is employed to calculate radionuclide dispersion coefficients, concentrations, and yearly doses and population doses for 16 wind sectors and up to 12 downwind distances (192 sector-segments) around the area source.

The manner in which the diffusion equation is utilized to account for the distributed nature of an area source is described in detail in the program manual.

The code was designed to be flexible by providing the user with various options. The user can specify the shape of the area source (rectangular or circular) and the degree of accuracy in accounting for the distributed nature of the source. The code provides an option for calculating inhalation doses only at specific receptor locations or at locations in the population wheel, or both. Since the code calculates radionuclide dispersion coefficients and radionuclide concentrations at various desired locations, by appropriate redefinitions of the dose conversion factor, the user can adapt the code to calculate any desired quantity which is proportional to radionuclide concentration. Thus, the code can be adopted to calculate semi-infinite cloud gamma doses, and, by setting the decay constant to zero, airborne concentrations of non-radioactive gaseous emissions from area sources.

The code, utilized to its maximum capacity, requires 48 k bytes of storage space, and runs about 12 seconds on an IBM 370. It is written in FORTRAN IV.

2. Mathematical Models

2.1 Diffusion of Airborne Emissions from Area Sources

In general, the steady State concentration, χ (Ci/M^3), of airborne radionuclides emitted from a point source can be specified at an arbitrary receptor location by the product of source strength, $\dot{Q}$ (radionuclide rate of emission - Ci/sec), and a function $\chi/\dot{Q}$, which depends only on the mechanism by which the radionuclides are transported from the point of emission to the receptor location. Expressed mathematically:

$$\chi = \dot{Q} \cdot \chi/\dot{Q} \quad . \tag{1}$$

Likewise, the concentration, $d\chi$, of airborne radionuclides, which are emitted at the rate of q Ci/sec per unit of area from a differential area element dA of a distributed source is:

$$d\chi = \chi/\dot{Q} \; qdA \tag{2}$$

where both $\chi/\dot{Q}$ and q are functions of dA for a fixed receptor location.

The concentration of airborne radionuclides emitted from the entire area source may be obtained by integrating equation 2 over the surface of the source. Performing the integration:

$$\chi = \int_A \chi/\dot{Q} \cdot qdA$$

or, if q is independent of position,

$$\chi = q\int_A \chi/\dot{Q} \; dA \quad . \tag{3}$$

Solution of equation 3 requires a two or, if the height of the area source is not uniform, three dimensional integration of a complicated diffusion function. However, an approximate solution may be obtained by approximating the integral with a summation of the integrand over the source area. Thus, if the source area, A, is divided into n small area elements, then

$$\chi \simeq q \sum_n \chi/\dot{Q}_k \; \Delta A_k$$

where:

ΔA_k is the area of the k^{th} area element and $\chi/\dot{Q}_k$ is the value of the diffusion function $\chi/\dot{Q}$ at source position ΔA_k.

If all the area elements are of the same size, ΔA, they can be taken outside the summation sign, and the radionuclide concentration at the fixed receptor location is:

$$\chi \simeq q\Delta A \sum_k \chi/\dot{Q}_k \quad .$$

Furthermore, if Q is the rate of radionuclide emission from the entire source, it follows that

$$\chi \simeq \frac{\dot{Q}}{n} \sum_n \chi/\dot{Q}_k \quad . \tag{4}$$

If one defines the function $\chi/\dot{Q}_A = \frac{1}{n} \sum_n \chi/\dot{Q}_k$ to be an area source diffusion function, then

$$\chi \simeq \dot{Q} \cdot \chi/\dot{Q}_A \tag{5}$$

and the similarity of equation 5 to equation 1 becomes apparent.

The definition of $\chi/\dot{Q}_A$ is used in AREAC to calculate area source dispersion coefficients ($\chi/\dot{Q}_A$'s) and corresponding radionuclide concentrations and doses at receptor locations specified by the code user.

2.2 Diffusion Function

The point source diffusion function used in AREAC to calculate the area source diffusion function is a standard sector-averaged Gaussian diffusion equation (2,3) modified to include radionuclide decay by time of flight.

2.3 AREAC Coordinate System

The basic coordinate system used in AREAC is a two-dimensional rectangular coordinate system in which the positive x-axis points in the eastern direction, the positive y-axis points in the northern direction, and the origin is in the center of the area source. In instances where the polar coordinate system is used, its coordinates are defined in terms of the rectangular coordinate system as shown in the following figure:

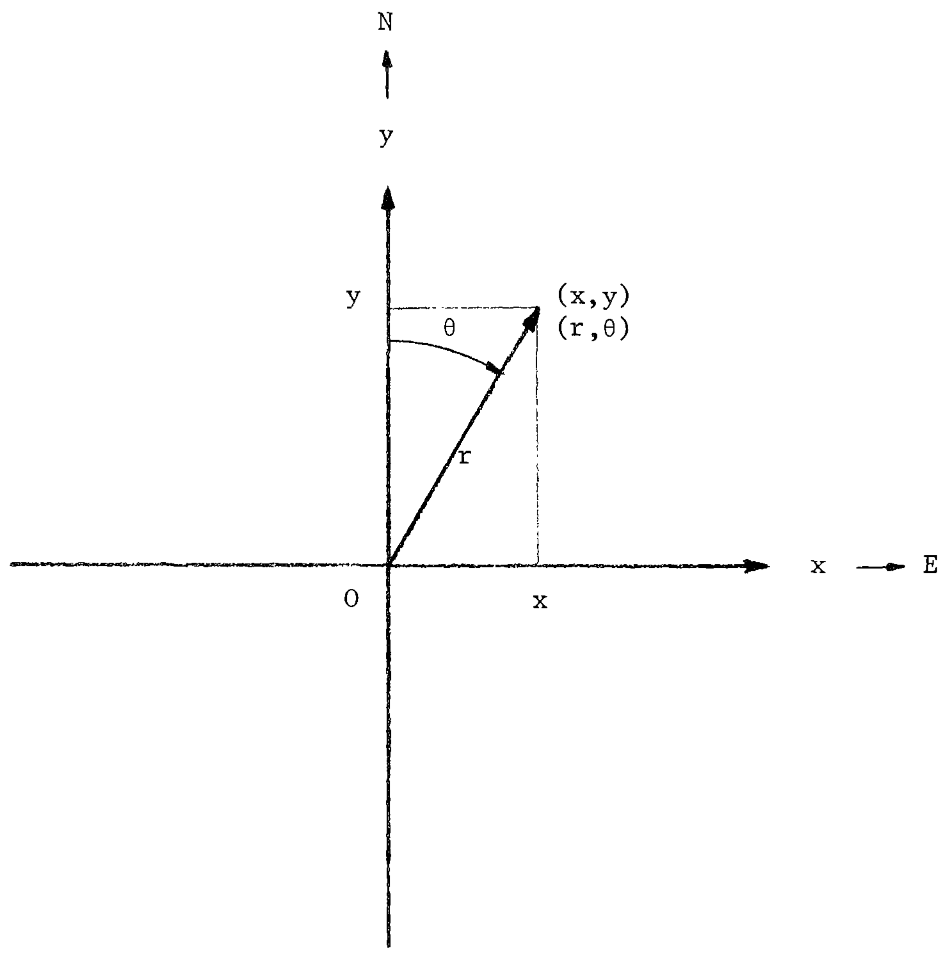

Figure 1. AREAC Coordinate System

2.4 Diffusion Geometry

The geometrical scheme of AREAC is similar to a cartwheel. It is illustrated in figure 2. Winds blow the emissions from each source area element down pie-shaped sectors centered on the area element. The concentration of radionuclides in the sectors is assumed to have a Gaussian distribution in the vertical direction, centered at the effective release height, and to be uniform in the horizontal direction across each sector. As illustrated in figure 2, there are 16 sectors corresponding to 16 compass directions (N, NNE, NE...NNW) toward which the winds blow.

Atmospheric stability, which determines the standard deviation (σ_z) of the vertical distribution of radionuclide concentration, is characterized by six stability classes which are described in table 1.

The concentration standard deviation in the vertical direction increases monotonically with distance from the source area element. according to figure 3 (3), until it is set equal to 0.8 of the mixing layer height (3). This value determines the maximum extent of cloud diffusion in the vertical direction. Values of mixing layer heights may be obtained from references (1) and (4).

2.5 Receptor Location Geometry

AREAC consists of two main parts. In the first part, area source dispersion coefficients ($X/\dot{Q}_A$'s), radionuclide concentrations,

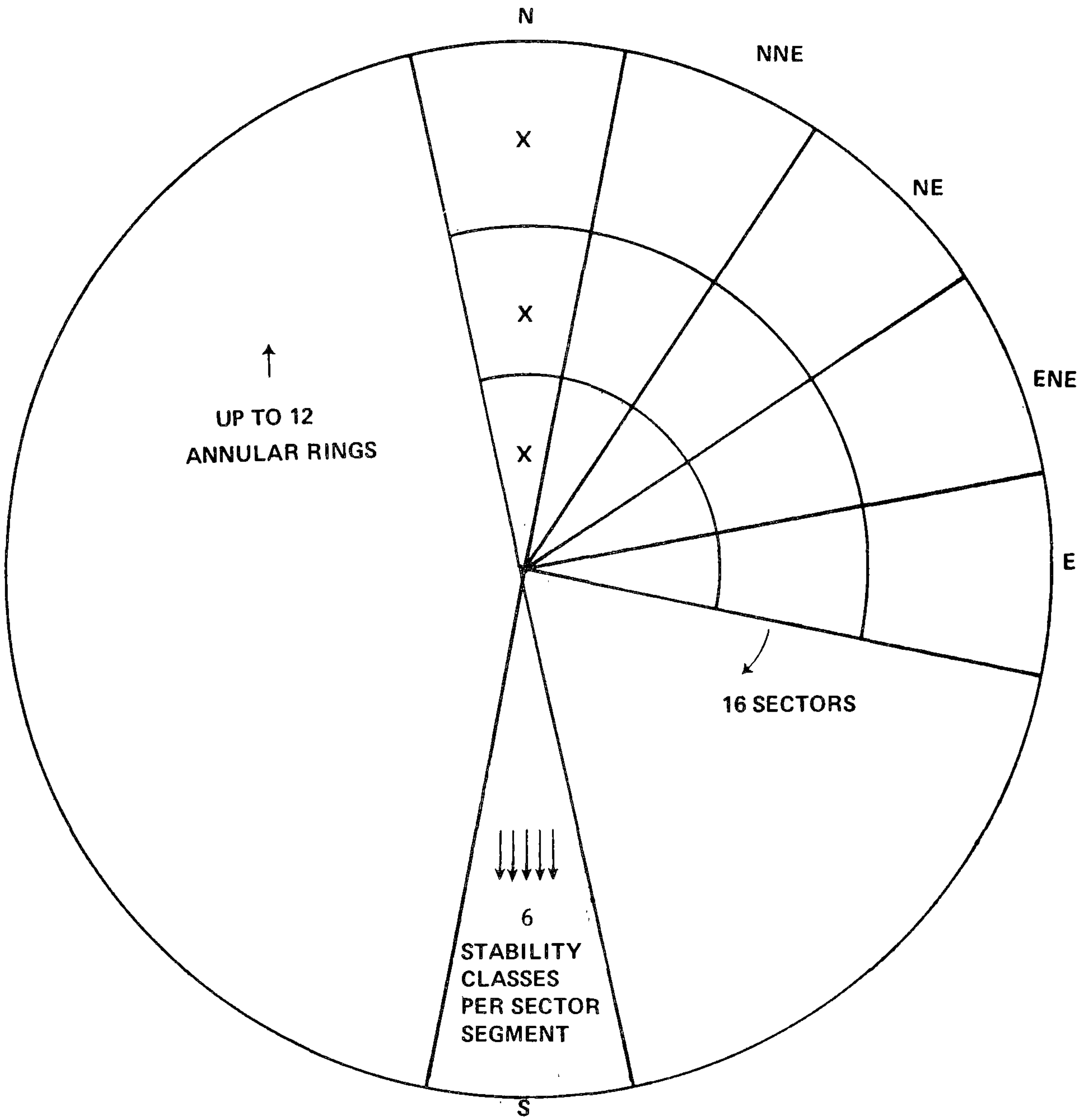

Figure 2. Geometry of AREAC - plan view

Table 1. Classification of Atmospheric Stability

Stability classification	Pasquill categories	σ_θ[a] (degrees)	Temperature change with height (°C/100 m)
Extremely unstable	A	25.0	<-1.9
Moderately unstable	B	20.0	-1.9 to -1.7
Slightly unstable	C	15.0	-1.7 to -1.5
Neutral	D	10.0	-1.5 to -0.5
Slightly stable	E	5.0	-0.5 to 1.5
Moderately stable	F	2.5	1.5 to >4.0

[a]Standard deviation of horizontal wind direction fluctuation over a period of 15 minutes to 1 hour. The values shown are averages for each stability classification.

Reference: AEC Safety Guide 23.

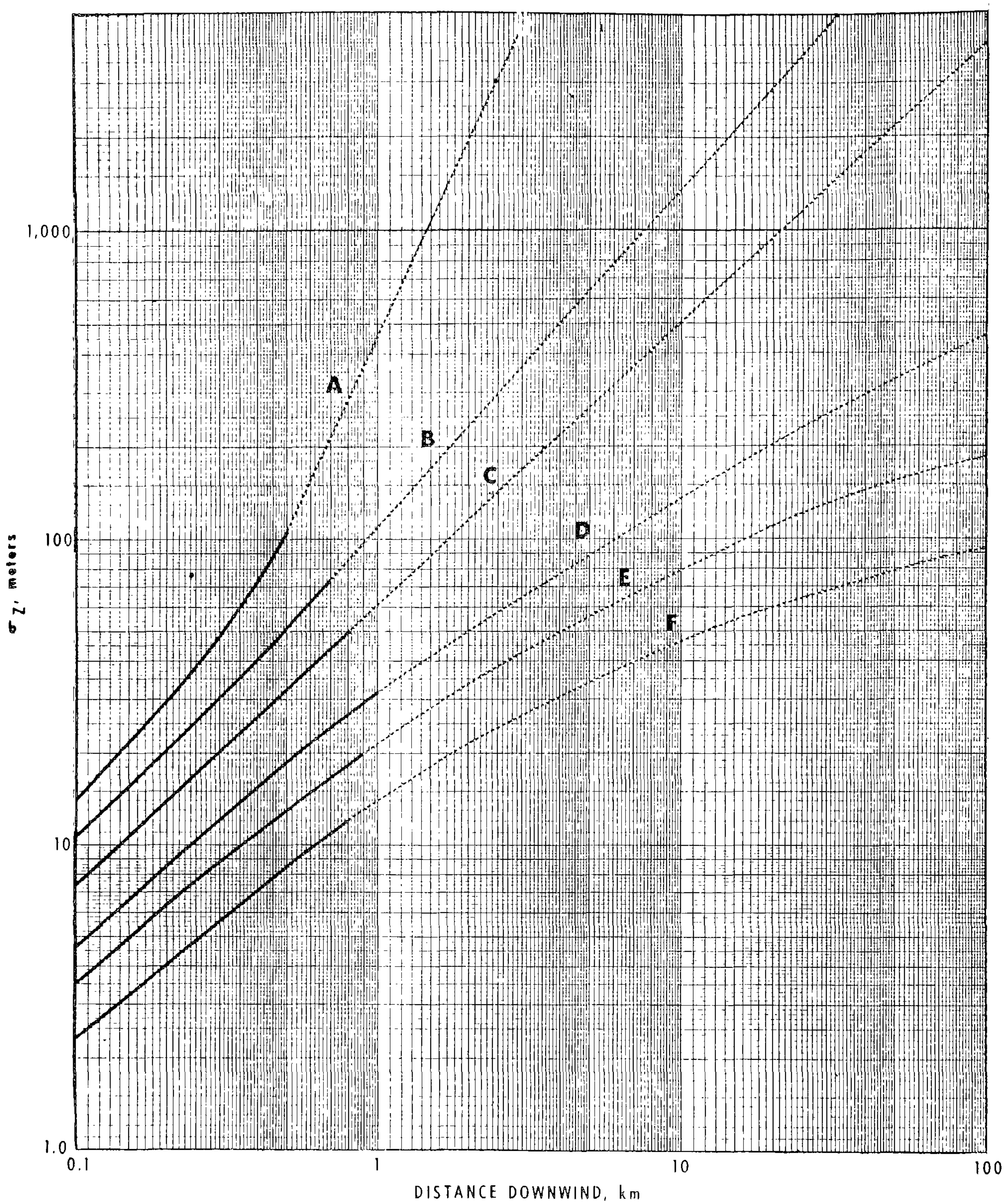

Figure 3. Vertical Dispersion Coefficient as a Function of Downwind Distance from the Source (3)

and yearly individual inhalation doses are calculated at up to six (6) receptor positions specified by the code user. These locations have to be specified in polar coordinates defined in section 2.3.

In the second part, area source dispersion coefficients, radionuclide concentrations, individual and, if desired, population doses are calculated at up to 192 locations in a population wheel around the source. The population wheel, which is illustrated in figure 2, has its center in the center of the area source and is divided into sixteen (16) 22.5 degree sectors and up to twelve (12) annular rings. The sixteen sectors and up to twelve annular rings form a circular grid of up to 192 sector segments. Individual doses within this grid are calculated at the centers of the sector segments. The contribution to the total population dose from each sector segment is the product of the dose and population within the sector segment.

2.6 Area Source Geometry

The code user has the option of approximating the shape of the area source by either a rectangle or a circle. In either case, as discussed in section 2.1, the source area is divided into a number of equal area elements to account for the distributed nature of the source.

A. Rectangular Area Source

If the shape of the source is approximated by a rectangle, it is assumed to have two sides of length XL parallel to the x-axis and two sides of length YL parallel to the y-axis (see section 2.3). It is divided into a grid of NX by NY area elements, where NX is the number of divisions along the x-axis and NY is the number of divisions along the y-axis, and radionuclides are assumed to be emitted from the centers of the area elements.

NX and NY can range from 1 to 10. If both NX and NY are equal to 1, the radionuclides are assumed to be emitted from the center of the area source. This is equivalent to approximating an area source by a point source.

By choosing appropriate values of XL and YL, distributed sources ranging in shape from squares to finite line sources can be approximated.

B. Circular Area Source

If the shape of the source is approximated by a circle of radius RL, then NX is the number of sectors and NY is the number of annular rings into which it is subdivided, and radionuclides are assumed to be emitted from the centers of the NX · NY sector segments which are formed. The division of the circle into sectors is, except for a minor difference, similar to the division of the population wheel.

In order to assure that the areas of all the sector segments are of the same size, the following procedure was chosen for dividing the circle into the NY annular rings.

If ΔA is the area of a sector segment, then $NX\Delta A$ is the area of an annular ring, and since ΔA has to be constant, the areas of all annular rings must be the same.

If RL is the radius of the circular area source, then the area of the source

$$A = \pi RL^2$$

and, since there are NY annular rings of equal area, the area of a ring

$$A_R = \frac{\pi RL^2}{NY} \quad .$$

Thus, if R_0 is set equal to zero and R_i is the radial distance to the outer boundary of the i^{th} annular ring, then

$$\pi R_i^2 = \pi R_{i-1}^2 + \frac{\pi RL^2}{NY}$$

or, dropping the constant π,

$$R_i = \sqrt{R_{i-1}^2 + RL^2/NY} \quad .$$

This procedure for determining annular boundaries will assure that all area elements in the circular source grid are of the same size.

2.7 Diffusion at Large Distances from Area Sources

In a problem in which the area source is divided into 10 by 10 area elements and dose calculations are performed at 6 specific and 192 (16 sectors x 12 annular rings) general receptor locations, there are 10 x 10 x (192 + 6) = 19,800 source to receptor distances for which the point source diffusion equation has to be solved.

Since at large receptor distances an area source approaches a point source, this amount of calculation is most often unnecessary, and to save computation time (and money), AREAC provides the code user with an option for treating the area source as a point source at large receptor distances.

The manner in which this is accomplished is outlined in Appendix A.

3. AREAC Input

Up to 80 lines of input data are required to run AREAC. The input card sequence and data format are summarized in table 2 and illustrated in the sample program in Appendix C.

First Card

This is a title card which identifies the input problem. No calculations are made with data on this card.

Second Card

KGEOM is an area source geometry number. If KGEOM = 0, the shape of the source is approximated by a rectangle. If KGEOM = 1, the shape of the source is approximated by a circle.

Third Card

If the source has the shape of a rectangle (KGEOM = 0), the card should contain the X-length, Y-length, and height of the source (meters). If the source has the shape of a circle (KGEOM = 1), the card should contain the radius and height of the source (meters).

Fourth Card

Source strength (Ci/s), radionuclide decay constant (s^{-1}), and dose conversion factor (mrem/yr per Ci/m^3) are required on this card.

Fifth Card

Area Source Division Numbers

If source has the shape of a rectangle, NX and NY are, respectively, the number of divisions in the X and Y directions into which the source is subdivided.

Table 2. AREAC Input Card Sequence and Data Format

Card Sequence	Columns	Description[a]	Format
1 card	1-20	Source name	5A4
	21-25	Number of months of data	F5.0
	27-30	Beginning month	A4
	31-35	Beginning year	I5
	37-40	Ending month	A4
	41-45	Ending year	I5
1 card	1	KGEOM[a] (0 or 1)	I1
1 card	1-10	X-length of area source (m) } KGEOM=0	F10.0
	11-20	Y-length of area source (m) } KGEOM=0	F10.0
	21-30	Height of source (m) } KGEOM=0	F10.0
	or		
	1-10	Radius of area source (m) } KGEOM=1	F10.0
	11-20	Height of source (m) } KGEOM=1	F10.0
1 card	1-10	Source strength (Ci/s)	E10.3
	11-20	Radionuclide decay constant (s^{-1})	E10.3
	21-30	Dose conversion factor (mrem/yr per Ci/m^3)	E10.3
1 card	1- 5	NX[a] (10 max.)	I5
	6-10	NY[a] (10 max.)	I5
1 card	1	KDIF[a]	I1
16 cards	1-60	Wind frequencies by stability class (%), 10 columns each	6F10.0
16 cards	1-60	Wind speeds by stability class (m/s), 10 columns each	6F10.0
1 card	1-10	SIGMAX[a] (m)	F10.0
1 card	1	KPROB[a]	I1

[a]See glossary in Appendix B.

Table 2. AREAC Input Card Sequence and Data Format (continued)

Card Sequence	Columns	Description[a]	Format
1 card	1	Number of specific receptors (IND) (6 max.)	I1
1 card	1-60	Receptor radial positions (m), 10 columns each	6F10.0
1 card	1-60	Receptor angular positions (degrees) 10 columns each	6F10.0
1 card	1- 2	Number of annuli in poulation wheel (MRAD) (12 max.)	I2
MRAD cards	1-30	Midpoint, lower and upper radii (m), 10 columns each	3F10.0
2 MRAD cards	1-80	Annular ring population, 8 sectors to a card, 10 columns each	8F10.0

If source has the shape of a circle, NX and NY are, respectively, the number of annular rings and sectors into which the source is subdivided.

Sixth Card

KDIF is an area source diffusion number which provides the user with an option for treating the area source as a point source at large source to receptor distances. If KDIF = 1, the area source is treated as a distributed source at all receptor locations.

If KDIF $\neq$ 1, the area source is treated as a point source at large receptor distances.

Wind Rose Data

Wind frequencies (%) and wind speeds (m/s) are entered in a clockwise direction beginning with the north sector. Sixteen frequency and sixteen wind speed cards are required (1 card per sector). Each card contains six entries which correspond to stability classes A through F. Wind direction is the direction toward which the wind blows.

SIGMAX Card

SIGMAX sets the maximum value of the standard deviation in the vertical direction. It should be equal to 0.8 times the height of the inversion layer (1,3).

Receptor Set Identification Card

KPROB is a number which identifies the set of receptors for which dose calculations will be performed. If KPROB = 1, only dose calculations for specific receptors will be performed. If KPROB = 2, only dose calculations for the population wheel will be performed. If KPROB is any other number, calculations for both specific receptors and the population wheel will be performed.

Specific Receptor Number Card

If KPROB = 2, this card should be omitted.

This card should contain the number of specific receptors (IND) for which dose calculations are to be performed ($1 \leq IND \leq 6$).

Specific Receptor Radial Positions

If KPROB = 2, this card should be omitted.

This card should contain the distances in meters of receptors 1 through IND as measured from the center of the area source.

Specific Receptor Angular Positions

If KPROB = 2, this card should be omitted.

This card should contain the angular positions in degrees of receptors 1 through IND as measured in the clockwise direction from the y-axis (see section 2.3). If KPROB = 1, this is the last data card.

Population Wheel Annuli Card

This card should contain the number of annuli (MRAD) in the population wheel ($1 \leq MRAD \leq 12$). The number of sectors is always 16

Annular Boundary Cards

These MRAD cards should contain the radial distances from the center of the area source to the midpoints, inner, and outer boundaries of the MRAD population wheel annuli. The minimum midpoint radius which can be used is 100 m + DTEST/2[1].

Population Data Cards

Population data are entered clockwise starting in the north sector and within inner annulus. Two MRAD cards are required. If KPROB ≠ 1, this is the last set of data cards.

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[1] See glossary in Appendix B for definition of term.

4. AREAC Output

The output of AREAC consists of four main parts: source input data, meteorological input data, specific receptor input data and calculational results, and population wheel input data and calculational results.

If no calculations are desired for either a set of specific receptors or a population wheel, then that part is omitted. Error messages are printed out, and program is terminated if the source area shape is not specified or the number of specific receptors is outside of the allowed range. If a specific receptor is less than 100 m from the area source, calculations for that receptor are omitted. However, if this occurs at a location in the population wheel, the program is terminated. The sample problem in Appendix C illustrates the output sequence and format.

5. AREAC Structure

AREAC consists of a main program, subroutines DIFUSN, GEOM0 and GEOM1, and function SIGZ. Figure 4 presents a simplified program flow chart.

All input and output operations and many calculations are performed in the main program. If the source has the shape of a rectangle, subroutine GEOM0 is called by the main program to calculate the centers of area elements into which the area is subdivided. If the source has the shape of a circle, this function is performed by subroutine GEOM1. Subroutine DIFUSN is called by the main program to calculate an area source $\chi/\dot{Q}$ at a receptor location specified by the main program. DIFUSN also informs the main program when a receptor is too close to the area source. Function SIGZ (1) is called by DIFUSN to provide the concentration standard deviation in the vertical direction (σ_z) for a receptor location and meteorological stability class specified by DIFUSN. Communication between the main program and subroutines is accomplished through the use of a blank COMMON.

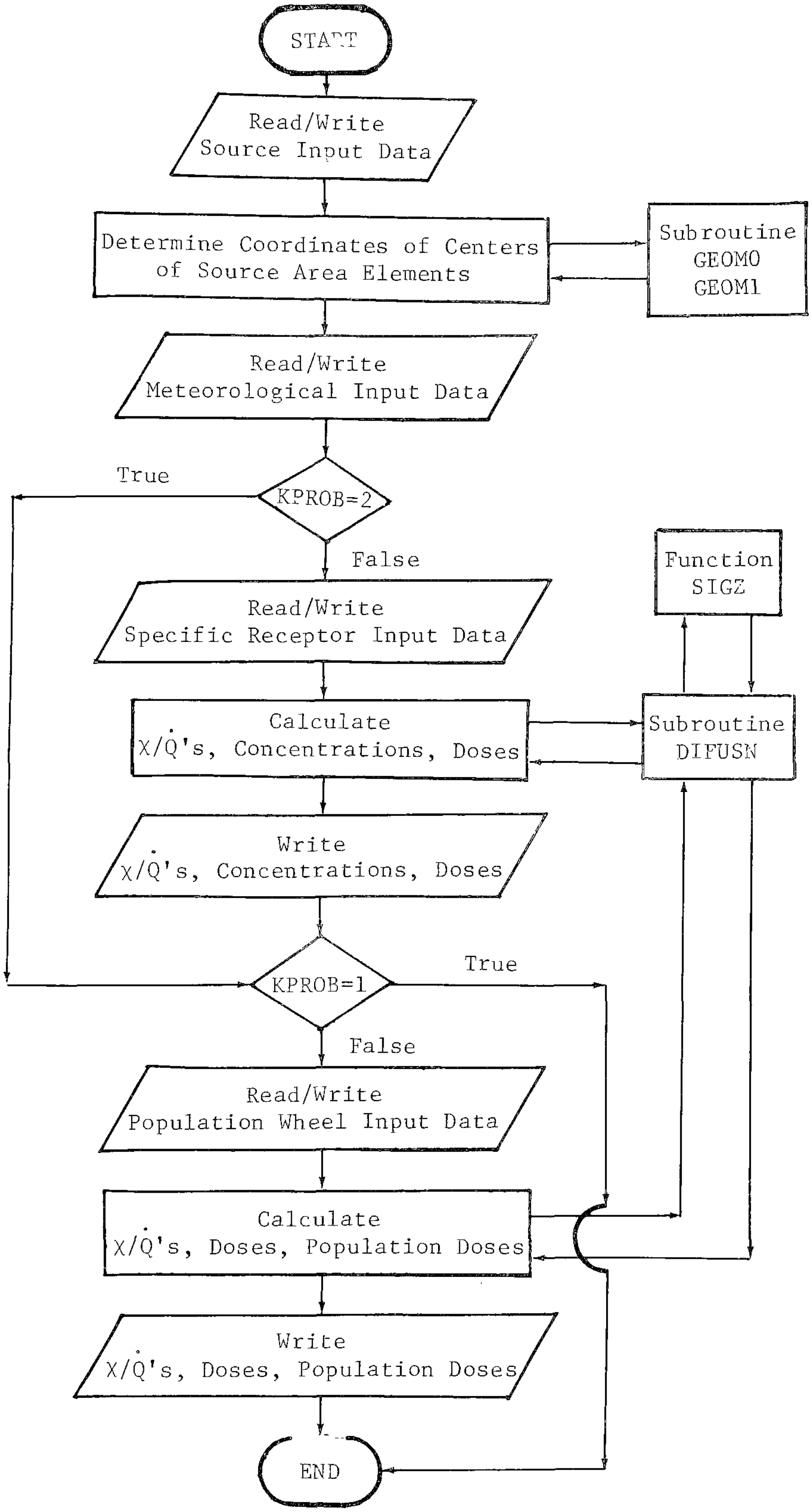

Figure 4. Simplified AREAC Flow Chart

6. Sample Problem Description

AREAC was employed in a sample problem to assess the potential radiological impact of airborne emissions of radon-222 from a radium bearing phosphate gypsum pile. The shape of the pile was approximated by a circular disc with a radius of 590 m and an average height of 29 m. The pile area was divided into a grid of 10 by 10 area elements and, at large receptor to source distances, the pile was treated as a point source. Based on measurements of radon exhalation rate from the pile, the pile emission rate of radon-222 was taken to be approximately 4.3×10^{-6} Ci/s. A concentration to dose conversion factor of 4×10^{12} mrem/yr per Ci/m^3 (4 mrem/yr per pCi/m^3) to the bronchial epithelium region of the lung was assumed (5).

Meteorological data for the pile area, covering a period of 60 months from January 1969 to December 1973, was obtained from the Environmental Data Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, and a SIGMAX value of 1000 meters was assumed. The code was used to calculate yearly doses at six specific locations west of the pile and to calculate yearly doses, population doses, and the total population dose in a population wheel comprised of 16 sectors and 12 annuli extending to a distance of 80 kilometers from the pile The population distribution was obtained from the Census Bureau's Master Enumeration District List with Coordinates as edited by the

Office of Telecommunications of the U.S. Department of Commerce. The input data for this problem is shown in Appendix C together with the output and the program listing.

APPENDIX A

Point Source Approximation of an Area Source at Large Receptor Distances

This appendix presents the derivation of a criterion for treating an area source as a point source at large sources to receptor distances. The criterion is derived by showing that in calculating the yearly average radionuclide concentrations at receptor positions beyond a certain distance from an area source, both the crosswind and the downwind extent of the source can be neglected.

Consider a ground level line source of airborne emissions of length L, which is bisected by line AB which is perpendicular to the source (figure 1A). Let point A be the point of intersection, and let line AB bisect a wind rose sector whose apex is located at point A.

By method analogous to that which is discussed in section 2.1, the yearly average radionuclide concentration at a point located on line AB may be calculated, approximately, by dividing the line source into a number of point sources and summing the contribution of each source to the radionuclide concentration at the receptor location.

If the line source is assumed to be a point source located at the center of the line source (point A), then the radionuclide concentration at a receptor location on line AB is obtained by

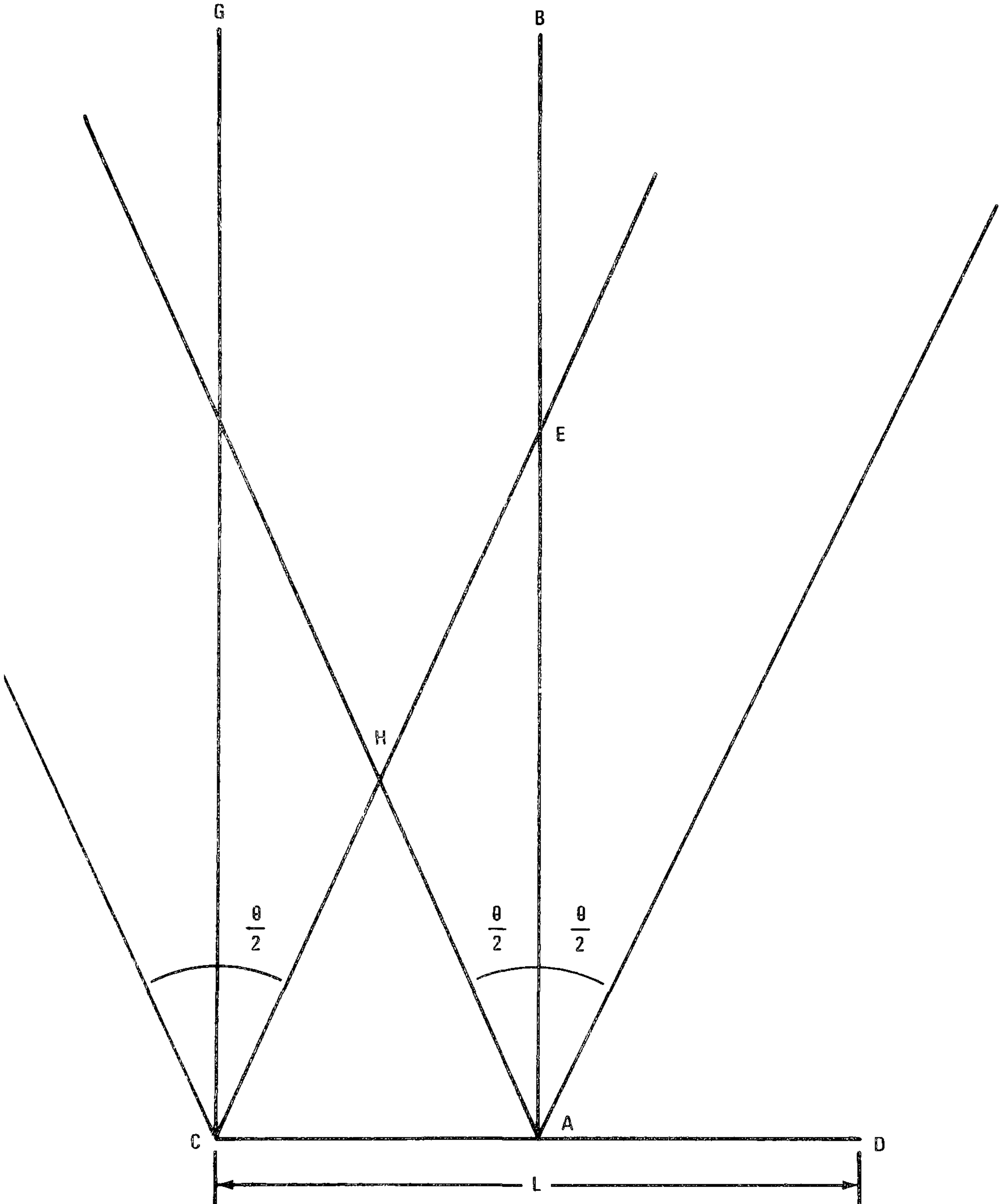

FIGURE 1A. GEOMETRY OF LONG TERM SECTOR AVERAGED DIFFUSION FROM A LINE SOURCE NORMAL TO WIND DIRECTION considering the contribution of only point A.

In both cases, the procedure for calculating the dispersion coefficients from an individual point is identical. The point to receptor distance and wind rose sector orientation are determined, and the sector averaged Gaussian diffusion equation is solved for the appropriate distance and joint wind-speed and direction-frequency distribution.

If the line source is assumed to be a point source, a receptor will always be located in the same wind rose sector. If, for example, line AB points north, then a receptor will always be in the northern sector regardless of its distance from the source.

For a point located on a line source, however, the sector orientation of a receptor on line AB will depend on its distance from the source. For example, a receptor located immediately to the north of point A will be in the eastern sector, as viewed from point C, and will approach the northern sector with increasing source to receptor distance. At the distance where the receptor is in the same sector with respect to points A and C, it is in the same sector for all points between A and C and, by symmetry, all points on the line source.

If, in figure 1A angle FCE is the angular width of a wind rose sector centered on line CG, then point E will be in the same sector with respect to all points on the line source. If θ is the width of a sector, then according to elementary geometry, angle CEA is equal to $\theta/2$, and the length of line segment $\overline{AE}$ is:

$$\overline{AE} = \frac{L}{2 \tan (\theta/2)} . \qquad (1)$$

The distance from a point on the line source to point E ranges from the length of line segment $\overline{AE}$ to the length of line segment $\overline{CE}$. If R is the ratio of $\overline{CE}$ to $\overline{AE}$, then

$$R = \frac{1}{\cos(\theta/2)} .$$

In a wind rose consisting of 16 sectors, θ = 22.5 degrees and

$$\overline{AE} = 2.51 \text{ L} ,$$

and $R = 1.02$.

Therefore, since beyond point E the joint wind speed and direction-frequency distribution is identical for all points on the line source, and the source to receptor distance is constant to within 2 percent, distance $\overline{AE}$ may be taken as the distance beyond which the line source can be treated as a point source.[1]

Since a distributed area source can be thought of as an infinite number of line sources, the above discussion indicates that if L is the width of the source in the crosswind direction, the crosswind extent of the source can be neglected beyond a distance of 2.51 L from the source. This will be true of receptor

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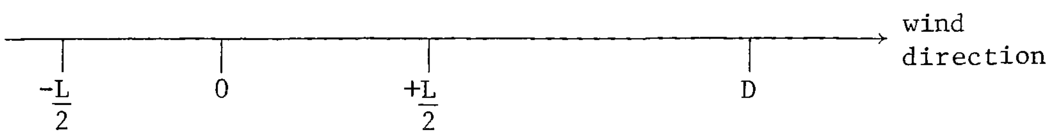
[1]Indeed, the joint wind speed and direction-frequency distribution becomes identical at point H, but at that distance, the source to receptor distance can no longer be assumed to be constant.

locations anywhere within a sector since the joint wind speed and direction-frequency distribution is constant within a sector.

It can also be shown that, at the distance of 2.51L, the extent of the area source in the prevailing wind direction can also be neglected.

Consider a ground level line source of length L extending from $-\frac{L}{2}$ to $+\frac{L}{2}$ along an axis pointing in the prevailing wind direction. The origin of the axis coincides with the center of the line source, and a receptor is located at a distance D from the center of the source. This situation is illustrated in figure 2A.

Figure 2A. Geometry of Diffusion from a Line Source Tangential to Wind Direction



The concentration of radionuclides at point D can be obtained by integrating the point source difussion function along the line source from D $-\frac{L}{2}$ to D $+\frac{L}{2}$. It should also be possible to obtain the concentration at point D by assuming that all radionuclides are emitted from some point located between $-\frac{L}{2}$ and $+\frac{L}{2}$ and at a distance X_o from point D.[2]

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[2] Since the point source diffusion function is continuous on $\left[-\frac{L}{2}, +\frac{L}{2}\right]$, then, according to the Mean Value Theorem for integrals, such a point must exist (6).

If $f(x)$ is the diffusion function which gives the radionuclide concentration at a distance x from the point of emission, and q is the radionuclide release rate per unit of source length, then x_o must satisfy the following equation:

$$Lqf(x_o) = \int_{D-\frac{L}{2}}^{D+\frac{L}{2}} q\ f(x)dx \qquad . \qquad (2)$$

Assuming a uniform release rate one can see that:

$$f(x_o) = \frac{1}{L} \int_{D-\frac{L}{2}}^{D+\frac{L}{2}} f(x)dx \qquad , \qquad (3)$$

or that x_o is that distance from the receptor at which $f(x)$ is equal to its average value over the source length.

For low source height, the long term sector averaged diffusion function is proportional to $(x\sigma_z)^{-1}$, where σ_z is the concentration standard deviation in the crosswind direction. If σ_z is considered to be proportional to x^c, then $f(x)$ is proportional to x^{-r}, where c is a constant and $r = 1+c$. Using figure 3-3, reference 3, and a source to receptor distance of 1 km, the values of c, the scope of the curve, and r, as a function of stability class, are approximately:

Stability Class	c	r
A	2.1	3.1
B	1.1	2.1
C	.92	1.92
D	.67	1.67
E	.61	1.61
F	.57	1.57

When the x^{-r} expression for f(x) is substituted into equation 3, then, after carrying out the integration and simplifying the result, one obtains:

$$\left(\frac{x_o}{D}\right)^{-r} = \frac{D}{L} \frac{\left[1 + \frac{L}{2D}\right]^{1-r} - \left[1 - \frac{L}{2D}\right]^{1-r}}{1-r} \quad . \qquad (4)$$

At the source to receptor distance at which the crosswind extent of the area source can be neglected $\frac{L}{2D}$ = Tan (11.25°), and substituting in the appropriate values for r one finds that the value of $\frac{x_o}{D}$ ranges from 0.97 for stability class A to 0.98 for stability class F. At larger source to receptor distances the value of $\frac{L}{2D}$ approaches 0 and consequently, the value of $\frac{x_o}{D}$ quickly approaches unity.[3]

Since D is the distance from the receptor to the center of the line source, it has thus been shown that a distance approximately equal to 2.51 times the greatest dimension of an area source, the extent or the source in both the crosswind and downwind directions can be neglected, and all radionuclides can be assumed to be emitted from the center of the area source.

---

[3]This can easily be shown by expanding terms on the right side of equation 4 in Taylor series (6).

In AREAC, the results of the previous discussion have been utilized to provide the code user with an option for treating an area source as a point source at large receptor distances. This calculational "shortcut" is based on a modified form of equation 1 in which L was chosen to be the largest projection of the area source in the crosswind direction. If the source has the shape of a rectangle, then L is its diagonal, and if the source is a circle, then L is its diameter. Also, since the smallest distance between the edge of an area source and a receptor located at a distance D from the center of the source can be equal to $D-\frac{L}{2}$, the distance from the center of an area source at which the point source assumption can be made has been conservatively extended by $\frac{L}{2}$. Thus, the area source is treated as a point source at receptor distance x at which

$$x \geq \frac{L}{2}\left[1 + \frac{1}{\tan(11.25°)}\right].$$

APPENDIX B

Glossary of Terms in AREAC

TERM	DESCRIPTION
APOS(I)	Angular position of I^{th} specific receptor (degrees)
CHIOQ	Ratio of concentration to release rate at a specific receptor location
CHIQ(I,J)	Ratio of concentration to release rate at the center of population wheel sector segement (I,J)
CONC	Radionuclide concentration in air (Ci/m^3)
DCF	Dose conversion factor (mrem/yr per Ci/m^3)
DEC	Radionuclide decay constant (s^{-1})
DIR(I)	Compass direction of the I^{th} sector (N, NNE...NNW)
DOS(I,J)	Dose at center of population wheel sector segment (I,J) (rem/yr)
DOSE	Dose at a specific receptor location (mrem/yr)
DTEST	The longest possible projection of the area source in a crosswind direction (m). If source has the shape of a circle, DTEST is its diameter. If source has the shape of a rectangle, DTEST is its diagonal. It is used in approximating the area source by a point source at large receptor to source distances (see Appendix A).
FACIL	Area source description (name, etc.)
FREQ(I,J)	Frequency that the wind blows toward sector I in stability class J (%)
IND	Number of specific receptors

KDIF	Area source diffusion number. If KDIF = 1, the area source is treated as a distributed source at all receptor locations. If KDIF ≠ 1, the area source is treated as a point source at large source to receptor distances.
KGEOM	Area source geometry number (0 or 1). If KGEOM = 0 or 1, the shape of the source is assumed to be a rectangle or a circle respectively.
KK	Number by which the main program is informed whether a receptor is located too close to the area source
KPROB	Receptor set identification number. If KPROB = 1, only calculations for specific receptors are performed. If KPROB = 2, only locations in the population wheel are considered. If KPROB ≠ 1 and KPROB ≠ 2, calculations for both specific receptors and the population wheel are performed.
MONTHS	Number of months represented by input data
MONTH1	Beginning month represented by input data
MONTH2	Ending month represented by input data
MRAD	Number of annuli in the population wheel (12 max.)
MSEC	Number of sectors in the population wheel (16 always)
NX NY	Area source division numbers. If area source has the shape a rectangle, NX and NY are, respectively, the number of divisions in the X and Y directions (see section 2.6) into which the source is subdivided. If area source has the shape of a circle, NX and NY are, respectively, the number of annular rings and sectors into which the source is subdivided.
NYR1	Beginning year represented by input data
NYR2	Ending year represented by input data
POP(I,J)	Population in population wheel sector segment (I,J)
POPDOS(I,J)	Population dose received by population in sector segment (I,J) (1000 person-rem/yr)

RINN(I)	Radial distance to inner boundary of Ith annular ring from center of area source (m)
RL	Radius of circular area source (m)
RMID(I)	Radial distance to middle of Ith annular ring from center of area source (m)
ROUT(I)	Radial distance to outer boundary of Ith annular ring from center of area source
RPOS(I)	Radial position of Ith specific receptor (m)
SIGMAX	Maximum value of SZ
SOURCE	Area source radionuclide emission rate (Ci/s)
SPEED(I,J)	Average wind speed in sector I for stability class J (m/s)
SX(I,J)	X-coordinate of center of source area element (I,J) (m)
SY(I,J)	Y-coordinate of center of source area element (I,J) (m)
SZ	Standard deviation of concentration in the vertical direction, σ_z
WSA	Angular width of a sector (22.5 degrees)
XL	Width of a rectangular area source in the X-direction (m)
XPOS(I)	X-coordinate of Ith specific receptor (m)
YL	Width of a rectangular area source in the Y-direction (m)
YPOS(I)	Y-coordinate of the Ith specific receptor (m)
ZH	Height (average) of the area source (m)

APPENDIX C

AREAC sample problem input, output, and program listing

```
C     SAMPLE PILE      60  JAN 1969  DEC 1973
1
590.      29.
 0.428E-05 0.210E-05 0.400E+13
   10   10

        0.02        0.37        0.85        2.50        0.80        0.74          N
        0.01        0.35        0.86        1.43        0.35        0.34        NNE
        0.01        0.40        0.71        0.93        0.47        0.44         NE
        0.03        0.58        1.12        1.18        0.36        0.42        ENE
        0.02        1.02        2.61        3.62        0.82        0.66          E
        0.0         0.19        0.52        1.94        0.77        0.72        ESE
        0.0         0.16        0.41        2.04        1.13        1.29         SE
        0.02        0.17        0.41        1.86        0.86        1.01        SSE
        0.02        0.31        0.51        1.98        1.18        1.45          S
        0.02        0.31        0.50        1.69        0.92        1.04        SSW
        0.02        0.28        0.73        2.64        1.38        1.95         SW
        0.01        0.29        1.11        3.43        2.36        3.04        WSW
        0.02        0.46        1.95        5.68        3.25        4.67          W
        0.0         0.42        1.02        2.91        1.69        2.13        WNW
        0.01        0.38        0.81        2.38        1.05        1.23         NW
        0.0         0.40        0.98        1.95        0.85        1.03        NNW
        1.06        2.18        3.78        4.18        2.98        1.30          N
        1.69        2.56        3.81        4.44        2.92        1.24        NNE
        1.69        2.86        3.75        3.82        2.88        1.48         NE
        1.62        3.08        3.58        4.39        3.25        1.28        ENE
        1.59        2.88        4.45        4.70        3.25        1.35          E
        0.0         2.16        3.60        4.75        3.17        1.45        ESE
        0.0         1.89        4.40        5.14        3.29        1.49         SE
        1.59        2.14        3.84        5.09        3.25        1.37        SSE
        1.59        2.21        3.43        4.38        3.32        1.44          S
        1.59        2.31        3.60        4.26        3.29        1.39        SSW
        1.59        2.26        3.58        4.38        3.26        1.44         SW
        1.69        2.12        3.55        4.17        3.14        1.41        WSW
        1.59        2.15        3.46        4.18        3.09        1.42          W
        0.0         1.80        3.70        4.21        3.06        1.26        WNW
        1.69        2.19        3.19        4.27        3.20        1.21         NW
        0.0         2.25        3.64        4.21        3.00        1.35        NNW
     1000.

  6
700.        2400.       4000.       12000.      36000.      72000.
270.        270.        270.        270.        270.        270.
12
        800.          0.       1600.
       2400.       1600.       3200.
       4000.       3200.       4800.
       5600.       4800.       6400.
       7200.       6400.       8000.
      12000.       8000.      16000.
      20000.      16000.      24000.
      28000.      24000.      32000.
      36000.      32000.      40000.
      44000.      40000.      48000.
      56000.      48000.      64000.
      72000.      64000.      80000.
          0.          0.          0.          0.          0.          0.          0.          0.
          0.          0.          0.          0.          0.          0.          0.          0.
          0.          0.          0.          0.          0.          0.        554.        382.
          0.          0.          0.          0.          0.          0.          0.          0.
       1959.          0.       1004.          0.          0.          0.       3246.          0.
          0.          0.          0.          0.          0.          0.          0.          0.
         95.          0.       1569.          0.        333.          0.          0.          0.
          0.          0.          0.          0.          0.          0.          0.          0.
       2690.       4611.          0.          0.       1892.          0.          0.          0.
          0.          0.          0.          0.          0.          0.       1098.          0.
      27128.       5553.       9715.       8282.       1717.          0.       1975.          0.
       1966.          0.          0.       6006.      16170.      41001.      60194.      67785.
      29460.       7626.       4589.       4049.          0.       1291.          0.       2611.
       4247.       3099.          0.      13040.       4814.          0.      34954.      72175.
       4419.       1069.      13558.      11545.        958.       1703.         97.          0.
        583.          0.       6087.     146580.      51630.       1356.       1731.       9725.
          0.          0.       2430.       6888.       1608.       1374.          0.       1842.
          0.       6238.          0.      70734.      74806.      62451.       4361.       1935.
       2940.       9670.       2045.      46413.       4934.        176.          0.          0.
       1683.      47816.        143.          0.      34921.      39267.      11875.       1913.
       2560.      15222.       3895.      51496.      17317.       8820.        864.        599.
      27584.      73137.       5048.          0.          0.          0.      28529.      11439.
      13054.       4074.        436.      47175.      17057.       7338.       3022.          0.
      20162.       9173.          0.          0.          0.          0.          8.         76.
```

AREAC

AREA SOURCE RADIOLOGICAL EMISSIONS ANALYSIS CODE

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
ENVIRONMENTAL ANALYSIS DIVISION
401 M STREET, S.W.
WASHINGTON, D.C. 20460

SOURCE INPUT DATA

FACILITY, NO. MONTHS OF DATA, PERIOD
C SAMPLE PILE 60. JAN 1969 DEC 1973

SOURCE AREA HAS THE SHAPE OF A CIRCLE

PILE RADIUS = 590. M. , HEIGHT = 29. M.

SOURCE STRENGTH,CI/SEC	DECAY CONSTANT,1/SEC	DOSE CONVERSION FACTOR,MREM/YR PER CI/CU.M.
4.280E-06	2.100E-06	4.000E+12

THE SOURCE AREA HAS BEEN SUBDIVIDED INTO 10 ANNULAR RINGS AND 10 SECTORS

AT LARGE DISTANCES THE SOURCE AREA WILL BE TREATED AS A POINT SOURCE

METEOROLOGICAL INPUT DATA

WIND FREQUENCY IN PERCENT BY STABILITY CLASS FOR EACH SECTOR

DIR	A	B	C	D	E	F
N	0.02	0.37	0.85	2.50	0.80	0.74
NNE	0.01	0.35	0.86	1.43	0.35	0.34
NE	0.01	0.40	0.71	0.93	0.47	0.44
ENE	0.03	0.58	1.12	1.18	0.36	0.42
E	0.02	1.02	2.61	3.62	0.82	0.66
ESE	0.0	0.19	0.52	1.94	0.77	0.72
SE	0.0	0.16	0.41	2.04	1.13	1.29
SSE	0.02	0.17	0.41	1.86	0.86	1.01
S	0.02	0.31	0.51	1.98	1.18	1.45
SSW	0.02	0.31	0.50	1.69	0.92	1.04
SW	0.02	0.28	0.73	2.64	1.38	1.95
WSW	0.01	0.29	1.11	3.43	2.36	3.04
W	0.02	0.46	1.95	5.68	3.25	4.67
WNW	0.0	0.42	1.02	2.91	1.69	2.13
NW	0.01	0.38	0.81	2.38	1.05	1.23
NNW	0.0	0.40	0.98	1.95	0.85	1.03

WIND SPEEDS IN METERS PER SECOND BY STABILITY CLASS FOR EACH SECTOR

DIR	A	B	C	D	E	F
N	1.06	2.18	3.78	4.18	2.98	1.30
NNE	1.69	2.56	3.81	4.44	2.92	1.24
NE	1.69	2.86	3.75	3.82	2.88	1.48
ENE	1.62	3.08	3.58	4.39	3.25	1.28
E	1.59	2.88	4.45	4.70	3.25	1.35
ESE	0.0	2.16	3.60	4.75	3.17	1.45
SE	0.0	1.89	4.40	5.14	3.29	1.49
SSE	1.59	2.14	3.84	5.09	3.25	1.37
S	1.59	2.21	3.43	4.38	3.32	1.44
SSW	1.59	2.31	3.60	4.26	3.29	1.39
SW	1.59	2.26	3.58	4.38	3.26	1.44
WSW	1.69	2.12	3.55	4.17	3.14	1.41
W	1.59	2.15	3.46	4.18	3.09	1.42
WNW	0.0	1.80	3.70	4.21	3.06	1.26
NW	1.69	2.19	3.19	4.27	3.20	1.21
NNW	0.0	2.25	3.64	4.21	3.00	1.35

SIGMAX= 1000. METERS

THERE ARE 6 SPECIFIC RECEPTORS

RECEPTOR NUMBER	RADIAL POSITION,METERS	ANGULAR POSITION,DEGREES
1	700.	270.
2	2400.	270.
3	4000.	270.
4	12000.	270.
5	36000.	270.
6	72000.	270.

RECEPTOR NUMBER	CHI/Q SEC/CU.M.	RADIONUCLIDE CONCENTRATION CI/CU.M.	DOSE RATE MREM/YR
1	1.139E-06	4.877E-12	19.51
2	9.031E-07	3.865E-12	15.46
3	5.323E-07	2.278E-12	9.11
4	1.271E-07	5.439E-13	2.18
5	2.951E-08	1.263E-13	0.51
6	1.195E-08	5.116E-14	0.20

THERE ARE 16 SECTORS AND 12 ANNULI IN THE POPULATION WHEEL

DISTANCES,IN METERS,TO THE MIDDLE,AND INNER AND OUTER BOUNDARIES OF POPULATION WHEEL ANNULI

ANNULUS NUMBER	RMID	RINN	ROUT
1	800.	0.	1600.
2	2400.	1600.	3200.
3	4000.	3200.	4800.
4	5600.	4800.	6400.
5	7200.	6400.	8000.
6	12000.	8000.	16000.
7	20000.	16000.	24000.
8	28000.	24000.	32000.
9	36000.	32000.	40000.
10	44000.	40000.	48000.
11	56000.	48000.	64000.
12	72000.	64000.	80000.

POPULATIONS IN SECTOR SEGMENTS,TWO LINES PER RADIUS(READ CLOCKWISE), AND TOTAL POPULATION IN ANNULI

I	N/S/TOTAL	NNE/SSW	NE/SW	ENE/WSW	E/W	ESE/WSW	SE/NW	SSE/NNW
1	0.	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.	0.
	0.							
2	0.	0.	0.	0.	0.	0.	554.	382.
	0.	0.	0.	0.	0.	0.	0.	0.
	936.							
3	1959.	0.	1004.	0.	0.	0.	3246.	0.
	0.	0.	0.	0.	0.	0.	0.	0.
	6209.							
4	95.	0.	1569.	0.	333.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.	0.
	1997.							
5	2690.	4611.	0.	0.	1892.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	1098.	0.
	10291.							
6	27128.	5553.	9715.	8282.	1717.	0.	1975.	0.
	1956.	0.	0.	6006.	16170.	41001.	60194.	67785.
	247492.							
7	29460.	7626.	4589.	4049.	0.	1291.	0.	2611.
	4247.	3099.	0.	13040.	4814.	0.	34954.	72175.
	181955.							
8	4419.	1069.	13558.	11545.	958.	1703.	97.	0.
	583.	0.	6087.	146580.	51630.	1356.	1731.	9725.
	251041.							
9	0.	0.	2430.	6888.	1608.	1374.	0.	1842.
	0.	6238.	0.	70734.	74806.	62451.	4361.	1935.
	234667.							
10	2940.	9670.	2045.	46413.	4934.	176.	0.	0.
	1683.	47816.	143.	0.	34921.	39267.	11875.	1913.
	203796.							
11	2560.	15222.	3895.	51496.	17317.	8820.	864.	599.
	27584.	73137.	5048.	0.	0.	0.	28529.	11439.
	246510.							
12	13054.	4074.	436.	47175.	17057.	7338.	3022.	0.
	20162.	9173.	0.	0.	0.	0.	8.	76.
	121575.							

CHI/Q SUMMED OVER STABILITY CLASSES

DIR	DISTANCE (METERS)										
	800.	2400.	4000.	5600.	7200.	12000.	20000.	28000.	36000.	44000.	56000.	72000.
N	5.32E-07	2.10E-07	1.26E-07	8.01E-08	5.67E-08	2.80E-08	1.39E-08	8.82E-09	6.30E-09	4.82E-09	3.50E-09	2.51E-09
NNE	4.60E-07	1.33E-07	6.50E-08	4.09E-08	2.88E-08	1.41E-08	6.94E-09	4.41E-09	3.15E-09	2.42E-09	1.76E-09	1.26E-09
NE	4.44E-07	1.27E-07	6.56E-08	4.17E-08	2.95E-08	1.46E-08	7.26E-09	4.63E-09	3.32E-09	2.55E-09	1.86E-09	1.34E-09
ENE	5.29E-07	1.43E-07	6.93E-08	4.38E-08	3.09E-08	1.52E-08	7.54E-09	4.82E-09	3.46E-09	2.66E-09	1.95E-09	1.40E-09
E	5.82E-07	2.61E-07	1.36E-07	8.49E-08	5.92E-08	2.87E-08	1.40E-08	8.88E-09	6.35E-09	4.86E-09	3.54E-09	2.54E-09
ESE	5.78E-07	2.00E-07	1.02E-07	6.53E-08	4.65E-08	2.32E-08	1.15E-08	7.35E-09	5.26E-09	4.03E-09	2.94E-09	2.11E-09
SE	5.03E-07	2.58E-07	1.47E-07	9.62E-08	6.92E-08	3.50E-08	1.77E-08	1.13E-08	8.11E-09	6.24E-09	4.55E-09	3.28E-09
SSE	4.80E-07	2.32E-07	1.25E-07	8.18E-08	5.88E-08	2.97E-08	1.49E-08	9.55E-09	6.86E-09	5.27E-09	3.84E-09	2.77E-09
S	5.10E-07	2.95E-07	1.68E-07	1.10E-07	7.90E-08	4.00E-08	2.02E-08	1.29E-08	9.28E-09	7.14E-09	5.21E-09	3.76E-09
SSW	6.03E-07	2.49E-07	1.31E-07	8.51E-08	6.11E-08	3.08E-08	1.55E-08	9.89E-09	7.10E-09	5.46E-09	3.98E-09	2.87E-09
SW	8.22E-07	4.00E-07	2.21E-07	1.44E-07	1.04E-07	5.26E-08	2.66E-08	1.70E-08	1.22E-08	9.40E-09	6.86E-09	4.95E-09
WSW	1.09E-06	6.27E-07	3.49E-07	2.29E-07	1.65E-07	8.35E-08	4.22E-08	2.70E-08	1.94E-08	1.49E-08	1.09E-08	7.86E-09
W	1.18E-06	9.03E-07	5.32E-07	3.48E-07	2.51E-07	1.27E-07	6.41E-08	4.11E-08	2.95E-08	2.27E-08	1.66E-08	1.20E-08
WNW	1.04E-06	5.10E-07	2.75E-07	1.80E-07	1.29E-07	6.55E-08	3.30E-08	2.11E-08	1.52E-08	1.17E-08	8.50E-09	6.12E-09
NW	7.93E-07	3.28E-07	1.76E-07	1.14E-07	8.18E-08	4.11E-08	2.06E-08	1.32E-08	9.45E-09	7.25E-09	5.28E-09	3.79E-09
NNW	6.28E-07	2.59E-07	1.40E-07	9.05E-08	6.46E-08	3.24E-08	1.62E-08	1.03E-08	7.42E-09	5.70E-09	4.16E-09	3.00E-09

DOSE RATE TO AN INDIVIDUAL IN THE INDICATED COMPASS SECTOR AND ANNULAR RING (REM/YR)

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
800.	0.009	0.008	0.008	0.009	0.010	0.010	0.009	0.008	0.009	0.010	0.014	0.019	0.020	0.018	0.014	0.011
2400.	0.004	0.002	0.002	0.002	0.004	0.003	0.004	0.004	0.005	0.004	0.007	0.011	0.015	0.009	0.006	0.004
4000.	0.002	0.001	0.001	0.001	0.002	0.002	0.003	0.002	0.003	0.002	0.004	0.006	0.009	0.005	0.003	0.002
5600.	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.001	0.002	0.004	0.006	0.003	0.002	0.002
7200.	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.003	0.004	0.002	0.001	0.001
12000.	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001
20000.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000
28000.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
36000.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
44000.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
56000.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
72000.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

POPULATION DOSE RATE IN THE INDICATED COMPASS SECTOR AND ANNULAR RING (1000 PERSON-REM/YR)
AVERAGED TO CONFORM TO THE POPULATION WHEEL WIND SECTORS
FOR THE ESTIMATED POPULATION

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	RUNNING TOTAL
800.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2400.	0.0	0.0	0.0	0.0	0.0	0.0	0.002	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.004
4000.	0.004	0.0	0.001	0.0	0.0	0.0	0.008	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.017
5600.	0.000	0.0	0.001	0.0	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.019
7200.	0.003	0.002	0.0	0.0	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.002	0.0	0.028
12000.	0.013	0.001	0.002	0.002	0.001	0.0	0.001	0.0	0.001	0.0	0.0	0.009	0.035	0.046	0.042	0.038	0.220
20000.	0.007	0.001	0.001	0.001	0.0	0.000	0.0	0.001	0.001	0.001	0.0	0.009	0.005	0.0	0.012	0.020	0.279
28000.	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.0	0.000	0.0	0.002	0.068	0.036	0.000	0.000	0.002	0.391
36000.	0.0	0.0	0.000	0.000	0.000	0.000	0.0	0.000	0.0	0.001	0.0	0.024	0.038	0.016	0.001	0.000	0.471
44000.	0.000	0.000	0.000	0.002	0.000	0.000	0.0	0.0	0.000	0.004	0.000	0.0	0.014	0.008	0.001	0.000	0.502
56000.	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.002	0.005	0.001	0.0	0.0	0.0	0.003	0.001	0.517
72000.	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.0	0.001	0.000	0.0	0.0	0.0	0.0	0.000	0.000	0.522

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0001            COMMON NX,NY,SIGMAX,SX(10,10),SY(10,10),FREQ(16,6),SPEED(16,6),ZH,
              1        PI,DEC,DTEST,KDIF
0002            DIMENSION RPOS(6),APOS(6),XPOS(6),YPOS(6),DIR(16),RINN(12),ROUT(12
              1),DOS(12,16),POPDOS(12,16),CHIQ(12,16),POP(12,16),RMID(12),FACIL(5
              1)
0003            REAL MONTHS
0004            PI=3.141593
0005            DATA DIR/'N   ','NNE ','NE  ','ENE ','E   ','ESE ','SE  ','SSE ','
              1S   ','SSW ','SW  ','WSW ','W   ','WNW ','NW  ','NNW '/
0006            WRITE(6,10)
0007         10 FORMAT(1H1,T32,'AREAC'//
              1        1X,T12,'AREA SOURCE RADIOLOGICAL EMISSIONS ANALYSIS CODE'/
              2        1H+,T12,'_',T17,'_',T24,'_',T37,'_',T47,'_',T56,'_'//
              3        1X,T20,'ENVIRONMENTAL PROTECTION AGENCY'/
              4        1X,T20,'OFFICE OF RADIATION PROGRAMS'/
              5        1X,T20,'ENVIRONMENTAL ANALYSIS DIVISION'/
              6        1X,T20,'401 M STREET,S.W.'/
              7        1X,T20,'WASHINGTON D.C. 20460'//)
          C     READ/WRITE SOURCE DATA
0008            WRITE(6,20)
0009         20 FORMAT(1H0,'SOURCE INPUT DATA'/)
0010            WRITE(6,30)
0011         30 FORMAT(1H0,'FACILITY, NO.MONTHS OF DATA, PERIOD')
0012            READ(5,40) FACIL,MONTHS,MONTH1,NYR1,MONTH2,NYR2
0013         40 FORMAT(5A4,F5.0,1X,A4,I5,1X,A4,I5)
0014            WRITE(6,50) FACIL,MONTHS,MONTH1,NYR1,MONTH2,NYR2
0015         50 FORMAT(1X,5A4,F5.0,1X,A4,I5,1X,A4,I5/)
0016            READ(5,60)KGEOM
0017         60 FORMAT(I1)
0018            IF(KGEOM.NE.0.AND.KGEOM.NE.1) GO TO 1250
0019            IF(KGEOM.EQ.1) GO TO 1000
0020            WRITE(6,70)
0021         70 FORMAT(1H0,'SOURCE AREA HAS THE SHAPE OF A RECTANGLE'/)
          C     READ/WRITE PILE LENGTH(XL),WIDTH(YL),HEIGHT(ZH),ALL IN METERS
0022            READ(5,80)XL,YL,ZH
0023         80 FORMAT(3F10.0)
0024            WRITE(6,90) XL,YL,ZH
0025         90 FORMAT(1H0,'PILE LENGTH =',F6.0,' M. ,    WIDTH =',F6.0,' M. ,
              1HEIGHT =',F6.0,' M.'/)
          C     DTEST IS THE DIAGONAL OF THE RECTANGULAR AREA SOURCE.
          C     IT REPRESENTS THE LONGEST PROJECTION OF THE AREA SOURCE
          C     IN THE CROSSWIND DIRECTION.
          C     THE RATIO OF DTEST TO DISTANCE FROM THE SOURCE PROVIDES A
          C     CRITERION FOR TREATING THE AREA SOURCE AS A POINT
          C     SOURCE AT LARGE DISTANCES FROM THE PILE.
0026            DTEST=SQRT(XL*XL+YL*YL)
0027            GO TO 1010
0028       1000 WRITE(6,100)
0029        100 FORMAT(1H0,'SOURCE AREA HAS THE SHAPE OF A CIRCLE'/)
          C     READ/WRITE PILE RADIUS(RL),AND HEIGHT(ZH),ALL IN METERS
0030            READ(5,110)RL,ZH
0031        110 FORMAT(2F10.0)
0032            WRITE(6,120)RL,ZH
0033        120 FORMAT(1H0,'PILE RADIUS =',F6.0,' M. ,    HEIGHT =',F6.0,' M.'/)
          C     DTEST IS THE DIAMETER OF THE CIRCULAR AREA SOURCE.
          C     IT IS USED IN THE SAME MANNER AS IN A RECTANGULAR AREA SOURCE.
0034            DTEST=2.*RL
          C     READ/WRITE SOURCE STRENGTH
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                C      READ/WRITE SOURCE STRENGTH(SOURCE),RADIONUCLIDE DECAY
                C      CONSTANT(DEC),AND DOSE CONVERSION FACTOR(DCF)
0035             1010  READ(5,130)SOURCE,DEC,DCF
0036              130  FORMAT(3E10.3)
0037                   WRITE(6,140)
0038              140  FORMAT('0SOURCE STRENGTH,CI/SEC',T30,'DECAY CONSTANT,1/SEC',T60,'D
                      1OSE CONVERSION FACTOR,MREM/YR PER CI/CU.M.')
0039                   WRITE(6,150)SOURCE,DEC,DCF
0040              150  FORMAT( T5,1PE10.3,T35,1PE10.3,T65,1PE10.3/)
                C      READ/WRITE NX AND NY.
                C      IF THE PILE IS A RECTANGLE,NX IS THE NUMBER OF DIVISIONS
                C      ALONG THE X AXIS,AND NY IS THE NUMBER OF DIVISIONS ALONG
                C      THE Y AXIS INTO WHICH THE PILE HAS BEEN SUBDIVIDED.
                C      THE POSITIVE X-AXIS IS ORIENTED TOWARD THE EAST
                C      THE POSITIVE Y-AXIS IS ORIENTED TOWARD THE NORTH
                C      THE ORIGIN OF THE X-Y COORDINATE SYSTEM IS IN THE
                C      CENTER OF THE AREA SOURCE
                C      IF THE PILE IS A CIRCLE,NX IS THE NUMBER OF ANNULAR RINGS,
                C      AND NY IS THE NUMBER OF SECTORS INTO WHICH THE PILE HAS
                C      BEEN SUBDIVIDED.
0041                   READ(5,160)NX,NY
0042              160  FORMAT(2I5)
0043                   IF(KGEOM.EQ.0) WRITE(6,170) NX,NY
0044              170  FORMAT(1H0,'THE SOURCE AREA HAS BEEN SUBDIVIDED INTO ',I3,' BY',I3
                      1,' RECTANGULAR AREA ELEMENTS'/)
0045                   IF(KGEOM.EQ.1) WRITE(6,175) NX,NY
0046              175  FORMAT(1H0,'THE SOURCE AREA HAS BEEN SUBDIVIDED INTO ',I3,' ANNULA
                      1R RINGS AND',I3,' SECTORS'/)
                C      CALCULATE THE X-Y COORDINATES OF SOURCE AREA ELEMENTS
0047                   IF(KGEOM.EQ.0) CALL GEOM0(XL,YL)
0048                   IF(KGEOM.EQ.1) CALL GEOM1(RL)
                C      READ KDIF.IF KDIF IS NOT EQUAL TO 1,THE SOURCE AREA WILL BE
                C      TREATED AS A POINT SOURCE AT LARGE DISTANCES FROM THE PILE.
                C      IF KDIF IS EQUAL TO 1, THE SOURCE AREA WILL BE TREATED AS A
                C      DISTRIBUTED SOURCE EVEN AT LARGE DISTANCES FROM THE PILE.
0049                   READ(5,180) KDIF
0050              180  FORMAT(I1)
0051                   IF(KDIF.EQ.1) GO TO 1020
0052                   WRITE(6,190)
0053              190  FORMAT(1H0,'AT LARGE DISTANCES THE SOURCE AREA WILL BE TREATED AS
                      1A POINT SOURCE')
0054                   GO TO 1030
0055             1020  WRITE(6,200)
0056              200  FORMAT(1H0,'SOURCE AREA WILL BE TREATED AS A DISTRIBUTED SOURCE IN
                      1 ALL CALCULATIONS')
                C      READ/WRITE METEOROLOGICAL DATA
                C      THERE ARE ALWAYS 16 COMPASS DIRECTIONS
                C      AND 6 METEOROLOGICAL STABILITY CLASSES
0057             1030  WRITE(6,210)
0058              210  FORMAT(1H1,'METEOROLOGICAL INPUT DATA')
                C      READ/WRITE WIND FREQUENCIES BY STABILITY CLASS
0059                   DO 1040I=1,16
0060                   READ(5,220)(FREQ(I,J),J=1,6)
0061              220  FORMAT(6F10.0)
0062             1040  CONTINUE
0063                   WRITE(6,230)
0064              230  FORMAT(1H0,'WIND FREQUENCY IN PERCENT BY STABILITY CLASS FOR',
                      1' EACH SECTOR',/
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                  2 1X,'DIR',8X,'A',9X,'B',9X,'C',9X,'D',9X,'E',9X,'F')
0065                DO 1050I=1,16
0066                WRITE(6,240)DIR(I),(FREQ(I,J),J=1,6)
0067            240 FORMAT(1X,A4,6F10.2)
0068           1050 CONTINUE
              C     READ/WRITE WIND SPEEDS BY STABILITY CLASS
0069                DO 1060I=1,16
0070                READ(5,220)(SPEED(I,J),J=1,6)
0071           1060 CONTINUE
0072                WRITE(6,250)
0073            250 FORMAT(1H0,'WIND SPEEDS IN METERS PER SECOND BY STABILITY CLASS FO
                  1R EACH SECTOR',/
                  1 1X,'DIR',8X,'A',9X,'B',9X,'C',9X,'D',9X,'E',9X,'F')
0074                DO 1070I=1,16
0075                WRITE(6,240) DIR(I),(SPEED(I,J),J=1,6)
0076           1070 CONTINUE
0077                READ(5,260)SIGMAX
0078            260 FORMAT(F10.0)
0079                WRITE(6,270)SIGMAX
0080            270 FORMAT(1H0,'SIGMAX=',F10.0,' METERS')
              C     READ KPROB.IF KPROB =1,ONLY DOSE CALCULATIONS FOR SPECIFIC
              C     RECEPTORS WILL BE PERFORMED. IF KPROB =2,ONLY DOSE CALCULATIONS
              C     FOR THE POPULATION WHEEL WILL BE PERFORMED. IF KPROB IS ANY
              C     OTHER NUMBER,BOTH CALCULATIONS WILL BE PERFORMED.
0081                READ(5,280) KPROB
0082            280 FORMAT(I1)
0083                IF(KPROB.EQ.2) GO TO 1150
              C     READ/WRITE NUMBER OF SPECIFIC RECEPTORS
0084                READ(5,290)IND
0085            290 FORMAT(I3)
0086                IF(IND.LT.1.OR.IND.GT.6) GO TO 1265
0087                WRITE(6,300)IND
0088            300 FORMAT(1H1,'THERE ARE ',I3,' SPECIFIC RECEPTORS')
              C     READ/WRITE RADIAL AND ANGULAR POSITIONS OF
              C     SPECIFIC RECEPTORS
              C     RADIAL POSITION IS THE RADIAL DISTANCE,IN METERS,
              C     FROM THE CENTER OF THE AREA SOURCE TO THE RECEPTOR POSITION
              C     ANGULAR POSITION IS THE CLOCKWISE ANGULAR DISPLACEMENT OF THE
              C     RECEPTOR POSITION,IN DEGREES,FROM THE POSITIVE Y-AXIS
0089                READ(5,310)(RPOS(I),I=1,IND)
0090                READ(5,310)(APOS(I),I=1,IND)
0091            310 FORMAT(6F10.0)
0092                WRITE(6,320)
0093            320 FORMAT(1H0,'RECEPTOR NUMBER',T30,'RADIAL POSITION,METERS',T60,'ANG
                  1ULAR POSITION,DEGREES')
0094                DO 1080I=1,IND
0095                WRITE(6,330)I,RPOS(I),APOS(I)
0096            330 FORMAT(1X,I3,T35,F10.0,T65,F10.0)
0097           1080 CONTINUE
              C     CONVERT RECEPTOR POSITIONS TO X-Y COORDINATES
0098                DO 1100I=1,IND
0099                THETA=PI*APOS(I)/180.
0100                XPOS(I)=RPOS(I)*SIN(THETA)
0101                YPOS(I)=RPOS(I)*COS(THETA)
0102           1100 CONTINUE
              C     CALCULATE AND OUTPUT DOSERATES,ETC.,
              C     AT SPECIFIC RECEPTOR LOCATIONS
0103                WRITE(6,380)
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0104       380 FORMAT(1H0,'RECEPTOR NUMBER',T35,'CHI/Q',T55,'RADIONUCLIDE CONCENT
              1RATION',T93,'DOSE RATE',/,T33,'SEC/CU.M.',T63,'CI/CU.M.',T94,'MREM
              2/YR')
0105           DO 1140I=1,IND
0106           CALL DIFUSN(XPOS(I),YPOS(I),CHIOQ,KK)
0107           IF(KK.EQ.0) GO TO 1130
0108           CONC=CHIOQ*SOURCE
0109           DOSE=CONC*DCF
0110           WRITE(6,390)I,CHIOQ,CONC,DOSE
0111       390 FORMAT(1X,I3,T30,1PE12.3,T60,1PE12.3,T90,0PF10.2)
0112           GO TO 1140
0113      1130 WRITE(6,400) I
0114       400 FORMAT(1X,I3,T20,'RECEPTOR IS TOO CLOSE TO THE SOURCE AREA')
0115      1140 CONTINUE
0116           WRITE(6,405)
0117       405 FORMAT(/////////////////////)
0118           IF(KPROB.EQ.1) GO TO 1270
          C    READ/WRITE THE NUMBER OF ANNULI(MRAD) IN THE POPULATION WHEEL
          C    THE NUMBER OF SECTORS IS ALWAYS 16
0119           IF(KPROB.NE.2) GO TO 1155
0120      1150 WRITE(6,406)
0121       406 FORMAT(1H1)
0122      1155 MSEC=16
0123           READ(5,410) MRAD
0124       410 FORMAT(I2)
0125           WRITE(6,420) MSEC,MRAD
0126       420 FORMAT(1H0,'THERE ARE ',I2,' SECTORS AND ',I2,' ANNULI IN THE POPU
              1LATION WHEEL')
          C    READ/WRITE RADIAL DISTANCES,IN METERS,FROM THE CENTER OF THE
          C    SOURCE AREA TO THE MIDDLE,AND INNER AND OUTER BOUNDARIES OF THE
          C    MRAD POPULATION WHEEL ANNULI
0127           WRITE(6,430)
0128       430 FORMAT(1H0,'DISTANCES,IN METERS,TO THE MIDDLE,AND INNER AND OUTER
              1BOUNDARIES OF POPULATION WHEEL ANNULI'//' ANNULUS NUMBER',T20,'RMI
              2D',T40,'RINN',T60,'ROUT')
0129           DO 1160I=1,MRAD
0130           READ(5,440) RMID(I),RINN(I),ROUT(I)
0131       440 FORMAT(3F10.0)
0132           WRITE(6,450) I,RMID(I),RINN(I),ROUT(I)
0133       450 FORMAT(1X,T5,I2,T15,F10.0,T35,F10.0,T55,F10.0)
0134      1160 CONTINUE
          C    READ/WRITE POPULATION IN SECTOR SEGMENTS BOUNDED BY THE POPULATION
          C    WHEEL ANNULI. POP(I,J) IS THE POPULATION IN ANNULUS I AND SECTOR J
0135           DO 1170I=1,MRAD
0136           READ(5,460) (POP(I,J),J=1,8)
0137           READ(5,460) (POP(I,J),J=9,16)
0138       460 FORMAT(8F10.0)
0139      1170 CONTINUE
0140           WRITE(6,470)
0141       470 FORMAT(1H1,'POPULATIONS IN SECTOR SEGMENTS,TWO LINES PER RADIUS',
              1'(READ CLOCKWISE), AND TOTAL POPULATION IN ANNULI'/
              21X,' I',1X,'N/S/TOTAL',3X,
              3'NNE/SSW',5X,'NE/SW',3X,'ENE/WSW',7X,
              4'E/W',3X,'ESE/WSW',5X,'SE/NW',3X,'SSE/NNW')
0142           DO 1190I=1,MRAD
0143           WRITE(6,480) I,(POP(I,J),J=1,8)
0144       480 FORMAT(1X,I2,T5,8F10.0)
0145           WRITE(6,490)(POP(I,J),J=9,16)
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0146          490 FORMAT(1X,T5,8F10.0)
0147              SUM=0.
0148              DO 1180J=1,16
0149              SUM=SUM+POP(I,J)
0150         1180 CONTINUE
0151              WRITE(6,500) SUM
0152          500 FORMAT(1X,T5,F10.0)
0153         1190 CONTINUE
            C     NOW INDIVIDUAL AND POPULATION DOSE CALCULATIONS
            C     WILL BE PERFORMED
0154              DO 1200 J=1,16
0155              ANGLE=22.5*FLOAT(J-1)*PI/180.
0156              SINUS=SIN(ANGLE)
0157              COSIN=COS(ANGLE)
0158              DO 1200 I=1,MRAD
            C      CALCULATE THE X-Y COORDINATES OF THE CENTER OF
            C     POPULATION WHEEL SECTOR SEGMENT (I,J)
0159              X=RMID(I)*SINUS
0160              Y=RMID(I)*COSIN
0161              CALL DIFUSN(X,Y,CHIOQ,KK)
0162              IF(KK.EQ.0) GO TO 1260
0163              CHIQ(I,J)=CHIOQ
0164              CONC=CHIOQ*SOURCE
0165              DOS(I,J)=CONC*DCF/1000.
0166              POPDOS(I,J)=DOS(I,J)*POP(I,J)/1000.
0167         1200 CONTINUE
0168              WRITE(6,510)
0169          510 FORMAT(1H0,4X,'CHI/Q SUMMED OVER STABILITY CLASSES')
0170              WRITE(6,520) (RMID(I),I=1,MRAD)
0171          520 FORMAT(1H0,56X,'DISTANCE (METERS)'/1X,'DIR',12F10.0/)
0172              DO 1210 J=1,16
0173              WRITE(6,530) DIR(J),(CHIQ(I,J),I=1,MRAD)
0174          530 FORMAT(1X,A4,1P12E10.2)
0175         1210 CONTINUE
0176              WRITE(6,540) (DIR(J),J=1,16)
0177          540 FORMAT(1H1,25X,'    DOSE RATE TO AN INDIVIDUAL IN THE INDICATED C
                 1OMPASS SECTOR AND ANNULAR RING  (REM/YR)'//4X,'  DIST',1X,16A7)
0178              DO 1220 I=1,MRAD
0179              WRITE(6,550) RMID(I),(DOS(I,J),J=1,16)
0180          550 FORMAT(1X,F10.0,16F7.3)
0181         1220 CONTINUE
0182              WRITE(6,560) (DIR(J),J=1,16)
0183          560 FORMAT(1H0,//15X,' POPULATION DOSE RATE IN THE INDICATED COMPASS',
                 1 ' SECTOR AND ANNULAR RING (1000 PERSON-REM/YR)'/31X,'AVERAGED',
                 2' TO CONFORM TO THE POPULATION WHEEL WIND SECTORS'/43X,'FOR THE ES
                 3TIMATED POPULATION  ',//123X,'RUNNING',/4X,'  DIST',1X,16A7,T126,
                 4'TOTAL')
0184              TOTAL=0.
0185              DO 1240 I=1,MRAD
0186              SUM=0.
0187              DO 1230 J=1,16
0188              SUM=SUM+POPDOS(I,J)
0189         1230 CONTINUE
0190              TOTAL=TOTAL+SUM
0191              WRITE(6,570) RMID(I),(POPDOS(I,J),J=1,16),TOTAL
0192          570 FORMAT(1X,F10.0,17F7.3)
0193         1240 CONTINUE
0194              GO TO 1270
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0195          1250 WRITE(6,580)
0196           580 FORMAT(1H1,'ERROR.SOURCE AREA GEOMETRY HAS NOT BEEN SPECIFIED.PROG
                  1RAM TERMINATED.')
0197               GO TO 1270
0198          1260 WRITE(6,590)
0199           590 FORMAT(1H1,'ERROR.ONE SECTOR SEGMENT TOO CLOSE TO SOURCE AREA.PROG
                  1RAM TERMINATED.')
0200               GO TO 1270
0201          1265 WRITE(6,600)
0202           600 FORMAT(1H1,'ERROR.NUMBER OF SPECIFIC RECEPTORS OUTSIDE OF ALLOWED
                  1RANGE (1-6).PROGRAM TERMINATED.')
0203          1270 STOP
0204               END
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0001          SUBROUTINE DIFUSN(XX,YY,TCHIOQ,KK)
0002          COMMON NX,NY,SIGMAX,SX(10,10),SY(10,10),FREQ(16,6),SPEED(16,6),ZH,
             1      PI,DEC,DTEST,KDIF
        C     THIS SUBROUTINE PERFORMS DIFFUSION CALCULATIONS
        C     THE CHIOQ CONTRIBUTION FROM EACH SOURCE AREA ELEMENT IS
        C     ADDED TO OBTAIN THE TOTAL CHIOQ AT THE RECEPTOR POSITION (XX,YY)
        C     THE DIFFUSION CALCULATION UTILIZES EQUATION 3.144 IN METEOROLOGY
        C     AND ATOMIC ENERGY,AND FUNCTION SIGZ. THE VALUE OF
        C     SIGZ IS SET TO A MAXIMUM VALUE OF SIGMAX
        C     THE CHIOQ CONTRIBUTION FROM EACH AREA ELEMENT IS DECAYED
        C     BY TIME OF FLIGHT
        C     THE TOTAL RADIONUCLIDE CONCENTRATION DISPERSION FACTOR,TCHIOQ,
        C     AT A RECEPTOR LOCATION,IS NORMALIZED WITH RESPECT TO THE TOTAL
        C     SOURCE AREA BY DIVIDING IT BY THE NUMBER OF AREA ELEMENTS,(NX*NY),
        C     AND PRINTED OUT. THEN,IT IS MULTIPLIED BY THE TOTAL SOURCE AREA
        C     RADIONUCLIDE RELEASE RATE AND DOSE CONVERSION FACTOR TO
        C     YIELD A YEARLY DOSE .
        C     THIS PROCEDURE IS VALID ONLY WHEN THE AREA ELEMENTS ARE OF
        C     EQUAL SIZE.
        C     THE INTEGER KK INFORMS THE MAIN PROGRAM WHEN A RECEPTOR
        C     POSITION IS LESS THAN 100 METERS FROM A SOURCE AREA ELEMENT
        C     DETERMINE THE CONSTANT IN EQUATION 3.144 (N=16).
        C     CONST=16.*0.01*SQRT(2./PI)/(2.*PI)
0003          CONST=0.0203
        C     THE ANGULAR WIDTH OF A SECTOR,WSA,IS 22.5 DEGREES.
0004          WSA=22.5
0005          II=NY
0006          JJ=NX
0007          IF(KDIF.EQ.1) GO TO 500
        C     THE FOLLOWING STATEMENTS DETERMINE WHETHER THE AREA
        C     CAN BE TREATED AS A POINT SOURCE.
0008          RTEST=SQRT(XX*XX+YY*YY)
0009          WSR=PI*WSA/(180.*2.)
0010          D=DTEST*(1.+1./TAN(WSR))/2.
0011          IF(RTEST.GT.D) II=1
0012          IF(RTEST.GT.D) JJ=1
        C     INITIALIZE THE TOTAL CHIOQ TO ZERO
0013      500 TCHIOQ=0.
0014          DO 6000 I=1,II
0015          DO 6000 J=1,JJ
        C     DETERMINE THE DISTANCE FROM THE (I,J) AREA ELEMENT TO THE
        C     RECEPTOR LOCATION
0016          DIFX=XX-SX(I,J)
0017          DIFY=YY-SY(I,J)
0018          IF(KDIF.EQ.1) GO TO 600
0019          IF(RTEST.GT.D) DIFX=XX
0020          IF(RTEST.GT.D) DIFY=YY
0021      600 R=SQRT(DIFX**2+DIFY**2)
        C     IF RECEPTOR LOCATION IS LESS THAN 100 METERS,THE MAIN PROGRAM
        C     WILL BE INFORMED BY SETTING KK=0.
0022          IF(R-100.) 1000,2000,2000
0023     1000 TCHIOQ=0.
0024          KK=0
0025          GO TO 7000
        C     DETERMINE THE SECTOR ORIENTATION OF RECEPTOR
0026     2000 THET=ATAN2(DIFX,DIFY)
0027          THET=180.*THET/PI
0028          IF(THET.LT.0.) THET=THET+360.
```

```
               C      NOW THET RUNS FROM 0 TO 360 DEGREES
               C      DETERMINE IN WHICH SECTOR THET FALLS
               C      KSEC IS THE SECTOR NUMBER
 0029                 THET=THET+WSA/2.
 0030                 KSEC=THET/WSA+1.
               C      SUM CHIOQ OVER STABILITY KLASSES
               C      CONVERT RECEPTOR DISTANCE FROM METERS TO KILOMETERS
 0031                 RKM=0.001*R
 0032                 CHIOQ=0.
               C      SUM OVER STABILITY CLASSES
 0033                 DO 5000 KLASS=1,6
               C      TO AVOID UNDERFLOWS DUE TO RAPID DECAY OF SHORTLIVED RADIONUCLIDES
               C      THE CHIOQ WILL BE SET TO ZERO IF THE RADIONUCLIDE HAS DECAYED
               C      BY MORE THAN 30 MEAN LIVES.
               C      THE CHIOQ WILL ALSO BE SET EQUAL TO ZERO IF FREQ OR SPEED ARE LESS
               C      THAN 0.01
 0034                 IF(FREQ(KSEC,KLASS)-0.01) 4700,4700,4500
 0035            4500 IF(SPEED(KSEC,KLASS)-0.01) 4700,4700,4600
 0036            4600 XLIVES=DEC*R/SPEED(KSEC,KLASS)
 0037                 IF(30.-XLIVES) 4700,4700,4800
 0038            4700 B=0.
 0039                 GO TO 4900
 0040            4800 IF(SIGMAX.LT.1.) SIGMAX=1.E+04
 0041                 SZ=SIGZ(KLASS,RKM)
 0042                 IF(SZ.GT.SIGMAX) SZ=SIGMAX
 0043                 DECAY=EXP(-XLIVES)
 0044                 ARG=ZH*ZH/(2.*SZ*SZ)
 0045                 IF(ARG.GT.100.) ARG=100.
 0046                 DENOM=SZ*SPEED(KSEC,KLASS)*R
 0047                 B=CONST*FREQ(KSEC,KLASS)*DECAY*EXP(-ARG)/DENOM
 0048            4900 CHIOQ=CHIOQ+B
 0049            5000 CONTINUE
 0050                 TCHIOQ=TCHIOQ+CHIOQ
 0051            6000 CONTINUE
 0052                 TCHIOQ=TCHIOQ/FLOAT(II*JJ)
 0053                 KK=1
 0054            7000 RETURN
 0055                 END
```

```
0001                  SUBROUTINE GEOMO(XL,YL)
               C      THIS SUBROUTINE DETERMINES THE X-Y COORDINATES OF THE CENTERS OF
               C      AREA ELEMENTS.THERE ARE NX BY NY ELEMENTS ARRANGED IN A MATRIX OF
               C      NY ROWS AND NX COLUMNS.ELEMENT (1,1) IS IN THE NORTHWESTERN CORNER
               C      OF THE MATRIX, AND ELEMENT (NY,NX) IS IN THE SOUTHEASTERN CORNER.
               C      SX(I,J) AND SY(I,J) ARE,RESPECTIVELY,THE X AND Y COORDINATES
               C      OF THE CENTER OF AREA ELEMENT (I,J)
               C      ALL AREA ELEMENTS HAVE THE SAME AREA
0002                  COMMON NX,NY,SIGMAX,SX(10,10),SY(10,10),FREQ(16,6),SPEED(16,6),ZH,
                     1       PI,DEC,DTEST,KDIF
0003                  DELTX=XL/FLOAT(NX)
0004                  DELTY=YL/FLOAT(NY)
0005                  DO 600 I=1,NY
0006                  DO 600 J=1,NX
0007                  SY(I,J)=YL/2.-DELTY*(2*I-1)/2.
0008                  SX(I,J)=-XL/2.+DELTX*(2*J-1)/2.
0009              600 CONTINUE
0010                  RETURN
0011                  END
```

```
0001             SUBROUTINE GEOM1(RL)
           C     THIS SUBROUTINE DETERMINES THE X-Y COORDINATES OF CENTERS OF AREA
           C     ELEMENTS INTO WHICH THE CIRCULAR PILE HAS BEEN DIVIDED.RL IS THE
           C     RADIUS OF THE PILE.NX IS THE NUMBER OF ANNULI AND NY IS THE NUMBER
           C     OF SECTORS.SX(I,J) AND SY(I,J) ARE,RESPECTIVELY,THE X AND Y
           C     COORDINATES OF THE AREA ELEMENT(I,J).I DENOTES THE ANNULUS NUMBER,
           C     STARTING WITH 1 NEAR THE CENTER AND INCREASING OUTWARD,AND J
           C     DENOTES THE SECTOR WHICH SPANS THE ANGLE FROM (J-1)*360/NY
           C     TO J*360/NY,AS MEASURED IN THE CLOCKWISE DIRECTION FROM THE NORTH.
           C     IF NX=1 AND NY=1 THE SUBROUTINE YIELDS THE CENTER OF THE CIRCLE.
           C     ALL AREA ELEMENTS HAVE THE SAME AREA
0002             COMMON NX,NY,SIGMAX,SX(10,10),SY(10,10),FREQ(16,6),SPEED(16,6),ZH,
                1       PI,DEC,DTEST,KDIF
0003             DIMENSION R(11),RM(10),THET(10)
0004             IF(NX.EQ.1.AND.NY.EQ.1) GO TO 40
0005             XNX=FLOAT(NX)
0006             YNY=FLOAT(NY)
0007             AREA=RL*RL/XNX
0008             R(1)=0.
0009             NN=NX+1
0010             DO 10 I=2,NN
0011             ARG=AREA+R(I-1)*R(I-1)
0012             R(I)=SQRT(ARG)
0013          10 CONTINUE
0014             DO 20 I=1,NX
0015             RM(I)=(R(I)+R(I+1))/2.
0016          20 CONTINUE
0017             DELTR=2.*PI/YNY
0018             DO 30 I=1,NY
0019             THET(I)=(2*I-1)*DELTR/2.
0020          30 CONTINUE
0021             DO 35 I=1,NX
0022             DO 35 J=1,NY
0023             SX(I,J)=RM(I)*SIN(THET(J))
0024             SY(I,J)=RM(I)*COS(THET(J))
0025          35 CONTINUE
0026             GO TO 45
0027          40 SX(1,1)=0.
0028             SY(1,1)=0.
0029          45 RETURN
0030             END
```

```
0001              FUNCTION SIGZ(KLASS,X)
            C     FUNCTIONS ARE OAP/EPA FITS TO SIGMA ZEES
            C     IN EPA OFFICE OF AIR PROGRAMS DOCUMENT NO.AP-26.(USGPO,WASH.,DC.
            C     STOCK NO.5503-0015, PRICE ONE DOLLAR)
            C     FUNCTION CALCULATES THE STANDARD DEVIATION OF PLUME CONCENTRATION
            C          IN THE Z DIRECTION FOR STABILITY KLASS (1 = A, 2 = B, 3 = C,
            C          4 = D, 5 = E, 6 = F) AND THE DISTANCE ALONG THE CENTERLINE OF
            C          THE PLUME IN KILOMETERS, X.
            C     THE STANDARD DEVIATION IS IN METERS.
            C     AS WRITTEN, A CAPPING LAYER (SIGMAX)   UPPER BOUNDS SIGZ
            C
            C     THE RUN IS STOPPED IF X(MM) IS LESS THAN 100. METERS
            C
0002          100 IF(X-0.1) 110,130,130
0003          110 WRITE(3,120)
0004          120 FORMAT(1X,'ONE DISTANCE R IS TOO SMALL')
0005              STOP
0006          130 XX=ALOG(X)
0007              SIGMAX=10000.
0008              GO TO(140,170,180,190,200,210),KLASS
0009          140 IF(X-1.5)150,150,160
0010          150 SIGZ=EXP(6.126788+XX*(2.214445+XX*(-0.041129+XX*
                 1(-0.379863+XX*(-0.099597)))))
0011              IF(SIGZ-SIGMAX)220,220,230
0012          160 SIGZ=500.*X**2
0013              IF(SIGZ-SIGMAX)220,220,230
0014          170 SIGZ=EXP(4.686302+XX*(1.062550+XX*(0.018771)))
0015              IF(SIGZ-SIGMAX)220,220,230
0016          180 SIGZ=61.141032*X**.914651
0017              IF(SIGZ-SIGMAX)220,220,230
0018          190 SIGZ=EXP(3.416367+XX*(0.729577+XX*(-0.031207)))
0019              IF(SIGZ-SIGMAX)220,220,230
0020          200 SIGZ=EXP(3.057629+XX*(0.679089+XX*(-0.044892)))
0021              IF(SIGZ-SIGMAX)220,220,230
0022          210 SIGZ=EXP(2.625488+XX*(0.658866+XX*(-0.054137)))
0023              IF(SIGZ-SIGMAX)220,220,230
0024          230 SIGZ=SIGMAX
0025          220 RETURN
0026              END
```

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