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# XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations

Final Report

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## Figures



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## ABSTRACT

Provided is a user's guide for the U. S. Nuclear Regulatory Commission's (NRC) computer program XOQDOQ which implements Regulatory Guide 1.111. This NUREG supercedes NUREG-0324 which was published as a draft in September 1977. This program is used by the NRC meteorology staff in their independent meteorological evaluation of routine or anticipated intermittent releases at nuclear power stations. It operates in a batch input mode and has various options a user may select. Relative atmospheric dispersion and deposition factors are computed for 22 specific distances out to 50 miles from the site for each directional sector. From these results, values for 10 distance segments are computed. The user may also select other locations for which atmospheric dispersion deposition factors are computed. Program features, including required input data and output results, are described. A program listing and test case data input and resulting output are provided.

## SUMMARY

A user's guide for the U.S. Nuclear Regulatory Commission computer program XOQDOQ is presented. This program is used by the staff in their independent meteorological evaluation of routine or anticipated, intermittent releases of radionuclides at commercial nuclear power stations. The program is not intended to evaluate the meteorological aspects of the consequences of accidental releases.

The present version of the program operates in a batch-input mode with various options that are user selectable. Relative atmospheric dispersion factors, X/Q values, and deposition factors, D/Q values, are computed for 22 specific distances out to 50 miles from the site. From these values, X/Q and D/Q values for 10 distance segments are computed. Both X/Q and D/Q values are computed for user-inputted specific points of interest.

The program is based on a straight-line trajectory Gaussian plume model. At the user's option, the plume concentration can be depleted by dry deposition and radioactive decay. The computed ground-level concentration can be modified to account for plume recirculation or stagnation. The program computes an effective plume height that accounts for physical release height, aerodynamic downwash, plume rise, and terrain features.

This version of the program was developed on a CDC 7600 computer in Fortran IV language. The structure of the program is such that it should be easily converted to other computer systems.

## ACKNOWLEDGMENTS

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# USER GUIDE FOR XOQDOQ: EVALUATING ROUTINE EFFLUENT RELEASES AT COMMERCIAL NUCLEAR POWER STATIONS

## 1.0 INTRODUCTION

This document provides a user's guide for the computer program XOQDOQ which is used by the Nuclear Regulatory Commission (NRC) in its independent meteorological evaluation of continuous and anticipated intermittent releases from commercial nuclear power reactors. This program has evolved form an earlier program developed by Sangendorf (1974) for NRC's predecessor, the Atomic Energy Commission (AEC). The program described in this document is a revised version of an earlier program (Sagendorf and Goll, 1976) and was developed on a CDC 7600 computer in Fortran IV language. Its structure is such that it could be easily converted to other computer systems. The earlier version of the program was also used by the NRC staff in its evaluations connected with Appendix I to 10 CFR, Part 50.

The program is based on the theory that material released to the atmosphere will be normally distributed (Gaussian) about the plume centerline. In predicting concentrations for longer time periods, the Gaussian distribution is assumed to be evenly distributed within the directional sector. A straight-line trajectory is assumed between the point of release and all receptors.

The program implements the assumptions outlined in Section C (excluding C1a and C1b) of NRC Regulatory Guide 1.111 (USNRC, 1977). In evaluating routine releases from nuclear power plants, it primarily is designed to calculate annual relative effluent concentrations, X/Q values, and annual average relative deposition, D/Q values, at locations specified by the user, and at various standard radial distances and segments for downwind sectors. Evaluations of anticipated intermittent (e.g. containment or purge) releases which occur during routine operation may also be evaluated using the program. Evaluation of intermittent releases provides both X/Q and D/Q values at various standard locations, as well as user-inputted specific points of interest.

It operates in a batch-input mode and has various options that a user may select. They can account for variation in the location of release points, additional plume dispersion due to building wakes, plume depletion via dry deposition and radioactive decay, and adjustments to consider non-straight trajectories. It computes an effective plume height that accounts for physical release height, aerodynamic downwash, plume rise, and terrain features. It cannot handle multiple emission sources, plume depletion via wet deposition, or evaluate the meteorological aspects of the consequences of accidental releases.

Provided in various sections of this user's guide is information on basic program features, format of the required data, a description of the program and subroutines, and a description of the expected program output. Appendices to this guide include a listing of the program, sample data inputs and the resulting data output.

The program described in this guide is compatible with a CDC 7600 computer system under the NOS 1.0 operating system. Any questions regarding the program or problems encountered should be directed or reported to the Meteorology Staff, U.S. Nuclear Regulatory Commission, Washington, D.C.

## 2.0 INPUT CARD FORMAT

The required input data for program execution are listed in Table 2.1. The input data are categorized by card types, ranging from 1 to 17. For some card types, more than one physical card will be inputted.

Card Type 1 initializes options, known as KOPT's, for each release point to be evaluated. If multiple sites are to be evaluated with the program, then additional data sets, starting with Card Type 1, are required.

## 3.0 PROGRAM FEATURES

The program is based on the principle that diffusion of material released to the atmosphere can be described by a Gaussian distribution within the plume with transport described by a straight-line trajectory. A discussion of a Gaussian plume model is provided elsewhere (e.g. Slade, 1968). This model, though, only approximates the actual atmospheric transport and diffusion of effluents. Various terms used in it, namely, the horizontal and vertical dispersion coefficients, are empirically determined, largely from observations at or near ground level. Predicting plume concentrations at locations other than ground level will introduce additional errors into the calculation. Nevertheless, this modelling approach is especially useful for evaluating routine releases of material to the atmosphere and predicting resulting normalized concentrations and deposition amounts over long time periods.

The program has the following options:

1. The release may be

   a. always elevated
   b. always ground level, or
   c. a mixed mode, which is primarily used in the analysis of vent release points at or above the height of adjacent structures.

## TABLE 2.1. List of Input Data

Card Type 1 is an array (KOPT) of options, such that 1 = do, 0 = bypass. These options remain in effect for all release points run. Thus, all release points must have the same assumptions.

| Card Type | Columns | Variable Name | Format | Description |
|---|---|---|---|---|
| 1 | 1 | KOPT(1) | I1 | Option to distribute calms as the first wind-speed class (if calms are already distributed by direction in Card Type 6, KOPT(1) = 0, and Card Type 5 is blank). If KOPT(1) = 1, the calm values of Card Type 5 are distributed by direction in the same proportion as the direction frequency of wind-speed class two. |
| 1 | 2 | KOPT(2) | I1 | Option to input joint frequency distribution data as percent frequency. |
| 1 | 3 | KOPT(3) | I1 | Option to compute a sector spread for comparison with centerline value in purge calculation (Normally = 1). |
| 1 | 4 | KOPT(4) | I1 | Option to plot short-term X/Q values versus probability of occurrence (Normally = 0). |
| 1 | 5 | KOPT(5) | I1 | Option to use cubic spline in lieu of least square function for fitting intermittent release distribution (Normally = 1). |
| 1 | 6 | KOPT(6) | I1 | Option to punch radial segment X/Q and D/Q values (Normally = 1). |
| 1 | 7 | KOPT(7) | I1 | Option to punch output of X/Q and D/Q values of the points of interest (Normally = 1). |
| 1 | 8 | KOPT(8) | I1 | Option to correct X/Q and D/Q values for open terrain recirculation. |
| 1 | 9 | KOPT(9) | I1 | Option to correct X/Q and D/Q values using site specific terrain recirculation data. |

TABLE 2.1. List of Input Data

| Card Type | Columns | Variable Name | Format | Description |
|---|---|---|---|---|
| 1 | 10 | KOPT(10) | I1 | Option to use desert sigma curves (Normally = 0). |
| 1 | 11 | KOPT(11) | I1 | Option to calculate annual X/Q averages with 30 degree sectors for north, east, south and west and 20 degree sectors for all others (Normally = 0, and the code will use 22-1/2 degree sectors). |
| 2 | 1-80 | TITLM | 20A4 | The main title printed at the beginning of the output. |
| 3 | 1-5 | NVEL | I5 | The number of velocity categories (maximum of 14). |
| 3 | 6-10 | NSTA | I5 | The number of stability categories (maximum of 7) (1 always equals Pasquill stability class A, 2 = B, ..., 7 = G). |
| 3 | 11-15 | NDIS | I5 | The number of distances with terrain data for each sector. The number of distances must be the same for each sector (Card Type 10)(maximum of 10). |
| 3 | 16-20 | INC | I5 | The increment in percent for which plotted results are printed out (Normally = 15). |
| 3 | 21-25 | NPTYPE | I5 | The number of titles of receptor types (cow, garden, etc.) (Card Type 13)(maximum of eight) |
| 3 | 26-30 | NEXIT | I5 | The number of release exit points (maximum of five). |
| 3 | 31-35 | NCOR | I5 | The number of distances of site specific correction factors for recirculation (maximum of 10). |
| 4 | 1-5 | PLEV | F5.0 | The height (in meters, above ground level) of the measured wind presented in the joint frequency data (Card Type 7). (For elevated/ground-level mixed release, use the 10-meter level winds). |

## TABLE 2.1. List of Input Data

| Card Type | Columns | Variable Name | Format | Description |
|---|---|---|---|---|
| 4 | 6-20 | DECAYS(I) I=1, 3 | 3F5.0 | For each I: The half-life (days) used in the X/Q calculations: if DECAYS > 100, no decay will occur; if DECAYS < 0, depletion factor will be used in the X/Q calculations; if DECAYS = 0, X/Q will not be calculated. (Normally, DECAYS(1) = 101, (2) = 2.26, (3) = -8.00.) |
| 4 | 21-25 | PLGRAD | F5.0 | Plant grade elevation (feet above sea level). If PLGRAD = 0.0, DIST and HT data Card Type 10 and 11 must be in meters. If PLGRAD < 0.0, DIST in miles and HT data in feet above plant grade. If PLGRAD > 0.0 above DIST in miles and HT data in feet above sea level. |
| 5 | 1-35 | CALM(I) I=1, NSTA | 7F5.0 | The number of hours, or percent, of calm for each stability category; if KOPT(1) = 0, insert blank card. (Note: I=1 is stability class A, 2=B, ..., 7=G). |
| 6 | 1-80 | FREQ(K,I,J) K=1, 16 I=1, NVEL (if KOPT(1) = 0) I=2, NVEL (if KOPT(1) = 1) J=1, NSTA | | The joint frequency distribution in hours (or percent). The values for 16 (K) sectors are read on each card for each combination of wind-speed class (I) and stability class (J). The loop to read these value cycles first on direction continuing in a clockwise fashion), then on wind class and finally on stability class. |
| 7 | 1-5 | UCOR | F5.0 | A correction factor applied to wind-speed classes. If UCOR < 0: no corrections will be made. If UCOR > 100: the wind-speed classes will be converted from miles/hour to meters/second. |

## TABLE 2.1. List of Input Data

| Card Type | Columns | Variable Name | Format | Description |
|---|---|---|---|---|
| 7 | 6-75 | UMAX(I) | 14F5.0 | The maximum wind speed in each wind-speed class, in either miles/hour or meters/second. (If given in miles/hour, set UCOR > 100.) |
| Card Types 8 and 9 are read in for each correction factor and distance given, I = 1,NCOR | | | | |
| 8 | 1-80 | VRDIST(K,I) K=1,16 | 16F5.0 | The distance in meters at which correction factors are given. These values are read in beginning with south and proceeding in a clockwise direction (maximum of 10). |
| 9 | 1-80 | VRCR(K,I) K=1,16 | 16F5.0 | Correction factor to be applied to X/Q and D/Q values corresponds to distances specified in VRDIST. |
| Card Types 8 and 9 are repeated for the remaining distances and correction factors. Card Types 10 and 11 are read in for each terrain distance and height given, I = 1,NDIS. | | | | |
| 10 | 1-80 | DIST(K,I) K=1,16 | 16F5.0 | The distance in meters at which terrain heights are given. These values are read in beginning with south and proceeding in a clockwise direction (maximum of ten distances). |
| 11 | 1-80 | HT(K,I) K=1,16 | 16F5.0 | The terrain heights (in meters, above plant grade level) corresponding to the distances specified in the DIST array (Card Type 10). These values are read in the same order as the DIST array. For a given direction and distance, the terrain height should be the highest elevation between the source and that distance anywhere within the direction sector. |

Card Types 10 and 11 are repeated for the remaining distances and heights.

TABLE 2.1. List of Input Data

| Card Type | Columns | Variable Name | Format | Description |
|---|---|---|---|---|
| 12 | 1-25 | NPOINT(I) I=1, NPTYPE | 5I5 | The number (maximum of 30) of receptor locations for a particular receptor type (such as the number of cows, gardens, or site boundaries). |
| Card Types 13 and 14 are read in for each receptor type, thus I=1, NPTYPE | | | | |
| 13 | 1-16 | TITLPT(I,J) | 4A4 | The title (cows, gardens, etc.) of the receptor type for the receptor locations (Card Type 14) (a maximum of 16 spaces). |
| 14 | 1-80 | KDIR(I,N) PTDIST(I,N) N=1,NPOINT(I) | 8(I5, F5.0) | The receptor direction and distance. KDIR is the direction of interest, such that 1 = South, 2 = SSW,..., 16 = SSE, PTDIST is *the distance, in meters, to the receptor* location. |
| Card Types 13 and 14 are repeated for the remaining receptor types.<br>Card Types 15, 16, and 17 read in for each plant release point, thus I = 1, NEXIT | | | | |
| 15 | 1-80 | TITLE(I,J) | 20A4 | The title for the release point whose characteristics are described on Card Types 16 *and* 17. |
| 16 | 1-5 | EXIT(I) | F5.0 | The vent average velocity (meters/second). (Note: if a 100% ground-level release is assumed, set EXIT = 0, DIAMTR = 0, and SLEV = 10 meters). |
| 16 | 6-10 | DIAMTR | F5.0 | The vent inside diameter (meters). |
| 16 | 11-15 | HSTACK(I) | F5.0 | The height of the vent release point (meters, plant grade level). If release is 100% elevated, input negative of height. |
| 16 | 16-20 | HBLDG(I) | F5.0 | The height of the vent's building (meters, above plant grade level). |

## TABLE 2.1. List of Input Data

| Card Type | Columns | Variable Name | Format | Description |
|---|---|---|---|---|
| 16 | 21-25 | CRSEC(I) | F5.0 | The minimum cross-sectional area for the vent's building (square meters). |
| 16 | 26-30 | SLEV(I) | F5.0 | The wind height used for the vent elevated release (meters, above plant grade level). |
| 16 | 31-35 | HEATR(I) | F5.0 | The vent heat emission rate (cal/sec) (Normally = 0). |
| 17 | 1 | RLSID(I) | A1 | A one letter identification for the release point. |
| 17 | 2-5 | IPURGE(I) | I4 | IPURGE = 1, 2 or 3 if the vent has intermittant releases. The 1, 2 or 3 corresponds to DECAYS(1), DECAYS(2), or DECAYS(3) (Card Type 4), respectively, whichever is used as the base for intermittent release calculations (normally no decay/no deplete X/Q, such that IPURGE(I) = 1); if a vent has no intermittent releases, IPURGE = 0. |
| 17 | 6-10 | NPURGE(I) | I5 | The number of intermittent releases per year for this release point. |
| 17 | 11-15 | NPRGHR(I) | I5 | The average number of hours per intermittent release. |

Card Types 15, 16 and 17 are repeated for the remaining release points.
Card Types 1-17 may be repeated for the next case.

2. The effluent plume for elevated releases can undergo plume rise due to momentum and/or buoyancy.

3. Ground-level releases can be affected by additional dispersion due to nearby building wakes.

4. Wind speeds measured at one level may be extrapolated to other elevations for release point evaluation.

5. Plume growth parameters ($\sigma_y$ and $\sigma_z$) can be described by
   a. Pasquill-Gifford curves (Slade, 1968)
   b. desert curves by Markee (Yanskey et al, 1966).

6. For elevated releases, topography can be inputted for use in calculation of the effective plume height.

7. The plume may undergo radioactive decay for varied half-lives.

8. The plume may be depleted via dry deposition.

9. X/Q and D/Q values may be modified by standard or inputted values to account for local air recirculation or air stagnation.

10. X/Q and D/Q values can be punched for predetermined distance segments and for specific points of interest.

11. The joint frequency data may be inputted as a percent frequency of occurrence or as total frequency of occurrence.

Specific information on program capabilities are given in Section 4.0.

Meteorological data is input into the program as a joint frequency table, which is a table of the fractional occurrence during a given time period of a particular combination of stability class type, wind direction, and wind speed class. The wind direction has been broken into sixteen sectors proceeding clockwise from N through NNW. The wind speeds are grouped into classes, with the program allowing up to 14 separate classes, which includes a class for calm wind speeds. Atmospheric stability is grouped according to seven categories from extremely unstable to extremely stable.

## 3.1 MULTIPLE SITE ANALYSIS

The present version of the program can handle multiple site analysis by simply adding additional data sets. Each data set would begin with the Card Type 1 (KOPT DATA) and include the same type of information as the previous data set. The program terminates by reading an end of file (EOF) card, so within the normal run-time limit of the operating system, an unlimited number of sites can be analyzed. Presently, the program is limited to five separate release points. If more release points for a specific site exist, multiple data sets differing only in release point characteristics could be used.

The advantage of running multiple data sets is to reduce compilation time of the program. However, in most computers which swap jobs in the central processing units (CPU), the job turn-around time will probably increase.

## 3.2 CONTINUOUS RELEASE ANALYSIS

As noted in Section 4.1, continuous releases are analyzed according to a sector spread version of the Gaussian plume equation. The program also has the ability to compute a centerline concentration value for comparison with the sector spread concentration, with the most conservative value retained. If this comparison is desired appropriate lines commented in Subroutine ANNUAL should be changed to active statements. (See listing in Appendix A.)

For a special case of a continuous ground level release in a desert-type environment, the building wake term will only apply under certain conditions. For unstable and neutral atmospheric conditions, normal building wake calculations prevail. For stable atmospheric conditions, the building wake calculation will be set to zero. This condition applies for both sector spread and centerline calculations at specific points of interest and at set distances. The rationale for this feature is the desert sigmas include the effect of plume meander. During stable atmospheric conditions the effect of plume meander dominates the effects of building wake. These conditions, however, are not used for intermittent releases because these releases may be for short time intervals during which plume meander is not considered to have occurred.

## 3.3 INTERMITTENT RELEASE ANALYSIS

If a intermittent release point is to be evaluated, the user should set IPURGE = 1 on Card Type 17. The number of intermittent releases per year and average number of hours per release are inputted on Card Type 17 as NPURGE and NPRGHR, respectively. Since the program evaluates intermittent releases in terms of total hours of release, the computed results for two intermittent releases of 10 hours will be the same as 1 intermittent release of 20 hours, if emission height and rate are the same.

A discussion of how X/Q values for intermittent releases are calculated is given in Section 4.6.

## 3.4 PUNCHED DATA OUTPUT

The user can specify various data to be punched out by the program. If KOPT(6) = 1 on Card Type 1, the segment X/Q and D/Q values will be punched. If KOPT(7) = 1 on Card Type 1, the X/Q and D/Q values for the user-inputted points of interest will be punched.

If a user is evaluating both a continuous and purge release in the same data set, and both KOPT(6) and KOPT(7) = 1, the segment X/Q and D/Q values will only be punched once. If the user desires punched segment X/Q and D/Q values for a purge release calculation, that release point should be evaluated as a separate data set.

## 3.5 EFFECTIVE STACK HEIGHT

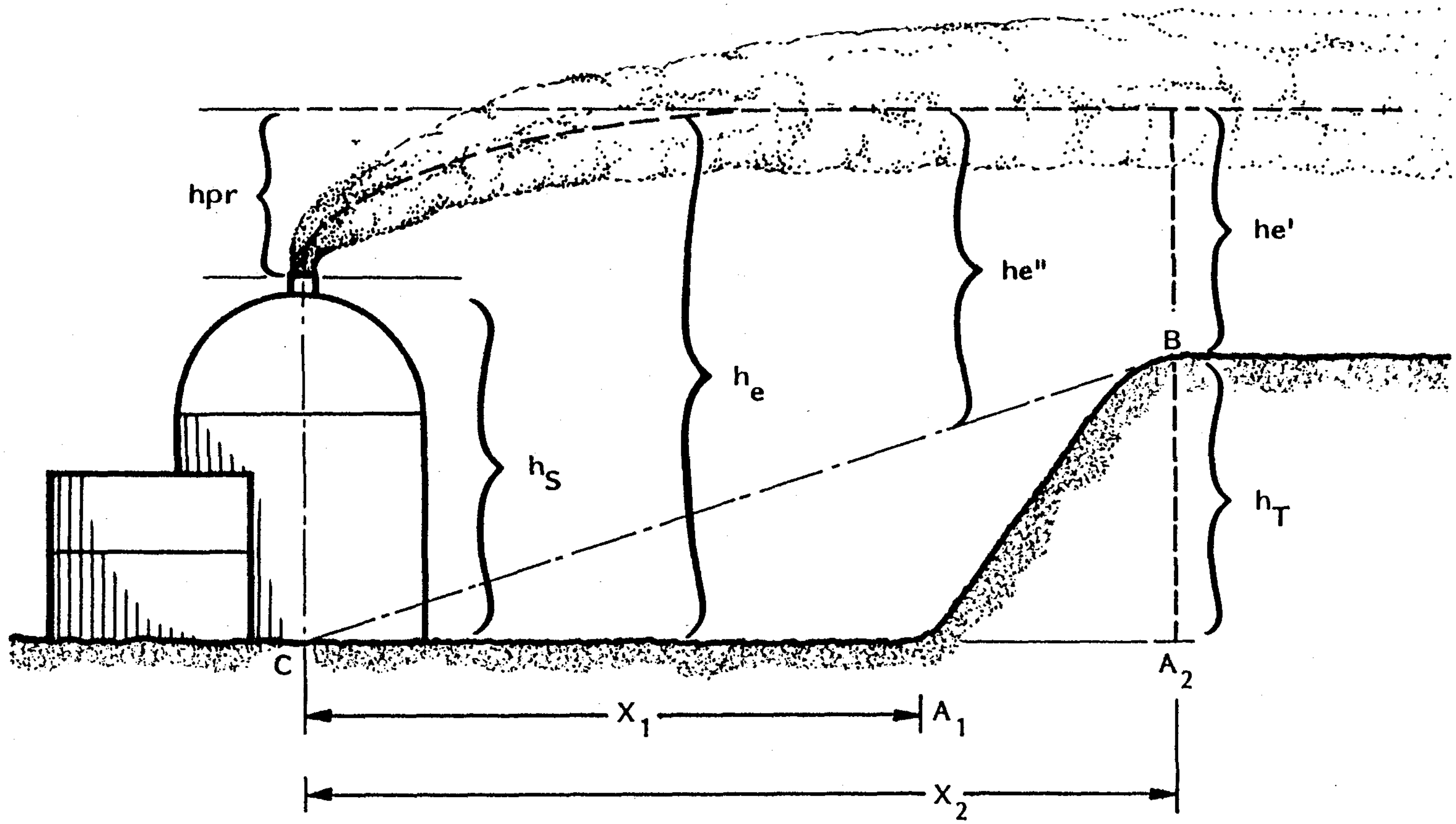
For both an elevated and mixed-mode release an effective stack height is computed. This value, which will vary according to direction and distance from the site, incorporates initial plume rise above the release point, any effects of aerodynamic downwash, and reduced height due to user inputted terrain features. For a particular inputted terrain feature the program linearly interpolates a terrain height from plant grade to the height of the terrain feature. This feature is illustrated in Figure 3.1.

In Figure 3.1 the terrain feature starts at point $A_1$ at distance $X_1$ from the site and reaches it's maximum elevation at point $A_2$ at distance $X_2$ from the site. The plume centerline is represented by a dashed line and reaches a height that is the sum of the plume rise, $h_{pr}$, and height of the vent, or stack, $h_s$. At distances less than $x_1$ the effective plume height, $h_e$, is not reduced by terrain features. If the user inputs distance, $x_1$, with a terrain height equal to plant grade and inputs distance, $x_2$, with terrain height, $h_T$, the program will linearly interpolate a terrain height between point $x_1$ and B with the effective terrain height becoming $h_e'$ at distance $x_2$. If the user inputs $x_2$ as the distance for the first terrain height of $h_t$, the program will interpolate a terrain height as shown by line CB so that the effective terrain height at point $A_1$ would be $h_e''$, not $h_e$. The user will, therefore, have a lower than desired effective plume height and compute conservative X/Q and D/Q values at distance $x_1$. Once an effective plume height, such as $h_e'$, has been established in the program only an inputted terrain feature higher than $h_T$ will produce an effective plume height less than $h_e'$.

## 3.6 STANDARD AND SITE-SPECIFIC CORRECTION FACTORS

Adjustments to represent non-straight line trajectories (recirculation or stagnation) may be accomplished in two ways. First, standard default correction factors for each directional sector can be implemented by setting KOPT(8) = 1 on Card Type 1. If that option is chosen, all values of X/Q and D/Q will be multiplied by a specific factor as a function of the distance that is given in Figure 3.2. This correction is applied uniformly to all directional sectors.

Second, specific adjustments may be known for a site as a result of field diffusion experiments or comparison of results from a variable trajectory model. If such data does exist, the user should set KOPT(9) = 1 on Card Type 1 and input those factors via Card Types 8 and 9. The number of data sets to be entered is set by parameter NCOR on Card Type 3. Specific correction factors to be entered do not have to be at the same distance for each directional sector. The user may enter specific factors in the north sector for, e.g., 1000, 2000, 3000 meters, and specific factors in the south sector at distances of, e.g., 5000, 6000 and 7000 meters. The only restriction is the same number of correction factors must be inputted for each directional sector.




$h_S$ = HEIGHT OF STACK (RELEASE Pt)

hpr = HEIGHT DUE TO PLUME RISE

he = EFFECTIVE STACK HEIGHT

he', he" = EFFECTIVE STACK HEIGHT WITH TERRAIN CORRECTION

$h_T$ = TERRAIN HEIGHT ABOVE PLANT GRADE

$X_1$, $X_2$ = DISTANCE TO TERRAIN FEATURES

FIGURE 3.1. Calculation of Effective Stack Height

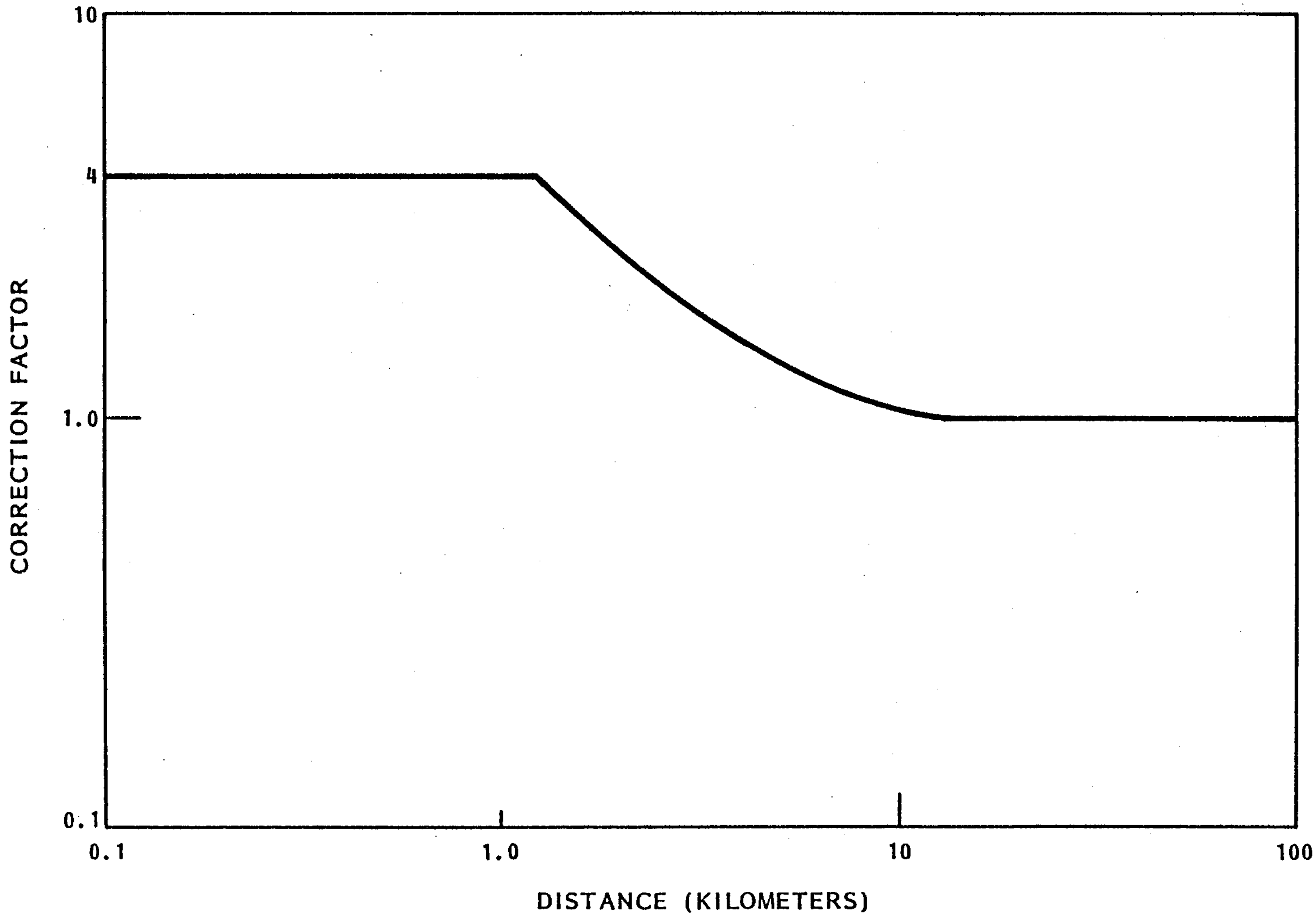



FIGURE 3.2. Open Terrain Correction Factor

If specific correction factors are to be used, the program will use the first correction factor for each directional sector for all computed X/Q and D/Q values to the distance of the first specific correction factor. The program linearly interpolates between correction factors to apply appropriate corrections to those X/Q and D/Q values lying between distances of the correction factors. The X/Q and D/Q values at distances greater than the greatest distance from the site with a correction factor will be adjusted by that correction factor.

### 3.7 WIND SPEED CLASSES

The maximum value for each wind-speed class is entered via input variable UMAX on Card Type 7. If these values are in miles per hour, the parameter UCOR on Card Type 7 must be set to some value greater than 100. If the values are in meters per second, UCOR should be set to some value less than 0; e.g., -100. The number of maximum wind-speed class values entered must correspond to the number entered for NVEL on Card Type 3.

If the number or frequency of calms occurring for each stability class is being inputted, and KOPT(1) = 1 on Card Type 1, the first value for UMAX on Card Type 7 should represent the starting threshold of the wind speed sensor. If KOPT(1) = 0 on Card Type 1, the first UMAX value is the maximum value of the first non-calm wind speed category.

If the last wind-speed class is of the format, wind speeds > than some value, the user must establish a maximum wind speed for that class. Generally, a value of 5 units greater than the largest wind speed noted is acceptable.

### 3.8 CALMS

Data on the number or frequency of calms by stability class is inputted to the program via Card Type 5. If calms are included in the first wind-speed class, a blank card should input for Card Type 5. If calm data does exist, the user has two options: (1) to create a separate wind-speed class for the calm data, or (2) to distribute the calms according to the directional distribution of the first non-calm wind-speed class.

If KOPT(1) = 1 on Card Type 1 a separate wind-speed class for the the calm data will be established. The user should remember to add 1 to the value of NVEL that normally exist.

## 4.0 DESCRIPTION OF PROGRAM XOQDOQ, INCLUDING SUBROUTINES

This program reads in and prints out the inputted data selected by the user. It also calls the subroutines required to evaluate both continuous or purge releases. The main program structure is given in Figure 4.1 in which the basic subroutine calling sequence to evaluate each release point is noted.

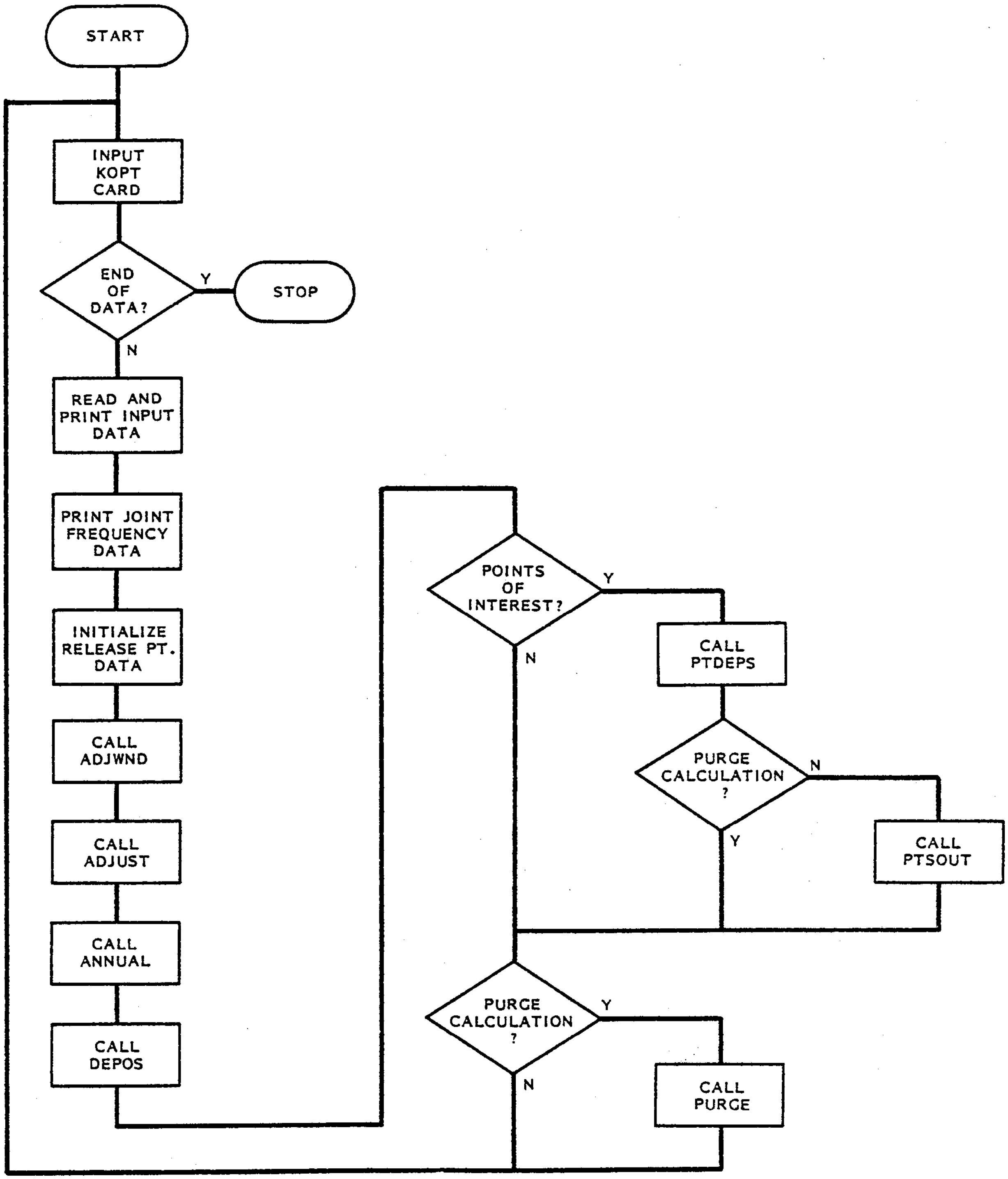



FIGURE 4.1. Flow Chart for XOQDOQ

The program can distribute inputted calms according to the options selected, either as a separate wind-speed class or into the first wind-speed class. A more detailed discussion of the capability is given in Section 3.8.

The program is structured so multiple sites can be evaluated by a single execution of the program. If the program is used in this mode, multiple data sets, including inputted joint frequency distribution data, are required. With a single meteorological data set, a maximum of five release points can be evaluated.

A description of all subroutines is given below. In the descriptions, references are made to the input cards described in Section 2.0. Flow diagrams for each of the major subroutines in the XOQDOQ program are given in Figures 4.2 through 4.5. Flow diagrams for the subroutines MIXD15 and CALC, which are called by PURGE, are given in Figures 4.6 and 4.7.

## 4.1 SUBROUTINE ANNUAL

This routine calculates long-term or annual average values of X/Q. It assumes a continuous release and that resulting effluent concentrations will be distributed evenly across a 22-1/2 degree direction sector. This subroutine calculates concentrations for ground-level and elevated releases only. If the release is in a mixed mode, concentrations for both elevated and ground-level releases are calculated, and the resultant concentration value is based on the percentage of time each type of release would occur.

For elevated releases, concentrations are predicted using the modified equation from Slade.(1968) given below:

$$\frac{\bar{X}}{Q}(x, K) = \frac{2.032}{x} \cdot RF(x, K) \sum_{i,j}^{N,7} \frac{DEPL_{ij}(x, K)\ DEC_i(x)\ \ f_{ij}(K)}{\bar{U}_i(x)\ \sigma_{zj}(x)} \cdot \exp -0.5\left(\frac{h_e^2}{\sigma_{zj}(x)^2}\right) \quad (1)$$

where:

$X_{(x,K)}$ = average effluent concentration normalized by source strength at distance x in directional sector K (second/cubic meter)

x = the downwind distance (meters)

i = the ith wind-speed class

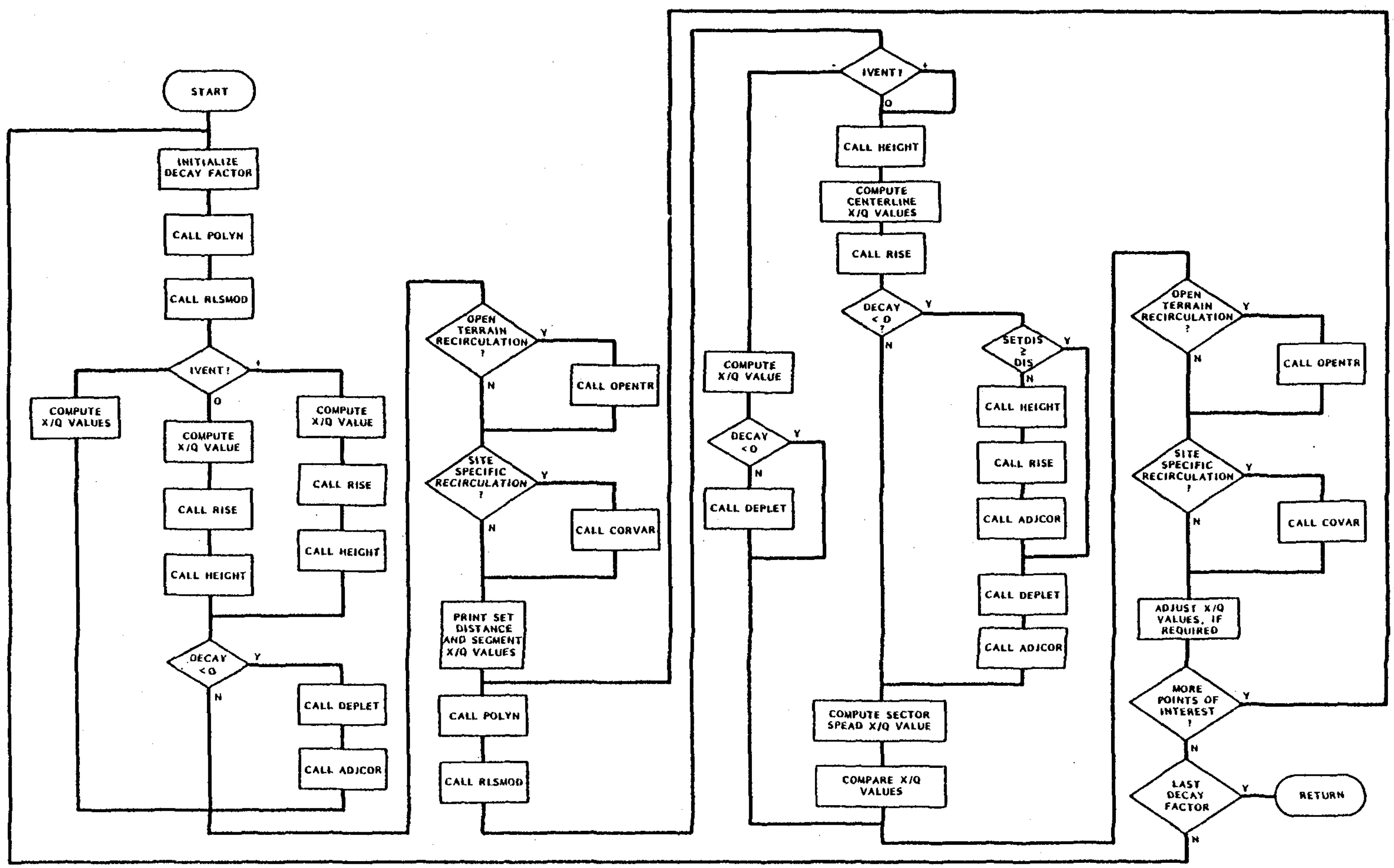



FIGURE 4.2. Flow Chart for ANNUAL

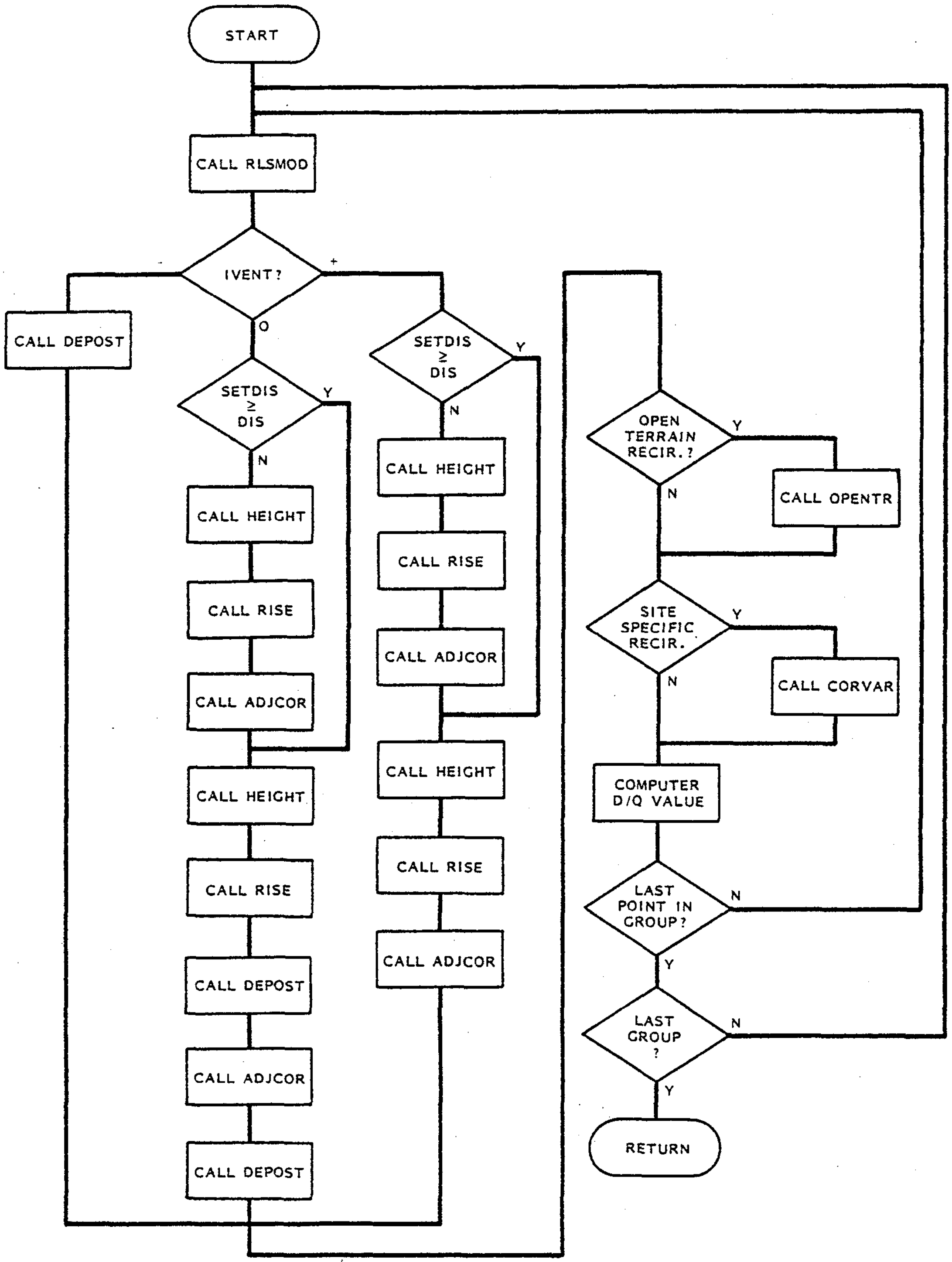



FIGURE 4.3. Flow Chart for PTDEPS

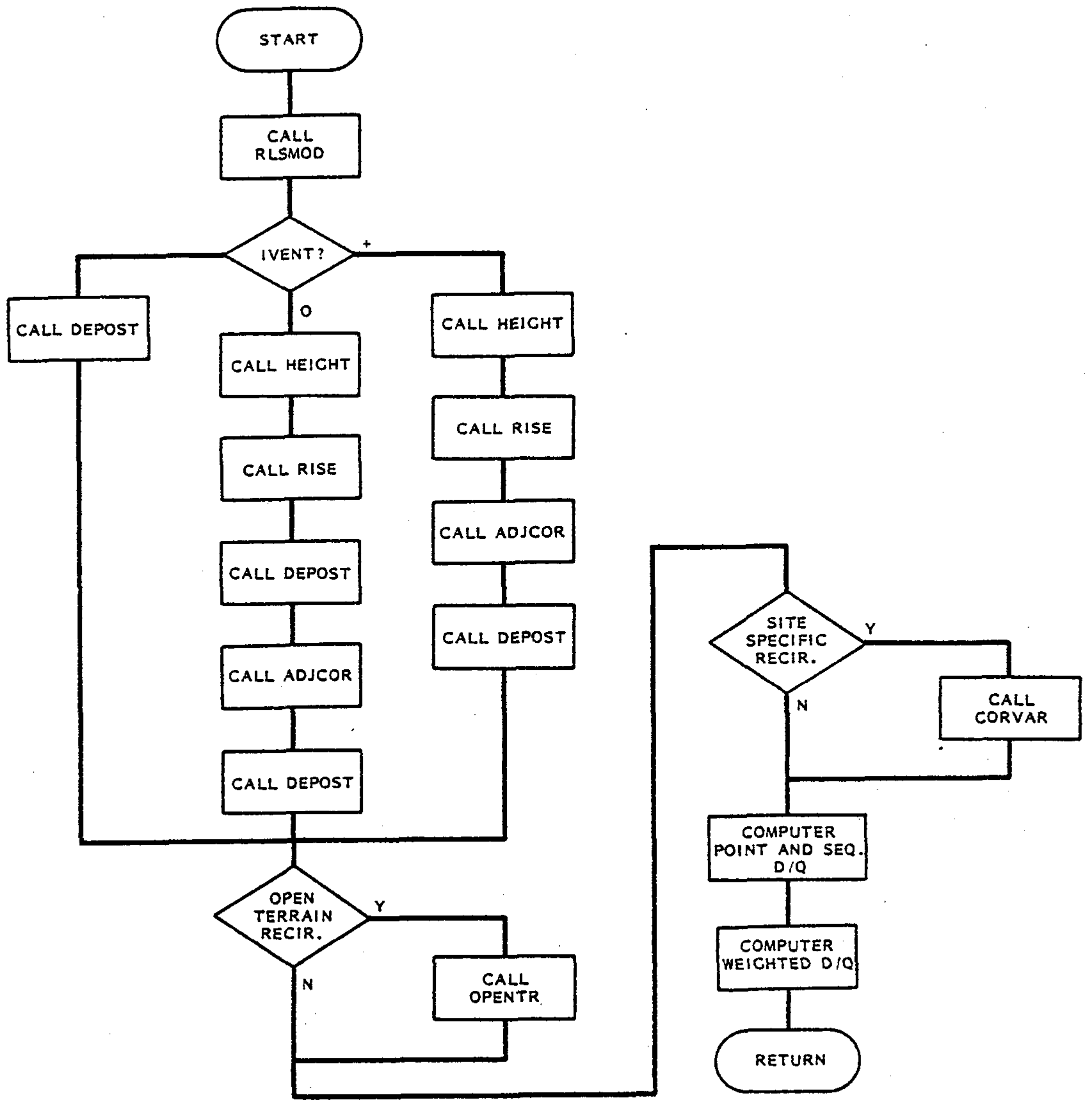



FIGURE 4.4. Flow Chart for DEPOS

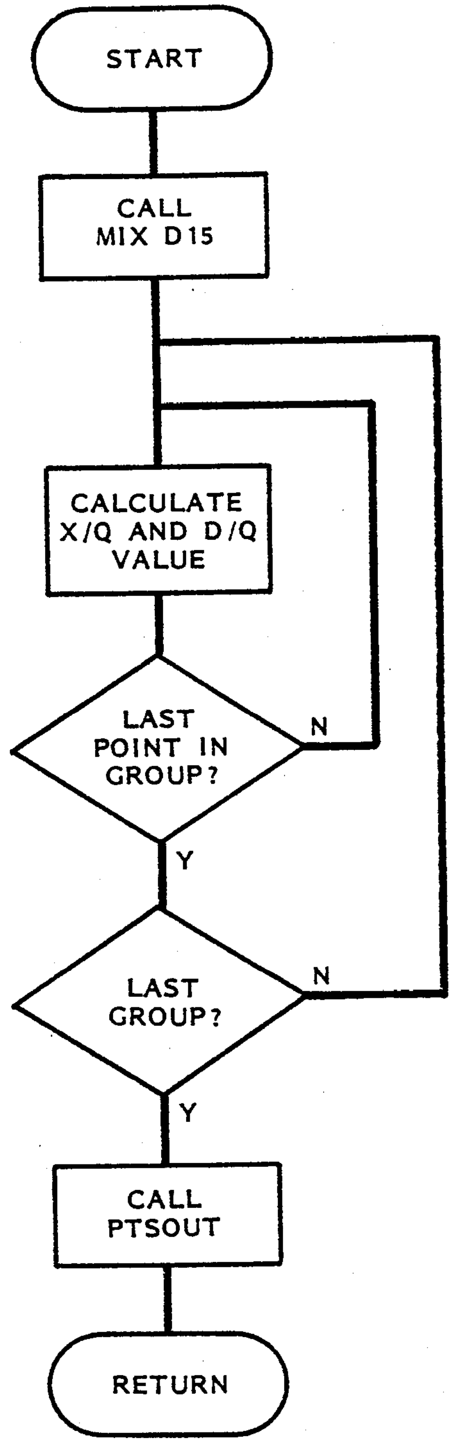



FIGURE 4.5. Flow Chart for PURGE

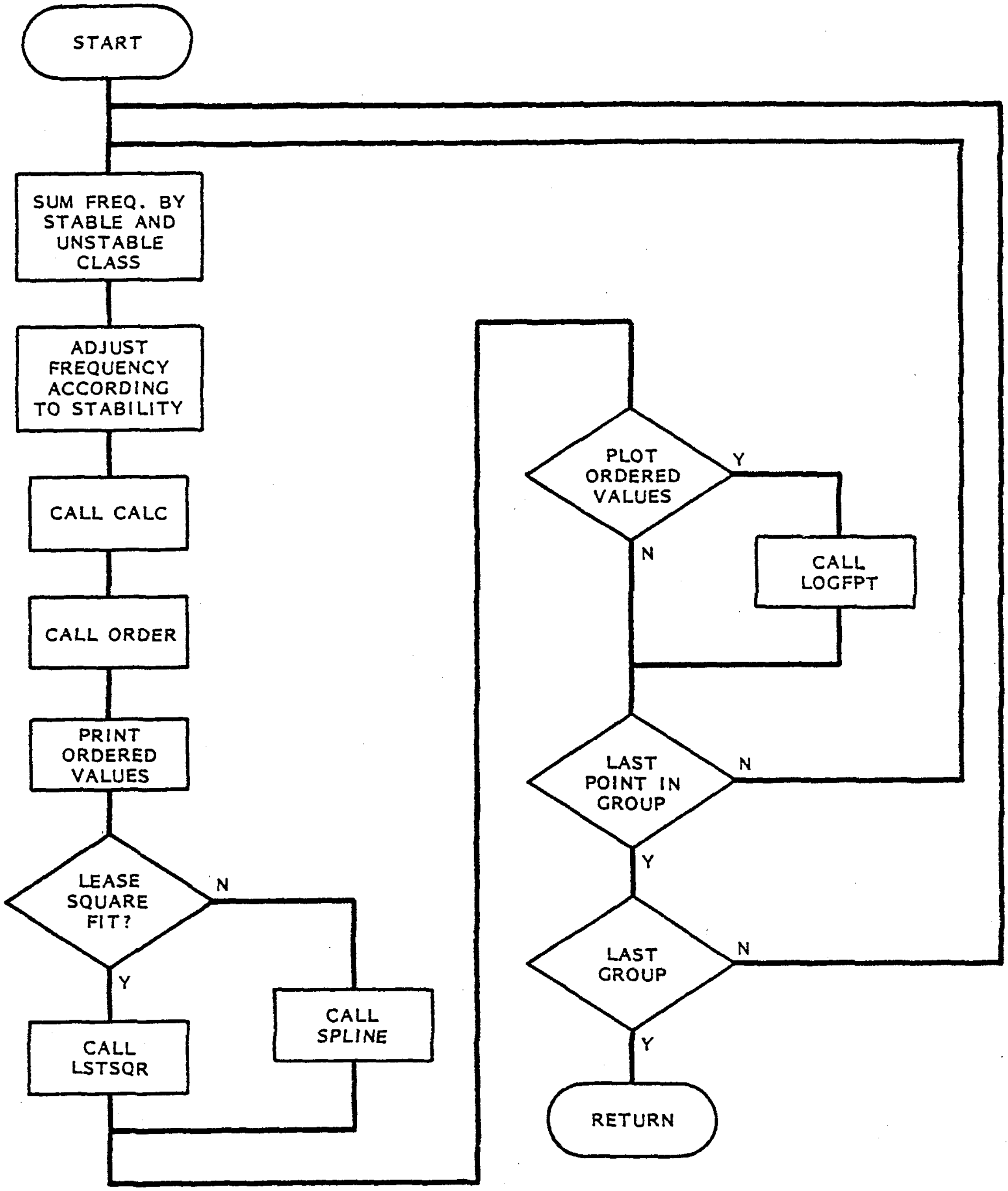



FIGURE 4.6. Flow Chart for MIXD15

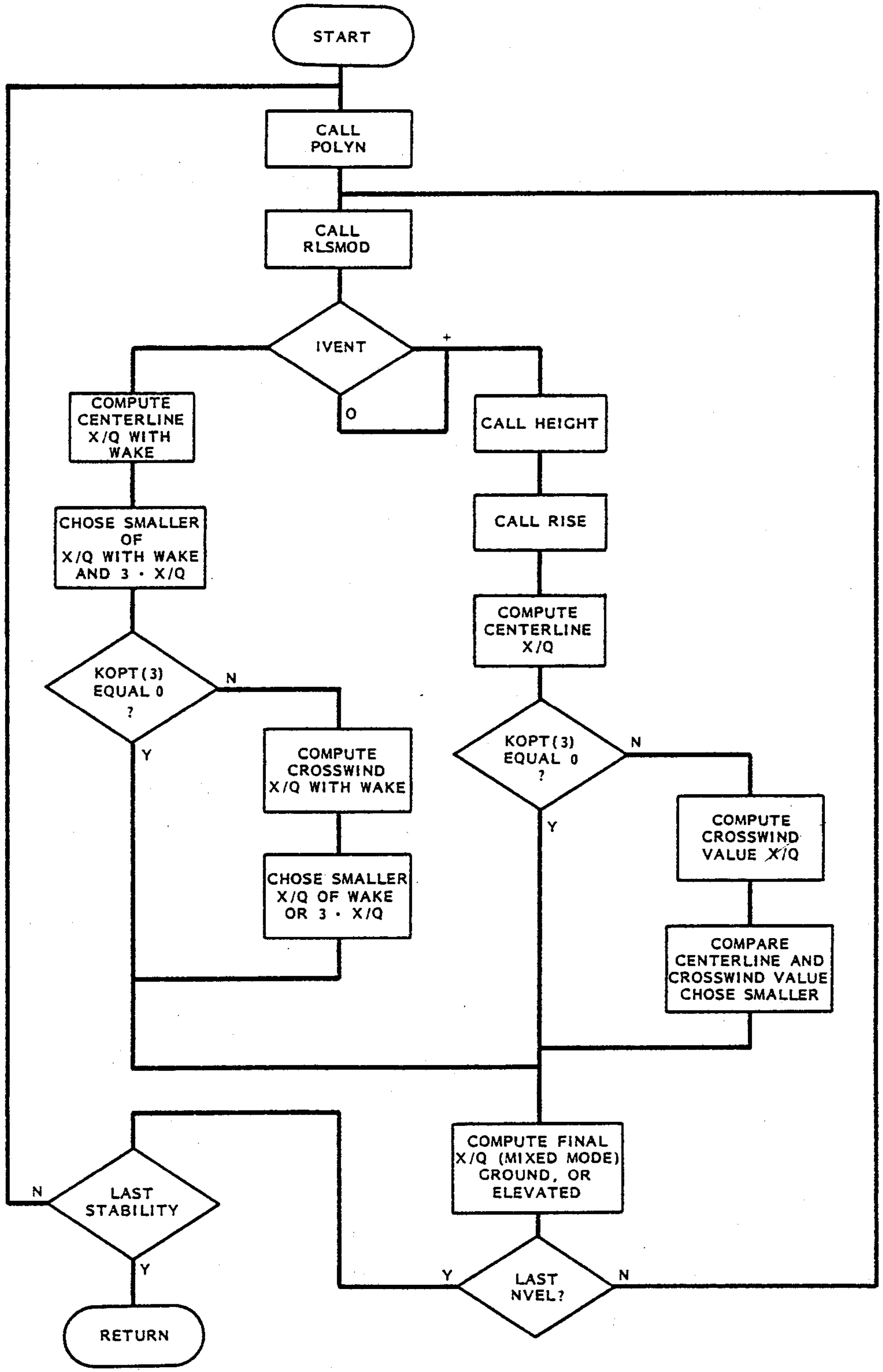



FIGURE 4.7. Flow Chart for CALC

$j$ = the jth atmospheric stability class, grouped into seven classes according to Regulatory Guide 1.23

$K$ = kth wind-direction class

$U_i$ = mid-point value of the ith wind-speed class

$\sigma_{z_j}(x)$ = the vertical plume spread for stability class j at distance x, determined from subroutine POLYN (meters)

$f_{ij}(k)$ = joint probability of occurrence of the ith wind-speed class, jth stability class, and kth wind-direction sector.

$h_e$ = effective plume height, determined from Subroutine RISE (meters)

$DEC_i(x)$ = reduction factor due to radioactive decay at distance x for the ith wind-speed class

$DEPL_{ij}(x,K)$ = reduction factor due to plume depletion at distance x for the ith wind-speed class, jth stability class, and Kth wind-direction class

$RF(x,K)$ = correction factor for recirculation and stagnation at downwind distance x and Kth wind-direction class; standard values can be used [KOPT(8)], inputted by the user [KOPT(9) and Card Type 8 and 9], or not used [KOPT(8) and KOPT(9) = 0].

For elevated release, a plume rise is determined and the effective plume height is calculated for each wind-direction sector, K, as a function of distance, x, from the site. If topography data is inputted, the effective plume height is reduced. A more complete discussion of effective plume height is given in Section 3.5

Ground-level release concentrations are calculated using the following two equations modified from Slade (1968):

$$\frac{\bar{\chi}}{Q}(x,K) = \frac{2.032}{x} RF(x,k) \sum_{i,j}^{N7} DEPL_{ij}(x,K)\, DEC_i(x)\, f_{ij}(K) \left[\bar{U}_i(\sigma_{zj}^2(x) + CD_z^2/\pi)^{1/2}\right]^{-1} \qquad (2)$$

and

$$\frac{\overline{X}}{Q}(x,K) = \frac{2.032}{x} RF(x,K) \sum_{i,j}^{N7} DEPL_{ij}(x,K)\ DEC_i(x)\ f_{ij}(K)\ [\sqrt{3}\overline{U}_i \sigma_{zj}(x)]^{-1} \quad (3)$$

where X/Q(x,K), i,j,K, $U_i$, $\sigma_{zj}(x)$ $f_{ij}(K)$, $DEC_i(x)$,$DEPL_{ij}(x,K)$, and RF (x,K) have been defined previously; and

$D_z$ = building height used to compute additional atmospheric dispersion due to the building wake, based on Yanskey et al. (1966).

Equation 3 represents the maximum additional dispersion due to the building wake. The program compares the results from Equation 2 and 3 and retains the higher (most conservative) X/Q value.

The values obtained from Equation 1 and/or Equations 2 and 3 are a function of downwind distance (x) and wind-direction sector (K). The program is designed to compute concentrations for 22 downwind distances (x) between 0.25 and 50 miles for each of the 16 directional sectors. Therefore, normalized effluent concentrations are predicted at 352 downwind locations.

This subroutine, using the predicted downwind concentrations, computes concentrations for 10 downwind segments for each of the 16 directional sectors. The computed value represents an average concentration for the downwind directional sector bounded by the range of the segment. For example, a $\overline{X}$/Q value for the segment 40-50 miles in the North sector represents an average $\overline{X}$/Q value for any point north of the site between 40 and 50 miles north of the site.

The technique for computing the $\overline{X}$/Q segment values is given by the following relationship:

$$\overline{X}/Q_{seg}(K) = \frac{R_1\ X/Q(R_1,K) + r_1 \cdot X/Q(r_1,K) + \dots + r_n \cdot X/Q(r_n,K) + R_2 \cdot X/Q(R_n,\ K)}{R_1 + r_1 \dots + r_n + R_2} \quad (4)$$

where

$X/Q_{seg}(K)$ = average value of X/Q for the segment for the directional sector K

$X/Q(R_1, K)$ = X/Q value at downwind distance $R_1$ for the directional sector K

$R_1, R_2$ = downwind distance of the segment boundaries

$r_1 \ldots r_n$ = selected radii between $R_1$ and $R_2$.

In addition to calculating concentrations for the 22 downwind distances for each directional sector, this subroutine will calculate normalized concentrations, X/Q values, at up to 150 individual receptor locations specified by the user. The same techniques described by Equations 1, 2, and 3 are used to calculate concentrations at receptor points.

Equations 1, 2 and 3 require information on a reduction factor due to radioactive decay. That term, $DEC_i(x)$, is calculated by the following relationship as given by Slade (1968):

$$DEC_i(x) = EXP\ (-0.693\ t_i/T) \qquad (5)$$

where

$t_i = x/(86400 \cdot U_i)$
$T$ = half-life, in days, of the radioactive material
$t_i$ = travel time, in days
$x$ = downwind or travel distance, in meters
$U_i$ = Midpoint of the ith wind-speed class in meters/second.

The value for T, half-life in days, is inputted via Card Type 4. Up to three separate decay half-life values can be inputted into the program, with the maximum allowable half-life being 100 days.

Calculated concentrations can include the effect of plume depletion due to dry deposition, using data given in Figures 3 through 6 of Regulatory Guide 1.111 (USNRC, 1977). The depletion factor is adjusted for changes in topography. The technique used in that adjustment is given in Section 4.15. The correction factor to account for non-straight line trajectories can be based on a standard correction factor for open terrain correction (Card Type 1, KOPT(8) = 1) or based on user inputted data (Card Type 1, KOPT(8) = 1, and Card Type 8 and 9). If both KOPT(8) and KOPT(9) = 0, no correction factor will be applied.

### 4.2 SUBROUTINE DEPOS

This subroutine calculates the relative deposition per unit area, D/Q, by directional sector for 22 downwind specific distances and 10 downwind segments between 0.25 and 50 miles. The specific and segment distances used are the same as those used in ANNUAL to produce X/Q values. Deposition amounts computed assumed the effluent release to be elevated only, ground level only, or a mixed elevated/ground-level release that is determined by computing the ratio of the effluent exit velocity to the exit level wind speed. Information on resultant plume rise, topography, and deposition adjustment factors calculated in subroutine ADJCOR are included in the computational scheme. The resultant deposition amounts can be modified according to standard recirculation factors as produced in subroutine OPENTR or specific correction factors inputted by the user (see discussion for CORVAR).

For each directional sector, relative deposition is computed by the following relationship for a specific downwind distance:

$$\frac{\overline{D}}{Q}(x, K) = \frac{RF(x, K) \sum_{ij}^{N7} D_{ij} f_{ij}(K)}{(2\pi/16)\, x} \qquad (6)$$

where

$D/Q(x,K)$ = average relative deposition per unit area at a downwind distance x and direction K, in meters$^{-2}$

$D_{ij}$ = the relative deposition rate from Figures 7 through 10 of Regulatory guide 1.111 (USNRC, 1977) for the ith wind-speed class (since plume height is dependent on wind speed) and the jth stability class, in meters.

$f_{ij}(K)$ = joint probability of the ith wind-speed class, jth stability class, and kth wind-direction sector

x = downwind distance, in meters

$\pi$ = 3.14159265

$RF(x,K)$ = correction factor for air recirculation and stagnation at distance x and Kth wind direction.

D/Q segment values are computed by technique given in Equation 4 except the term X/Q is replaced by D/Q.

## 4.3 SUBROUTINE PTDEPS

This subroutine computed relative deposition values, D/Q, for inputted receptor locations. This subroutine is basically identical to subroutine DEPOS (Section 4.2).

## 4.4 SUBROUTINE PURGE

Using the short-term X/Q values calculated in Subroutine MIXD15, and the annual average X/Q values calculated in Subroutine ANNUAL, this subroutine calculates X/Q and D/Q values for intermittent releases for each of the user-specified receptor locations. The user specifies what level short-term percentile values is to be used (Card Type 3, INC, usually 15) and if a decayed and/or depleted annual X/Q values is to be used in the computation (Card Type 17, IPURGE). Normally the user should set IPURGE = 1 so that the undecayed, undepleted annual X/Q value is used. The short term X/Q value that is computed in Subroutine CALC is an undecayed, undepleted value.

A graphic representation of how computational procedure works is illustrated in Figure 4.8. In that figure the abscissa is the time that increases as you move to the right. The ordinate is X/Q values increasing as you go up. The 15 percentile X/Q value, which is larger than the annual X/Q value, is plotted according to 1 hour of time. The annual average value occurs for a standard time period of a year (8,760 hours). The straight line connecting these points represents X/Q values for intermittent, or purge releases, ranging in duration from 1 hour to 8,760 hours. The duration time for each release is the number of times the purge release occurs times the length of the release. In Figure 4.8 a duration time of 80 hours is illustrated which could present 4 purge releases at 20 hours, 2 purge releases at 40 hours or other combinations. The ratio of the X/Q values for intermittent, or purge release, and the annual average X/Q value is used to determine the appropriate X/Q values for the other decay, depletion combinations as well as a value for D/Q. As indicated above IPURGE is normally set to 1, so the ratio is based on undecayed, undepleted X/Q values.

If the 15 percentile X/Q value is less than the annual average X/Q value, or less conservative, the 15 percentile X/Q value will be set to the annual average value X/Q; the slope of the connecting line will be zero, and the X/Q values for purge releases of any duration will be equal to annual average X/Q values. This condition normally could only occur with unique combination of joint frequency of wind speed, wind direction, and atmospheric stability data.

This calculation is repeated for each individual receptor location inputted by the user.

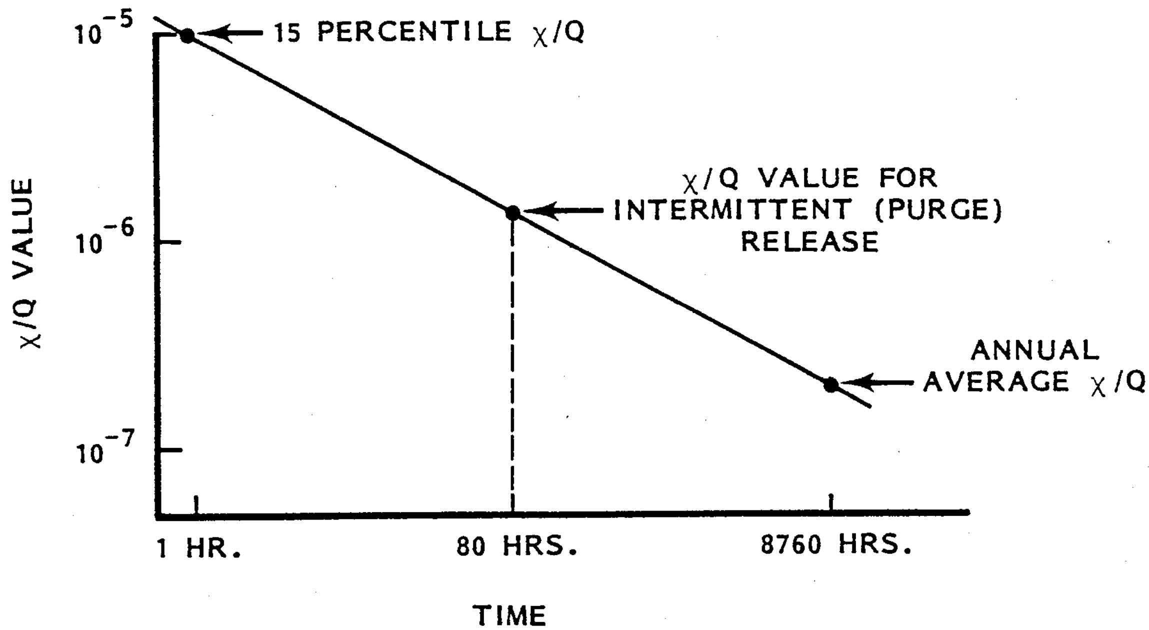



FIGURE 4.8. Subroutine PURGE Calculations

## 4.5 SUBROUTINE MIXD15

This subroutine coordinates the calculations of the short-term X/Q values used in the intermittent release calculations of subroutine PURGE. Subroutine CALC, which is called by MIXD15, calculates specific short-term X/Q values from all combinations of wind-speed class and stability categories in the inputted joint frequency distribution. The values are then ordered by Subroutine ORDER, from high to low values, and their cumulative frequencies are summed. Subroutine CONV, which is called by MIXD15, then transforms the frequency array onto a probability axis and, either subroutine LSTSQR or SPLINE, depending on the choice of the user, fits a curve to the log (X/Q) values versus transformed frequency data points. This curve is shifted up by two standard deviations to approximate the upper envelope of the X/Q values. The upper envelope X/Q values at five percent frequency increments are printed and can be plotted if desired by the user (Card Type 1, KOPT(4) = 1). The desired percentile value that was requested by the user is then passed to Subroutine PURGE to be used in computing X/Q values for the purge release.

## 4.6 SUBROUTINE CALC

This subroutine calculates short-term centerline X/Q values at the given individual receptor locations specified by the user. X/Q values are calculated for each combination of wind-speed class and atmospheric stability category. The calculations use the following equations:

$$X/Q = [U_i(\pi\sigma_{y_i}(x)\sigma_{z_j}(x) + CA)]^{-1} \quad (7)$$

and

$$X/Q = [3U_i\pi\sigma_{y_i}(x)\sigma_{z_j}(x)]^{-1} \quad (8)$$

and

$$X/Q = [U_i\pi\sigma_{y_i}(x)\sigma_{z_j}(x)]^{-1} \exp [-1/2(h_e/\sigma_{z_j}(x))^2] \quad (9)$$

where

$X/Q$ = effluent concentration normalized by source strength (sec/cubic meter)

$U_i$ = upper limit of the ith wind-speed class, inputted by user as Card Type 7 (m $sec^{-1}$)

$\sigma_{y_j}(x)$ = horizontal standard deviation of material in the plume for stability category j at distance x, value computed in Subroutine POLYN (m)

$\sigma_{z_j}(x)$ = vertical standard deviation of material in the plume for stability category j at distance x, value computed in Subroutine POLYN (m)

$h_e$ = effective plume height, value computed in Subroutine RISE (m)

C = building-wake constant, value set in program to 0.5

A = minimum cross-section area of the reactor building ($m^2$)

x = downwind distance (m)

The user also has the option, via Card Type 1, to assume the plume is uniformly distributed in the horizontal within a 22-1/2 degree directional sector. This option is appropriate for intermittent releases greater than eight hours duration or for a large number of shorter period releases. Thus in addition to the computations of Equations 7, 8, and 9, the following computations are completed if the option is selected:

$$X/Q = 2.032\ [xU_i(\sigma_{z_j}{}^2(x) + CD_z{}^2/\pi)^{1/2}] \qquad (10)$$

$$X/Q = 2.032\ [\ 3U_i\sigma_{z_j}\ (x)\cdot x]^{-1} \qquad (11)$$

$$X/Q = \frac{2.032}{\sigma_z\ (x)U_i\cdot x}\ [\exp(-1/2[h_e/\sigma_{z_j}]^2)] \qquad (12)$$

where X/Q, $U_i$, $\sigma z_j(x)$, $h_e$, C, x, are given above, and

$D_z$ = height of the building (m),

x = the downwind distance (m).

Equations 9 and 12 are used for elevated releases. The results from these equations are compared and the largest X/Q value is retained. For ground level releases and KOPT(3) = 1, the values from Equations 7, 8, 10, and 11 are compared and the larger value retained. The terms CA in Equation 7 and $CD_z^2$ in Equation 12 are the building-wake contributions to dilution (Yanskey et al, 1966). Equations 8 and 11 represent X/Q values considering the maximum allowable building-wake dilution.

## 4.7 SUBROUTINE ORDER

This subroutine uses the shell method to order the array of X/Q values calculated in Subroutine CALC from the greatest to least value. Associated frequencies are also summed.

## 4.8 SUBROUTINE CONV

This subroutine transforms the cumulative frequency array generated in Subroutine ORDER onto a probability axis. This subroutine calls a function, GAUSS, that uses a Gauss-Legendre integration technique to integrate the normal function.

## 4.9 SUBROUTINE LSTSQR

This subroutine is used to perform the least square fit on log (X/Q) values versus frequency data transformed in Subroutine CONV. This routine is considered the standard for fitting log (X/Q) values.

## 4.10 SUBROUTINE INVERS

This subroutine, which is called by Subroutine LSTSQR, is used to perform a matrix inversion.

## 4.11 SURROUTINES LOGFPT, PPLT, DEVATE, AREA

These subroutines, which are called in Subroutine MIXD15, are used to plot, on logarithmic versus probability axes, the following data:

1. the X/Q values calculated by subroutine CALC versus probability

2. the X/Q values determined from the upper envelope of X/Q values calculated in Subroutine MIXD15 versus probability.

The plots are not produced unless desired by the user; see Card Type 1, KOPT(4).

## 4.12 SUBROUTINE SPLINE

As an option to the user, a cubic spline curve fitting technique can be used instead of a least square fitting technique. To use this technique KOPT(5) is set to 1 on Card Type 1.

## 4.13 SUBROUTINE DEPLET

This subroutine solves polynomial regression equations for the depletion curves of Figures 3 through 6 of Regulatory Guide 1.111 (USNRC, 1977).

## 4.14 SUBROUTINE DEPOST

This subroutine solves polynomial regression equations for the deposition curves of Figures 7 through 10 of Regulatory Guide 1.111 (USNRC, 1977).

## 4.15 SUBROUTINE ADJUST

Figures 3 through 10 of Regulatory Guide 1.111 (USNRC, 1977) contain curves for deposition and depletion for plumes 100, 60, 30 and 0 meters above the ground. For plumes between 0 and 15 meters above the ground, the program uses the ground-level release graphs; for those between 15 and 45 meters, it uses the 30 meter curves; between 45 and 80 meters, the 60 meter curves; and for those plumes greater than 80 meters above the ground, it uses the 100 meter curves. The program assumes that, after full plume rise is achieved, the plume cannot get higher from the ground. The derivation of these curves assumed no change in terrain height with downwind distance. But because topography does change with distance, and likewise the vertical distance between the plume centerline and the ground will change, it is usually necessary to read from more than one depletion or deposition curve of Regulatory Guide 1.111 (USNRC, 1977) as the plume travels with distance.

The actual depletion to a point depends on the depletion rate which the plume has experienced prior to reaching that point. Thus when the plume changes elevation due to topography (i.e., it is necessary to shift from one curve to the next), an adjustment of depletion and deposition estimates must be made to account for the plume's prior history. To approximate the adjustment for deposition in changing terrain, the program assumes that at the point where a new curve is read (i.e., crossover point, the point where the plume is 80, 45, or 15 meters above ground level) the adjustment factor is the ratio of the fraction remaining of the plume from the upper height depletion curve to the fraction remaining in the plume as read on the lower height depleting curve. The deposition values beyond this point are multiplied by this ratio. For depletion, the curve adds the difference in the value of the depletion curves (higher curve minus lower curve) at the crossover point to the values of the lower height curve at distances beyond the crossover distance.

For each combination of wind speed, stability category, and downwind sector, this subroutine determines the downwind distance at which the plume will be 80, 45, and 15 meters above the ground, and determines the respective depletion and deposition adjustment factors.

## 4.16 SUBROUTINE ADJCOR

This subroutine keeps track of the crossover heights which each plume passes for each direction, wind-speed class, and stability category. It determines which depletion and deposition adjustment factors derived in subroutine ADJUST are needed.

## 4.17 SUBROUTINE ADJWND

Elevated releases should use winds measured at the release height, and ground-level releases should use 10-meter winds. If the winds were not measured at the proper height, or a mixed elevated-ground level release is being evaluated, the program corrects the wind speeds to reflect the proper elevation. It uses the following relationship from Smith (1968):

$$COR = \left(\frac{SL}{PL}\right)^{EX} \qquad (13)$$

COR = the correction factor applied to the measured wind speeds

PL = the measured wind height

SL = the desired wind height

EX = 0.25, for unstable or neutral atmospheric conditions and

0.50, for stable conditions.

## 4.18 SUBROUTINE RLSMOD

This subroutine computes the ratio of the plume exit velocity to the wind speed and determines whether the release will be elevated, ground level or a mixture of the two. If a mixture is indicated, the proportion of the plume considered to be elevated and the proportion considered to be ground-level are determined by the following relationships:

$$E_t = 1.0 \qquad \text{for } W_o/\bar{u} \leq 1.0$$

$$E_t = 2.58(W_o/\bar{u}) - 1.58\ (W_o/\bar{u}) \qquad \text{for } 1.0 < W_o/\bar{u} \leq 1.5 \qquad (14)$$

$$E_t = 0.3 - 0.06\ (W_o/\bar{u}) \qquad \text{for } 1.5 < W_o/\bar{u} \leq 5.0$$

$$E_t = 0.0 \qquad \text{for } W_o/\bar{u} > 5.0$$

where

$E_t$ = fraction of the time when the release is ground level

$W_o$ = the plume exit velocity

$\bar{u}$ = average wind speed at the vent height.

## 4.19 SUBROUTINE HEIGHT

This subroutine linearly interpolates a terrain height for a specific location. For a given direction and distance, the inputted terrain heights should be the highest terrain elevation between the source and the given distance anywhere in the direction sector (Card Type 10 and 11).

## 4.20 SUBROUTINE RISE

For elevated releases, the program determines the effective stack height from

$$h_e = h_s + h_{pr} - h_t \quad (h_e \geq 0) \tag{15}$$

where

$h_e$ = effective plume height (meters)

$h_s$ = physical stack height (meters)(Card Type 16, HSTACK)

$h_{pr}$ = plume rise (meters)(subroutine RISE)

$h_t$ = terrain height (meters)(subroutine Height).

This routine, using formulae from Briggs (1969), calculates plume rise caused by either momentum or buoyancy.

Nuclear power stations generally have ambient temperature plumes, so the heat emission rate, HEATR (Card Type 16) is read in as zero; and the plume rise is calculated from the momentum equations. Thus for neutral or unstable conditions, plume rise is calculated by the following relationship:

$$h_{pr} = 1.44\left(\frac{W_o}{u}\right)^{2/3} \cdot \left(\frac{x}{D}\right)^{1/3} \cdot D \tag{16}$$

where

$h_{pr}$ = plume rise (meters)

$W_o$ = stack or vent exit velocity (meters/second)(Card Type 16)

x = downwind distance (meters)

U = wind-speed at release height (meters/second)(Card Type 16) and

D = internal stack diameter (meters)(Card Type 16).

When the exit velocity is less than 1.5 times the wind speed, a correction (Gifford, 1972) for downwash is subtracted from Equation 16:

$$C = 3\left(1.5 - \frac{W_o}{u}\right)D \tag{17}$$

where C is the value to be subtracted, and the other terms are defined as in Equation 16. The result from Equation 16, corrected by Equation 17 if necessary, is compared with

$$h_{pr} = 3\left(\frac{W_o}{u}\right) D \qquad (18)$$

and the smaller value of $h_{pr}$ is used.

For stable conditions, the results from Equations 16 and 18 are compared with results from the following two equations:

$$h_{pr} = 4\left(\frac{F_m}{S}\right)^{1/4} \qquad (19)$$

and

$$h_{pr} = 1.5\left(\frac{F_m}{u}\right)^{1/3} \cdot S^{-1/6} \qquad (20)$$

where

$$F_m = (W_o D/2)^2 \qquad (21)$$

and

$$S = \frac{g}{T} \frac{\partial\theta}{\partial z} \qquad (22)$$

and

$F_m$ = the momentum flux parameter (meters$^4$/second$^2$)

S = restoring acceleration per unit vertical displacement for adiabatic motion in the atmosphere (seconds$^{-2}$)

$g$ = acceleration of gravity (meters/second$^2$)

$T$ = ambient air temperature (degrees Kelvin)

$\partial\theta/\partial z$ = vertical potential temperature gradient (degrees Kelvin/meter).

For the purposes of this routine, S is defined as $8.7 \times 10^{-4}$ for E stability, $1.75 \times 10^{-3}$ for F stability, and $2.45 \times 10^{-3}$ for G stability. The smallest value of $h_{pr}$, calculated from Equations 16, 18, 19, and 20, is used.

If a value for heat emission rate is inputted, then an additional downwind distance, x*, is computed. For neutral and unstable conditions,

$$x^* = 0.5\ F^{2/5}\ h_s^{\ 3/5}\left[\frac{\text{seconds}^{6/5}}{\text{feet}^{6/5}}\right] \text{ when } (h_s < 1{,}000 \text{ ft}) \tag{23}$$

$$x^* = 33\ F^{2/5}\left[\frac{\text{seconds}^{6/5}}{\text{feet}^{3/5}}\right] \qquad \text{when } (h_s \geq 1{,}000 \text{ ft}) \tag{24}$$

where

$$F = \text{buoyancy flux parameter} = 4.3 \times 10^{-3}\ Q_h\ \frac{\text{ft}^4/\text{sec}^3}{\text{cal/sec}} \tag{25}$$

$h_s$ = physical stack height (feet).

For stable conditions,

$$X^* = 2.4\ US^{-1/2} \tag{26}$$

Then for buoyant plume rise, the following equations are used:

1) for $x < x^*$,

$$h_{pr} = 1.6\ F^{1/3}\ u^{-1} x^{2/3} \tag{27}$$

2) for $x \geq x^*$ for unstable and neutral conditions,

$$h_{pr} = \frac{1.6\, F^{1/3}\, {x^*}^{2/3} \left[ \frac{2}{5} + \frac{16}{25} \; \frac{x}{x^*} + \frac{11}{5} \left( \frac{x}{x^*} \right)^2 \right]}{u \; 1 \left( + \frac{4x}{5x^*} \right)^2} \tag{28}$$

At $x = 5x^*$, the plume is assumed to reach its maximum height; for stable conditions,

$$h_{pr} = 2.4 \; (F/uS)^{1/3} \tag{29}$$

with S as defined for Equation 22.

## 4.21 SUBROUTINE POLYN

This subroutine calculates values of $\sigma_y$ and $\sigma_z$ versus downwind distance, using equations of the form

$$\sigma_z = ax^b + C \tag{30}$$

$$\sigma_y = ax^b \tag{31}$$

where

$\sigma_{y,\,z}$ = horizontal crosswind ($\sigma_y$) or vertical ($\sigma_z$) standard deviation of material in the plume due to ambient free-stream turbulence

$\sigma_x$ = downwind distance

a,b,c = coefficients, derived by Eimutis and Konicek (1972), as functions of stability class and distances.

Both $\sigma_y$ and $\sigma_z$ are limited to 1000 meters.

By setting KOPT(10) to 1 on Card Type 1, the $\sigma_y$ and $\sigma_z$ values computed will be representative of desert conditions. Information on how these values were determined is given in Yanskey, et al. 1966.

### 4.22 SUBROUTINE OPENTR

This subroutine solves a set of polynomial regression equations that describe the curve given in Figure 3.2. The value returned is recirculation correction factor for open terrain. This option is selectable by the user by setting KOPT(8) = 1 on Card Type 1. This feature should be used for all sites unless specific diffusion test, or other data, indicate other factors are more appropriate. In that case the user would input site specific correction factors via Card Types 8 and 9 and set KOPT(9) = 1 on Card Type 1.

### 4.23 SUBROUTINE CORVAR

If recirculation factors have been determined (e.g. by field experiments) for a specific site, they may be applied to computed X/Q and D/Q values. This option is implemented by setting KOPT(9) equal to 1 on Card Type 1 and inputting correction factors according to card Types 8 and 9. The factors entered are linearly interpolated by this subroutine and applied to computed X/Q and D/Q values.

### 4.24 SUBROUTINE PTSOUT

This subroutine prints the outputted X/Q and D/Q values obtained in subroutines ANNUAL, PTDEPS, and PURGE, for the input-specified receptor locations.

### 4.25 SUBROUTINE PRNTIN

This subroutine prints the building, vent, and release-type characteristics after all outputted X/Q and D/Q values.

### 4.26 SUBROUTINE INTCOM

This subroutine is a DATA statement to label the 16 directional sectors.

## 5.0 DESCRIPTION OF PROGRAM OUTPUT

The output from the program was designed to present the maximum amount of information on each release point for the user. Each output page is identified as to the version of program, run date, and run time. The sequence of outputted information is as follows.

1. inputted data cards

2. summarized joint frequency data of wind speed and wind direction by stability class

3. for each decay value

   - X/Q values at 22 specific distances ranging from 0.50 to 50 miles from the site
   - X/Q values for 10 distance segments
   - If depletion occurs, D/Q values at 22 specific distances ranging from 0.50 to 50 miles from the site
   - If depletion occurs, D/Q values for 10 distance segments
   - Data on emission, release, height, and physical building dimensions. If a mixed mode release, data on velocities levels producing elevated, ground level, and mixed-mode conditions

4. for purge releases with specific points of interest, ordered short-term X/Q values, a probability distribution of X/Q values, a probability distribution of X/Q values, and percentile value selected by the user to be used in computing X/Q and D/Q values for the release

5. for specific points of interest, X/Q values for specific decays inputted by the user, and a D/Q value if depletion occurs

6. for multiple releases, up to five, Steps 3 through 5 are repeated.

If KOPT(4) = 1 on Card Type 1, then program generated plots of short-term X/Q values versus probability distribution are produced. These plots will only be generated if a purge release is to be evaluated, and specific points of interest have been inputted by the user.

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