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Atmospheric Relative Concentrations in Building Wakes

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Pacific Northwest National Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

This report documents the ARCON96 computer code developed for the U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation for potential use in control room habitability assessments. It includes a user's guide to the code, a description of the technical basis for the code, and a programmer's guide to the code. The ARCON96 code uses hourly meteorological data and recently developed methods for estimating dispersion in the vicinity of buildings to calculate relative concentrations at control room air intakes that would be exceeded no more than five percent of the time. These concentrations are calculated for averaging periods ranging from one hour to 30 days in duration.

ARCON96 is a revised version of ARCON95, which was developed for the NRC Office of Nuclear Regulatory Research. Changes in the code permit users to simulate releases from area sources as well as point sources. The method of averaging concentrations for periods longer than 2 hours has also been changed. The change in averaging procedures increases relative concentrations for these averaging periods. In general, the increase in concentrations is less than a factor of two. The increase is greatest for relatively short averaging periods, for example 0 to 8 hours and diminishes as the duration of the averaging period increases.

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1 Introduction

General Design Criterion 19 of 10 CFR 50, Appendix A sets forth the requirements for control rooms at nuclear power plants. This criterion states that "Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem...." The code described in this manual, Atmospheric Relative Concentrations in Building Wakes (ARCON), is a tool for potential use by the U.S. Nuclear Regulatory Commission (NRC) staff in their review of licensee submittals related to control room habitability.

ARCON implements a model for calculating concentrations in the vicinity of buildings that was developed by the Pacific Northwest National Laboratory (PNNL) under a previous contract with the NRC. A preliminary version of the code was tested by NRC staff and contractors. The present version of the code is called ARCON96 to distinguish it from the previous version of the code, ARCON95.

The differences between ARCON96 and ARCON95 are relatively modest. ARCON96 allows users to enter initial diffusion coefficients that may be used to approximate dimensions of diffuse area sources. The method of calculating average relative concentrations for periods longer than 2 hours has also been changed. Centerline concentrations are now used for the first 8 hours in each time period longer than 8 hours duration. Sector-average concentrations are used for the remaining hours.

Following this introduction, the ARCON96 code documentation is divided into three parts. The first part of the documentation is a user's guide to the ARCON96 code. It contains the information needed to install and run the code. The user's guide includes six example problems that illustrate application of the code and highlight some results that might not be expected. The second part describes the technical basis for the code. The technical basis information is presented to provide the background material needed to properly interpret and apply the ARCON96 results. The third part is a programmer's guide to the portion of the code that performs the data manipulations and calculations. This information is provided for use by anyone who may be called upon to modify the code.

2 ARCON96 User's Guide

This user's guide to the ARCON96 code consists of four sections. The first section provides information to assist you in getting started. It describes the hardware requirements for and installation of the code. The second section describes how to run the code. It covers the user interface and entering data. The third section describes the input required by ARCON96. It provides a description of each item and gives acceptable limits for the items. The fourth section contains six example problems and lists partial ARCON96 output for each problem.

2.1 Getting Started

This section of the user's guide covers the installation of the ARCON96 code on your computer. The code is supplied on a single disk. If you have the required hardware and sufficient disk space, installation of the code will be a simple matter.

2.1.1 Hardware Requirements

ARCON96 is a DOS program that runs on personal computers using the 80386 and more recent 32-bit processor (IBM compatible) computers with a math coprocessor. Problems running the code will be encountered if the math coprocessor is a 16-bit coprocessor (e.g., 80287).

To ensure that the program will run correctly, the computer must have the following:

- a high density floppy disk drive (either 3.5 or 5.25 inch disks) and a hard disk
- 640 kilobytes of memory
- a VGA color monitor
- a mouse.

Running ARCON95 required more than 470 kilobytes of free memory. ARCON96 has been compiled using a 32-bit compiler that is capable of addressing memory not normally accessible to DOS programs. As a result, the ARCON96 may run on some systems that were not able to run ARCON95.

If ARCON96 will not run, check to see if there is sufficient available memory. An error message will be displayed on the monitor. However, the message may flash by so rapidly that it isn't readable. If the program creates a run specification file containing the input data but doesn't read the meteorological data or create output files, insufficient memory is likely to be the problem.

ARCON96 consists of a user interface and a computational program. The user interface program is a DOS program designed for color monitors displaying 50 lines of text. If ARCON96 is run on a computer with a monochrome monitor, the colors used in the input programs may make it difficult to distinguish some of the controls used in the programs.

A mouse is recommended. It facilitates moving through the program and selecting program options. However, ARCON96 can be run on computers without a mouse by using highlighted letters to select desired options.

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If neither a color monitor or a mouse are available, ARCON96 may be run by bypassing the shell programs used for data input. An ASCII text editor can be used to create the user input file that controls ARCON96. This file is called the run specification file. ARCON96 may then be run by typing "ARCON96F" followed by a space and then the name of the run specification file. The contents and format of the run specification file are described in Section 4.4.1.

2.1.2 Installation

The ARCON96 code consists of six files:

- ARCON96.BAT
- ARCONVB.EXE
- ARCONVB2.EXE
- ARCON96F.EXE
- ARHELP.TXT
- DOSXMSF.EXE.

The first 5 of these files must be placed in the subdirectory from which the program is to be run; the DOSXMSF.EXE file may be placed in the program subdirectory or any other subdirectory that is listed in the DOS PATH command. Other files used and generated by the program may be placed in other subdirectories, if desired. ARCON96 supports path names of up to 40 characters for meteorological data and output files. Problems in program execution may arise if the program is embedded too deeply in a directory structure.

An installation program is included with the ARCON96 code. This program will create an ARCON96 directory and copy the program files from the installation disk to the ARCON96 directory. To run the installation program, place the ARCON96 installation disk in your computer disk drive and make the drive containing the installation disk the active drive by typing the drive letter followed by a colon at the prompt.

The installation program is started by typing A96_INST followed by the path to the directory to where the program is to be installed on the command line. The installation command has the general form

```
A96_INST Drive Name1 Name2 Name3 Name4
```

where A96_INST is the name of the installation program, Drive is the destination drive, and names Name1 through Name4 define the path to the installation directory. There must be spaces between the command line arguments.

The command line entry to install ARCON96 from a disk in the B: drive to directory C:\ARCON96\CODE would appear as

```
B:\> A96_INST C: ARCON96 CODE
```

The Drive in the path must contain both the drive designation and the colon. The names do not require backslashes. They will be provided by the program. The installation program supports a path that includes four subdirectory levels. You must specify at least the Drive; it is not necessary to specify any subdirectory names.

When the installation program begins, it will create the directories listed on the command line, working from left to right across the command line. If a directory exists, its existence will be noted and the program will move to the next level. This process will continue until the final subdirectory in the path is reached. The program will then copy all files on the installation disk to the subdirectory.

Additional subdirectories may be created to hold the meteorological data files used by ARCON96 and to receive the output files generated by ARCON96. You will have to create these directories manually.

The ARCON96 installation program will not erase or overwrite ARCON95 files. If you wish to recover the disk space occupied by ARCON95 files you must delete the files manually. Be sure to make backup copies of important files prior to deleting them from your hard disk!

If you intend to run ARCON96 in a DOS window in Windows 3.1 or directly in DOS under a version prior to Version 7.0, no customization is required after the files have been copied to the appropriate subdirectories; the program may be run by typing "ARCON96" at the DOS prompt. However, if you normally run your computer console in a 43- or 50-line mode, you may wish to customize the ARCON96.BAT file. The mode commands in ARCON96.BAT change the console to the 50-line mode prior to running ARCON96, and then change the console to the 25-line mode when ARCON96 is complete. If you normally run in the 50-line mode, both of the mode commands in ARCON96.BAT may be deleted. If you normally run in the 43-line mode, the second mode command should be changed from:

```
mode con lines=25
```

to

```
mode con lines=43.
```

Any text editor that produces ASCII files, for example the editor invoked by the DOS EDIT command, may be used to make this change.

If you intend to run ARCON96 in a DOS window in Windows95, the DOS mode.com may not be in a subdirectory in your path statement. In a standard installation of Windows95, mode.com is found in c:\windows\command. Edit the ARCON96.BAT file to include the full path to mode.com. If you try to run ARCON96 and do not see full data entry screens, you probably have not set the 50 line mode.

If you are a Windows95 user and copy the ARCON96 files to your computer as a described above you may also set up ARCON96 in the following manner. Find the icon for the ARCONVB.EXE using the Explorer in My Computer. Click once on the icon for the program. Then click on Properties on the File menu. This will you to customize the computer settings used when ARCON96 is started by double clicking on the ARCONVB icon. Click on the screen tab to gain access to screen setting options. When the options appear set the initial size to 50 lines. At this time you may set the program to run in the full screen mode.

After you have completed customization of the computer settings, you may also wish to create a shortcut to ARCON96. by dragging the ARCONVB.EXE icon on to the desk top and renaming

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the shortcut. If you start ARCON96 by double clicking on the shortcut, the program will use the custom settings.

2.2 Running ARCON96

ARCON96 runs from a Visual Basic shell under the DOS operating system. The shell provides a graphical user interface for data entry and initiates execution of the computational program. When computations are complete, the shell permits revision of input for a new set of computations. This section describes the procedures for running ARCON96 within the Visual Basic shell.

If you are running Windows95, have installed ARCON96 according to the directions above, and have created a shortcut to ARCON96, start ARCON96 by double clicking on the ARCON96 icon on the desktop.

If you are not running Windows95, use the following procedure to start ARCON96. Set the default directory to the subdirectory where the ARCON96 program files are installed. For example, if ARCON96 is installed on the C: drive in a sub-directory named ARCON96, type `cd ARCON96` at the `C:\>` prompt. You should see

```
C:\>cd ARCON96
```

When you press `<ENTER>`, the prompt will change to

```
C:\ARCON96>
```

to indicate that you are in the ARCON96 directory. ARCON96 may then be run by typing ARCON96 and pressing `<ENTER>`. This will start ARCON96.

2.2.1 The User Interface

This section presents general information about interacting with the computer to run ARCON96. The Visual Basic shell program consists of a series of screens that provide information about ARCON96 and accept input required for the calculations. Online help is available during data entry if you are using a mouse. Help is obtained by clicking on the word **Help** in the menu bar at the top of the screen.

2.2.2 Entering Data

ARCON96 is designed to be run with a mouse. In general, the instructions that follow will assume that you are using a mouse. However, there are keyboard substitutes for the mouse actions required to run the program. ARCON96 uses several methods to obtain input. These methods are:

- command buttons
- text boxes
- choice lists

Command buttons initiate some sort of action. To activate a command button, place the mouse cursor on the button and click with the left button on the mouse. If you are not using a mouse, you activate a command button by using the <TAB> key to highlight the button and then pressing <ENTER>. You can tell when a command button becomes active because its appearance will change.

Command buttons are labeled. The labels include **OK**, **CONTINUE**, and **YES** and **NO**. These labels are self explanatory. There are five additional buttons that have meanings that are less obvious. The **CANCEL** button causes the program to return to the previous input screen without saving any of the data that you have entered or modified. The **File Search** button appears when you are asked to enter the name of an input data file. If you click on the **File Search** button when it appears you will be presented with two windows. One of the windows allows you to change directories, and the other lists names of files. Use of these windows will be described later. The **DONE** button appears on data entry forms. It is used to save the data you have entered when you are finished entering data. The last two buttons **VALUES** and **RUN** are found at the bottom of the main data entry screen. After all data have been entered, the **VALUES** button is used to have ARCON96 check to see that all required data have been entered and are within range. After the values have been checked, the **RUN** button is used to initiate calculations.

Text boxes are used for entering either text or numerical information. The information is entered from the keyboard. You make a text box active by clicking on the box, or using the <TAB> key. When you move from a text box after entering data, ARCON96 will check the entry to ensure that it is proper. If an improper entry is detected, a message box will appear and you will be returned to the text box where the error is.

Choice lists are used to obtain information when the number of options is small. A choice list is used to specify the wind speed units and another choice list is used to enter the release type. After you activate the choice list, you can move within the list using either the mouse or the up and down arrow keys.

There is a menu bar at the top of data input screens. You must have a mouse to use the menu bar. The menu bar lists three options -- **Input**, **Help**, and **Quit**. You use the menu bar by clicking on a listed item so you can gain access to the item. The **Input** option provides access to data input forms after data have been entered and saved. It also provides access to several model parameters that have default values that are not likely to need changing in routine application of ARCON96. The **Help** option activates ARCON96 Help. If you have questions about entering specific data items, you may be able to find an answer in Help without leaving the program or without having to find this manual. The final option on the menu bar is **Quit**. **Quit** is used to exit the Visual Basic shell program without running ARCON96 or saving any data. You leave the program by clicking on **Quit**.

2.2.3 Exiting ARCON96

The method used to exit ARCON96 depends on where you are in the program. If you are at the title or disclaimer screen, you exit the program by using the **CANCEL** button. Between the disclaimer screen and the scenario input screen, use the **CANCEL** button to return to the title screen. While you are in the scenario input screen, you exit the program by clicking on **Quit** in the menu bar. Finally, if you have just completed running the program, use the **NO** button

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when asked if you wish to run another scenario. When you exit ARCON96 in any of these ways, your screen will return to its initial operating mode.

If you wish to exit ARCON96 while the computational part of the code is running, you may use CONTROL-C to stop the code. If you use this method of exiting ARCON96 running under DOS or Windows V3.1, your screen will be in the 50-line mode. To return your screen to the 25-line mode, type.

```
mode con lines=25
```

at the DOS prompt and then press <ENTER>. If you are running ARCON96 under Windows95, your screen will return to its normal mode automatically.

2.3 ARCON96 Input

When you start ARCON96 the first screen you will see is a title screen. The title screen contains the program name and buttons that offer two choices: **CONTINUE** or **CANCEL**. Place the cursor on **CONTINUE** and click the left mouse button if you wish to start the program, or click on **CANCEL** to exit from the code and return to the DOS command line.

NOTE: If you are not using a mouse, you may use the highlighted letters in the option buttons: **CONTINUE** and **CANCEL**. By typing ALT-o (pressing the ALT button and letter o key at the same time), you will be doing the same thing as clicking the mouse on Continue. You may abort the program using the same method but substituting the letter n for o (i.e., ALT-n).

If you elect to continue, you will see a legal disclaimer. Again, you must decide to continue the program or abort the program. Clicking on **OK** or pressing the <ENTER> key will allow the program to continue. The **OK** button default is set to continue. Clicking on **CANCEL** causes program execution to stop and returns you to the DOS command line.

2.3.1 Input Data File Name

The first data input screen follows the disclaimer. The screen has two sets of options. The first set of options allows you to choose to recall and revise an existing input file or enter data in an entirely new file prior to running ARCON96. You select either **Input New Data** or **Open an Existing Input File**. You make your selection by placing the cursor between the appropriate parentheses and clicking the left button of the mouse. The second set of options is represented by the **CONTINUE** and **CANCEL** buttons. If you place the cursor on **CANCEL** and click with the left mouse button, you will return to the title screen. You may exit ARCON96 from there. Figure 1 shows this screen. If you haven't run ARCON96 before or you are starting a new analysis, you should select **Input New Data** before clicking on **CONTINUE**.

ARCON96 uses a file to transfer data entered by users to the code used for computations. This file is called the run specification file. When you click on **CONTINUE** after selecting **Input New Data**, ARCON96 displays the form used for entering the name of the run specification file name. This form is shown in Figure 2. It consists of a text box labeled "File Name:". This box suggests a file name with an .RSF extension. You enter a file name by moving the cursor

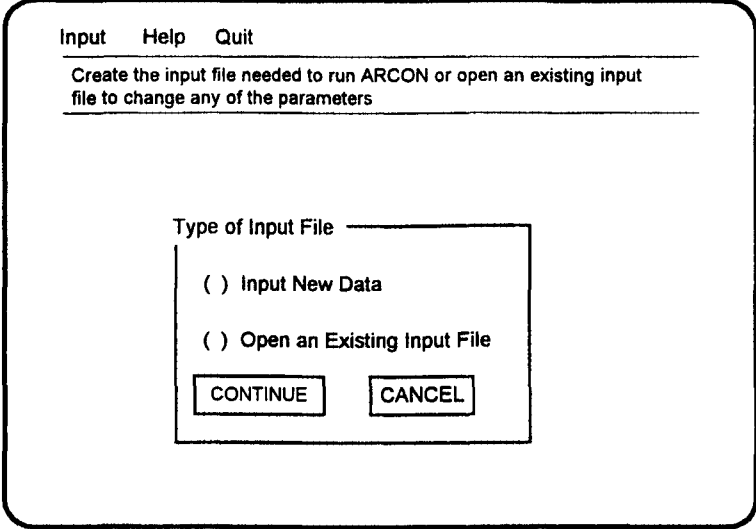


Figure 1 Input file selection screen

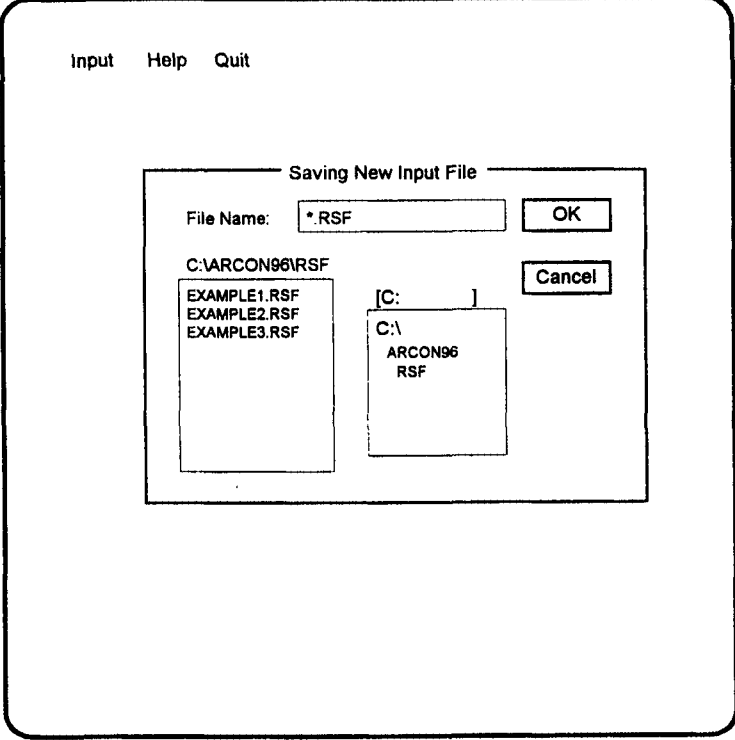


Figure 2 Run specification file name entry screen

to the asterisk, deleting it, and typing the name of your choice. File names are limited to eight characters. In addition, the combined length of the file name and the path to the file must be 40 characters or fewer. The boxes below the text box used for entering the run specification file name contain information about existing run specification files. The box on the left shows the names of files in the current directory with .RSF extensions, and the right-hand box shows the path to the current directory. Use these boxes to ensure that you don't unintentionally overwrite an existing file, or to select an existing file that has most of the input that you need. However, be warned that if you select an existing file and don't change the path or file name, the original file will be overwritten when you save your new scenario. When you have entered the file name and the appropriate path, click on the **OK** button to proceed to the scenario entry screen.

If you click on the **CANCEL** button, ARCON96 returns to the previous form where you may change your selection.

When you click on **CONTINUE** after selecting **Open an Existing Input File**, ARCON96 displays the form used for entering the name of a run specification file to be updated. This form appears to be identical to the form used for entering the name of a new run specification file except for the title displayed at the top of the form. However, the essential difference between the forms is in the responses to a click on the **OK** button. When you elect to modify an existing file, clicking on the **OK** button moves you to the forms used for entering the scenario, but an additional form overlays the scenario entry forms. This form is used to enter the name of the file to be used when saving the revised run specification file. The name of the file being revised is the default name for the revised file. If you use this name the original file will be overwritten. After you enter the new file name, you continue with data entry by clicking on the **OK** button.

2.3.2 Scenario Description

Six forms are used for entering the data for the run specification file. However, typical users will generally only enter or change values in five of the forms. Four of the data entry forms are shown in separate boxes on the Scenario Input Screen when it first appears. These boxes are labeled:

- Meteorological Input
- Receptor Input
- Source Input
- Output Files.

Figure 3 shows the Scenario Input Screen without the detailed structure of the four data entry forms. You will note the menu bar at the top of the screen, the four data entry forms that cover the majority of the screen, and a box at the bottom of the screen that contains two buttons. You will also note that each of the four data entry forms has a **DONE** button. When you complete entering data in each form, click on the **DONE** button to save your entries for inclusion in the run specification file. If you don't click on the **DONE** button, your entries will not be saved. After you click on the **DONE** button the data entry form will disappear. Figure 4 shows the screen as it will appear after all data entry is complete. At this time you should click on the **VALUES** button to have ARCON96 check your data entries to ensure that all required data have been entered and that the data are within the acceptable range. If all required data have not been entered a warning message will appear. When you understand the message, click on **OK**.

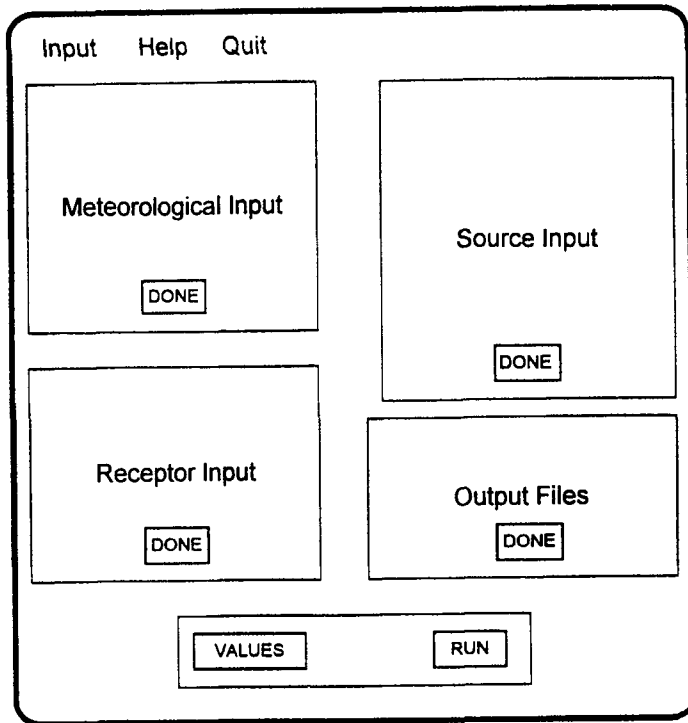


Figure 3 Scenario input screen layout

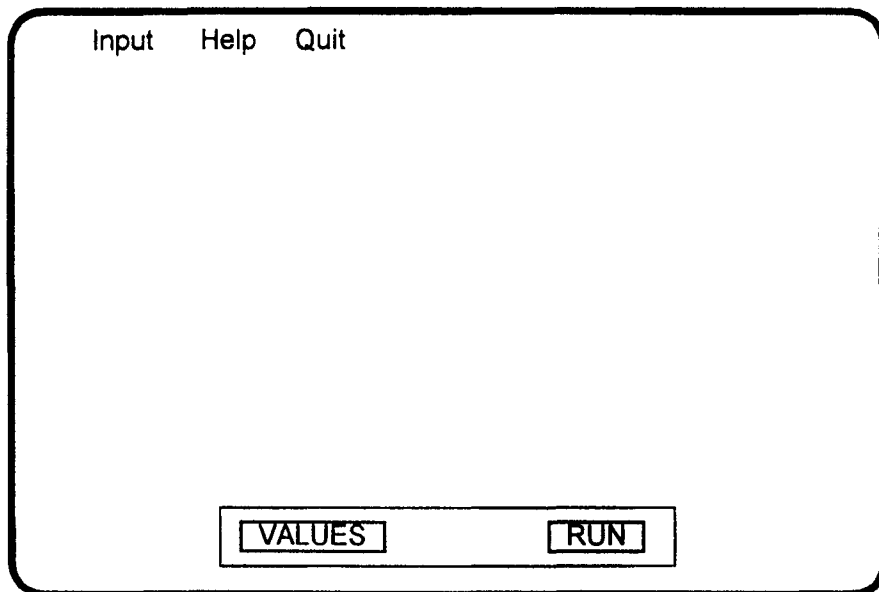


Figure 4 Completed scenario input screen without data entry forms

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If you get the warning message that indicates you must enter additional data, or if you would like to change data after clicking a **DONE** button, you may reopen one or more data entry forms by clicking on **Input** on the menu bar. Clicking on the menu bar will display a list of the six data input forms. This list is shown in Figure 5. Click on the form used for entering the data that you wish to change and the form will reappear. The Met File Name(s) data entry form is used for selecting meteorological data files. It appears after you enter the number of meteorological files in the meteorological data entry form. The Default data entry form is used to change model parameters that normally don't need to be modified. It only appears when requested from the **Input** menu. You should not alter the parameters on the Default form unless you are familiar with the technical bases for the models used in ARCON96.

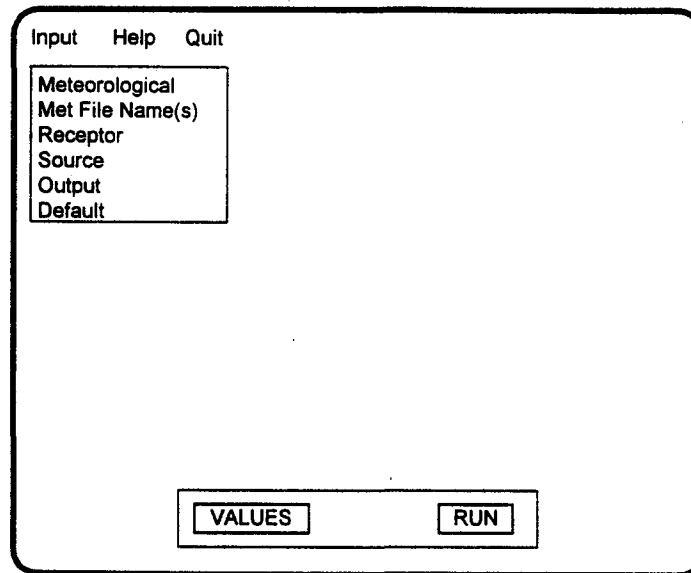


Figure 5 Input menu

You may enter data in the forms in any order. However, you must enter data in every form, and the data must be within limits before ARCON96 will begin its calculations. If you enter data that are not within reason, ARCON96 will display an error message, and the text box where the value/letters were entered will be highlighted. You should correct the entry before continuing.

When you start with an existing data file, the **DONE** buttons will be enabled when you reach the scenario input screen signifying that a run may be started with the data as they are. If you change one or more entries, you must click on the **DONE** button to update data in the file. If you do not click on the **DONE** button, the new file will retain the data from the original file.

If you are entering data for a new file, you must click on the **VALUES** button to ensure that all data are entered correctly before you can start the calculations. This provides another check on the validity of the values by confirming that all the input boxes have a value. After clicking on **VALUES**, you will be informed on the status of the data entry. If all required information is present and within range, the **RUN** button will be activated. You are only required to click on the **VALUES** button when creating a new file, but you may use it anytime to see if all required data have been entered.

After all the data are correct, ARCON96 computations are started by clicking on the **RUN** button.

2.3.3 Meteorological Data

The Meteorological Input form is located in the upper left of the ARCON96 Scenario Input Screen. This form is shown in Figure 6. Four pieces of information are entered in this form. The first three pieces are entered in text boxes. The entry in each box should be a number. The fourth entry is made by selecting the appropriate wind speed units from an option list.

Meteorological data are input to ARCON96 using meteorological data files. At least one meteorological data file is required, but the program will accept meteorological data on as many as 10 files. The meteorological data file entry form will appear after you enter the number of meteorological data files. This form is shown in Figure 7. It has a text box for entering the file name. If you are modifying an existing run specification file, the meteorological files used in the previous scenario will be used as default file names. If these files are correct, click on the **DONE** button. Otherwise if you know the file names you may enter the names of new files in the boxes and click on the **DONE** button.

Meteorological Input

| | |
|--------------------------|-----------------------------------|
| Number of Met Data Files | <input type="text" value="1"/> |
| Lower Measurement Height | <input type="text" value="10.0"/> |
| Upper Measurement Height | <input type="text" value="63.4"/> |

Wind Speed () mph
 () m / s
 () knots

Figure 6 Meteorological input form

Quit

Meteorological Input File Names

First Met File

Figure 7 Meteorological input file names form

If you don't know the name of the meteorological data files, click on the **File Search** button. When you click on the **File Search** button, a form will appear that is similar to the form used for entering the run specification file name. This form, shown in Figure 8, is overlaid on the meteorological data file entry form. You can select a file from the list in the left hand box by clicking on the file name and then on the **OK** button. If the file doesn't exist in the current directory, you can use the right-hand box to change directories.

File names should be entered so that the meteorological data are in chronological order. ARCON96 assumes that the data form a continuous time series. If the data in the files are not a continuous time series, the χ/Q values calculated for averaging periods that are longer than one hour will be meaningless.

If you enter names manually, the file and path name combined is limited to 40 characters. **File Search** works in the same manner as the directory search described earlier for input file names. After you finish entering file names, click on the **DONE** button to return to the previous form to complete the scenario description.

You must enter a name for each meteorological file to exit from the meteorological file data entry screen in a normal manner. If you can't find a meteorological file and wish to quit ARCON96 to continue the search or create a meteorological data file, you may do so by clicking on **Quit** on the menu bar at the top of the screen. If you want to return to the Scenario Input Screen without quitting ARCON96, you may enter any name.

Quit

Meteorological Input File Names

First Met File

Second Met File

Open Met File

File Name:

| | |
|----------------|---------|
| C:\ARCON96\MET | C:\ |
| EXAMPLE1.MET | ARCON96 |
| EXAMPLE2.MET | MET |
| EXAMPLE3.MET | |

Figure 8 Meteorological input files form for two files

The meteorological data files require one record per hour. Each record must include the day of the year, the hour of the day, the stability, and the wind direction and wind speed at the lower measurement level. The record may also include a five-character location identifier, and a wind direction and speed for the upper level. Section 4.4.1 provides a complete description of the meteorological data file structure.

The second and third text boxes on the Meteorological Input form are used to enter wind speed measurement heights. Enter the heights in meters. The height of the lower-level measurement may not be greater than 100 m, and the height of the upper-level measurement may not be greater than 300 m. If wind data are available for only a single measurement height, enter the height in the text box for the lower level.

2.3.4 Receptor Data

The Receptor Input Form is used to enter data related to the receptor. In control room habitability assessments the receptor is the control room air intake. The Receptor Input form, shown in Figure 9, is located in the lower left-hand corner of the Scenario Input Screen. All entries on this form are numerical values.

| Receptor Input | |
|----------------------|------|
| Distance to Receptor | 35.0 |
| Intake Height | 20.0 |
| Elevation Difference | 0.0 |
| Direction to Source | 245 |
| DONE | |

Figure 9 Receptor input form

The distance from the source to the receptor refers to the horizontal distance between the release point and the air intake. This distance may not exceed 10,000 m.

The intake height is the height of the intake above grade. It may not exceed 100 m.

Elevation difference is the difference in plant grade between the positions of the intake and release. This difference will normally be zero. Enter zero if the release point and intake are on the same structure or the heights of the release point and intake are measured from the same reference plane. If the release point and intake are widely separated, there may be a difference in the height of the reference plane. In this case the difference in elevation should be entered. Enter the difference as a positive value if the grade elevation at the release point is higher than at the intake. If the grade elevation at the intake is higher, enter a negative value. ARCON96 will accept elevation differences from -1,000 m to +1,000 m.

The direction from the intake to the source is the last item entered in the Receptor Input form. This direction is used to determine when the wind carries effluents from the release point to the intake. Assuming that the wind directions in the meteorological data file follow the standard convention of recording the direction from which the wind blows, you will enter the proper direction if you imagine that you are standing at the intake facing the release point. If you are looking north, enter north (360°). If you are looking southwest, enter southwest (225°), etc. ARCON96 will transform the wind direction to the transport direction for you.

The distance from the receptor to the air intake, the height of the air intake, and the difference in grade elevation between the positions of the intake and the release point must be entered in meters. The direction to the source is entered in degrees. The data may be entered in the text boxes in any order.

2.3.5 Source Data

Information describing the release point is entered in the Source Input form. This form, shown in Figure 10, is located in the upper right-hand corner of the Scenario Input Screen. The option list at the top of the form is used to enter a general description of release. ARCON96 uses this description in determining if your input is sufficient and if the values are within acceptable limits. It also uses this description in selection of the equations used for calculating χ/Q . The text boxes below the choice list are used to enter a more detailed description of the release.

The image shows a 'Source Input' form with the following fields and values:

| Field | Value |
|-------------------|-------------------------------------|
| Release Type | () ground () vent () stack |
| Release Height | 2.0 |
| Building Area | 1600 |
| Vertical Velocity | 10.0 |
| Stack Flow | 10.0 |
| Stack Radius | 0.564 |

A 'DONE' button is located at the bottom of the form.

Figure 10 Source input form

If you select a ground-level release in the choice list at the top of the Source Input form, you may enter zeros in all of the text boxes. ARCON96 will assume a ground-level release height and will not use the vertical velocity or stack radius, even if entered.

If you select either a ground-level or vent release and wish to include wake diffusion in your calculations, you must enter a building area. Building area controls the distance down wind that building-wake effects will be felt. The larger the area, the farther downwind they will be felt. The projected building area depends on the problem being addressed. It is not necessarily the area of the entire building. In some instances, the appropriate area may be the projected area of a portion of the building. The range of acceptable values for building area is 0 to 10,000 m². A building area is not required. If you don't enter an area, intake concentrations will be calculated assuming normal dispersion.

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A release height is required if you select a vent or elevated release. It can be any value between 1 and 300 m. ARCON96 does not compute plume rise. Therefore, if you wish to include plume rise in your calculation, you must combine plume rise with the actual stack height to get an effective stack height and enter the effective stack height in the text box in place of the actual height.

The vertical velocity is used in both vent- and elevated-release calculations. In vent release calculations, the vertical velocity of the vent exhaust is compared with the release height wind speed to determine how much of the exhaust enters the building wake. When the ratio of vertical velocity to the wind speed exceeds 5, the exhaust rises above the wake; when the ratio is less than 1, the exhaust is completely trapped in the wake, and at intermediate ratios, part of the exhaust enters the wake. In elevated-release calculations, the vertical velocity is used to determine if the stack height should be reduced to account for downwash. Downwash is included in the calculation whenever the ratio of the vertical velocity to the release height wind speed is less than 1.5. ARCON96 accepts vertical velocities ranging from 0 to 50 m/s. A vertical velocity of zero should be entered if the vent is capped.

The stack flow is used in model calculations whenever entered. Its function is to ensure that effluent concentrations in the atmosphere are always less than the concentration at the release point. The closer together the release point and receptor are and the larger the flow, the more important it is to include the flow in the calculations. ARCON96 accepts flows ranging from 0 to 100 m³/s.

The last entry in the Source Input form is for the stack radius. Stack radius is used only in elevated release calculations. It determines the maximum stack height reduction during downwash conditions. ARCON96 will accept stack radius entries from 0 to 10 m.

In reality, the stack or vent exit velocity, stack flow, and stack radius are related. However, the stack or vent exit velocity is not necessarily directed in the vertical. Vents are frequently capped or horizontal. Therefore, ARCON96 does not check to make sure that these three entries are consistent. You must do that.

2.3.6 Output Files

The Output Files form shown in Figure 11 is the fourth form on the Scenario Input Screen. It is located in the lower right-hand corner of the screen. This form is used to specify the names of two files to receive the normal ARCON96 output.

The name of the file to receive the primary output is entered in the Output File text box. When the run is complete, this file will contain heading information related to the ARCON96 code, the date and time that the code was run (if the date and time in the computer's clock are correct), a listing of the input to the code, and the output from the code. The output from the code includes the number of hours of data processed by the code, the number of hours of missing data, the range of predicted concentrations for hourly concentrations, the 95th percentile concentration estimates.

The .CFD File text box is used to enter a name for the file to receive the cumulative frequency distributions of the concentrations calculated for ten averaging intervals. This file is designed to be imported into a spreadsheet for further data analysis and display. These distributions may be

The figure shows a graphical user interface window titled "Output Files". Inside the window, there are three text input fields. The first field is labeled "Output File" and contains the text "Arcon96.log". The second field is labeled "CFD File Name" and contains the text "Arcon96.cfd". The third field is labeled "Expanded Output" and contains the text "n". Below these fields, centered at the bottom of the window, is a button labeled "DONE".

Figure 11 Output files form

used to determine concentrations at percentiles other than the 95 percentile. You must enter a name for the primary output file, but entering the .CFD file name is optional. ARCON96 will allow you to run the code if you don't enter a .CFD file name. However, you will be required to enter a name for the file when ARCON96's calculations are complete.

If you click in an Output File text box and then click in another area of the input form, ARCON96 will enter a default name. The default file names are Arcon96.log for the primary output file and Arcon96.cfd for the cumulative distribution file.

ARCON96 will not overwrite an existing primary output file or a .CFD file. If you enter the name of an existing file for either of these files, ARCON96 will abort. An error message will be displayed on your screen, but it may not remain long enough to read.

The last entry in the Output Files form is a control that enables ARCON96's expanded output option. The Expanded Output option is included primarily to give advanced modelers access to intermediate information for use in code verification. In general, you can ignore this text box and accept the default value, n. If you wish to look at the expanded output, change the n (no) to a y (yes). ARCON96 will only accept lower-case letters. When you request expanded output you will be asked for a file name as soon as the computational program begins. This file is referred to as the QA file.

The QA file contents include diffusion coefficients and wind speed correction factors used by the code, a copy of the meteorological data file, the centerline and sector-average χ/Q values calculated for each hour, and frequency distributions of the average concentrations. Consequently when ARCON96 is run with the expanded output option and a large meteorological data set, the result will be a large (several hundred kilobytes) QA file.

Figure 12 shows a Scenario Input Screen as it might appear following data entry prior to clicking on any **DONE** buttons.

Scenario Input Screen

Input Help Quit

| | |
|---|--|
| <p>Meteorological Input</p> <p>Number of Met Data Files 1</p> <p>Lower Measurement Height 10.0</p> <p>Upper Measurement Height 63.4</p> <p>Wind Speed () mph () m / s () knots</p> <p style="text-align: center;"><input type="button" value="DONE"/></p> | <p>Source Input</p> <p>Release Type () ground () vent () stack</p> <p>Release Height 2.0</p> <p>Building Area 1600</p> <p>Vertical Velocity 10.0</p> <p>Stack Flow 10.0</p> <p>Stack Radius 0.564</p> <p style="text-align: center;"><input type="button" value="DONE"/></p> |
| <p>Receptor Input</p> <p>Distance to Receptor 35.0</p> <p>Intake Height 20.0</p> <p>Elevation Difference 0.0</p> <p>Direction to Source 245</p> <p style="text-align: center;"><input type="button" value="DONE"/></p> | <p>Output Files</p> <p>Output File Arcon96.log</p> <p>CFD File Name Arcon96.cfd</p> <p>Expanded Output n</p> <p style="text-align: center;"><input type="button" value="DONE"/></p> |

Figure 12 Completed scenario input form

2.3.7 Default Data

The remaining data input form is called the Default Values form. It is used to change default values for parameters used in the dispersion model. It is also used to modify the averaging intervals for χ/Q . It is generally not necessary to change these parameters; therefore, the form is not displayed routinely.

The Default Values form, shown in Figure 13, is accessed by clicking on **Default** on the **Input** menu. The **Input** menu will be displayed if you click on the word **Input** in the menu bar at the top of the screen. The parameters included on the form are the surface roughness length, the width of the wind direction window, the minimum wind speed, sector-averaging width constant, number of hours for each averaging interval, and the minimum number of hours for a valid average. All of these parameters are defined and discussed in Section 3. If you aren't comfortable with the information in Section 3, you probably shouldn't be changing default values. The Default Values form is also used to enter the initial diffusion coefficients that define area sources. The use of initial diffusion coefficients for this purpose is demonstrated in example problems 5 and 6 in Sections 2.5.6 and 2.5.7, respectively.

| Default Values | |
|-------------------------------------|--|
| Surface Roughness Length | <input type="text" value="0.10"/> |
| Wind Direction Window (degrees) | <input type="text" value="90"/> |
| Minimum Wind Speed (m/s) | <input type="text" value="0.5"/> |
| Averaging Sector Width Constant | <input type="text" value="4.0"/> |
| Initial Diffusion Coefficients (m) | <input type="text" value="3.94"/> <input type="text" value="1.0"/> Sigma Y Sigma Z |
| Hours in Averages | <input type="text" value="1"/> <input type="text" value="2"/> <input type="text" value="4"/> <input type="text" value="8"/> <input type="text" value="12"/> <input type="text" value="24"/> <input type="text" value="96"/> <input type="text" value="168"/> <input type="text" value="360"/> <input type="text" value="720"/> |
| Minimum Number of Hours | <input type="text" value="1"/> <input type="text" value="2"/> <input type="text" value="4"/> <input type="text" value="8"/> <input type="text" value="11"/> <input type="text" value="22"/> <input type="text" value="87"/> <input type="text" value="152"/> <input type="text" value="324"/> <input type="text" value="648"/> |
| <input type="button" value="DONE"/> | |

Figure 13 Default values form

2.4 ARCON96 Output

In the Output Files form of the Scenario Input Screen you entered a name for a file to be used for the primary output from ARCON96. This section describes the primary output file.

The primary output file from ARCON96 is an ASCII text file. It may be viewed, edited, annotated, and/or printed using a text editor or word processor. Some of the lines of text in the file exceed 80 characters in length. As a result, the best results will be obtained if you use a text editor or word processing program that allows you to control the font size and number of characters on a line. The files can be printed on 8.5- by 11- inch paper using 0.5-inch margins with 16.67 characters per inch.

The contents of ARCON96's primary file are divided into three sections. The first section is a header. The second section lists the input to the code, and the third section summarizes the results of the calculations. These sections are discussed below.

2.4.1 Header

The header in the ARCON96 primary output file provides information about the code. Figure 14 shows a file header. The first three items in the header identify the code. They are the code name, the organization sponsoring code development, and the date and time that the code was compiled. The time of code compilation establishes what version of the code was used for the calculations. The next two items list people who can be contacted about the code and gives the reference for the code documentation. The names and phone numbers listed in the header were

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```
Program Title: ARCON96.
Developed For: U.S. Nuclear Regulatory Commission
               Office of Nuclear Reactor Regulation
               Division of Reactor Program Management
Date:          May 9, 1997    3:00 p.m.
NRC Contacts: J. Y. Lee      Phone: (301) 415 1080
               e-mail: jy1@nrc.gov
               J. J. Hayes   Phone: (301) 415 3167
               e-mail: jjh@nrc.gov
               L. A. Brown   Phone: (301) 415 1232
               e-mail: lab2@nrc.gov
Code Developer: J. V. Ramsdell Phone: (509) 372 6316
               e-mail: j_ramsdell@pnl.gov
Code Documentation: NUREG/CR-6331 Rev. 1
The program was prepared for an agency of the United States Government. Neither
the United States Government nor any agency thereof, nor any of their
employees, makes any warranty, expressed or implied, or assumes any legal
liability or responsibilities for any third party's use, or the results of such
use, of any portion of this program or represents that its use by such third
party would not infringe privately owned rights.
Program Run  5/ 9/1997 at 15:03:19
```

Figure 14 ARCON96 primary output file header

current when this guide was written. These items are followed by a disclaimer. The disclaimer was provided by the NRC for inclusion in software developed for the agency. The final line of the header gives the date and time that the program was run. This time may be used to identify the results of the most recent model run if ARCON96 is run several times with the same input and output file names.

2.4.2 Input Data

The second section of the ARCON96 primary output file is a listing of the user input. Figure 15 shows the Input Data section of a primary output file. This listing contains all of the information in the run specification file. It also shows the range of wind directions that are assumed to carry effluents from the release point to the intake. This range is calculated from the direction of the source from the intake and the wind direction sector width. The example shown in Figure 15 is for an ARCON96 run that did not include expanded output. When the expanded output option is selected, the last line of the input section contains the QA output file name.

2.4.3 ARCON96 Results

The final section of the primary output file contains the results of the ARCON96 calculations. Figure 16 shows the results section of a primary output file.

The first six lines of the results section summarize the meteorological data. The first line shows the number of hours of data processed. A normal year has 8760 hours; leap years have 8784. The second line shows the number of hours that ARCON96 was unable to calculate a χ/Q . Fewer than 10 percent of the hours processed should have missing data if the meteorological data have been obtained with a well-maintained system. The third line shows the number of

```

***** ARCON INPUT *****

Number of Meteorological Data Files = 1
Meteorological Data File Names
  example.MET

Height of lower wind instrument (m) = 10.0
Height of upper wind instrument (m) = 53.4
Wind speeds entered as knots

Ground-level release
Release height (m) = .0
Building Area (m^2) = 1900.0
Effluent vertical velocity (m/s) = .00
Vent or stack flow (m^3/s) = .00
Vent or stack radius (m) = .00

Direction .. intake to source (deg) = 326
Wind direction sector width (deg) = 90
Wind direction window (deg) = 281 - 011
Distance to intake (m) = 45.0
Intake height (m) = 15.0
Terrain elevation difference (m) = .0

Output file names
  ex1_96.log
  ex1_96.cfd

Minimum Wind Speed (m/s) = .5
Surface roughness length (m) = .10
Sector averaging constant = 4.0

Initial value of sigma y = .00
Initial value of sigma z = .00

Expanded output for code testing not selected
  
```

Figure 15 Input data section of an ARCON96 primary output file

```

Total number of hours of data processed = 8760
Hours of missing data = 10
Hours direction in window = 1529
Hours elevated plume w/ dir. in window = 0
Hours of calm winds = 3134
Hours direction not in window or calm = 4087

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL
AVER. PER.      1      2      4      8     12     24     96    168    360    720
UPPER LIM.  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02
LOW LIM.    1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06
ABOVE RANGE  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
IN RANGE    4663.      5557.      6423.      7373.      7922.      8425.      8671.      8608.      8436.      8112.
BELOW RANGE  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
ZERO        4087.      3185.      2303.      1321.      815.       291.       0.         0.         0.         0.
TOTAL X/Qs  8750.      8742.      8726.      8694.      8737.      8716.      8671.      8608.      8436.      8112.
% NON ZERO  53.29     63.57     73.61     84.81     90.67     96.66     100.00     100.00     100.00     100.00

95th PERCENTILE X/Q VALUES
1.43E-03  1.31E-03  1.23E-03  1.14E-03  9.61E-04  7.44E-04  5.22E-04  4.67E-04  4.09E-04  3.94E-04

95% X/Q for standard averaging intervals
0 to 2 hours      1.43E-03
2 to 8 hours      1.04E-03
8 to 24 hours     5.46E-04
1 to 4 days       4.49E-04
4 to 30 days      3.75E-04

HOURLY VALUE RANGE
MAX X/Q      MIN X/Q
CENTERLINE   2.40E-03    6.88E-04
SECTOR-AVERAGE 1.50E-03    4.31E-04

NORMAL PROGRAM COMPLETION
  
```

Figure 16 Results section of ARCON96 primary output file

hours with a wind direction in the window that carries effluent from the release point to intake. The size of this number depends on the orientation of the line between the release point and the intake with respect to the prevailing wind direction. If the prevailing wind direction tends to carry material from the release point to the intake, the number of hours in the window can approach 50 percent of the total hours. If the wind rarely blows from the release point to the intake, the number of hours in the window could be 10 percent or less. The fourth line gives the number of hours of elevated plumes during the time that the wind is calm or the wind direction is in the window. This number should be zero unless you have specified a vent release with an uncapped vent or a stack release. The fifth line is the number of hours of calm winds (wind speed less than the minimum wind speed set in the Default Values form). The final line is the number of hours for which χ/Q was assumed to be zero because the wind direction was not in the window and the wind was not calm.

The next ten lines contain a summary of the intermediate result of the calculations by averaging period (in hours). ARCON96 calculates χ/Q s and creates a χ/Q frequency distribution using χ/Q bins. The lines labeled Upper Lim. and Lower Lim. define the range of χ/Q bins use to compile the χ/Q frequency distribution for each averaging period. The range should cover four orders of magnitude. Ranges for the 1- and 8-hour averaging periods will be the same, as will the ranges for the 12- through 720-hour periods. However, the ranges for these two groups of averaging periods may not be the same.

The distribution of χ/Q s calculated for each averaging period is summarized in the five lines following the line giving the lower limit for the χ/Q bins. The first of these lines gives the number of χ/Q s that were greater than the upper limit of the bins. This number should be zero unless you have processed more than 10,000 hours of data. When you process more than 10,000 hours of data, the bin limits are set based on the first 10,000 χ/Q s calculated. As a result, if you process more than 10,000 hours of data and the highest χ/Q s don't occur in the first 10,000, there could be a small number of χ/Q s above the range of bins. The next line gives the number of χ/Q s within the range of bins, and the following line gives the number of χ/Q s below the range. If you are running a vent- or stack-release scenario, you may find some χ/Q s that are listed as below the range. These χ/Q s are within an order of magnitude of the lower limit. Values that are more than an order of magnitude lower than the lower limit are counted as zero because they are not a factor in determining the 95th percentile χ/Q s. The zero line gives the number of χ/Q s that were more than an order of magnitude below the lower limit of the bins. The total χ/Q line gives the total numbers of hours that are bases for calculating the 95th percentile χ/Q s.

The line labeled 95th Percentile χ/Q Values gives the 95th percentile values for averaging periods beginning at the start of release. Thus, the 2-hour average is for the 0- to 2-hour time period. Similarly, the 8-hour value is for the 0- to 8-hour time period, and the 96-hour value is for the 0- to 96-hour time period. In general, these values should decrease as the duration of the averaging period increases. However, it is possible to have the 95th percentile value increase as the averaging interval increases. This unexpected behavior is most likely to occur with elevated or uncapped vent releases.

Thus with the default averaging periods, the χ/Q s for 1, 2, 4, and 8 hours are centerline values. Average χ/Q s for periods longer than 8 hours consist of centerline χ/Q s for the first 8 hours and sector-average χ/Q s for the remainder of the period. For example, each 24-hour average χ/Q is made up of an average of 8 one-hour centerline χ/Q s followed by 16 one-hour sector-average

χ/Q s. This change makes ARCON consistent with NRC guidance on the use of centerline and sector-average χ/Q s found in Regulatory Guides 1.3, 1.4, 1.111, and 1.145.

Control room habitability assessments generally involve the use of different χ/Q s as the postulated accident progresses. The χ/Q s for various intervals during the accident can be calculated directly from the 95th percentile values. Section 3.7 discusses the calculation of the values for time periods that don't begin at the beginning of the release. Values for five standard averaging intervals are given following the 95th percentile values. The χ/Q value for the 0- to 2-hour averaging period is usually the 1-hour value. However, if the 95th percentile 2-hour average χ/Q is larger than the 1-hour value, the 2-hour value is used.

Revision of the method for calculating average relative concentrations in ARCON96 has a second benefit. In the discussion of ARCON95 results in the next to last paragraph of Section 2.4.3 of NUREG/CR-6331, there is mention of a computational artifact related to combination of results of the centerline and sector-average models. The revised averaging procedure avoids this artifact. With the revised procedure the χ/Q s for 0 to 2 hours and 2 to 8 hours are based only on centerline values. Similarly, the χ/Q s for 8 to 24 hours, 1 to 4 days, and 4 to 30 days are based only on sector-average values.

If the default averaging periods are changed, the combination of centerline and sector-average χ/Q s will change. As in ARCON95, ARCON96 will calculate χ/Q s for the standard averaging periods only if the averaging periods are defined as follows:

- the 0 to 2 hour χ/Q will be calculated and presented only if the first averaging period is 1 hour
- the 2 to 8 hour χ/Q will be calculated and presented only if the first averaging period is 1 hour and the fourth averaging period is 8 hours
- the 8 to 24 hour χ/Q will be calculated and presented only if the fourth averaging period is 8 hours and the sixth averaging period is 24 hours
- the 1 to 4 day χ/Q will be calculated and presented only if the sixth averaging period is 24 hours and the seventh averaging period is 96 hours
- the 4 to 30 day χ/Q will be calculated and presented only if the seventh averaging period is 96 hours and the tenth averaging period is 720 hours.

Calculation and presentation of the χ/Q s for each of the standard averaging intervals is independent of the calculation and presentation of χ/Q s for the other intervals. Thus, if the criteria are met for calculation and presentation of χ/Q for a standard averaging interval, the χ/Q will be calculated and presented. If the criteria are not met, the χ/Q will not be presented.

The last part of the results section of the log file lists the maximum and minimum 1-hour χ/Q values calculated by the centerline and sector-average models. These values may be used to check the range of χ/Q bins.

The line NORMAL PROGRAM COMPLETION should be the last line of the log file. If it isn't, the program has ended in an error mode and the results should not be used.

2.5 Examples

This section contains six example problems. The first four examples demonstrate the use of ARCON96 to assess the consequences of ground-level, capped and uncapped vent, and elevated releases. These examples were included in the ARCON95 documentation. The last two examples demonstrate the use of ARCON96 in calculating χ/Q_s for area sources. The meteorological data for the examples are in a file named EXAMPLE.MET. This file will be used in each of the examples. However, each example makes a different set of assumptions about the meteorological measurement system used in collection of the data.

Each example includes a scenario description that provides all of the information required to run ARCON96 and sufficient output for you to check the results of your calculations. The header sections of the log files and the lower portions of the cumulative frequency distribution files have been deleted.

2.5.1 Example 1 -- Ground-Level Release

The first example is a ground-level release scenario. The release point is at the base of a building with a cross-sectional area of 1,900 m². The direction from the intake to the release point is 326°, and the distance between the intake and release point is 45 m. The intake is located 15 m above the ground. Use the meteorological file, with the understanding that the wind speeds are in knots (nautical miles per hour) and that the wind sensors are located at the 10- and 53.4-m levels of the meteorological tower. Name the output files ex1_96.log and ex1_96.cfd.

The log file for Example 1 is shown in Figures 14 through 16 in Section 2.4. Figure 17 shows a portion of the cumulative distribution file for the example. After comparing the results in your log file with those in Figure 14 through 16, look at the cumulative distribution in Figure 17. Notice that the cumulative frequency of 1-hour χ/Q_s increases from 0 to the maximum 4663 in a χ/Q range of less than an order of magnitude. The range of χ/Q_s increases as the averaging period increases up to about 96 hours (4 days). When the length of the averaging period increases beyond 4 days, the range of values decreases until it is only about a factor of 2 for a 30-day average.

2.5.2 Example 2 -- Uncapped Vent Release

The second example is an uncapped roof-top vent release. The direction from the air intake to the vent is 083°, and the distance is 18 m. The vent has a radius of 1 m; under accident conditions it has a nominal flow of 15.7 m³/s, and it is uncapped. The plant drawings indicate that the heights of the air intake and vent are 25 and 29 m above the plant reference elevation, respectively, and that the cross-sectional area of the building on which the vent is located is 1730 m². Hourly meteorological data are available in a file named EXAMPLE.MET. The wind data were measured at 10 and 92.1 m, and the wind speeds are reported in meters per second. Name the primary ARCON96 output file ex2_96.log, and the cumulative frequency distribution file ex2_96.cfd. When you run the program you should get the output shown in Figure 18 in the ex2_96.log file. If you didn't, perhaps you forgot to calculate and enter the vertical velocity. The vertical velocity is the flow divided by the vent area of 3.14 m², assuming a round vent.

| X/Q CUMULATIVE FREQUENCY DISTRIBUTIONS | | | | | | | | | | | |
|--|---------|---------|---------|--------|------------|---------|---------|-------|-------|-------|-------|
| X/Q | | | | | X/Q | | | | | | |
| Abv. Lim. | 1 | 2 | 4 | 8 | Abv. Lim. | 12 | 24 | 96 | 168 | 360 | 720 |
| 9.120E-03 | 0. | 0. | 0. | 0. | 9.120E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| ... | | | | | | | | | | | |
| 2.512E-03 | 0. | 0. | 0. | 0. | 2.512E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 2.291E-03 | 8. | 2. | 0. | 0. | 2.291E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 2.089E-03 | 39. | 14. | 4. | 0. | 2.089E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.905E-03 | 109. | 60. | 26. | 10. | 1.905E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.738E-03 | 186. | 130. | 81. | 53. | 1.738E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.585E-03 | 290. | 211. | 142. | 90. | 1.585E-03 | 26. | 0. | 0. | 0. | 0. | 0. |
| 1.445E-03 | 421. | 294. | 217. | 154. | 1.445E-03 | 47. | 0. | 0. | 0. | 0. | 0. |
| 1.318E-03 | 594. | 432. | 340. | 226. | 1.318E-03 | 91. | 2. | 0. | 0. | 0. | 0. |
| 1.202E-03 | 767. | 570. | 473. | 339. | 1.202E-03 | 144. | 17. | 0. | 0. | 0. | 0. |
| 1.096E-03 | 962. | 721. | 598. | 497. | 1.096E-03 | 222. | 32. | 0. | 0. | 0. | 0. |
| 1.000E-03 | 1087. | 897. | 758. | 677. | 1.000E-03 | 358. | 84. | 0. | 0. | 0. | 0. |
| 9.120E-04 | 1324. | 1123. | 1005. | 901. | 9.120E-04 | 536. | 141. | 0. | 0. | 0. | 0. |
| 8.318E-04 | 1464. | 1309. | 1259. | 1203. | 8.318E-04 | 761. | 228. | 0. | 0. | 0. | 0. |
| 7.586E-04 | 1635. | 1463. | 1382. | 1303. | 7.586E-04 | 1013. | 391. | 0. | 0. | 0. | 0. |
| 6.918E-04 | 1845. | 1663. | 1557. | 1483. | 6.918E-04 | 1324. | 590. | 4. | 0. | 0. | 0. |
| 6.310E-04 | 2094. | 1886. | 1758. | 1655. | 6.310E-04 | 1702. | 885. | 35. | 0. | 0. | 0. |
| 5.754E-04 | 2394. | 2146. | 2003. | 1883. | 5.754E-04 | 2169. | 1332. | 172. | 40. | 0. | 0. |
| 5.248E-04 | 2744. | 2463. | 2307. | 2171. | 5.248E-04 | 2660. | 1947. | 419. | 151. | 0. | 0. |
| 4.786E-04 | 3144. | 2832. | 2655. | 2485. | 4.786E-04 | 3205. | 2687. | 692. | 319. | 34. | 0. |
| 4.365E-04 | 3594. | 3227. | 3031. | 2814. | 4.365E-04 | 3817. | 3537. | 1253. | 721. | 268. | 0. |
| 3.981E-04 | 4094. | 3683. | 3452. | 3190. | 3.981E-04 | 4507. | 4403. | 2296. | 1423. | 486. | 338. |
| 3.631E-04 | 4644. | 4183. | 3931. | 3633. | 3.631E-04 | 5287. | 5141. | 3508. | 2614. | 1848. | 979. |
| 3.311E-04 | 5244. | 4743. | 4455. | 4155. | 3.311E-04 | 6167. | 5985. | 4573. | 4292. | 3597. | 3723. |
| 3.020E-04 | 5904. | 5357. | 5037. | 4685. | 3.020E-04 | 7167. | 6950. | 5572. | 5435. | 5462. | 5705. |
| 2.754E-04 | 6624. | 6037. | 5687. | 5301. | 2.754E-04 | 8307. | 8074. | 6309. | 6409. | 6747. | 6943. |
| 2.512E-04 | 7404. | 6777. | 6387. | 6001. | 2.512E-04 | 9607. | 9358. | 6864. | 7219. | 7718. | 7790. |
| 2.291E-04 | 8244. | 7577. | 7147. | 6731. | 2.291E-04 | 11067. | 10737. | 7234. | 7662. | 8091. | 7980. |
| 2.089E-04 | 9144. | 8437. | 7967. | 7511. | 2.089E-04 | 12687. | 12317. | 7554. | 7884. | 8222. | 8112. |
| 1.905E-04 | 10104. | 9357. | 8847. | 8351. | 1.905E-04 | 14447. | 14037. | 7808. | 8066. | 8361. | 8112. |
| 1.738E-04 | 11124. | 10337. | 9787. | 9251. | 1.738E-04 | 16367. | 15917. | 8034. | 8246. | 8436. | 8112. |
| 1.585E-04 | 12204. | 11377. | 10767. | 10151. | 1.585E-04 | 18447. | 17957. | 8174. | 8374. | 8436. | 8112. |
| 1.445E-04 | 13344. | 12377. | 11717. | 11051. | 1.445E-04 | 20687. | 20157. | 8243. | 8430. | 8436. | 8112. |
| 1.318E-04 | 14544. | 13437. | 12767. | 12051. | 1.318E-04 | 23087. | 22517. | 8318. | 8472. | 8436. | 8112. |
| 1.202E-04 | 15804. | 14557. | 13817. | 13151. | 1.202E-04 | 25647. | 25037. | 8371. | 8513. | 8436. | 8112. |
| 1.096E-04 | 17124. | 15737. | 14917. | 14251. | 1.096E-04 | 28367. | 27717. | 8404. | 8563. | 8436. | 8112. |
| 1.000E-04 | 18504. | 17077. | 16167. | 15451. | 1.000E-04 | 31247. | 30557. | 8439. | 8585. | 8436. | 8112. |
| 9.120E-05 | 20044. | 18477. | 17457. | 16851. | 9.120E-05 | 34287. | 33557. | 8477. | 8589. | 8436. | 8112. |
| 8.318E-05 | 21744. | 20037. | 18997. | 18351. | 8.318E-05 | 37497. | 36717. | 8503. | 8592. | 8436. | 8112. |
| 7.586E-05 | 23604. | 21757. | 20697. | 19951. | 7.586E-05 | 40977. | 40117. | 8552. | 8595. | 8436. | 8112. |
| 6.918E-05 | 25624. | 23637. | 22557. | 21651. | 6.918E-05 | 44727. | 43827. | 8594. | 8599. | 8436. | 8112. |
| 6.310E-05 | 27804. | 25677. | 24537. | 23451. | 6.310E-05 | 48747. | 47817. | 8637. | 8603. | 8436. | 8112. |
| 5.754E-05 | 30144. | 27877. | 26537. | 25351. | 5.754E-05 | 53047. | 52117. | 8684. | 8607. | 8436. | 8112. |
| 5.248E-05 | 32644. | 30197. | 28557. | 27351. | 5.248E-05 | 57627. | 56717. | 8734. | 8608. | 8436. | 8112. |
| 4.786E-05 | 35304. | 32637. | 30697. | 29351. | 4.786E-05 | 62477. | 61617. | 8786. | 8608. | 8436. | 8112. |
| 4.365E-05 | 38124. | 35297. | 32957. | 31351. | 4.365E-05 | 67597. | 66817. | 8840. | 8608. | 8436. | 8112. |
| 3.981E-05 | 41104. | 38177. | 35437. | 33351. | 3.981E-05 | 73097. | 72317. | 8896. | 8608. | 8436. | 8112. |
| 3.631E-05 | 44244. | 41277. | 38697. | 36051. | 3.631E-05 | 78977. | 78217. | 8954. | 8608. | 8436. | 8112. |
| 3.311E-05 | 47544. | 44597. | 41477. | 38851. | 3.311E-05 | 85247. | 84517. | 9014. | 8608. | 8436. | 8112. |
| 3.020E-05 | 51004. | 48137. | 44897. | 41551. | 3.020E-05 | 91977. | 91317. | 9076. | 8608. | 8436. | 8112. |
| 2.754E-05 | 54724. | 51897. | 48477. | 44751. | 2.754E-05 | 99127. | 98517. | 9140. | 8608. | 8436. | 8112. |
| 2.512E-05 | 58704. | 55877. | 52017. | 48051. | 2.512E-05 | 106727. | 106217. | 9206. | 8608. | 8436. | 8112. |
| 2.291E-05 | 62944. | 60077. | 56297. | 51451. | 2.291E-05 | 114777. | 114317. | 9274. | 8608. | 8436. | 8112. |
| 2.089E-05 | 67444. | 64497. | 60817. | 55051. | 2.089E-05 | 123277. | 122817. | 9344. | 8608. | 8436. | 8112. |
| 1.905E-05 | 72204. | 69137. | 65697. | 58851. | 1.905E-05 | 132227. | 131817. | 9416. | 8608. | 8436. | 8112. |
| 1.738E-05 | 77224. | 74097. | 70817. | 62951. | 1.738E-05 | 141627. | 141217. | 9490. | 8608. | 8436. | 8112. |
| 1.585E-05 | 82504. | 79377. | 76297. | 67451. | 1.585E-05 | 151477. | 151117. | 9566. | 8608. | 8436. | 8112. |
| 1.445E-05 | 88044. | 84977. | 81917. | 72151. | 1.445E-05 | 161777. | 161417. | 9644. | 8608. | 8436. | 8112. |
| 1.318E-05 | 93844. | 90897. | 87697. | 77251. | 1.318E-05 | 172527. | 172117. | 9724. | 8608. | 8436. | 8112. |
| 1.202E-05 | 99904. | 97137. | 93817. | 82751. | 1.202E-05 | 183727. | 183317. | 9806. | 8608. | 8436. | 8112. |
| 1.096E-05 | 106224. | 103697. | 100297. | 88251. | 1.096E-05 | 195377. | 194917. | 9890. | 8608. | 8436. | 8112. |
| 1.000E-05 | 112804. | 110497. | 107097. | 94051. | 1.000E-05 | 207477. | 207017. | 9976. | 8608. | 8436. | 8112. |
| ... | | | | | | | | | | | |
| 1.000E-06 | 4663. | 5557. | 6423. | 7373. | 1.000E-06 | 7922. | 8425. | 8671. | 8608. | 8436. | 8112. |
| Belw. Lim. | 0. | 0. | 0. | 0. | Belw. Lim. | 0. | 0. | 0. | 0. | 0. | 0. |

Figure 17 ARCON96 cumulative frequency distribution file for example 1

As you look at the results in Figure 18 notice that there are a number of χ/Q values that are below the lower limit of the χ/Q bins. These values occur during light winds when the vertical velocity of the vent release is sufficiently large that release is treated as if it were from a stack.

ARCON96

```

Number of Meteorological Data Files = 1
Meteorological Data File Names
  example.MET

Height of lower wind instrument (m) = 10.0
Height of upper wind instrument (m) = 92.1
Wind speeds entered as meters/second

Vent release
Release height (m) = 29.0
Building Area (m^2) = 1730.0
Effluent vertical velocity (m/s) = 5.00
Vent or stack flow (m^3/s) = 15.70
Vent or stack radius (m) = 1.00

Direction .. intake to source (deg) = 083
Wind direction sector width (deg) = 90
Wind direction window (deg) = 038 ~ 128
Distance to intake (m) = 18.0
Intake height (m) = 25.0
Terrain elevation difference (m) = .0

Output file names
  ex2_96.log
  ex2_96.cfd

Minimum Wind Speed (m/s) = .5
Surface roughness length (m) = .10
Sector averaging constant = 4.0

Initial value of sigma y = .00
Initial value of sigma z = .00

Expanded output for code testing not selected

Total number of hours of data processed = 8760
Hours of missing data = 10
Hours direction in window = 1774
Hours elevated plume w/ dir. in window = 714
Hours of calm winds = 750
Hours direction not in window or calm = 6226

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL
AVER. PER.      1      2      4      8      12      24      96      168      360      720
UPPER LIM.  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02
LDW LIM.    1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06
ABOVE RANGE  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
IN RANGE   1643.     2021.     2661.     3628.     4399.     5946.     8458.     8608.     8436.     8112.
BELOW RANGE  167.      404.      552.      670.      683.      425.      114.      0.         0.         0.
ZERO       6940.     6317.     5513.     4396.     3655.     2345.     99.        0.         0.         0.
TOTAL X/Qs  8750.     8742.     8726.     8694.     8737.     8716.     8671.     8608.     8436.     8112.
% NON ZERO  20.69     27.74     36.82     49.44     58.17     73.10     98.86     100.00    100.00    100.00

95th PERCENTILE X/Q VALUES
1.94E-03  1.93E-03  1.87E-03  1.76E-03  1.52E-03  1.10E-03  6.79E-04  5.40E-04  4.28E-04  3.28E-04

95X X/Q for standard averaging intervals
0 to 2 hours      1.94E-03
2 to 8 hours      1.71E-03
8 to 24 hours     7.74E-04
1 to 4 days       5.37E-04
4 to 30 days      2.74E-04

HOURLY VALUE RANGE
MAX X/Q  MIN X/Q
CENTERLINE  9.59E-03  2.98E-31
SECTOR-AVERAGE  6.37E-03  6.91E-32

NORMAL PROGRAM COMPLETION

```

Figure 18 ARCON96 results for example 2

2.5.3 Example 3 -- Capped Vent Release

Repeat the problem in Example 2, except assume that the vent is capped. What changes occur as a result of the change in assumptions? How much difference do you think the change in assumptions makes in the 95th percentile χ/Qs ? You can check yourself by comparing the input and results sections of the log file shown in Figures 19 with the comparable file shown in Figures 18.

You should have set the vertical velocity to zero to represent the capped vent. Did you? Did you change the names of the output files before you tried to rerun the problem?

As you look at the results in the log file, compare the number of χ/Qs for 1-hour averages in Figures 18 and 19. There are no χ/Qs within an order of magnitude of the bottom of the range of bins when the vent is capped. The number of χ/Qs in the range of bins in Example 3 is larger than the number in and below the range in Example 2. The differences are the result of setting the vertical velocity of the effluent to zero in Example 3. When this is done, ARCON96 treats the vent release as a ground-level release.

Next notice that the 95th percentile χ/Qs in Example 3 are about a factor of 5 larger than those in Example 2. This difference in values illustrates the importance of checking on whether a vent is capped or not. Vents on the sides of structures that have horizontal flow should be treated the same as capped vents.

2.5.4 Example 4 -- Stack Release

The fourth example is a stack release. In this example, a 65-m stack is located 210 m from the intake at a bearing of 284°. The diameter of the stack exit is 2 m, and the nominal flow is 31.4 m³/s. The air intake is 25 m above grade. Assume that there is no change in grade between the locations of the intake and stack. Use the meteorological data file, assuming that the wind speeds in the file are now given in miles per hour and the wind measurement heights are 10 and 63.9 m. Name the output files ex4_96.log and ex4_96.cfd.

In addition to demonstrating that the χ/Qs calculated for this type of scenario are significantly lower than for ground or vent releases, this example shows one set of conditions under which the 95th percentile, 2-hour average χ/Q can exceed the 1-hour average. The results in Figure 20 show that the 95th percentile 1-hour χ/Q is 2.08×10^{-7} s/m³ and that the 2-hour value is 1.53×10^{-5} s/m³. The total χ/Qs line in Figure 20 shows that 8750 χ/Qs were considered in calculating the 95th percentile 1-hour average χ/Q , and 8742 were considered in calculating the 2-hour value. In both cases the 95th percentile χ/Q is exceeded by about 437 values.

To verify the result that the 1-hour value is lower than the 2-hour value is correct, look at the cumulative frequency distributions in Figure 21 which contains an excerpt from the output file ex4_96.cfd. The maximum 1-hour χ/Qs exceed the maximum 2-hour values as expected. But, the tail of the distribution is long and there is a small group of values in the tail. Reducing the highest values by 50 percent gives values that are still in the upper 5th percentile of the χ/Q distribution. As a result the 95th percentile 2-hour average χ/Q occurs at about 2.5×10^{-5} s/m³, while the corresponding 1-hour average at about 2.1×10^{-7} . Thus, it is apparent that the result is correct.

ARCON96

```

Number of Meteorological Data Files = 1
Meteorological Data File Names
  example.MET

Height of lower wind instrument (m) = 10.0
Height of upper wind instrument (m) = 92.1
Wind speeds entered as meters/second

Vent release
Release height (m) = 29.0
Building Area (m^2) = 1730.0
Effluent vertical velocity (m/s) = .00
Vent or stack flow (m^3/s) = 15.70
Vent or stack radius (m) = 1.00

Direction .. intake to source (deg) = 083
Wind direction sector width (deg) = 90
Wind direction window (deg) = 038 - 128
Distance to intake (m) = 18.0
Intake height (m) = 25.0
Terrain elevation difference (m) = .0

Output file names
  ex3_96.log
  ex3_96.cfd

Minimum Wind Speed (m/s) = .5
Surface roughness length (m) = .10
Sector averaging constant = 4.0

Initial value of sigma y = .00
Initial value of sigma z = .00

Expanded output for code testing not selected

Total number of hours of data processed = 8760
Hours of missing data = 10
Hours direction in window = 1774
Hours elevated plume w/ dir. in window = 0
Hours of calm winds = 750
Hours direction not in window or calm = 6226

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL
AVER. PER.      1      2      4      8      12      24      96      168      360      720
UPPER LIM.  1.00E-01  1.00E-01  1.00E-01  1.00E-01  1.00E-01  1.00E-01  1.00E-01  1.00E-01  1.00E-01  1.00E-01
LOW LIM.    1.00E-05  1.00E-05  1.00E-05  1.00E-05  1.00E-05  1.00E-05  1.00E-05  1.00E-05  1.00E-05  1.00E-05
ABOVE RANGE  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
IN RANGE    2524.      3250.      4075.      5154.      5980.      7252.      8606.      8608.      8436.      8112.
BELOW RANGE  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
ZERO        6226.      5492.      4651.      3540.      2757.      1464.      65.        0.         0.         0.
TOTAL X/Qs  8750.      8742.      8726.      8694.      8737.      8716.      8671.      8608.      8436.      8112.
% NON ZERO  28.85     37.18     46.70     59.28     68.44     83.20     99.25     100.00    100.00    100.00

95th PERCENTILE X/Q VALUES
  1.04E-02  9.89E-03  9.29E-03  8.69E-03  7.25E-03  5.57E-03  3.66E-03  2.99E-03  2.55E-03  2.07E-03

95% X/Q for standard averaging intervals
0 to 2 hours      1.04E-02
2 to 8 hours      8.12E-03
8 to 24 hours     4.00E-03
1 to 4 days       3.03E-03
4 to 30 days      1.82E-03

HOURLY VALUE RANGE
CENTERLINE        MAX X/Q      MIN X/Q
SECTOR-AVERAGE  1.61E-02    3.99E-03
                  1.11E-02    2.56E-03

```

NORMAL PROGRAM COMPLETION

Figure 19 ARCON96 results for example 3

Note that if the stack were much closer to the intake in this problem, all of the predicted concentrations would be orders of magnitude smaller than they are in Figures 20 and 21. While it is likely that most of the concentrations would be near zero, there is a possibility that the concentrations experienced under light wind conditions could be much higher than predicted by

```

Number of Meteorological Data Files = 1
Meteorological Data File Names
  example.MET

Height of lower wind instrument (m) = 10.0
Height of upper wind instrument (m) = 63.9
Wind speeds entered as miles per hour

Elevated release
Release height (m) = 65.0
Building Area (m^2) = .0
Effluent vertical velocity (m/s) = 10.00
Vent or stack flow (m^3/s) = 31.40
Vent or stack radius (m) = 1.00

Direction .. intake to source (deg) = 284
Wind direction sector width (deg) = 90
Wind direction window (deg) = 239 - 329
Distance to intake (m) = 210.0
Intake height (m) = 25.0
Terrain elevation difference (m) = .0

Output file names
  ex4_96.log
  ex4_96.cfd

Minimum Wind Speed (m/s) = .5
Surface roughness length (m) = .10
Sector averaging constant = 4.0

Initial value of sigma y = .00
Initial value of sigma z = .00

Expanded output for code testing not selected

Total number of hours of data processed = 8760
Hours of missing data = 10
Hours direction in window = 3118
Hours elevated plume w/ dir. in window = 1078
Hours of calm winds = 571
Hours direction not in window or calm = 5061

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL
AVER. PER.      1      2      4      8      12     24     96    168    360    720
UPPER LIM.  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03
LOW LIM.    1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07
ABOVE RANGE  0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
IN RANGE    702.       892.       1042.      1449.      1944.      3176.      5672.      6596.      7428.      8081.
BELOW RANGE 1551.      1765.      2111.      2236.      2770.      2990.      2723.      1987.      1008.      31.
ZERO        6497.      6085.      5573.      5009.      4023.      2550.      276.        25.         0.         0.
TOTAL X/Qs  8750.      8742.      8726.      8694.      8737.      8716.      8671.      8608.      8436.      8112.
% NON ZERO  25.75     30.39     36.13     42.39     53.95     70.74     96.82     99.71     100.00    100.00

95th PERCENTILE X/Q VALUES
2.08E-07  1.53E-05  1.58E-05  1.59E-05  1.22E-05  7.75E-06  4.72E-06  3.91E-06  3.71E-06  3.71E-06

95% X/Q for standard averaging intervals
0 to 2 hours      1.53E-05
2 to 8 hours      1.61E-05
8 to 24 hours     3.67E-06
1 to 4 days       3.71E-06
4 to 30 days     3.55E-06

HOURLY VALUE RANGE
MAX X/Q  MIN X/Q
CENTERLINE  1.92E-04  1.36E-23
SECTOR-AVERAGE  1.21E-04  3.74E-24

```

NORMAL PROGRAM COMPLETION

Figure 20 ARCON96 results for example 4

ARCON96. If ARCON96 predicts that all concentrations are near zero, another method should be used to estimate maximum concentrations.

ARCON96

| X/Q CUMULATIVE FREQUENCY DISTRIBUTIONS | | | | | | | | | | | |
|--|-------|-------|-------|-------|------------|-------|-------|-------|-------|-------|-------|
| X/Q | 1 | 2 | 4 | 8 | X/Q | 12 | 24 | 96 | 168 | 360 | 720 |
| Abv. Lim. | 0. | 0. | 0. | 0. | Abv. Lim. | 0. | 0. | 0. | 0. | 0. | 0. |
| ... | | | | | | | | | | | |
| 2.089E-04 | 0. | 0. | 0. | 0. | 2.089E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.905E-04 | 6. | 1. | 0. | 0. | 1.905E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.738E-04 | 6. | 1. | 0. | 0. | 1.738E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.585E-04 | 7. | 1. | 0. | 0. | 1.585E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.445E-04 | 7. | 1. | 0. | 0. | 1.445E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.318E-04 | 10. | 1. | 0. | 0. | 1.318E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.202E-04 | 11. | 1. | 0. | 0. | 1.202E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.096E-04 | 15. | 1. | 0. | 0. | 1.096E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 1.000E-04 | 17. | 1. | 0. | 0. | 1.000E-04 | 0. | 0. | 0. | 0. | 0. | 0. |
| 9.120E-05 | 20. | 12. | 3. | 0. | 9.120E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 8.318E-05 | 25. | 12. | 4. | 0. | 8.318E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 7.586E-05 | 29. | 16. | 6. | 0. | 7.586E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 6.918E-05 | 34. | 22. | 9. | 0. | 6.918E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 6.310E-05 | 53. | 39. | 11. | 0. | 6.310E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 5.754E-05 | 66. | 46. | 14. | 4. | 5.754E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 5.248E-05 | 91. | 65. | 25. | 8. | 5.248E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 4.786E-05 | 115. | 88. | 53. | 14. | 4.786E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 4.365E-05 | 146. | 109. | 65. | 25. | 4.365E-05 | 0. | 0. | 0. | 0. | 0. | 0. |
| 3.981E-05 | 189. | 137. | 96. | 33. | 3.981E-05 | 4. | 0. | 0. | 0. | 0. | 0. |
| 3.631E-05 | 214. | 171. | 116. | 47. | 3.631E-05 | 11. | 0. | 0. | 0. | 0. | 0. |
| 3.311E-05 | 246. | 199. | 153. | 59. | 3.311E-05 | 19. | 0. | 0. | 0. | 0. | 0. |
| 3.020E-05 | 275. | 236. | 191. | 83. | 3.020E-05 | 31. | 0. | 0. | 0. | 0. | 0. |
| 2.754E-05 | 288. | 262. | 222. | 99. | 2.754E-05 | 45. | 0. | 0. | 0. | 0. | 0. |
| 2.512E-05 | 304. | 288. | 259. | 158. | 2.512E-05 | 57. | 0. | 0. | 0. | 0. | 0. |
| 2.291E-05 | 311. | 323. | 300. | 207. | 2.291E-05 | 70. | 0. | 0. | 0. | 0. | 0. |
| 2.089E-05 | 323. | 357. | 329. | 257. | 2.089E-05 | 106. | 2. | 0. | 0. | 0. | 0. |
| 1.905E-05 | 335. | 390. | 367. | 306. | 1.905E-05 | 134. | 5. | 0. | 0. | 0. | 0. |
| 1.738E-05 | 339. | 413. | 389. | 352. | 1.738E-05 | 193. | 16. | 0. | 0. | 0. | 0. |
| 1.585E-05 | 348. | 430. | 435. | 438. | 1.585E-05 | 255. | 27. | 0. | 0. | 0. | 0. |
| 1.445E-05 | 357. | 448. | 461. | 468. | 1.445E-05 | 321. | 47. | 0. | 0. | 0. | 0. |
| 1.318E-05 | 367. | 468. | 490. | 505. | 1.318E-05 | 376. | 78. | 0. | 0. | 0. | 0. |
| 1.202E-05 | 370. | 469. | 536. | 556. | 1.202E-05 | 445. | 112. | 0. | 0. | 0. | 0. |
| 1.096E-05 | 378. | 477. | 568. | 605. | 1.096E-05 | 529. | 163. | 0. | 0. | 0. | 0. |
| 1.000E-05 | 384. | 489. | 609. | 646. | 1.000E-05 | 600. | 210. | 0. | 0. | 0. | 0. |
| 9.120E-06 | 393. | 497. | 637. | 691. | 9.120E-06 | 639. | 293. | 28. | 0. | 0. | 0. |
| 8.318E-06 | 400. | 509. | 660. | 734. | 8.318E-06 | 706. | 374. | 79. | 7. | 0. | 0. |
| 7.586E-06 | 410. | 521. | 685. | 780. | 7.586E-06 | 766. | 454. | 98. | 36. | 0. | 0. |
| 6.918E-06 | 419. | 532. | 696. | 826. | 6.918E-06 | 817. | 545. | 106. | 72. | 0. | 0. |
| 6.310E-06 | 420. | 540. | 712. | 868. | 6.310E-06 | 884. | 674. | 145. | 106. | 0. | 0. |
| 5.754E-06 | 423. | 542. | 714. | 936. | 5.754E-06 | 933. | 796. | 243. | 146. | 0. | 0. |
| 5.248E-06 | 425. | 550. | 722. | 992. | 5.248E-06 | 1006. | 984. | 296. | 179. | 47. | 0. |
| 4.786E-06 | 427. | 563. | 734. | 1040. | 4.786E-06 | 1068. | 1103. | 413. | 215. | 183. | 0. |
| 4.365E-06 | 427. | 573. | 738. | 1067. | 4.365E-06 | 1123. | 1244. | 551. | 303. | 326. | 11. |
| 3.981E-06 | 429. | 582. | 765. | 1088. | 3.981E-06 | 1210. | 1359. | 741. | 389. | 370. | 146. |
| 3.631E-06 | 432. | 593. | 777. | 1107. | 3.631E-06 | 1244. | 1478. | 906. | 606. | 436. | 480. |
| 3.311E-06 | 432. | 597. | 792. | 1143. | 3.311E-06 | 1335. | 1617. | 1065. | 886. | 662. | 662. |
| 3.020E-06 | 432. | 600. | 797. | 1146. | 3.020E-06 | 1367. | 1678. | 1338. | 1109. | 933. | 794. |
| 2.754E-06 | 432. | 605. | 810. | 1152. | 2.754E-06 | 1409. | 1720. | 1549. | 1357. | 1164. | 1186. |
| 2.512E-06 | 432. | 607. | 825. | 1159. | 2.512E-06 | 1461. | 1801. | 1801. | 1676. | 1429. | 1622. |
| 2.291E-06 | 432. | 607. | 836. | 1173. | 2.291E-06 | 1499. | 1913. | 2083. | 2008. | 1711. | 1935. |
| 2.089E-06 | 432. | 607. | 845. | 1202. | 2.089E-06 | 1542. | 2016. | 2232. | 2163. | 2120. | 2246. |
| 1.905E-06 | 432. | 613. | 856. | 1226. | 1.905E-06 | 1559. | 2086. | 2310. | 2334. | 2441. | 2541. |
| 1.738E-06 | 432. | 613. | 868. | 1241. | 1.738E-06 | 1576. | 2164. | 2533. | 2543. | 2848. | 2757. |
| 1.585E-06 | 432. | 613. | 871. | 1255. | 1.585E-06 | 1598. | 2259. | 2790. | 2808. | 3036. | 2956. |
| 1.445E-06 | 432. | 613. | 874. | 1274. | 1.445E-06 | 1622. | 2317. | 2913. | 2982. | 3245. | 3224. |
| 1.318E-06 | 432. | 613. | 876. | 1285. | 1.318E-06 | 1652. | 2393. | 3050. | 3220. | 3389. | 3451. |
| 1.202E-06 | 432. | 613. | 880. | 1317. | 1.202E-06 | 1663. | 2469. | 3308. | 3313. | 3480. | 3769. |
| 1.096E-06 | 432. | 613. | 880. | 1327. | 1.096E-06 | 1682. | 2570. | 3387. | 3479. | 3677. | 3867. |
| 1.000E-06 | 432. | 613. | 886. | 1343. | 1.000E-06 | 1706. | 2620. | 3527. | 3820. | 3880. | 3917. |
| ... | | | | | | | | | | | |
| 1.000E-07 | 702. | 892. | 1042. | 1449. | 1.000E-07 | 1944. | 3176. | 5672. | 6596. | 7428. | 8081. |
| Belw. Lim. | 1551. | 1765. | 2111. | 2236. | Belw. Lim. | 2770. | 2990. | 2723. | 1987. | 1008. | 31. |

Figure 21 ARCON96 cumulative frequency distribution for example 4

2.5.5 Comparison of ARCON95 and ARCON96 Results

These first four examples for point sources are the same examples that were contained in NUREG/CR-6331. These examples have been rerun using ARCON96 to show the effect that changing the averaging procedure has had on χ/Q . Figure 22 compares the 95% χ/Q for the two codes for each example. The χ/Q s for the first two hours don't change because the change in the averaging procedure only affects averaging periods longer than two hours. The maximum differences in 95% χ/Q s calculated with the two codes occur in averaging periods between two and eight hours. For intervals in this range centerline χ/Q s are averaged in ARCON96, whereas sector-average χ/Q s were averaged in ARCON95. The χ/Q s for longer than four days are nearly identical because the change in averaging procedure only affects a small fraction (< 10%) of the hourly χ/Q values included in the average.

Table 1 shows the χ/Q s for the standard averaging intervals used in NRC control room habitability assessments. Notice that the χ/Q s for ARCON96 for the 2-hour to 8-hour averaging period are about a factor of 2 higher than the corresponding values calculated using ARCON95. This result is consistent with the change in averaging procedures. Also note that for averaging periods longer than 8 hours, ARCON96 gives lower 95% χ/Q s than ARCON95. This result is also correct and is consistent with the change in averaging procedures.

Table 1 Comparison of ARCON95 and ARCON96 95th percentile χ/Q s for standard averaging intervals used in control room habitability assessments

| | | Averaging Interval | | | | |
|-----------|---------|--------------------|----------|-----------|------------|-------------|
| | | 0 - 2 hr | 2 - 8 hr | 8 - 24 hr | 1 - 4 days | 4 - 30 days |
| Example 1 | ARCON95 | 1.43 E-3 | 4.73 E-4 | 5.70 E-4 | 4.62 E-4 | 3.76 E-4 |
| | ARCON96 | 1.43 E-3 | 1.04 E-3 | 5.46 E-4 | 4.49 E-4 | 3.75 E-4 |
| Example 2 | ARCON95 | 1.94 E-3 | 9.09 E-4 | 8.12 E-4 | 5.55 E-4 | 2.77 E-4 |
| | ARCON96 | 1.94 E-3 | 1.71 E-3 | 7.74 E-4 | 5.37 E-4 | 2.74 E-4 |
| Example 3 | ARCON95 | 1.04 E-2 | 4.25 E-3 | 4.29 E-3 | 3.16 E-3 | 1.83 E-3 |
| | ARCON96 | 1.04 E-2 | 8.12 E-3 | 4.00 E-3 | 3.03 E-3 | 1.82 E-3 |
| Example 4 | ARCON95 | 1.53 E-5 | 8.08 E-6 | 4.52 E-6 | 3.91 E-6 | 3.56 E-6 |
| | ARCON96 | 1.53 E-5 | 1.61 E-5 | 3.67 E-6 | 3.71 E-6 | 3.55 E-6 |

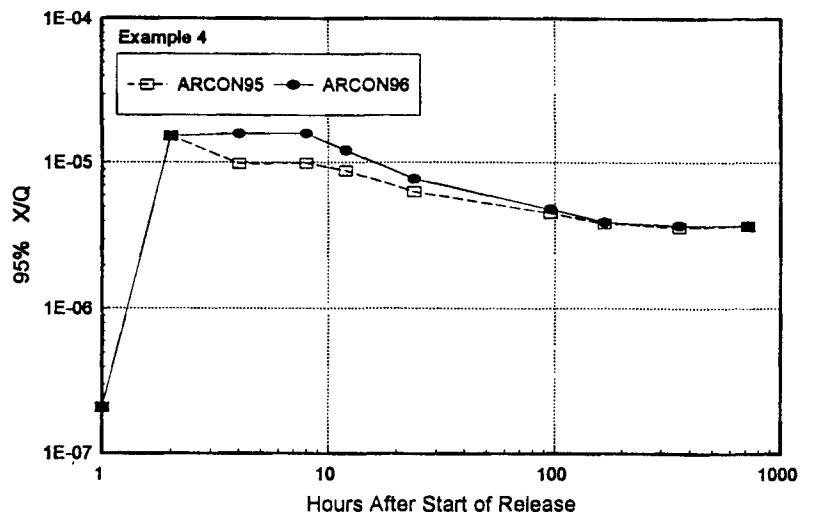
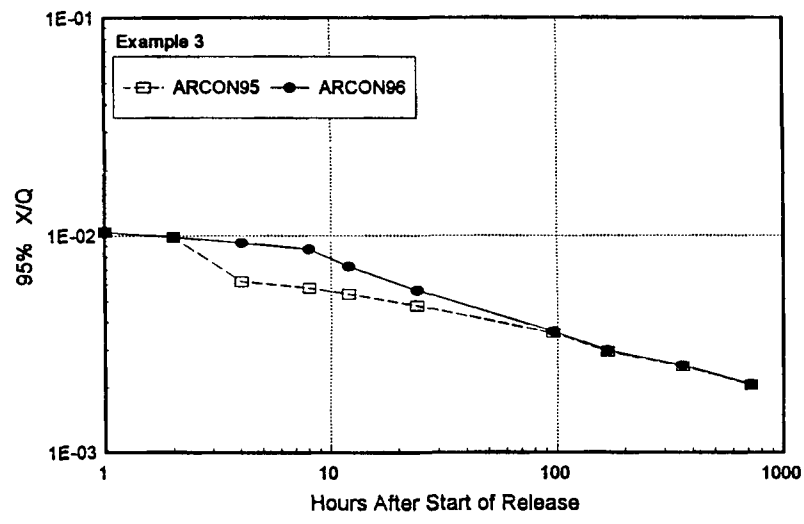
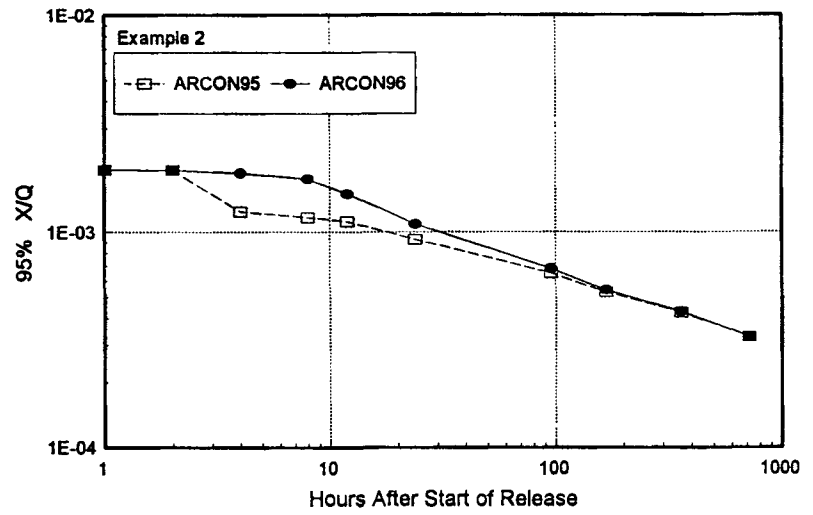
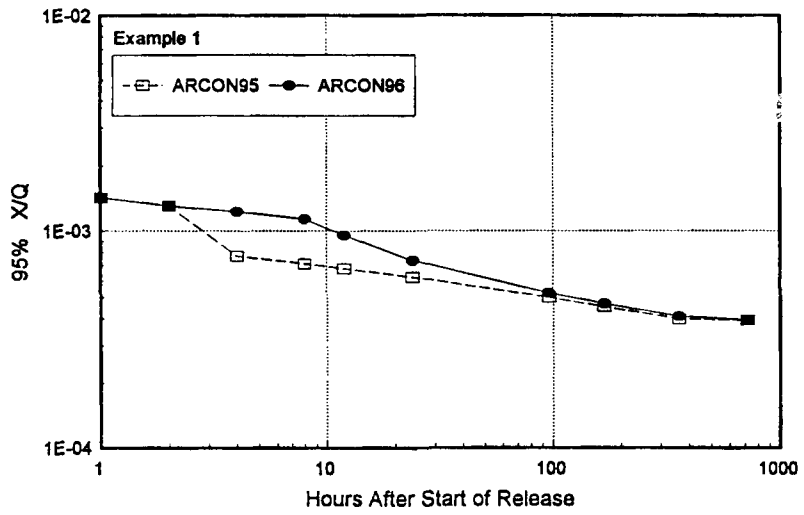


Figure 22 Comparison of ARCON95 and ARCON96 95th percentile χ/Q_s

2.5.6 Example 5 -- Multiple-Vent Release

Consider a release to the environment via a large open bay that is ventilated by 12 vents. Figure 23 shows a plan view of the roof. Note that there is air intake at the northwest corner of the roof. What is the relative atmospheric concentration at the air intake if the release occurs in the bay? Assume that the meteorological data in the file are representative of the site, that the wind measurements are made at elevations of 10 and 61 meters, and that the wind speeds are measured in meters per second. You may also assume the height of the roof is 20 meters above ground level, the building area is 1500 m². The vents are 1 m above the roof, have a radius of 0.5m, and are capped. Each vent has a flow of 5 m³/s. The intake is 3 m above the roof. The bearing and distance from the intake to the 12 vents are given in Table 2.

ARCON95 was designed to calculate relative dispersion (χ/Q) for releases from point sources. For example, there it has no problem calculating χ/Q s from individual vents; χ/Q s for the corner vents are included in Table 2. However, ARCON95 did not have an adequate method of estimating χ/Q at the intake when the release occurs simultaneously from 2 or more of the vents. You might assume that the relative concentration at the intake is the average of the relative concentration for each of the vents. However, the relative concentrations reported by

Table 2 Vent positions and intake χ/Q s for multiple-vent release scenario

| Vent | Bear. | Dist. | Averaging Interval | | | | |
|------|-------|-------|--------------------|----------|-----------|------------|-------------|
| | | | 0 - 2 hr | 2 - 8 hr | 8 - 24 hr | 1 - 4 days | 4 - 30 days |
| 1 | 161° | 47.5 | 1.87 E-3 | 1.09 E-3 | 3.75 E-4 | 3.76 E-4 | 3.39 E-4 |
| 2 | 145° | 54.5 | | | | | |
| 3 | 134° | 63.5 | | | | | |
| 4 | 126° | 75.0 | 6.96 E-4 | 4.44 E-4 | 1.54 E-4 | 1.53 E-4 | 1.38 E-4 |
| 5 | 169° | 61.5 | | | | | |
| 6 | 154° | 67.0 | | | | | |
| 7 | 143° | 75.5 | | | | | |
| 8 | 135° | 85.0 | | | | | |
| 9 | 169° | 76.5 | 8.22 E-4 | 4.92 E-4 | 1.72 E-4 | 1.64 E-4 | 1.50 E-4 |
| 10 | 158° | 81.0 | | | | | |
| 11 | 149° | 87.5 | | | | | |
| 12 | 141° | 96.5 | 4.60 E-4 | 2.98 E-4 | 9.42 E-5 | 1.04 E-4 | 9.33 E-5 |
| A1 | 147° | 70.0 | 6.73 E-4 | 4.43 E-4 | 1.40 E-4 | 1.60 E-4 | 1.38 E-4 |
| A2 | 156° | 57.0 | 1.01 E-3 | 6.59 E-4 | 2.06 E-4 | 2.29 E-4 | 1.97 E-4 |

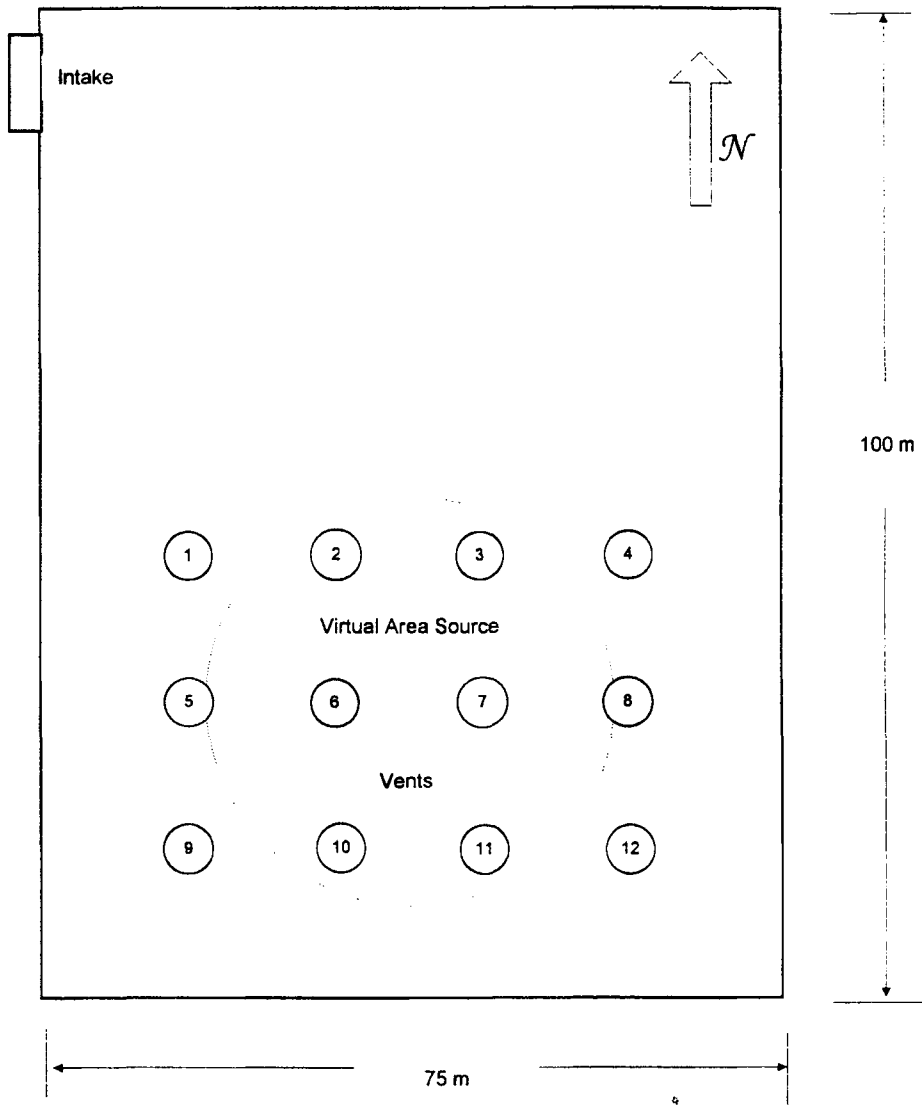


Figure 23 Multiple-vent release vent location diagram

ARCON95 are points on concentration distributions, not actual concentrations. There is no assurance that the average of the 95th percentile individual χ/Q s is the 95th percentile of the average χ/Q .

An alternative approach to estimating χ/Q at the intake is to assume that the release from the 12 vents acts as if the vents were an area source. ARCON96 permits specification of initial diffusion coefficients. These coefficients may be used to define a virtual area source. Methods for determining the initial diffusion coefficients that define a virtual area source involve subjective decisions. The following discussion illustrates one way in which the initial diffusion coefficients could be defined for this example.

- Assume 1) the area covered by the virtual area source is equal to the area of the rectangle formed by joining the centers of vents 1, 4, 9, and 12,
- 2) the center of the virtual area source is at the center of the rectangle. The distance between vent centers is 15 m.

The bearing and distance to the center of the virtual area source, A1, are given in Table 2.

To determine the characteristics of the area source we start by calculating its radius, r_A . The radius of the area source is

$$\begin{aligned}\pi r_A^2 &= 30 \times 45 = 1350 \text{ m}^2 \\ r_A &= 20.73 \text{ m}\end{aligned}\tag{1}$$

A virtual area source with radius r_A is shown in Figure 23.

Next, we estimate the initial horizontal diffusion coefficient from the radius. In a Gaussian distribution, approximately 90% of the area under the curve is within $\pm 2.15 \sigma$ of the center. On this basis, the edge of plumes have frequently been assumed to be $2.15 \sigma_y$ from the center, where σ_y is a horizontal diffusion coefficient. Therefore, we assume that the initial diffusion coefficient for the virtual area source σ_{y0} is

$$\begin{aligned}\sigma_{y0} &= r_A / 2.15 \\ &= 9.64 \text{ m}\end{aligned}\tag{2}$$

For the initial vertical diffusion coefficient, σ_{z0} , we note that the vents are 1 m above the roof and capped. On this basis we assume an initial vertical diffusion coefficient of 1 m.

The 95th percentile relative concentrations for this virtual source are shown in Table 2. In addition, the input data and results sections of the ARCON96 primary output file for this example are shown in Figure 24. Note that a stack radius of 10 m was entered. This is the upper limit of the range of acceptable values for stack radius. However, stack radius is only used for plume downwash calculations when the vertical velocity is greater than zero. If the vents had been uncapped, the radius and vertical velocity for an individual vent would be entered.

Other choices might be made for the area source, particularly if there is more information about the nature of the bay area and air flow within the bay. For example, if there were partitions in the bay that made it likely that the release would occur from vents 1, 2, 5, and 6, we might define an area source using these vents. The A2 row in Table 2 above gives the bearing and distance to the center of this area and the corresponding χ/Qs from ARCON96.

ARCON96

```

Number of Meteorological Data Files = 1
Meteorological Data File Names
EXAMPLE.MET

Height of lower wind instrument (m) = 10.0
Height of upper wind instrument (m) = 61.0
Wind speeds entered as meters/second

Vent release
Release height (m) = 21.0
Building Area (m^2) = 1500.0
Effluent vertical velocity (m/s) = .00
Vent or stack flow (m^3/s) = 60.00
Vent or stack radius (m) = 10.00

Direction .. intake to source (deg) = 147
Wind direction sector width (deg) = 90
Wind direction window (deg) = 102 - 192
Distance to intake (m) = 70.0
Intake height (m) = 23.0
Terrain elevation difference (m) = .0

Output file names
ex5e_96.log
ex5e_96.cfd

Minimum Wind Speed (m/s) = .5
Surface roughness length (m) = .10
Sector averaging constant = 4.0

Initial value of sigma y = 9.64
Initial value of sigma z = 1.00

Expanded output for code testing not selected

Total number of hours of data processed = 8760
Hours of missing data = 10
Hours direction in window = 2039
Hours elevated plume w/ dir. in window = 0
Hours of calm winds = 750
Hours direction not in window or calm = 5961

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL
AVER. PER.      1      2      4      8     12     24     96    168    360    720
UPPER LIM.    1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03  1.00E-03
LOW LIM.      1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07  1.00E-07
ABOVE RANGE   0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
IN RANGE     2789.      3495.      4387.      5628.      6591.      7595.      8664.      8608.      8436.      8112.
BELOW RANGE   0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
ZERO         5961.      5247.      4339.      3066.      2146.      1121.      9.         0.         0.         0.
TOTAL X/Qs   8750.      8742.      8726.      8694.      8737.      8716.      8673.      8608.      8436.      8112.
% NON ZERO   31.87     39.98     50.28     64.73     75.44     87.14     99.90     100.00    100.00    100.00

95th PERCENTILE X/Q VALUES
6.73E-04  6.23E-04  5.59E-04  5.00E-04  4.01E-04  2.60E-04  1.85E-04  1.69E-04  1.54E-04  1.44E-04

95X X/Q for standard averaging intervals
0 to 2 hours    6.73E-04
2 to 8 hours    4.43E-04
8 to 24 hours   1.40E-04
1 to 4 days     1.60E-04
4 to 30 days    1.38E-04

HOURLY VALUE RANGE
MAX X/Q  MIN X/Q
CENTERLINE  1.03E-03  2.12E-04
SECTOR-AVERAGE  6.63E-04  1.33E-04

NORMAL PROGRAM COMPLETION

```

Figure 24 ARCON96 results for example 5

2.5.7 Example 6 -- Diffuse Source Release

For the final example, consider the plant design shown in Figure 25. Now assume that an accident sequence at the plant results in releases from many openings on the southeast face of the

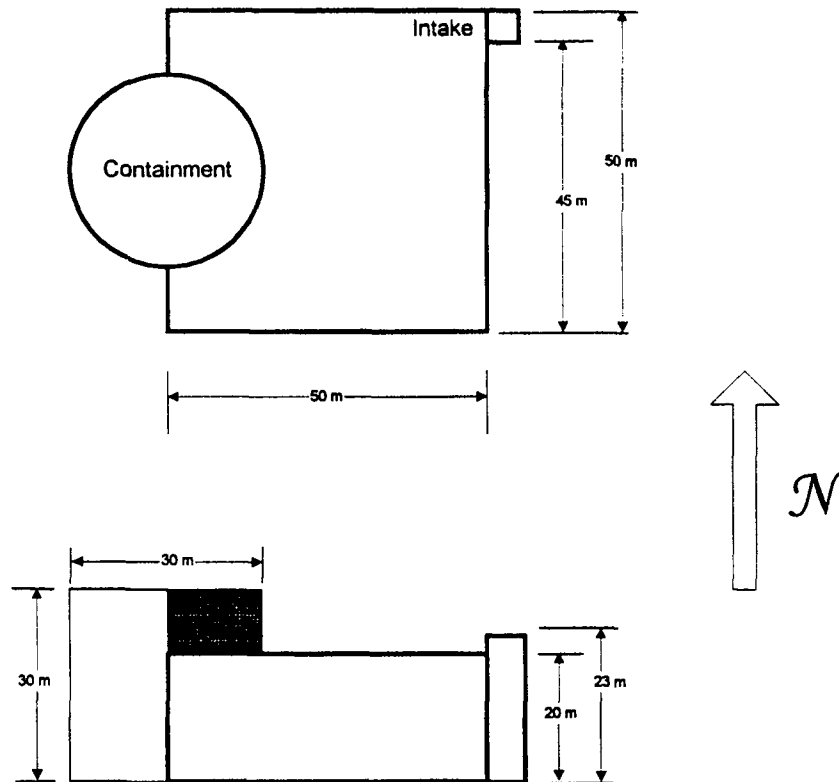


Figure 25 Diffuse-source release diagram

containment in the shaded area shown in the side view. Assume a building area of 2000 m^2 , that the bearing from the containment building wall to the intake is 240° , and that the average distance from the wall to the intake is 45 m. The meteorological data in EXAMPLE.MET were obtained at a representative location using wind instruments at 10 and 62 m above ground. The wind speeds are in meters per second. What are the 95% χ/Q_s for assessing control room habitability? Note that assumptions leading to estimates of the initial diffusion coefficients have been left to you.

One possible solution for this example is to make the following assumptions:

- 1) the source is a vertical area source (note that the previous example assumed a horizontal area source)
- 2) the release height is at the roof level
- 3) the initial vertical diffusion coefficient is 1/2 of the height of the exposed area (5 m)
- 4) the effective width of the area source is equal to the radius of the containment building (15 m) and that the initial horizontal diffusion coefficient is this width divided by 4.3
- 5) the intake height is 1.5 m above the roof.

ARCON96

With these assumptions ARCON96 calculates that the 95th percentile χ/Q at the intake for 0 to 2 hours is $1.19\text{e-}3 \text{ s/m}^3$. The full input data and results sections from the primary output file for this example are shown in Figure 26.

```

Number of Meteorological Data Files = 1
Meteorological Data File Names
  EXAMPLE.MET

Height of lower wind instrument (m) = 10.0
Height of upper wind instrument (m) = 62.0
Wind speeds entered as meters/second

Vent release
Release height (m) = 20.0
Building Area (m^2) = 2000.0
Effluent vertical velocity (m/s) = .00
Vent or stack flow (m^3/s) = .00
Vent or stack radius (m) = .00

Direction .. intake to source (deg) = 240
Wind direction sector width (deg) = 90
Wind direction window (deg) = 195 - 285
Distance to intake (m) = 45.0
Intake height (m) = 21.5
Terrain elevation difference (m) = .0

Output file names
  ex6_96.log
  ex6_96.cfd

Minimum Wind Speed (m/s) = .5
Surface roughness length (m) = .10
Sector averaging constant = 4.0

Initial value of sigma y = 3.50
Initial value of sigma z = 5.00

Expanded output for code testing not selected

Total number of hours of data processed = 8760
Hours of missing data = 10
Hours direction in window = 2677
Hours elevated plume w/ dir. in window = 0
Hours of calm winds = 750
Hours direction not in window or calm = 5323

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL
AVER. PER.      1      2      4      8      12      24      96      168      360      720
UPPER LIM.    1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02
LOW LIM.      1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06
ABOVE RANGE   0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
IN RANGE     3427.     4395.     5515.     6630.     7291.     8049.     8659.     8608.     8436.     8112.
BELOW RANGE   0.         0.         0.         0.         0.         0.         0.         0.         0.         0.
ZERO         5323.     4347.     3211.     2064.     1446.     667.      14.       0.         0.         0.
TOTAL X/Qs   8750.     8742.     8726.     8694.     8737.     8716.     8673.     8608.     8436.     8112.
% NON ZERO   39.17     50.27     63.20     76.26     83.45     92.35     99.84     100.00     100.00     100.00

95th PERCENTILE X/Q VALUES
.             1.19E-03  1.17E-03  1.12E-03  1.05E-03  8.76E-04  6.70E-04  4.36E-04  3.91E-04  3.50E-04  3.21E-04

95% X/Q for standard averaging intervals
0 to 2 hours   1.19E-03
2 to 8 hours   9.95E-04
8 to 24 hours  4.82E-04
1 to 4 days    3.59E-04
4 to 30 days   3.03E-04

HOURLY VALUE RANGE
CENTERLINE    MAX X/Q    MIN X/Q
SECTOR-AVERAGE  9.79E-04  1.85E-04

NORMAL PROGRAM COMPLETION

```

Figure 26 ARCON96 results for example 6

3 ARCON96 Technical Basis

The first part of this document is a User's Guide to the ARCON96 code. It provides basic information related to installation and operation of the ARCON96 code. This part of the documentation covers the technical basis for the code. It provides the information needed to understand and apply the results of the ARCON96 calculations. The last part of the document deals with the details of the computer code. It is intended for those who need to know about the organization of the code and the individual code modules.

3.1 Conceptual Model

The basic diffusion model implemented in the ARCON96 code is a straight-line Gaussian model that assumes the release rate is constant for the entire period of release. This assumption is made to permit evaluation of potential effects of accidental releases without having to specify a complete release sequence.

ARCON96 permits evaluation of ground-level, vent, and elevated releases. Building wake effects are considered in the evaluation of relative concentrations from ground-level releases. Vent releases are treated as a mixed ground-level and elevated release. The proportions of the mixture is determined by the ratio between the effluent vertical velocity and the release-height wind speed using the procedure included in the NRC XOQDOQ code (Sagendorf et al. 1982). Elevated releases are treated in the usual manner with correction for downwash and differences in terrain elevation between the stack and the control room intake.

Diffusion coefficients used in ARCON96 have three components. The first component is the diffusion coefficient used in other NRC models, for example XOQDOQ (Sagendorf, et al. 1982) and PAVAN (Bander 1982). The other two components are corrections to account for enhanced dispersion under low wind speed conditions and in building wakes. Derivations of the low wind speed and building wake corrections are described by Ramsdell and Fosmire (1995).

Parameter values for the correction factors are based on analysis of diffusion data collected in various building wake diffusion experiments. The experiments were conducted under a wide range of meteorological conditions. However, a large number of experiments were conducted during low wind speeds, when wake effects are minimal. The wake correction model included in ARCON96 treats diffusion under these conditions much better than previous models. Thus, the diffusion coefficients in ARCON96 account for both low-wind speed meander and wake effects.

ARCON96 calculates relative concentrations using hourly meteorological data. It then combines the hourly averages to estimate concentrations for periods ranging in duration from 2 hours to 30 days. Wind direction is considered as the averages are formed. As a result, the averages account for persistence in both diffusion conditions and wind direction. Cumulative frequency distributions are prepared from the average relative concentrations. Relative concentrations that are exceeded no more than five percent of the time (95th percentile relative concentrations) are determined from the cumulative frequency distributions for each averaging period. Finally, the relative concentrations for five standard averaging periods used in control room habitability assessments are calculated from the 95th percentile relative concentrations.

The following sections describe the model processes and components included in ARCON96. They also describe how the averages are formed, and how missing data are treated.

3.2 Diffusion Model

The ARCON96 code implements a straight-line Gaussian diffusion model. The basic model for a ground-level release is

$$\frac{\chi}{Q'} = \frac{1}{\pi \sigma_y \sigma_z U} \exp[-0.5(y/\sigma_y)^2] \quad (3)$$

where χ/Q' = relative concentration (concentration divided by release rate)
 $[(\text{ci}/\text{m}^3)/(\text{ci}/\text{s})]$
 σ_y, σ_z = diffusion coefficients (m)
 U = wind speed (m/s)
 y = distance from the center of the plume (m).

This equation assumes that the release is continuous, constant, and of sufficient duration to establish a representative mean concentration. It also assumes that the material being released is reflected by the ground. Diffusion coefficients are typically determined from atmospheric stability and distance from the release point using empirical relationships. A diffusion coefficient parameterization from the NRC PAVAN (Bander 1982) and XOQDOQ (Sagendorf et al. 1982) codes is used for σ_y and σ_z .

The diffusion coefficients have the general form

$$\sigma = a x^b + c \quad (4)$$

where x is the distance from the release point, in meters, and a , b , and c are parameters that are functions of stability. The parameters are defined for 3 distance ranges -- 0 to 100 m, 100 to 1000 m, and greater than 1000 m. The parameter values may be found in the listing of Subroutine NSIGMA1 in Appendix A.

3.2.1 Diffusion Coefficient Adjustments for Wakes and Low Wind Speeds

To estimate diffusion in building wakes, composite wake diffusion coefficients, Σ_y and Σ_z , replace σ_y and σ_z . The composite wake diffusion coefficients are defined by

$$\begin{aligned} \Sigma_y &= (\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2)^{1/2} \\ \Sigma_z &= (\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2)^{1/2} \end{aligned} \quad (5)$$

where σ_y and σ_z are the normal diffusion coefficients, $\Delta\sigma_{y1}$ and $\Delta\sigma_{z1}$ are the low wind speed corrections, and $\Delta\sigma_{y2}$ and $\Delta\sigma_{z2}$ are the building wake corrections. These corrections are described and evaluated in Ramsdell and Fosmire (1995). The form of the low wind speed corrections is

$$\begin{aligned}\Delta\sigma_{y1}^2 &= 9.13 \times 10^5 \left[1 - \left(1 + \frac{x}{1000U} \right) \exp\left(\frac{-x}{1000U} \right) \right] \\ \Delta\sigma_{z1}^2 &= 6.67 \times 10^2 \left[1 - \left(1 + \frac{x}{100U} \right) \exp\left(\frac{-x}{100U} \right) \right]\end{aligned}\tag{6}$$

where x is the distance from the release point to the receptor, in meters, and U is the wind speed in meters per second. It is appropriate to use the slant range distance for x because these corrections are made only when the release is assumed to be at ground level and the receptor is assumed to be on the axis of the plume. The diffusion coefficients corrections that account for enhanced diffusion in the wake have a similar form. These corrections are

$$\begin{aligned}\Delta\sigma_{y2}^2 &= 5.24 \times 10^{-2} U^2 A \left[1 - \left(1 + \frac{x}{10\sqrt{A}} \right) \exp\left(\frac{-x}{10\sqrt{A}} \right) \right] \\ \Delta\sigma_{z2}^2 &= 1.17 \times 10^{-2} U^2 A \left[1 - \left(1 + \frac{x}{10\sqrt{A}} \right) \exp\left(\frac{-x}{10\sqrt{A}} \right) \right]\end{aligned}\tag{7}$$

where A is the cross-sectional area of the building.

An upper limit is placed on Σ_y as a conservative measure. This limit is the standard deviation associated with a concentration uniformly distributed across a sector with width equal to the circumference of a circle with radius equal to the distance between the a source and receptor. This value is

$$\begin{aligned}\Sigma_{y\max} &= \frac{2\pi x}{\sqrt{12}} \\ &\approx 1.81 x\end{aligned}\tag{8}$$

The model described by Equations (3) through (7) is a replacement for the dispersion model in the control room habitability assessment procedure developed by Murphy and Campe (1974). Earlier building wake diffusion model studies conducted for the NRC (Ramsdell 1988, 1990) showed that the Murphy-Campe model did not predict the variations of the concentrations in the vicinity of buildings particularly well. The studies also showed that one of the primary reasons that the Murphy-Campe model did not predict concentration well was that it overpredicted concentrations during low wind speed conditions. The model described above overcomes the problems associated the Murphy-Campe model.

Figure 27 compares the relative concentration predictions of the two models as a function of wind speed for conditions that existed during diffusion experiments at seven reactor sites. The experiments are discussed in detail elsewhere (Ramsdell 1988, 1990). Figure 27 clearly shows that the primary differences in model predictions occur under low wind speed conditions. As a result, it is reasonable to assume that use of ARCON96 in place of the Murphy-Campe model would have the greatest effect at reactor sites with low average wind speeds. At those sites the effect of changing models would be a general reduction in the relative concentrations used to evaluate control room concentrations resulting from postulated reactor accidents.

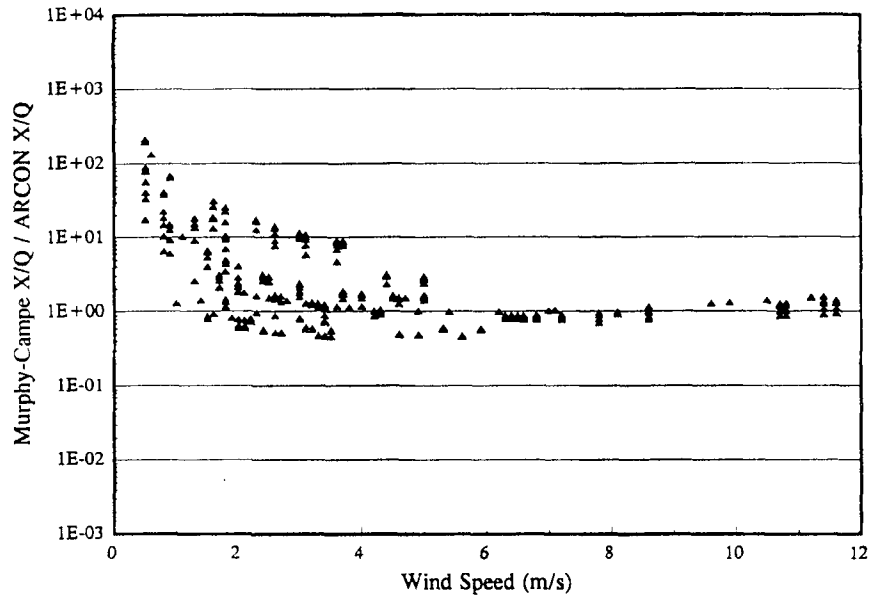


Figure 27 Murphy-Campe / ARCON concentration ratios by wind speed

Figure 28 compares the ratio of relative concentration predictions of the Murphy-Campe model to relative concentration predictions by the model in ARCON96 with relative concentrations observed in the field experiments. Ratios greater than one indicate that the Murphy-Campe model predicts higher concentrations than ARCON96, while ratios less than one indicate that ARCON96 predicts the higher concentrations. Data in the figure show that ARCON96 predicts some concentrations up to a factor of 2 higher than those predicted by the Murphy-Campe model. In contrast, there are numerous instances where ARCON96 predicts concentrations that are more than a factor of 10 lower than the Murphy-Campe model predictions. The figure also shows that the tendency for ARCON96 to predict lower concentrations than the Murphy-Campe model is rather uniform across the full range of observed concentrations.

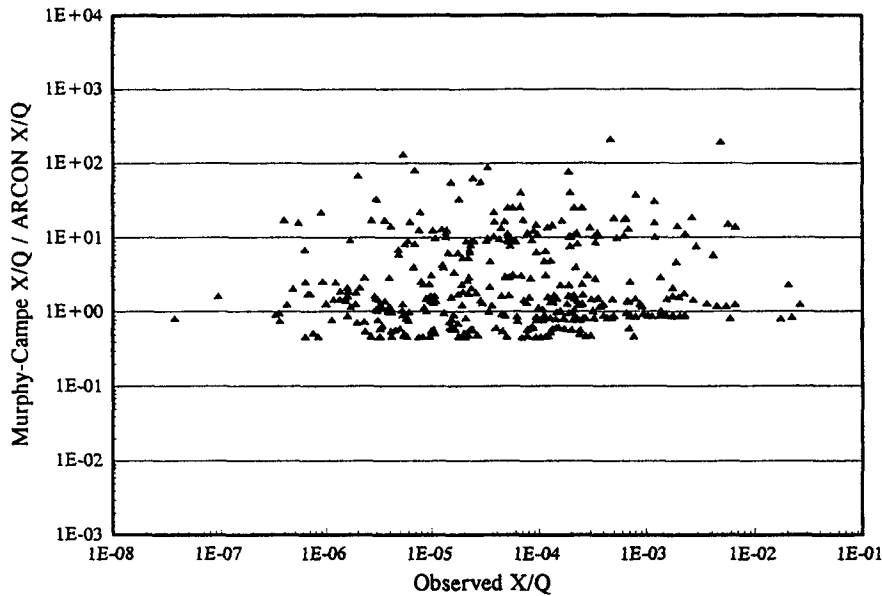


Figure 28 Murphy-Campe / ARCON concentration ratios by observed concentration

3.2.2 Sector-Average Diffusion Model

Equations (3) through (7) are appropriate for estimating relative concentrations for 1-hour periods. A sector-average relative concentration model is used to estimate concentrations for periods after the initial 0-8 hour period. The sector-average plume model is derived by integrating the concentration across the normal plume model to obtain a crosswind integrated concentration, CIC, which is

$$\begin{aligned} \frac{CIC}{Q'} &= \int_{-\infty}^{\infty} \frac{1}{\pi \Sigma_y \Sigma_z U} \exp\left[-0.5\left(\frac{y-y_0}{\Sigma_y}\right)^2\right] dy \\ &= \frac{2}{\sqrt{2\pi} \Sigma_z U} \end{aligned} \tag{9}$$

The relative concentration is then calculated by dividing CIC/Q' by the width of the sector, W_s

$$\begin{aligned} \frac{\chi_{sa}}{Q'} &= \frac{2}{\sqrt{2\pi} W_s \Sigma_z U} \\ &\approx \frac{0.80}{W_s \Sigma_z U} \end{aligned} \tag{10}$$

In most cases, the sector width is defined as the width of a 22.5° sector, which is a function of the distance downwind. This procedure works well except for small distances in unstable atmospheric conditions. In unstable atmospheric conditions the procedure gives sector average concentrations that are greater than the centerline concentration at small distances. This problem

can be avoided by redefining the definition of the sector width. For the ARCON96 code, the sector width is the larger of $\alpha \Sigma_y$, where α is a numerical constant with a value of 4, and $\pi x/8$, where x is the distance between source and receptor. The value of α is entered via the run specification file to permit use of values other than 4. The value of α is set in the Default Values form in the Visual Basic shell. Values in the range between 4 and 6 are reasonable. The default value of 4 was selected to be conservative. Approximately 95% of the material in a Gaussian plume is within $\pm 2 \Sigma_y$ of the plume axis.

To be consistent with the centerline model, and to be conservative, the sector width is limited to a maximum value. This maximum value is the circumference of a circle with a radius equal to the distance between the source and receptor, i.e.,

$$W_{\text{max}} = 2 \pi x \quad (11)$$

3.2.3 Elevated Release Diffusion Models

For elevated releases, the relative concentration is given by

$$\frac{\chi}{Q'} = \frac{1}{\pi \sigma_y \sigma_z U} \exp\left[-0.5 \left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-0.5 \left(\frac{h_c - h_i}{\sigma_z}\right)^2\right] \quad (12)$$

where h_c is the effect stack height and h_i is the height of the intake. Wake corrections are not made to diffusion coefficients used in calculating concentrations in elevated plumes. Effective stack height is determined from the actual stack height (h_s), the difference in terrain elevation between the stack and intake locations ($t_s - t_i$), and stack downwash (Δh_d) by

$$h_c = h_s + (t_s - t_i) + \Delta h_d \quad (13)$$

where the stack downwash is computed as

$$\Delta h_d = 4 r_s \left[\frac{w_o}{U(h_s)} - 1.5 \right] \quad (14)$$

and r_s is the radius of the stack, w_o is the vertical velocity of the effluent, and $U(h_s)$ is the wind speed at stack height. A release is considered elevated if the actual stack height is more than 2.5 times the height of structures in the immediate vicinity of the stack. Plume rise is not considered in calculating effective stack height in ARCON96. If consideration of plume rise is desired, the plume rise must be calculated manually and added to the release height before the release height is entered.

The sector-average model is used in calculating relative concentrations for elevated releases for averaging periods longer than 8 hours. The sector-average plume model for elevated releases may be derived in the same manner as the sector-average plume for ground-level releases. It is

$$\frac{\chi_{\text{sa}}}{Q'} = \frac{2}{\sqrt{2\pi} W_s \sigma_z U} \exp\left[-0.5 \left(\frac{h_c - h_i}{\sigma_z}\right)^2\right] \quad (15)$$

Note that use of the elevated plume models may lead to unrealistically low concentrations at control room intakes. Near the bases of stacks, the highest concentrations are likely to occur

during low wind speed conditions when there may be reversals in the wind direction. If a control room intake is near a stack and the concentrations predicted at the control room intake are all extremely low, other models should be used to estimate potential control room intake concentrations during low wind speed conditions.

3.2.5 Vent Release Diffusion Model

ARCON96 treats vent releases in addition to ground-level and elevated releases. A vent release is a release that takes place through a roof-top vent with an uncapped vertical opening. The treatment of these releases depends on the vertical velocity of the effluent and the wind speed at roof height. If the vertical velocity is more than 5 times the wind speed, the release is treated as an elevated release with a stack height equal to the height of the vent. If the vertical velocity is less than the wind speed, the release is treated as a ground-level release. Finally, if the vertical velocity is less than 5 times the wind speed but greater than the wind speed, the release is treated as a mixed-mode release based on the discussion in Regulatory Guide 1.111 (NRC 1977) and the implementation in XOQDOQ (Sagendorf et al. 1982).

The relative concentration for a mixed-mode release is a weighted average of the relative concentrations for elevated and ground-level releases. The weights for the mixed-mode release are determined as follows. An entrainment coefficient, E_t , is determined for those hours when w_v/U is between one and five:

$$E_t = 2.58 - 1.58\left(\frac{w_v}{U}\right) \quad \text{for } 1 < \frac{w_v}{U} \leq 1.5 \quad (16)$$

$$E_t = 0.3 - 0.06\left(\frac{w_v}{U}\right) \quad \text{for } 1.5 < \frac{w_v}{U} < 5$$

The weight given to the concentration from the ground-level plume is E_t , and the weight given to the elevated plume is $1 - E_t$.

3.2.6 Area Source Diffusion Model

The diffusion models incorporated in ARCON95 and ARCON96 are Gaussian models that assume that the release is from a point source. This assumption is reasonable for receptors (e.g. control room air intakes) that are "far downwind" from the release location. For area sources or a group of closely-spaced release points, "far downwind" may be defined in terms of a characteristic dimension associated with the source or combination of sources, although the selection of the characteristic dimension is subjective. For an area source the characteristic dimension could be the square root of the area. Similarly, for a group of closely-spaced release points, the characteristic dimension could be the radius of a circle that just encompasses the release points. If the distance between the source and the receptor is greater than about ten times the characteristic dimension of the source, a point source approximation is generally acceptable. If, however, the distance between the source and receptor is less than ten times the characteristic dimension, χ/Q_s calculated with point-source models will be too large because the models do not account for the finite dimensions of the source.

In ARCON95 the only method available for treating finite sources is by specifying a release flow. A second method has been added in ARCON96. In ARCON96 you may specify initial

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horizontal and vertical diffusion coefficients that are related to the characteristic dimensions of a source. The kind of rationale used to estimate initial diffusion coefficients from the characteristic dimensions of a source is illustrated in the last two example problems. The area source adjustment is made to the point source diffusion coefficients.

The ARCON96 computer code uses the initial diffusion coefficients to determine the distance from the center of the real source to virtual point source located upwind of the real source. Rearranging equation (4), the distance from the virtual point source to the center of the area source (virtual distance, x_v) is

$$x_v = \left(\frac{\sigma_o - c}{a} \right)^{1/b} \quad (17)$$

where σ_o is the initial diffusion coefficient. Virtual distances are calculated for both horizontal and vertical diffusion. It is unlikely that these two distances will be the same. The distances used in calculating σ_y and σ_z (the effective distances, x_e) are the sums of actual distance and the virtual distances.

Initial diffusion coefficients are entered using the Default Values form. The Default Values form is accessed through the pull-down menu displayed when you click on **Input** on the menu bar at the top of the screen.

Clicking on **Default** on the **Input** menu will display the Default Values form.

The horizontal diffusion coefficient is denoted as Sigma Y (σ_y), and Sigma Z (σ_z) is the vertical diffusion coefficient. The default value for both initial diffusion coefficients is zero. The range of acceptable initial values for σ_y is 0 to 100 m, and the range of acceptable initial values for σ_z is 0 to 50 m. Initial diffusion coefficients must be in meters.

3.3 Calm Winds

ARCON96 treats calm wind diffusion explicitly. The common derivation of the Gaussian plume model involves assumptions that eliminate the portion of the solution of the diffusion equation that describes diffusion when the wind speed approaches zero. An alternative, equally reasonable, derivation has been published by Frenkiel (1953). The basic assumptions in the derivation are that air motions do not cease even when the mean wind velocity approaches zero and that the diffusion coefficients are proportional to standard deviations of the wind fluctuations and the time following release. Frenkiel's model is described by Kao (1984).

Concentrations calculated by Frenkiel's model have a local minimum at $U = 0$. The concentration increases until it reaches a maximum at $U \approx 1$ m/s, and then it decreases as the U continues to increase. At high wind speeds, the concentration decreases proportional to $1/U$ as in the usual formulation of the Gaussian plume model. The exact wind speed at which the maximum occurs is a function of distance between source and receptor. It occurs at lower speeds for small distances.

The diffusion model described by Equation (3) has approximately the same behavior at low wind speeds as the Frenkiel model when the low wind speed corrections given by Equation (6) are applied to the normal diffusion coefficients. Therefore, ARCON96 uses Equation (3) with the low wind speed correction for calm wind conditions. Winds are defined as calm when the wind

speed falls below the minimum speed set in the Default Values form. This minimum speed is used for calculations when the winds speed are calm . This assumption yields concentrations that are within a few percent of the maximum for all distances.

Wind direction is not considered during calm winds. In all cases of calm winds the receptor is assumed to be directly downwind of the release point. This assumption should be conservative because it substitutes non-zero values of χ/Q for values that would normally be zero if wind direction were considered.

Building wake is not a significant factor at low wind speeds.

3.4 Vent/Stack Flow

The diffusion equations presented in Sections 3.2 and 3.3 assume point sources. Use of these equations to calculate concentrations at receptors near short stacks and vents can result in physically unreal concentration estimates. The concentrations calculated at the receptors can be higher than the concentrations in the stack or vent. ARCON96 limits the concentrations at receptors by allowing the user to specify the volumetric flow through the stack. Given an initial concentration estimate calculated using the equations previously described, relative concentrations corrected for stack flow, are calculated as

$$(\chi/Q')^* = \frac{1}{\frac{1}{\chi/Q'} + F} \quad (18)$$

where $(\chi/Q')^*$ is the corrected relative concentration and F is the flow.

3.5 Exposure Window

In computing average relative concentrations at the intake, ARCON96 assumes that material travels directly from the release point to the intake if the wind direction is within a window specified by the user. The wind direction window is based on the direction from the intake to release point and the angular width of the window. The direction from the intake to the release point is specified as part of the normal user input. The width of the window is taken from the Default Values form. It may be changed if necessary. The default width of the window is 90° ($\pm 45^\circ$ from the line between the release point and the intake). The actual window width is 1° wider than specified if the specified width is an even number and 1° narrower if it is odd.

3.6 Averaging Methods

Average relative concentrations are computed as running mean values. Overlapping mean values are used in compiling the χ/Q' cumulative frequency distributions. For periods 8 hours or less in duration, the average is based entirely on χ/Q' calculated using the centerline model:

$$\overline{\chi/Q'} = \frac{1}{N} \sum_{i=1}^N (\chi/Q')_i \quad (19)$$

For longer periods, the averages include both centerline and sector-average χ/Q' 's. They are calculated as:

$$\overline{\chi/Q'} = \frac{1}{N} \left[\sum_{i=1}^8 (\chi/Q')_i + \sum_{i=9}^N (\chi_{sa}/Q')_i \right] \quad (20)$$

3.7 Relative Concentrations for Standard Intervals

Standard Review Plan 6.4 (USNRC 1981) and various regulatory guides related to estimation of consequences of radionuclide releases following an accident require relative concentration estimates for various periods following the start of release. ARCON96 calculates concentrations for the following standard periods: 0 to 2 hours, 2 to 8 hours, 8 to 24 hours, 1 to 4 days, and 4 to 30 days. These values are calculated from the 95th percentile average relative concentrations as follows. The larger of the 1- and 2-hour average relative concentration is used for the 0-to 2-hour period. Average relative concentrations for the 2- to 8-hour period are calculated as

$$\overline{\chi/Q'}_{95}(2 \text{ to } 8 \text{ hr}) = \frac{8 \times \overline{\chi/Q'}_{95}(0 \text{ to } 8 \text{ hr}) - 2 \times \overline{\chi/Q'}_{95}(0 \text{ to } 2 \text{ hr})}{6 \text{ hr}} \quad (21)$$

where $\chi/Q'_{95}(0 \text{ to } 8 \text{ hr})$ and $\chi/Q'_{95}(0 \text{ to } 2 \text{ hr})$ are 95th percentile average values for 8 and 2 hours, respectively. The 6 hours in the denominator is the length of the averaging period. Relative concentrations for the remaining standard periods are calculated in the same manner.

3.8 Missing Data

ARCON96 uses time series of hourly meteorological data to properly account for the effects on wind direction persistence in reducing average relative concentrations for periods longer than 2 hours in duration. As a result, ARCON96 treats missing data by deleting hours with missing data from the calculation of the average relative concentrations used in determining the cumulative frequency distributions. Missing data tolerance criteria are used to determine when the number of hours of missing data make a specific average relative concentration unacceptable. The criterion for averages of 8 hours or less is zero missing data. For longer duration averages, up to 10% missing data are accepted. Averages are not calculated for periods in which the number of hours of missing data exceed the tolerance criteria. The missing data tolerance criteria are set in the run specification file. These criteria may be changed in the Default Value form.

The primary ARCON96 output contains a meteorological data summary and a summary of the relative concentrations by averaging intervals. These summary tables permit calculation of the number of averages not computed because of missing data.

Relative atmospheric concentrations (χ/Q_s') that are exceeded no more than 5% of the time during a year are determined from complementary cumulative frequency distributions of the averages for each averaging period. The basis for determining these values is the possible number of averages for the period minus the number of averages not available due to missing data. For example, assuming data for one year are being processed, there are 8760 possible hourly χ/Q' values. The 95th percentile relative concentration is that concentration exceeded by 438 values. However, if 10% of the data were missing, the 95th percentile relative concentration would be that concentration that is exceeded by 394 values.

4 Programmer's Guide to ARCON96

The first two parts of this document have dealt with ARCON96 from the user's perspective. They have provided the information needed to install and run the ARCON96 program and to understand and apply the results for the program. This part of the document deals specifically with the ARCON96 computer code. It is intended for individuals who may be called upon to revise the code or place the code in a different shell.

4.1 General Computational Approach

ARCON96 is implemented as a modular code. It includes three executable programs. Two of the programs are written in Visual Basic. They provide the shell program used for data input and permit ARCON96 to run one scenario after another without the user having to restart the program. The third program is written in FORTRAN. It performs ARCON96's computational tasks. This part of the document deals with the FORTRAN code.

The ARCON96 FORTRAN code consists of a main program to control the program execution and 14 subroutines and functions to handle the data and perform the model calculations. Each program unit is coded using a structured approach.

4.2 Code Languages

The computational portion of ARCON96 is written in standard ANSI FORTRAN-77 programming language, with some extensions designed to enhance code maintenance and promote structured programming style. Specific extensions used include long variable names, IMPLICIT NONE, INCLUDE and SELECT CASE statements, the DO WHILE and END DO statements.

The user interface is written in Visual Basic to provide a user-friendly shell. A second Visual Basic program links the FORTRAN-77 code and the shell to reduce computer memory requirements.

4.3 Coding Standards

The following coding standards are followed in all ARCON96 FORTRAN program units.

The code for each program unit includes two blocks:

- **definition block** - the definition block includes the program unit name, history, description, and relationship to other units and include files. It may also contain references, algorithm descriptions, and variable definitions.
- **code block** - code and comments.

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The code block in each FORTRAN program units begins with the statement `IMPLICIT NONE`. The type and dimensions of all variables are defined in type statements.

The primary method of passing variables between major program units is named common blocks. Common blocks contain related information, and the block name indicates the general nature of the information. The common blocks are defined in code segments contained in `INCLUDE` files. The `INCLUDE` files also contain `PARAMETER` statements, type definitions and dimensions associated with the variables defined in the file.

Argument lists are used to pass variables to subroutines and functions if use of a formal argument list facilitates program development, verification, and maintenance. Variables are passed to functions via argument lists. Common blocks are not used to pass information to functions.

Data statements used to define variables contained in common blocks are placed in a `BLOCK DATA` element. The `BLOCK DATA` element is included at the end of the file that contains the code for the main program.

The use of system dependent calls has been limited to two tasks. System calls in the ARCON96 main program get the name of the run specification file (data input file) from the command line invoking program execution, and system subroutines are used to get the date and time of program execution from the system clock and the cpu time used for various program functions.

Structured programming techniques (`IF ... THEN, ELSE IF... THEN, DO WHILE`) have been used, and the unnecessary use of statement numbers has been avoided. `END DO` statements have been used to decrease the number of statement numbers.

The ARCON96 code aborts execution in the event that an abnormal condition is encountered during execution of the code. Traps have been provided for abnormal conditions related to file operations, data input, and data output. In general, the error messages are written to the console, to the log file, and to other output files to describe the abnormal condition causing code execution to be aborted. However, when the program is run in the Visual Basic shell, the error messages may be overwritten before they can be read. If this happens, run ARCON96 from the DOS command line by typing ARCON96F followed by the run specification file name.

4.4 Data Input

ARCON96 runs in a batch mode. User interactions and data input are via data files except for input of the name of the run specification file and a name for the file used for expanded output if needed. The name of the run specification file is entered as a command line argument at the time code execution is initiated. If expanded output is selected in the run specification file, a name for the file will be requested as soon as program execution begins.

The files used to enter the information required by ARCON96 are described below.

4.4.1 Run Specification File

User input to the model for the purpose of program control is via a run specification file. The information included in the run specification file includes but is not limited to:

- run identification
- model option controls
- input data file names

In normal operation, the run specification file is created by the Visual Basic shell. It is an ASCII text file that can be modified in the Visual Basic shell or in a text editor.

The run specification file consists of 24 records if there is one meteorological data file. Each additional meteorological data file adds another record. The format for the run specification file is shown in Figure 29. The text on the right of the exclamation points is not part of a normal run specification file. It has been added to provide a brief explanation of the information being passed in the record. The format use to read the record is shown in parentheses at the end of the text.

| | | |
|------------------------------|--|--|
| 1 | | ! # of Met data files (i5) |
| EXAMPLE.MET | | ! Met data file names (a40) |
| 10.0 | | ! lower measurement height (f10.0) |
| 53.4 | | ! upper measurement height (f10.0) |
| 1 | | ! wind speed units type (i5) |
| 1 | | ! release type (i5) |
| 1.0 | | ! release height (f10.0) |
| 627.0 | | ! building area (f10.0) |
| 0.0 | | ! effluent vertical velocity (f10.0) |
| 0.0 | | ! stack or vent flow (f10.0) |
| 0.0 | | ! stack or vent radius (f10.0) |
| 201 90 | | ! direction to source and window (2i5) |
| 75. | | ! distance from to receptor (f10.0) |
| 0.0 | | ! intake height (f10.0) |
| 0.0 | | ! grade elevation difference (f10.0) |
| ARCON96.LOG | | ! primary output file name (a40) |
| ARCON96.CFD | | ! cfd file name (a40) |
| .1 | | ! surface roughness length (f10.0) |
| .5 | | ! minimum wind speed (calm) (f10.0) |
| 4.0 | | ! averaging sector width const (f10.0) |
| 1 2 4 8 12 24 96 168 360 720 | | ! hours in averages (10i4) |
| 1 2 4 8 11 22 87 152 324 648 | | ! minimum # of hours (10i4) |
| 0.00 0.00 | | ! initial σ_y and σ_z (2f10.0) |
| n | | ! flag for expanded output (a) |

Figure 29 Annotated run specification file

4.4.2 Meteorological Data Files

ARCON96 uses information contained in meteorological data files. The name/names of one or more meteorological data files must be passed to the program via the run specification file.

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The meteorological data file must have one record per hour. Each record must include the day of the year, the hour of the day, the stability, and the wind direction and wind speed at the lower measurement level. The record may also include a five-character location identifier, and a wind direction and speed for the upper level. The format for the records is:

(1x, A5, 3x, I3, I2, 2x, I3, I4, 1x, I2, 2x, I3, I4).

The order of information in the record is location identifier, Julian day, hour of the day, lower-level wind direction, lower wind speed, stability class, upper wind direction, and upper wind speed. Julian day is the day of the year and ranges from 1 to 366. The hour is entered using a 24-hour clock with midnight being entered as hour 0.

Wind directions are entered in degrees. A north wind (wind from the north) is entered as 360°, and a south wind is entered as 180°. Wind speeds are entered to the nearest tenth of a reporting unit without the decimal. A wind speed of 5.3 m/s would be entered as 53, while a speed of 5 m/s would be entered as 50.

Atmospheric stability is entered as a number from 1 through 7. A stability class of 1 represents extremely unstable conditions, and a stability class of 7 represents extremely stable conditions. Any other number will be interpreted as missing data.

4.5 Model Output

Normal ARCON96 output consists of two files. The first file is a run log. The run log documents the ARCON96 run and is the primary output file. It includes the program name and version number, appropriate disclaimers, the date and time of program execution (taken from the computer clock), a listing of the data entered via the run specification file, summary statistics related to the relative concentration calculations and the cumulative frequency distributions. The second file contains a heading record and the relative concentration cumulative frequency distributions. The primary output file is described in detail and examples of the log and cumulative distribution files are shown in the User's Guide.

When expanded output is selected in the run specification file, ARCON96 will create a third output file. This file contains information that may be used for code trouble-shooting and code verification. The expanded output file is called the QA_file in the program. It includes the following information:

- values for scenario-dependent parameters calculated during program initialization
- a listing of the meteorological data read by the program
- a listing of the hourly centerline and sector-average χ/Q_s calculated by the program along with the meteorological data used in the calculations
- frequency distributions for each of the averaging periods.

Consequently, the size of the expanded output file can become large. It approaches one megabyte when the meteorological data file contains data for a full year.

4.6 Program Description

The ARCON96 code consists of three executable programs. Two of these programs, ARCONVB and ARCONVB2 are primarily used for user input and to permit users to run several scenarios in rapid succession without having to restart the program. The third executable program, ARCON96F, does the calculations. Figure 30 shows the interactions among these programs.

Figure 31 shows the same organization but emphasizes the program functions rather than the program names. In addition, Figure 31 shows all three of the output files. The breaks between the programs are shown by dashed lines.

The following sections describe the ARCON96 FORTRAN code in detail. The main program and each of the subroutine and functions that comprise the code are discussed. Flow charts are provided for the main program and those program elements that calculate, process, and summarize the χ/Q_s . Appendix A contains a listing of the FORTRAN code, and Appendix B is a glossary of variable used in more than one ARCON96 program element.

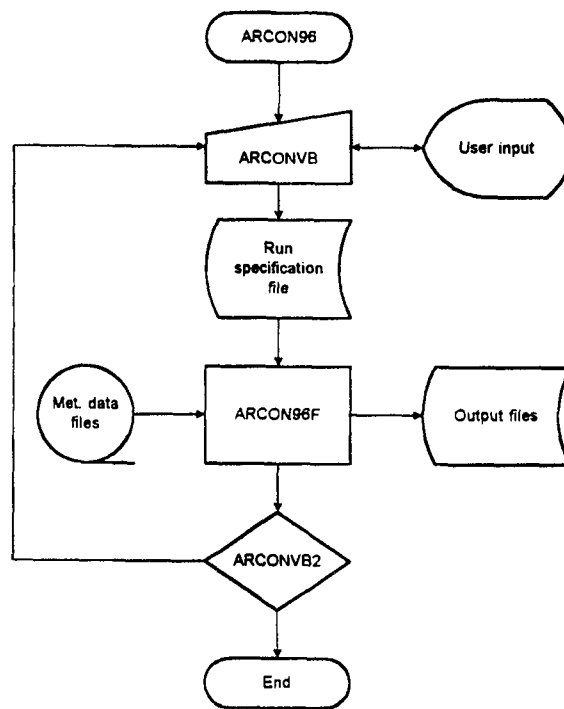


Figure 30 ARCON96 executable code organization

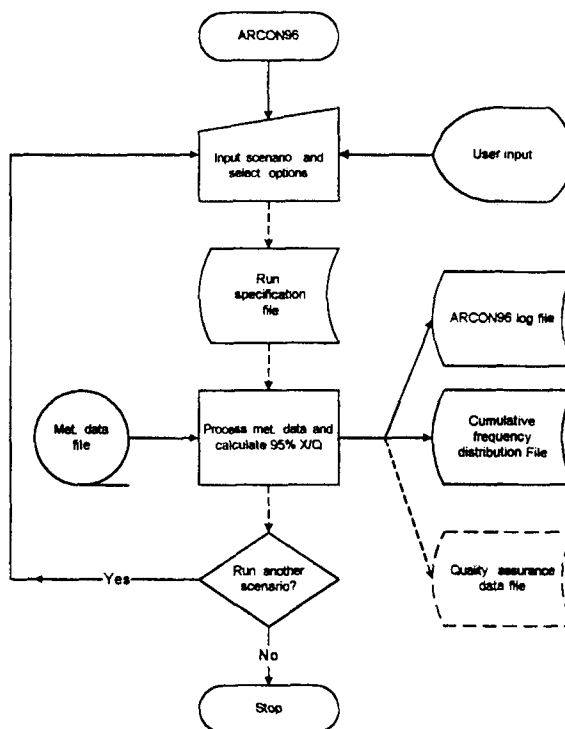


Figure 31 ARCON96 executable code organization by function

4.6.1 ARCON96

ARCON96 is the main program. It provides the general framework for the code. ARCON96 contains three parts -- an initialization section, main program section, and an end section. The initialization section determines the date and time of model execution and calls program elements used to initialize the code. The main section of the code controls the flow of the program as it reads meteorological data files, calculates hourly relative concentrations, combines the hourly concentrations into averages for longer periods, and stores the results of these calculations in frequency distributions. The end section of the program summarizes the results of the calculations when all meteorological data have been processed and writes the results of the calculations to the log and cumulative frequency distribution files. When the results have been written to these files, the end section writes a message indicating normal model termination in the log file, and closes files, as appropriate.

Figure 32 shows the logical organization of ARCON96 FORTRAN code. The initialization section of the program is shown at the top of the flow chart. The main section of the program starts with reading the meteorological data and ends when all meteorological data have been read and processed. When there are no more data to be processed, the program enters its final phase. Here the cumulative frequency distributions and 95th percentile χ/Q_s are calculated and written to the output files. This flow chart also shows which portions of the program write to each of the files.

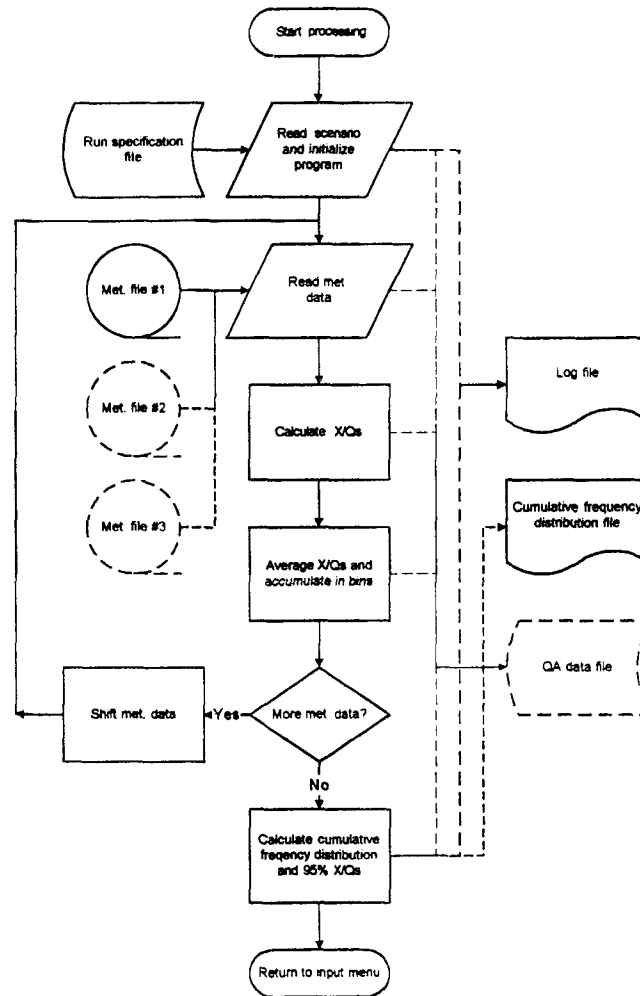


Figure 32 ARCON96 FORTRAN code organization

The organization of the program elements in the FORTRAN code is shown in Figure 33. Each rectangular box in the figure represents a subroutine or function. The flow of information in the code can be followed by noting the arrows. The single-headed arrows are generally associated with subroutines and functions called directly from the ARCON96 code. The two-headed arrows show calls to subroutines and functions that are not called directly by ARCON96.

Data transfer in ARCON96 is generally by named common blocks. These blocks are found in sections of code that are maintained separately in what are called "include files." These files are incorporated in the main program and subroutines when the program elements are compiled. Five "include files" are part of ARCON96. Each of these files contains information related to a specific area of the code. For example, the MET.INC file contains the meteorological data and associated information. Similarly, the SCENARIO.INC file contains information on the release point/receptor geometry, and the XOQ.INC file contains information related to χ/Q_s . In contrast, the PARAM.INC and UNITS.INC files are directly related to the code operations.

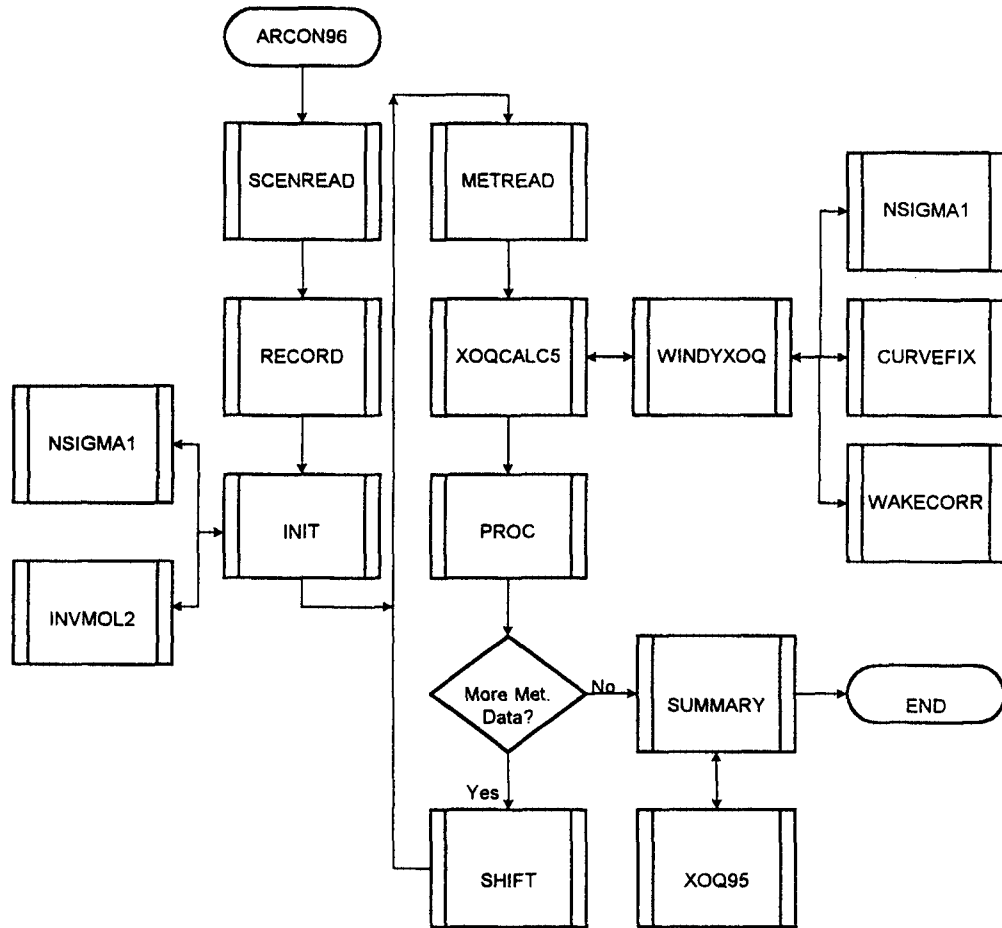


Figure 33 ARCON96 program element organization

The PARAM.INC file contains the parameters that limit the number of hours of meteorological data that can be stored within the program and the number of meteorological data files that can be processed in any run. These parameters are used as dimensions for arrays. The UNITS.INC file contains the variables that store file names and the logical unit assigned to each of the files. Table 3 shows the program elements and the "include files" that are incorporated in each element.

4.6.2 Subroutine CURVEFIX

Subroutine CURVEFIX calculates low-wind speed corrections to the diffusion coefficients used in the PAVAN (Bander 1982) and XOQDOQ (Sagendorf et al. 1982) programs. These corrections, which are described in Section 3.2, are functions only of distance and wind speed. Ramsdell and Fosmire (1995) present a detailed derivation and evaluation of the equations used to calculate the correction factors.

Table 3 Relationship between INCLUDE blocks and program elements

| PROGRAM ELEMENT | INCLUDE BLOCK | | | | |
|-----------------|---------------|-------|----------|-------|-----|
| | MET | PARAM | SCENARIO | UNITS | XOQ |
| ARCON96 | XXX | XXX | XXX | XXX | XXX |
| BLOCK DATA | XXX | XXX | XXX | XXX | XXX |
| CURVEFIX | | | | | |
| INIT | XXX | XXX | XXX | XXX | |
| INVMOL2 | | | | | |
| METREAD | XXX | XXX | | XXX | XXX |
| NSIGMA1 | | | | | |
| PROC | | XXX | XXX | XXX | XXX |
| RECORD | XXX | XXX | XXX | XXX | XXX |
| SCENREAD | XXX | XXX | XXX | XXX | XXX |
| SHIFT | XXX | XXX | | XXX | XXX |
| SUMMARY | | XXX | XXX | XXX | XXX |
| WAKECORR | | | | | |
| WINDYXOQ | | | | | |
| XOQCALC5 | XXX | XXX | XXX | XXX | XXX |
| XOQ95 | | XXX | | XXX | |

4.6.3 Subroutine INIT

Subroutine INIT calculates several model parameters that are depend only on the scenario. These parameters include the standard NRC diffusion coefficients and factors that adjust the measured wind speeds to a standard 10-meter measurement height and the release height. The standard NRC diffusion curves are functions of stability class and the distance between the release point and the intake.

The wind speed adjustment factors are based on the diabatic wind profiles (Panofsky and Dutton 1984). They are functions of the wind speed measurement heights, the stability class, and the surface roughness at the site. The surface roughness is one of the model parameters that may be changed using the Default Values form. Its default value is 0.1 meter.

If the expanded output option is selected, subroutine INIT will write the diffusion coefficients and the wind speed adjustment factors to the quality assurance file.

4.6.4 Function INVMOL2

Function INVMOL2 converts the stability class to the reciprocal of the Monin-Obukhov length that is used in the diabatic wind profiles. The conversion is based on Figure 5 in a paper by Golder (1972). This figure, which is based on analysis of experimental data, shows Monin-Obukhov length ranges as a function of stability class and surface roughness length. Function INVMOL2 is based on a function by the same name in the RATCHET computer code (Ramsdell et al. 1994) that includes uncertainty in the conversion process.

4.6.5 Subroutine METREAD

Subroutine METREAD reads the meteorological data file one record at a time and places the input data in the meteorological data vectors. The required meteorological data format is described in Section 4.4.2.

The data are read in a loop that is terminated when either 1) there are 10,000 hours of data in the vector, or the subroutine reaches the end of the last meteorological data file. If the subroutine reaches the end of a data file before it reaches 10,000 hours, it closes the file and increments the variable NEXT_MET by one. If NEXT_MET doesn't exceed the total number of meteorological data files, the subroutine opens the next file and continues reading data. If NEXT_MET exceeds the number of data files, the subroutine sets the logical flag END_MET to .TRUE. and places the index of the last data record in the variable LAST_MET.

As the meteorological data are read, the data are checked to ensure that each value is within the appropriate range. The ranges are:

- Stability class 1 through 7
- Wind directions 001° through 360°
- Wind speed 000 through 750.

Recall that wind speeds are entered in tenths of the measurement unit. If an out-of-range value is detected, 99 is used to indicate an invalid stability class, 999 is used to indicate an invalid wind direction, and 9999 is used to indicate an invalid wind speed. If expanded output has been selected, MET_READ will write each input record to the quality assurance file. In addition, every 100 hours subroutine MET_READ writes the hour of the year to the screen.

4.6.6 Subroutine NSIGMA1

Subroutine NSIGMA1 calculates the initial diffusion coefficients using the algorithms for approximating the Pasquill-Gifford diffusion coefficient curves (Gifford 1961) described by Martin and Tikvart (1968) and Tadmor and Gur (1969). These algorithms are the same as algorithms used in PAVAN (Bander 1982) and XOQDOQ (Sagendorf et al. 1982). Given a distance and stability class as input, the subroutine returns a horizontal diffusion coefficient (σ_y) and a vertical diffusion coefficient (σ_z).

If initial values are entered for the diffusion coefficient, NSIGMA1 will determine virtual distances associated with the initial values. The virtual distances for the horizontal and vertical diffusion coefficients may not be the same. NSIGMA1 will then base its calculation of diffusion coefficients on effective distances, which are the sum of the actual and virtual distances.

4.6.7 Subroutine PROC

Subroutine PROC processes the hourly χ/Q data. It is called after the meteorological data have been read and subroutine XOQCALC5 has calculated the hourly χ/Q values. Subroutine PROC combines the hourly values into running mean values for averaging periods specified in the Default Values Form and accounts for the data in the χ/Q frequency distributions. If, during any period there are too many missing hourly values, subroutine PROC discards the period.

Figure 34 shows the procedure followed in subroutine PROC. The first time that subroutine PROC is called it sets the range of bins for the cumulative frequency distribution. The upper limit to the range for the 1-, 2-, 4-, and 8-hour average χ/Q s is based on the maximum 1-hour centerline χ/Q encountered in the first 10,000 hours of data. The upper limit for longer period averages is based on the maximum sector-average χ/Q .

The subroutine then steps through the hourly χ/Q values and averaging periods. The procedure used to calculate the running mean χ/Q s uses the current hourly χ/Q and the oldest hourly χ/Q included in the current average. If the current χ/Q is good, it is added to a running sum and the counter associated with the sum is incremented. If there are sufficient good values in the sum, a new running mean is calculated and the value is counted in the appropriate frequency distribution bin. Next, the subroutine checks the oldest value. If it is good, the value is subtracted from the sum and the counter is decremented to prepare for processing the next hour.

4.6.8 Subroutine RECORD

Subroutine RECORD writes the information read from the run specification file by Subroutine SCENREAD to the primary output (log) file. In addition, the subroutine writes the lower and upper bounds for the wind direction window used to determine when effluent from the release point reaches the intake and the name of the expanded output file to the log file. Combined with Subroutine SCENREAD, Subroutine RECORD provides users with the opportunity to confirm that the scenario used in ARCON96 calculations is the intended scenario.

4.6.9 Subroutine SCENREAD

Subroutine SCENREAD reads the run specification file identified in the command line invoking the ARCON96F FORTRAN code. This file, which contains the user input to ARCON96, is described in detail in Section 4.4.1. In addition to reading the run specification file, the subroutine performs two functions. It calculates the lower and upper bounds of the wind direction window that determines when the plume reaches the intake, and it requests a file name for the expanded output file when expanded output is selected in the run specification file.

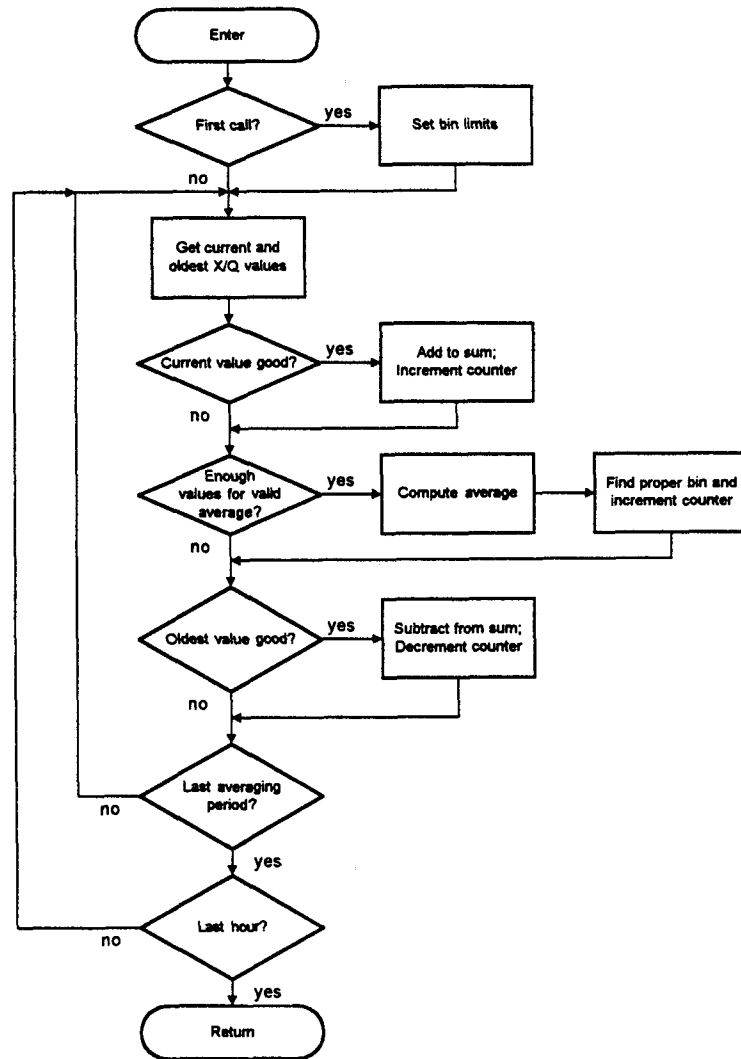


Figure 34 Subroutine PROC organization

4.6.10 Subroutine SHIFT

Subroutine SHIFT is called when processing of available data is complete and there is more meteorological data. The subroutine determines the length in hours, n , of the longest averaging period. It then moves the stability, wind, and hourly χ/Q data for the last $n-1$ hours from the ends of the vectors containing these data to the beginning of the vectors.

After the data have been moved, the subroutine sets the variable FIRST_MET to n . FIRST_MET is the index of the meteorological data vectors where the first new meteorological data will be placed. FIRST_XOQ will be set to this value in subroutine XOQCALC5 after it completes calculating the hourly χ/Q values.

4.6.11 Subroutine SUMMARY

Subroutine SUMMARY is the primary output routine for ARCON96. It is called after all meteorological data have been read and after all hourly χ/Q s have been calculated and processed. Then, subroutine SUMMARY calculates totals and writes summary statistics to the log file. If expanded output has been selected, subroutine SUMMARY writes the χ/Q frequency distributions to the quality assurance file. It calculates the cumulative frequency distributions and writes them to the cumulative frequency distribution file.

After the cumulative frequency distributions have been written, subroutine SUMMARY calls subroutine XOQ95, which calculates the χ/Q for each averaging period that is exceeded no more than 5 percent of the time. These 95th percentile χ/Q s are written to the log file by subroutine SUMMARY. The last section of subroutine SUMMARY calculates the 95th percentile χ/Q s for standard averaging intervals, e.g., 2 to 8 hours and 8 to 24 hours.

Figure 35 shows a flow chart for subroutine SUMMARY.

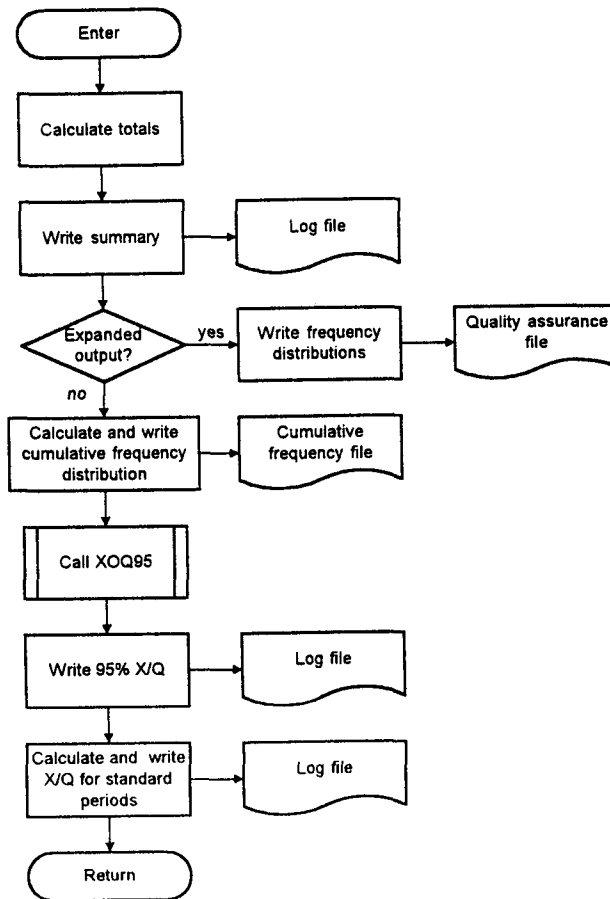


Figure 35 Subroutine SUMMARY organization

4.6.12 Subroutine WAKECORR

Subroutine WAKECORR calculates the building-wake corrections to the diffusion coefficients calculated by subroutine NSIGMA1. The corrections are functions of the building cross-sectional area, wind speed, and distance from the release point to the receptor. These corrections are described in Section 3.2. Ramsdell and Fosmire (1995) present a detailed derivation of the equations used to calculate the corrections.

4.6.13 Subroutine WINDYXOQ

Subroutine WINDYXOQ is used to calculate the hourly centerline and sector-average χ/Q s. When the wind is less than the minimum wind speed set in the Default Values form, the subroutine is called with the minimum wind speed regardless of wind direction. When the wind speed is greater than the minimum speed, the subroutine is called only if the wind direction falls within the wind direction window. In this case, the 10-meter wind is used if the release is at ground level (≤ 10 meters) and the release-height wind is used if the release is at a height greater than 10 meters.

The argument list for subroutine WINDYXOQ includes all of the parameters that define the release point, the release point-receptor geometry, and the meteorological conditions. It also includes the release type definition supplied by the user in the Source Input form. This type of definition is specified by the value of the variable rtype. It is 1 for ground-level releases, 2 for vent releases, and 3 for stack releases.

Figure 36 shows the process followed in subroutine WINDYXOQ. If rtype is two or greater the χ/Q for a stack release is calculated, and if it is two or less, the χ/Q is calculated for a ground-level release.

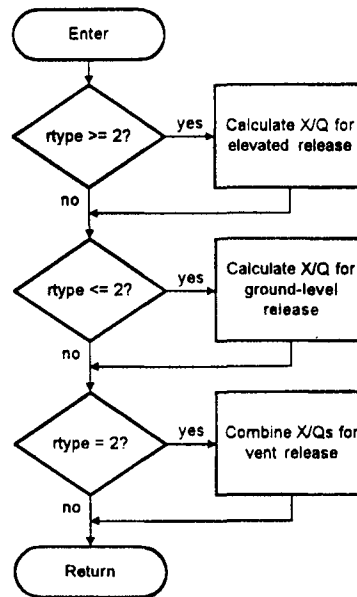


Figure 36 Subroutine WINDYXOQ organization

If rtype is two, the χ/Q is calculated for both an elevated release and a ground-level release. The two χ/Q values are combined to get a single value using the methodology for mixed-mode releases described in Section 3.2. This methodology follows the procedure described in Regulatory Guide 1.111 (NRC 1977) and implemented in the XOQDOQ computer code (Sagendorf et al. 1982).

4.6.14 Subroutine XOQCALC5

Subroutine XOQCALC5 processes the hourly meteorological data. It is called by ARCON96 following subroutine MET_READ. When subroutine XOQCALC5 is called, it steps through the meteorological data an hour at a time from the hour specified in the variable FIRST_MET to the hour specified in LAST_MET. The first time subroutine WINDYXOQ is called, FIRST_MET will be 1, in all subsequent calls FIRST_MET will be equal to the longest averaging period defined in the Default Values form. LAST_MET will be 10,000 until the last meteorological data file is read. Then it will have a value $\leq 10,000$ that is the index of the end of the meteorological data read from the last meteorological data file.

Figure 37 shows the procedure followed as subroutine XOQCALC5 processes the meteorological data. First the subroutine checks the stability class. If the stability class is missing, the subroutine cannot calculate a χ/Q . Consequently, the subroutine sets both the centerline and sector-average χ/Q s to -1.0 to indicate missing values. Next, the subroutine checks to see if both wind speeds are missing. If they are, the χ/Q s are set to -1.0. If either wind speed is present, the 10-meter and release-height wind speeds are calculated.

The subroutine then checks for calm winds. If the wind is less than the minimum wind speed set in the Default Values form, subroutine WINDYXOQ is called with the minimum speed as the wind speed. In this case the wind direction is not checked because the effluent is assumed to drift from the release point to the receptor regardless of wind direction.

Finally, if the wind is not calm, the subroutine checks the wind direction. If both wind directions are missing, the χ/Q s are set to -1.0. When the wind direction entry appears valid, the direction is compared with the wind direction window that contains the wind directions assumed to carry the effluent from the release point to the receptor. If the wind direction is not in the window, the χ/Q s are set to 0.0. Otherwise, subroutine XOQCALC5 calls subroutine WINDYXOQ to calculate the hourly χ/Q s.

After all hourly χ/Q s have been calculated, subroutine XOQCALC5 updates the record of maximum hourly values. These values are used to set the range of bins for the χ/Q frequency distributions the first time subroutine PROC is called, and the final values are written to the log file. The last task performed by subroutine XOQCALC5 prior to returning to the main program is to set the values of FIRST_XOQ, LAST_XOQ, and TOT_XOQ.

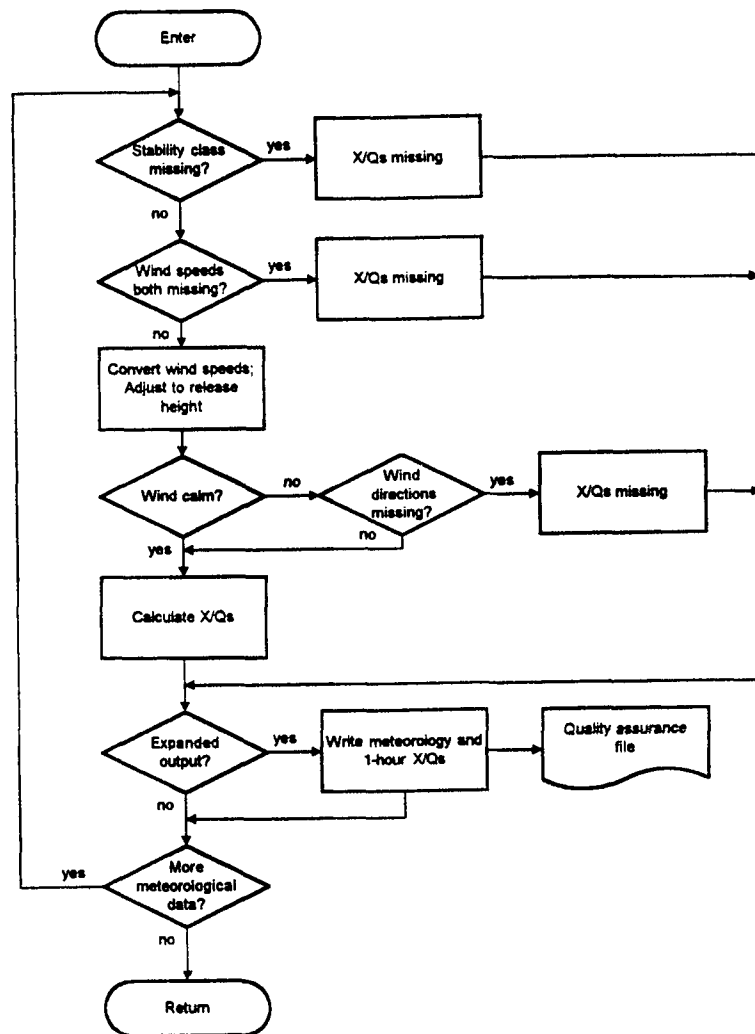


Figure 37 Subroutine XOQCALC5 organization

4.6.15 Subroutine XOQ95

Subroutine XOQ95 calculates the 95th percentile χ/Q for each averaging period. The subroutine starts by checking the number of averages calculated for each period. If fewer than 20 averages were calculated, the subroutine sets the 95th percentile value to 0.0 and skips further calculations.

When the number of averages is sufficient to permit calculation of the 95th percentile value, the subroutine calculates the number of hours represented by five percent of the total number of averages. It then searches the cumulative frequency distribution bins to find the bin containing the 95th percentile χ/Q . The 95th percentile χ/Q can not be determined if this bin is the bin used to count the number of values above the range of the cumulative frequency distribution. In this case, the 95th percentile χ/Q is set to -99999. If the 95th percentile χ/Q is in the bin that is

used to count the number of values below the range, the 95th percentile χ/Q is set to the lower bound of the range. Finally, if the 95th percentile χ/Q falls in a bin within the cumulative frequency distribution range, the 95th percentile χ/Q is calculated by linear interpolation between the upper and lower bounds of the bin.

4.7 Quality Assurance

ARCON95 was developed and tested in accordance with the requirements of ANSI/ASME NQA-1, 1986 edition (ASME 1986), *Quality Assurance Program Requirements for Nuclear Facilities*, as interpreted by the PNNL Quality Assurance (QA) Program. PNNL QA procedures have been used to determine specific Quality Assurance requirements. In addition to the use of the programming standards listed above the following measures undertaken to ensure program quality:

- Individual program elements that perform calculations have been tested independently. The tests include hand checks of representative calculations. The functioning of these elements was then rechecked in conjunction with tests of other program elements when ARCON95 was run.
- Program elements involved in data input were checked by writing input data to output files and comparing the data in the input and output files. This process also checked the storage and transfer of input data within ARCON95.
- A series of test cases were run using the full ARCON95 code. These test cases exercised the range of program options. Input and output files for each of the test cases were examined for accuracy and consistency.
- The code was placed under configuration control at the beginning of the developer's code tests. Changes in the code during the tests are logged in the code of the program element changed.
- Following completion of the ARCON95 code and a draft of this manual, an independent review was conducted. This review included examination of the design specification for ARCON95, the ARCON95 code, the records of the code tests by the developer, and this manual. No coding errors were identified during the review. This user's guide has been revised based on the reviewer's comments.
- The ARCON95 code included a disclaimer during development that stated that the code had not completed quality assurance tests. This disclaimer and the date of the code version were written to the ARCON95 log until the quality assurance tests were completed. The disclaimer was removed from the output and the ARCON95 code was recompiled with a version date and time of April 1, 1995, 7:00 am.
- The files distributed as part of Version 1.0 of ARCON95 have all been given an April 1, 1995 date and a 7:00 a.m. time.

Following the code modifications leading to ARCON96, the example problems in NUREG/CR-6331 were rerun. In each case the 1- and 2-hour χ/Q s calculated by ARCON96 were the same as those calculated by ARCON95. In addition, the 95th percentile 4- and 8-hour average χ/Q s

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for examples 1 and 4 calculated by ARCON96 were a factor of 1.6 larger than those calculated by ARCON95. Given equations (3) and (10) and equations (12) and (15) and the default assumptions in ARCON96, the ratios of centerline concentrations to sector-average concentrations should be 1.6. Further, the variation of the ratios between ARCON96 and ARCON95 95th percentile concentrations decreases to 1.0 as expected as the averaging period increases beyond 8 hours. This behavior demonstrates that the changes in the averaging method in ARCON96 were implemented correctly.

The implementation of the area source algorithm was tested initially by checking the virtual distance and diffusion coefficient computations in subroutine NSIGMA1. It was further tested by checking the computation of hourly values of χ/Q . The results of these checks demonstrate that the area source algorithm is correct.

ARCON96 Version 1.0 has a version date and time of August 1, 1996, 12:00 pm. All files distributed as part of ARCON96 Version 1.0 have this date and time.

5 References

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Appendix A ARCON96 FORTRAN Computer Code

A.1 ARCON96

C*****

C

C ARCON96

C

C J. V. Ramsdell, Jr., C. A. Simonen
 C Pacific Northwest National Laboratory
 C P.O. Box 999
 C Richland, Washington 99352

C

C Created: April 24, 1996 from ARCON_BF

C

C Revised: May 9, 1997

C

C Description: Program to estimate X/Q for control room habitability

C

C assessments.

C

C Relationship to other Modules:

C

C Calls: SCENREAD --- Read user input
 C RECORD --- Record model input in log file
 C INIT --- Compute diffusion coefficients
 C and other constants that don't change
 C METREAD --- Read meteorological data
 C XOQCALC5 --- Calculate relative concentrations
 C PROC --- Compute averages and accumulate
 C counts in bins
 C SHIFT --- Move old meteorological data and X/Qs
 C to the beginning of the data arrays
 C before reading new data
 C SUMMARY --- Convert counts in bins to frequency
 C distributions and determine 95th %
 C X/Q values

C

C*****

IMPLICIT NONE

INCLUDE 'PARAM.INC'
 INCLUDE 'MET.INC'
 INCLUDE 'SCENARIO.INC'
 INCLUDE 'UNITS.INC'
 INCLUDE 'XOQ.INC'

LOGICAL*1 UO

CHARACTER*8 RTIME
 CHARACTER*10 RDATE

INTEGER*2 SHR, SMIN, SSEC, S100, EHR, EMIN, ESEC, E100
 INTEGER*2 YY, MM, DD, HH, MIN, SS, HS

REAL DETIME, PROCTIME, SUMTIME, XOQTIME

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C Get date and time of code execution

```

RDATE = ' / / '
RTIME = ' : : '
CALL GETDAT(YY,MM,DD)
CALL GETTIM(HH,MIN,SS,HS)
WRITE( RDATE(1:2), '(I2)' ) MM
WRITE( RDATE(4:5), '(I2)' ) DD
WRITE( RDATE(7:10), '(I4)' ) YY
WRITE( RTIME(1:2), '(I2.2)' ) HH
WRITE( RTIME(4:5), '(I2.2)' ) MIN
WRITE( RTIME(7:8), '(I2.2)' ) SS

```

```

DETIME = 0.0
PROCTIME = 0.0
XOQTIME = 0.0
SUMTIME = 0.0

```

C Open Scenario Input File

```
OPEN( SCENUNIT, FILE=' ', STATUS='OLD', ERR=997 )
```

C Read Scenario Data

```
CALL SCENREAD
```

```

IF( TEST_FLG ) THEN
  OPEN(UNIT=qa_unit,FILE=qa_file,status='unknown')
  WRITE(*,'(2X,A,A)' ) 'qa_file = ', qa_file
ENDIF

```

C Open log file and output program name and run date

```
OPEN(UNIT=LOG_UNIT,FILE=LOG_FILE,STATUS='NEW', ERR=998)
```

```

WRITE(LOG_UNIT,1)
1 FORMAT(/
+ ' Program Title:  ARCON96.'//
+ ' Developed For:  U.S. Nuclear Regulatory Commission'/
+ '                  Office of Nuclear Reactor Regulation'/
+ '                  Division of Reactor Program Management'//
+ ' Date:           May 9, 1997      3:00 p.m. '//
+ ' NRC Contacts:   J. Y. Lee        Phone: (301) 415 1080'/
+ '                  e-mail: jy11@nrc.gov '/
+ '                  J. J. Hayes     Phone: (301) 415 3167'/
+ '                  e-mail: jjh@nrc.gov '/
+ '                  L. A. Brown     Phone: (301) 415 1232'/
+ '                  e-mail: lab2@nrc.gov '//
+ ' Code Developer: J. V. Ramsdell   Phone: (509) 372 6316'/
+ '                  e-mail: j_ramsdell@pnl.gov'//
+ ' Code Documentation:  NUREG/CR-6331 Rev. 1 '//
+ ' The program was prepared for an agency of the United States',
+ ' Government. Neither'/' the United States Government nor any',

```



```

+ ' agency thereof, nor any of their'/' employees, makes any',
+ ' warranty, expressed or implied, or assumes any legal'/'
+ ' liability or responsibilities for any third party''s use,',
+ ' or the results of such'/' use, of any portion of this',
+ ' program or represents that its use by such third'/' party',
+ ' would not infringe privately owned rights. ' / )

```

```

WRITE(LOG_UNIT, '(1X,A,2X,A,2X,A,2X,A)') 'Program Run',
+          RDATE, 'at', RTIME

```

C Record user input on log file

```
CALL RECORD
```

C Compute variables that are functions of the scenario and
C stability but not functions of wind speed or direction

```
CALL INIT
```

C Read and process data

```
DO WHILE ( .NOT. END_MET )
```

C Check on status of met data file, open new file if necessary

```
INQUIRE( UNIT=MET_UNIT, OPENED=UO )
```

```
IF( .NOT. UO ) THEN
```

C Open Meteorological Data File if another file exists

```
IF( NEXT_MET .LE. NMETFILE ) THEN
```

```
+ OPEN( MET_UNIT, FILE=MET_FILE(NEXT_MET), STATUS='OLD',
+     ERR=999 )
```

```
NEXT_MET = NEXT_MET + 1
```

```
ELSE ! No more meteorological data files
```

```
END_MET = .TRUE.
```

```
ENDIF
```

```
ENDIF
```

```
CALL GETTIM(SHR, SMIN, SSEC, S100)
```

C Read meteorological data files (<= 10,000 hours)

```
CALL METREAD
```

```
CALL GETTIM( EHR, EMIN, ESEC, E100)
```

```
+ DETIME = DETIME + 3600.*(EHR-SHR) + 60.*(EMIN-SMIN)
+           + (ESEC-SSEC) + (E100-S100)/100.
```

```
IF( TEST_FLG ) THEN
```

```
WRITE(qa_unit, '/2x,a)') 'ARCON95'
```

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```
WRITE(QA_UNIT, '(/5X,A,I6)') 'FIRST MET = ', FIRST_MET  
WRITE(QA_UNIT, '(5X,A,I6)') 'LAST MET = ', LAST_MET  
ENDIF
```

C Compute hourly X/Q values

```
CALL GETTIM(SHR, SMIN, SSEC, S100)
```

```
WRITE(*, '(//A)') ' CALCULATING X/Q '
```

```
CALL XOQCALC5
```

```
CALL GETTIM(EHR, EMIN, ESEC, E100)
```

```
XOQTIME = XOQTIME + 3600.*(EHR-SHR) + 60.*(EMIN-SMIN)  
+ (ESEC-SSEC) + (E100-S100)/100.
```

C Process first set of X/Q's -- set cfd limits, accumulate values

```
CALL GETTIM(SHR, SMIN, SSEC, S100)
```

```
WRITE(*, '(//A)') ' PROCESSING X/Q DATA'
```

```
CALL PROC
```

```
CALL GETTIM(EHR, EMIN, ESEC, E100)
```

```
PROCTIME = PROCTIME + 3600.*(EHR-SHR) + 60.*(EMIN-SMIN)  
+ (ESEC-SSEC) + (E100-S100)/100.
```

```
IF( .NOT. END_MET ) THEN
```

C Move residual met. data AND X/Q's to front of data arrays

```
CALL SHIFT
```

```
ENDIF
```

```
ENDDO ! End of data input and processing
```

C Summarize and output results of calculations

```
CALL GETTIM(SHR, SMIN, SSEC, S100)
```

```
WRITE(*, '(//A)') ' SUMMARIZING CALCULATIONS '
```

```
CALL SUMMARY
```

```
CALL GETTIM(EHR, EMIN, ESEC, E100)
```

```
SUMTIME = 3600.*(EHR-SHR) + 60.*(EMIN-SMIN)  
+ (ESEC-SSEC) + (E100-S100)/100.
```

C Normal end of program

```
IF( TEST_FLG ) THEN
```

```
        WRITE(qa_unit,'(/2x,a)') 'ARCON96'  
        WRITE( QA_UNIT,100) DETIME, XOQTIME, PROCTIME, SUMTIME  
100    FORMAT( /5X, 'DATA ENTRY TIME (SEC)           = ', F10.2,  
      .      /5X, 'X/Q COMPUTATION TIME (SEC)        = ', F10.2,  
      .      /5X, 'DATA PROCESSING TIME (SEC)         = ', F10.2,  
      .      /5X, 'SUMMARY TIME (SEC)                 = ', F10.2 )  
        CLOSE( QA_UNIT )  
      ENDIF  
  
      WRITE(LOG_UNIT,'(2X,/A)') ' NORMAL PROGRAM COMPLETION '  
  
      GO TO 1000  
  
C      Error end of program  
  
997 STOP  ' UNABLE TO OPEN SCENARIO INPUT DATA FILE '  
998 STOP  ' UNABLE TO OPEN LOG FILE ... CHECK FOR EXISTING NAME'  
999 WRITE( LOG_UNIT,'(2X,/A)' )  
      +    ' UNABLE TO OPEN METEOROLOGICAL DATA FILE '  
  
1000 CONTINUE  
  
      END
```

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A.2 BLOCK DATA

BLOCK DATA

INCLUDE 'PARAM.INC'
INCLUDE 'MET.INC'
INCLUDE 'SCENARIO.INC'
INCLUDE 'UNITS.INC'
INCLUDE 'XOQ.INC'

C Set I/O units

DATA SCENUNIT / 1 /, MET_UNIT / 2 /, LOG_UNIT / 3 /
DATA QA_UNIT / 10 /, CFD_UNIT / 11 /

C Initialize the met data counters

DATA END_MET / .FALSE. /, NEXT_MET / 1 /, TOT_MET / 0 /
+ FIRST_MET / 1 /, LAST_MET / MAXHOURS /

C Initialize the XOQ counters

DATA FIRST_XOQ / 0 /, LAST_XOQ / 0 /, TOT_XOQ / 0 /,
+ calm_xoq / 0 /, in_sect / 0 /, out_sect / 0 /, elevated / 0 /

C Wind Speed Conversion Factors

DATA CF / 1.0, .447, .5144 /

C Initialize the upper and lower X/Q bounds

DATA CLMAX / 0.0 /, CLMIN / 1.0 /, SAMAX / 0.0 /, SAMIN / 1.0 /

C Set flag for calculation of bin limits

DATA LIMITS / .TRUE. /

END

A.3 CURVEFIX

SUBROUTINE CURVEFIX(dist, UBAR, dsy, dsz)

```

C*****
C
C CURVEFIX
C
C J. V. Ramsdell, Jr.
C Pacific Northwest National Laboratory
C P.O. Box 999
C Richland, WA 99352
C
C Created: December 16, 1994
C Revised:
C
C Description: CURVEFIX computes wake dispersion coefficient
C increments for low wind speed conditions. These
C increments correct the NRC diffusion curves for
C for systematic underestimation of concentrations
C measured in wake diffusion studies under low wind
C speeds. The correction and its derivation is
C described in PNL-10286 (Ramsdell 1995).
C
C Input:      dist    ==> "stretched string" distance from release
C              point to receptor (m)
C              ubar    ==> release height wind speed (m/s)
C
C Output:     dsy     ==> correction to the NRC lateral diffusion
C              coefficient (m)
C              dsz     ==> correction to the NRC vertical diffusion
C              coefficient (m)
C
C*****

```

IMPLICIT None

REAL dist, ubar, dsy, dsz, hts, tt, vts

C Horizontal Time Scale for Meander in seconds ==> hts

hts = 1000.0

C Vertical Time Scale for Meander in seconds ==> vts

vts = 100.0

C Travel Time = dist / ubar ==> tt

tt = dist / ubar

C Compute low wind speed diffusion coefficient corrections

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dsy = SQRT(9.13E5 * (1.0 - (1.0+tt/hts) * EXP(-tt/hts)))

dsz = SQRT(6.67E2 * (1.0 - (1.0+tt/vts) * exp(-tt/vts)))

RETURN

END

A.4 INIT

SUBROUTINE INIT

```

C*****
C
C   INIT
C
C   J. V. Ramsdell, Jr., C. A. Simonen
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, Washington 99352
C
C   Created:      May 1993
C   Revised:     April 24, 1996
C
C   Description:  Compute diffusion coefficients and wind speed
C                 adjustment factor that are functions of stability
C                 class and the scenario.
C
C   Other Modules Required:  INVMOL2, NSIGMA1
C
C*****

      IMPLICIT NONE

      INCLUDE 'PARAM.INC'
      INCLUDE 'MET.INC'
      INCLUDE 'SCENARIO.INC'
      INCLUDE 'UNITS.INC'

      INTEGER    I1

      REAL       INVMOL2

      REAL       INVL(7), PI, TRHT, SIGY, SIGZ, PSI,
+              PSI1, PSI2, PSI10, PSIRH, X1, X2, Y10, YRH

      PI = 3.141593

C   Compute variables that are functions of the scenario and
C   stability but not functions of wind speed or direction

      DO I1 = 1,7

C       Normal Diffusion Coefficients

          CALL NSIGMA1(DIST, I1, sigz0, sigy0, SIGZ, SIGY)
          NSIGY(I1) = SIGY
          NSIGZ(I1) = SIGZ

C       z/L for the wind profile model

```

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```
INVL(I1) = INVMOL2(I1, Z0)
ZOL(I1) = 10.0 * INVL(I1)
```

C wind profile factors from the diabatic profile relationships

```
IF(I1 .LE. 3) THEN
  X1 = (1. - 16. * MHT1 * INVL(I1) )**0.25
  Y10 = (1. - 16. * 10.0 * INVL(I1) )**0.25
  YRH = (1. - 16. * RHT * INVL(I1) )**0.25

  PSI1 = ALOG( (1.+X1**2)/2. * ( (1.+X1)/2. )**2 )
+       - 2. * ATAN(X1) + PI/2
  PSI10 = ALOG( (1. + Y10**2)/2. * ( (1.+Y10)/2. )**2 )
+       - 2. * ATAN(Y10) + PI/2
  PSIRH = ALOG( (1. + YRH**2)/2. * ( (1.+YRH)/2. )**2 )
+       - 2. * ATAN(YRH) + PI/2

ELSE IF(I1 .GE. 5) THEN
  PSI1 = -5 * MHT1 * INVL(I1)
  PSI10 = -5 * 10.0 * INVL(I1)
  PSIRH = -5 * RHT * INVL(I1)
ELSE
  PSI1 = 0.0
  PSI10 = 0.0
  PSIRH = 0.0
ENDIF

IF( MHT2 .GT. 0 ) THEN
  IF( I1 .LE. 3 ) THEN
    X2 = (1. - 16. * MHT2 * INVL(I1) )**0.25
    PSI2 = ALOG( (1.+X2**2)/2. * ( (1.+X2)/2. )**2 )
+       - 2. * ATAN(X2) + PI/2
  ELSE IF(I1 .GE. 5) THEN
    PSI2 = -5 * MHT2 * INVL(I1)
  ELSE
    PSI2 = 0.0
  ENDIF
ENDIF
```

C ** Establish wind speed adjustment factors for each stability
C class using diabatic profile (Panofsky and Dutton, 1984)

C ** C1 converts SPDL to 10 m speed
C C2 converts SPDL to RHT speed
C C3 converts SPDU to 10 m speed
C C4 converts SPDU to RHT speed

```
C1(I1) = ( ALOG( 10.0 / Z0 ) - PSI10 )
+       / ( ALOG( MHT1 / Z0 ) - PSI1 )
TRHT = AMAX1(RHT,10.0)
PSI = PSI10
IF( RHT .GT. 10.0 ) PSI = PSIRH
```



```

      C2(I1) = ( ALOG( TRHT / Z0 ) - PSI )
+         / ( ALOG( MHT1 / Z0 ) - PSI1 )
      IF( MHT2 .GT. 0 ) THEN
+         C3(I1) = ( ALOG( 10.0 / Z0 ) - PSI10 )
+           / ( ALOG( MHT2 / Z0 ) - PSI2 )
+         C4(I1) = ( ALOG( TRHT / Z0 ) - PSI )
+           / ( ALOG( MHT2 / Z0 ) - PSI2 )
      ELSE
+         C3(I1) = 0.0
+         C4(I1) = 0.0
      ENDIF

ENDDO

IF( TEST_FLG) THEN
  WRITE(qa_unit,'(2x,a)') 'Subroutine INIT'
  WRITE(QA_UNIT,'(/2x,a,7f8.2)') 'SY= ', (nsigy(i1), i1=1,7)
  WRITE(QA_UNIT,'(2x,a,7f8.2)') 'SZ= ', (nsigz(i1), i1=1,7)
  WRITE(QA_UNIT,'(/2x,a,7f8.3)') 'C1= ', (c1(i1), i1=1,7)
  WRITE(QA_UNIT,'(2x,a,7f8.3)') 'C2= ', (c2(i1), i1=1,7)
  WRITE(QA_UNIT,'(2x,a,7f8.3)') 'C3= ', (c3(i1), i1=1,7)
  WRITE(QA_UNIT,'(2x,a,7f8.3)') 'C4= ', (c4(i1), i1=1,7)
ENDIF

RETURN

END

```

ARCON96

A.5 INVMOL2

FUNCTION INVMOL2(Stab, z0)

C*****

C

C INVMOL2

C

C J.V. Ramsdell, C.A. Simonen

C Pacific Northwest National Laboratory

C P.O. Box 999

C Richland, Washington 99352

C

C Created: August 25, 1994

C Revised:

C

C Description:

C

C INVMOL computes an estimate of the inverse of the Monin-Obukhov
C length (1/L) based the relationship between Turner stability
C class, z0, and 1/L shown in Figure 5 in Golder's paper in
C Boundary Layer Meteorology 3:47-58. The function returns a
C mid-range estimate of 1/L given the stability class and z0.

C

C Input: Turner stability ==> STAB

C Surface Roughness Length ==> Z0

C

C*****

IMPLICIT NONE

REAL INVMOL2, LoBnd, UpBnd, z0,

+ Bnd1L(7), Bnd1U(7), ! z0 .LE. 0.01
+ Bnd2LA(7), Bnd2LB(7), Bnd2UA(7), Bnd2UB(7), ! 0.01< z0 < 0.1
+ Bnd3LA(7), Bnd3LB(7), Bnd3UA(7), Bnd3UB(7), ! 0.1< z0 < 1.0
+ Bnd4L(7), Bnd4U(7) ! z0 .GE. 1.0

INTEGER Stab

DATA Bnd1L / -0.160, -0.106, -0.066, -0.024, 0.005, 0.010, 0.056 /
DATA Bnd1U / -0.106, -0.066, -0.024, 0.005, 0.010, 0.056, 0.120 /
DATA Bnd2LA / -0.160, -0.058, -0.014, 0.0, 0.002, 0.008, 0.008 /
DATA Bnd2LB / 0.0, 0.024, 0.026, 0.012, -0.0015, -0.001, -0.024 /
DATA Bnd2UA / -0.058, -0.014, 0.000, 0.002, 0.008, 0.008, 0.12 /
DATA Bnd2UB / 0.024, 0.026, 0.012, -0.0015, -0.001, -0.024, 0.0 /
DATA Bnd3LA / -0.16, -0.046, -0.008, -0.003, 0.002, 0.004, 0.014 /
DATA Bnd3LB / 0.0, 0.036, 0.032, 0.009, -0.0015, -0.005, -0.018 /
DATA Bnd3UA / -0.046, -0.008, -0.003, 0.002, 0.004, 0.014, 0.12 /
DATA Bnd3UB / 0.036, 0.032, 0.009, -0.0015, -0.005, -0.018, 0.0 /
DATA Bnd4L / -0.16, -0.046, -0.008, -0.003, 0.002, 0.004, 0.014 /
DATA Bnd4U / -0.046, -0.008, -0.003, 0.002, 0.004, 0.014, 0.12 /

IF((z0 .GT. 0.01) .AND. (z0 .LE. 0.1)) THEN

```
      LoBnd = Bnd2LA( Stab ) + Bnd2LB( Stab ) * ALOG10( z0 )
      UpBnd = Bnd2UA( Stab ) + Bnd2UB( Stab ) * ALOG10( z0 )
      ELSE IF( (z0 .GT. 0.1) .AND. (z0 .LT. 1.0) ) THEN
      LoBnd = Bnd3LA( Stab ) + Bnd3LB( Stab ) * ALOG10( z0 )
      UpBnd = Bnd3UA( Stab ) + Bnd3UB( Stab ) * ALOG10( z0 )
      ELSE IF( z0 .LE. 0.01 ) THEN
      LoBnd = Bnd1L( Stab )
      UpBnd = Bnd1U( Stab )
      ELSE IF( z0 .GE. 1.0 ) THEN
      LoBnd = Bnd4L( Stab )
      UpBnd = Bnd4U( Stab )
      ELSE
      STOP 'ERROR IN INVMOL'
      ENDIF

      INVMOL2 = LoBnd + 0.5 * (UpBnd - LoBnd)

      RETURN
      END
```

ARCON96

A.6 METREAD

SUBROUTINE METREAD

```
C*****
C
C METREAD
C
C J. V. Ramsdell, Jr., C. A. Simonen
C Pacific Northwest National Laboratory
C P.O. Box 999
C Richland, WA 99352
C
C Created: April 1993
C Revised: January 1995
C
C Description: Subroutine reads meteorological data for control
c room habitability assessments.
C
C*****
```

IMPLICIT NONE

```
INCLUDE 'PARAM.INC'
INCLUDE 'MET.INC'
INCLUDE 'UNITS.INC'
INCLUDE 'XOQ.INC'
```

```
INTEGER STL, NMET
INTEGER*2 LDIR, LSPD, UDIR, USPD
INTEGER I1, HR, MF
```

CHARACTER*5 SITE

C Read first set of meteorological data records

```
WRITE(*,'(A)') ' READING METEOROLOGICAL DATA '
```

```
NMET = 0
```

```
DO I1 = FIRST_MET, LAST_MET
```

```
READ(MET_UNIT,1000,END=10,ERR=998) SITE, JULDAY(I1), CHOUR(I1),
+ LDIR, LSPD, STL, UDIR, USPD
```

```
1000 FORMAT(1X,A5,3X,I3,I2,2X,I3,I4,1X,I2,2X,I3,I4)
NMET = NMET + 1
```

```
HR = (JULDAY(I1) - 1) * 24 + CHOUR(I1) + 1
```

```
IF( (STL .GE. 1) .AND. (STL .LE. 7) ) THEN
```

```
STAB(I1) = STL
```

```
ELSE
```

```
STAB(I1) = 99
```

```
ENDIF
```

```

IF( (LDIR .GE. 1) .AND. (LDIR .LE. 360) ) THEN
  DIRL(I1) = LDIR
ELSE
  DIRL(I1) = 999
ENDIF

IF( (LSPD .GE. 0) .AND. (LSPD .LE. 750) ) THEN
  SPDL(I1) = LSPD
ELSE
  SPDL(I1) = 9999
ENDIF

IF( (UDIR .GE. 1) .AND. (UDIR .LE. 360) ) THEN
  DIRU(I1) = UDIR
ELSE IF(DIRL(I1) .NE. 999) THEN
  DIRU(I1) = DIRL(I1)
ELSE
  DIRU(I1) = 999
ENDIF

IF( (USPD .GE. 0) .AND. (USPD .LE. 750) ) THEN
  SPDU(I1) = USPD
ELSE
  SPDU(I1) = 9999
ENDIF

IF( MOD(I1,100) .EQ. 0 ) WRITE(*,'(A,I4,)' )
+   '   HOUR # ', HR
CYCLE

10 CONTINUE           ! close unit and check for additional files

CLOSE(MET_UNIT)
IF( NEXT_MET .LE. NMETFILE) THEN
  MF = NEXT_MET
  NEXT_MET = NEXT_MET + 1

  OPEN(MET_UNIT,FILE=MET_FILE(MF), STATUS='OLD', ERR=999)
  READ( MET_UNIT,1000) SITE, JULDAY(I1), CHOUR(I1), LDIR, LSPD,
+     STL, UDIR, USPD

  NMET = NMET + 1
  HR = (JULDAY(I1) - 1) * 24 + CHOUR(I1) + 1

  IF( (STL .GE. 1) .AND. (STL .LE. 7) ) THEN
    STAB(I1) = STL
  ELSE
    STAB(I1) = 99
  ENDIF

  IF( (LDIR .GE. 1) .AND. (LDIR .LE. 360) ) THEN
    DIRL(I1) = LDIR

```

ARCON96

```
ELSE
  DIRL(I1) = 999
ENDIF

IF( (LSPD .GE. 0) .AND. (LSPD .LE. 750) ) THEN
  SPDL(I1) = LSPD
ELSE
  SPDL(I1) = 9999
ENDIF

IF( (UDIR .GE. 1) .AND. (UDIR .LE. 360) ) THEN
  DIRU(I1) = UDIR
ELSE IF(DIRL(I1) .NE. 999) THEN
  DIRU(I1) = DIRL(I1)
ELSE
  DIRU(I1) = 999
ENDIF

IF( (USPD .GE. 0) .AND. (USPD .LE. 750) ) THEN
  SPDU(I1) = USPD
ELSE
  SPDU(I1) = 9999
ENDIF

IF( MOD(I1,100) .EQ. 0 )
+   WRITE(*,'(A,I5)') '  HOUR # ', I1
  CYCLE
ELSE
  END_MET = .TRUE.
  GOTO 20          ! no more met data jump out of do loop
ENDIF
ENDDO

20 CONTINUE

LAST_MET = FIRST_MET + NMET - 1
TOT_MET = TOT_MET + NMET

IF( TEST_FLG ) THEN
  WRITE(QA_UNIT,'(/2X,a/)') 'Subroutine METREAD'
  DO I1 = first_met,last_met
    WRITE(QA_UNIT,'(2X,I5,5X,2I7,I5,2X,2I7)') I1,
&    dirl(I1), spdl(I1), stab(I1), diru(I1), spdu(I1)
  ENDDO
ENDIF

RETURN

998 WRITE( LOG_UNIT,'(/2X,A,A, /5X,A,I4,A,I4)')
+ 'ERROR READING MET. DATA FILE = ', MET_FILE(MF),
+ ' JULIAN DAY = ', JULDAY(I1-1), '; HOUR = ', CHOUR(I1-1)
STOP 'ERROR READING MET. DATA'
```

```
999 WRITE( LOG_UNIT, '(/2X,A,A)' ) 'UNABLE TO OPEN MET. DATA FILE = ',  
+ MET_FILE(MF)  
STOP 'ERROR OPENING MET. DATA FILE'  
  
END
```

ARCON96

A.7 NSIGMA1

SUBROUTINE NSIGMA1(x, stab, sigz0, sigy0, sigmaz, sigmay)

C*****

C NRCSIG1

C

C J.V. Ramsdell, Jr.

C Pacific Northwest National Laboratory

C P.O. Box 999

C Richland, Washington 99352

C

C Created: June 1986

C Revised: July 24, 1995

C

C Description: Computes diffusion coefficients given the
C distance from the source and atmospheric
C stability

C

C Other modules required: None

C

C*****

IMPLICIT NONE

INTEGER stab

REAL ay(7), az(7,3), bz(7,3), cz(7,3), x, sigmay, sigmaz,
* sigy0, sigz0, xv, xe1, xe2

DATA ay/ 0.3658, 0.2751,0.2089,0.1471,0.1046,0.0722,0.0481/
DATA az/ 0.192, 0.156, 0.116, 0.079, 0.063, 0.053, 0.032,
+ 0.00066,0.0382,0.113, 0.222, 0.211, 0.086, 0.052,
+ 0.00024,0.055, 0.113, 1.26, 6.73, 18.05, 10.83 /
DATA bz/ 0.936, 0.922, 0.905, 0.881, 0.871, 0.814, 0.814,
+ 1.941, 1.149, 0.911, 0.725, 0.678, 0.74, 0.74,
+ 2.094, 1.098, 0.911, 0.516, 0.305, 0.18, 0.18 /
DATA cz/ 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
+ 9.27, 3.3, 0.0, -1.7, -1.3, -0.35, -0.21,
+ -9.6, 2.0, 0.0, -13., -34.0, -48.6, -29.2 /

IF(sigy0 .GT. 0.0) THEN

c Calculate virtual distance from sigy0

xv = (sigy0 / ay(stab))**(1.0/0.9031)
xe1 = x + xv

ELSE

xe1 = x

ENDIF

sigmay = ay(stab) * xe1**0.9031


```

C ** SIGMA Z COMPUTATIONS

IF( sigz0 .GT. 0.0 ) THEN

c Calculate virtual distance from sigz0

  xv = (sigz0 / az(stab,1)) ** (1.0/bz(stab,1))
  xe2 = x + xv

  IF( xe2 .GT. 100.0 ) THEN
    IF( (sigz0 - cz(stab,2)) .GT. 0.0 ) THEN
      xv = ((sigz0 - cz(stab,2))
&          / az(stab,2))**(1.0/bz(stab,2))
    ELSE
      xv = 0.0
    ENDIF
    xe2 = x + xv
  ENDIF

  IF( xe2 .GT. 1000.0 ) THEN
    IF( (sigz0 - cz(stab,3)) .GT. 0.0 ) THEN
      xv = ((sigz0 - cz(stab,3))
&          / az(stab,3))**(1.0/bz(stab,3))
    ELSE
      xv = 0.0
    ENDIF
    xe2 = x + xv
  ENDIF

ELSE

  xe2 = x

ENDIF

IF( xe2 .LE. 100.0 ) THEN
  sigmaz = az(stab,1) * xe2**bz(stab,1)
ELSE IF( xe2 .LE. 1000.0 ) THEN
  sigmaz = az(stab,2) * xe2**bz(stab,2) + cz(stab,2)
ELSE IF( xe2 .GT. 1000.0 ) THEN
  sigmaz = az(stab,3) * xe2**bz(stab,3) + cz(stab,3)
ENDIF

RETURN
END

```

ARCON96

A.8 PROC

SUBROUTINE PROC

```
C*****
C
C   PROC
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Created: April 1993
C   Revised: May 9, 1997
C
C   Description: Processes X/Q values for control room habitability
C                 assessments.
C
C   Other modules required: None
C
C*****
```

IMPLICIT NONE

```
INCLUDE 'PARAM.INC'
INCLUDE 'SCENARIO.INC'
INCLUDE 'UNITS.INC'
INCLUDE 'XOQ.INC'
```

```
INTEGER I1, I2, I3, INDX(10), J, NAVE(10), Nave_Tot, cl_nave(10),
&       sa_nave(10)
```

```
REAL    CLUPLIM, SAUPLIM, v1, v2, AVE(10), RATIO, MINV(10),
&       Tot_sum, cl_sum(10), sa_sum(10), v1a, v1b, v2a, v2b
```

SAVE NAVE, AVE

```
C   Determine upper and lower limits for X/Q distributions from
C   maximum values in the first meteorological data set
```

```
IF ( LIMITS ) THEN
  CLUPLIM = AINT( ALOG10( CLMAX ) )
  DO I1 = 1,4
    UPLIM(I1) = CLUPLIM
    LOWLIM(I1) = CLUPLIM - 4.0
    MINV(I1) = 10**(UPLIM(I1) - 5.0)
  ENDDO
  SAUPLIM = AINT( ALOG10( (8*CLMAX + 4*SAMAX)/12.0 ) )
  DO I1 = 5,10
    UPLIM(I1) = SAUPLIM
    LOWLIM(I1) = SAUPLIM - 4.0
    MINV(I1) = 10**(UPLIM(I1) - 5.0)
```

```

        ENDDO
        LIMITS = .FALSE.
    ENDIF

C     generate frequency distributions

    IF ( TEST_FLG ) THEN
        WRITE(qa_unit, '(/2x,a)') 'Subroutine PROC'
        WRITE(qa_unit, '(3(/2x,A,1PE12.3,2X,A,1PE12.3))')
    +   ' CLMAX: ',CLMAX,' CLUPLIM: ', 10.0**CLUPLIM,
    +   ' SAMAX: ',SAMAX,' SAUPLIM: ', 10.0**SAUPLIM,
    +   ' LOWLIM(1): ', 10.0**LOWLIM(1),
    +   ' LOWLIM(3): ', 10.0**LOWLIM(3)
        WRITE(qa_unit, '(/5X, 10I5 )' ) (NA(I2), I2=1,10)
        WRITE(qa_unit, '(5X, 10I5 )' ) (NAVMIN(I2), I2=1,10)
    ENDIF

C ** Go through the entire set of X/Q values

    DO I1 = FIRST_XOQ, LAST_XOQ

C ** Do all averaging intervals

    DO I2 = 1,10

C ** find the values to be added and deleted from the sums used to
C compute the averages... add V1 prior to computing averages and
C delete V2 after computing the averages

        V2 = -1.0
        v1a = -1.0
        v2a = -1.0
        v2b = -1.0
        IF ( I2 .LE. 4 ) THEN
            V1 = CLXOQ(I1)
            IF ( I1 .GE. NA(I2) ) V2 = CLXOQ(I1 - NA(I2) + 1 )
        ELSE
            V1b = SAXOQ(i1)
            IF ( i1 .GE. (na(i2)-8) ) v2b = saxoq(i1-na(i2)+9)
            IF ( i1 .GE. (na(i2)-7) ) v1a = clxoq(i1-na(i2)+8)
            IF ( i1 .GE. na(i2) ) v2a = clxoq(i1 - na(i2) + 1)
        ENDIF

C ** Check for good values -- add to sums and increment counters if
C good values

        IF ( i2 .LE. 4) THEN
            IF (V1 .GE. 0.0 ) THEN
                SUM(I2) = SUM(I2) + V1
                NAVE(I2) = NAVE(I2) + 1
            ENDIF
        ELSE

```

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```
      IF (v1a .GE. 0.0 ) THEN
        cl_sum(i2) = cl_sum(i2) + v1a
        cl_nave(i2) = cl_nave(i2) + 1
      ENDIF
      IF (v1b .GE. 0.0 ) THEN
        sa_sum(i2) = sa_sum(i2) + v1b
        sa_nave(i2) = sa_nave(i2) + 1
      ENDIF
    ENDIF

C  **      Check for sufficient number of values to compute an acceptable
C          average

      IF ( I2 .LE. 4 ) THEN
        Nave_Tot = NAVE(I2)
        Tot_Sum = SUM(I2)
      ELSE
        Nave_Tot = cl_nave(i2) + sa_nave(i2)
        Tot_Sum = cl_sum(i2) + sa_sum(i2)
      ENDIF

      IF ( (I1 .GE. NAVMIN(I2)) .AND. (NAVE_Tot .GE. NAVMIN(I2)) )
+      THEN

C  **      Check for elevated plume, increment counter if plume elvated

      IF ( (I2 .EQ. 1) .AND.
+      ( V1 .GT. 0.0 ) .AND.
+      ( V1 .LE. MINV(1) ) ) elevated = elevated + 1

C  **      Sufficient number

      IF ( Tot_Sum .GT. (i2 * MINV(I2)) ) THEN

C  **      compute average

      AVE(I2) = Tot_Sum / Nave_Tot

C  **      compute index for bin, bin size = 1/25 order of mag.

      RATIO = ALOG10( AVE(I2) ) - LOWLIM(I2)
      IF ( RATIO .GE. 0.0 ) THEN
        I3 = IFIX( 25 * RATIO ) + 2
      ELSE
        I3 = 1
      ENDIF
      INDX(I2) = I3

C  **      accumulate in proper bin

      IF ( I3 .GE. 2 ) THEN
        IF ( I3 .LE. 101 ) THEN
          DISTR(I3,I2) = DISTR(I3,I2) + 1.0
```

```

        ELSE
            DISTR(102,I2) = DISTR(102,I2) + 1.0
        ENDIF
        ELSE
            DISTR(1,I2) = DISTR(1,I2) + 1.0
        ENDIF
        ELSE
C **      not necessary to compute average, sum = 0
            ZERO(I2) = ZERO(I2) + 1.
            SUM(I2) = 0.0
        ENDIF
        ENDIF
C **      Remove oldest values if not missing and decrement counters
        IF ( i2. LE. 4 ) THEN
            IF ( (I1 .GE. NA(I2) ) .AND.
+           (V2 .NE. -1.) ) THEN
                SUM(I2) = SUM(I2) - V2
                NAVE(I2) = NAVE(I2) - 1
            ENDIF
            IF ( SUM(I2) .LT. MINV(I2) ) SUM(I2) = 0.0
        ELSE
            IF ( i1 .GE. na(i2) ) THEN
                IF ( v2a .NE. -1 ) THEN
                    cl_sum(i2) = cl_sum(i2) - v2a
                    cl_nave(i2) = cl_nave(i2) - 1
                ENDIF
                IF( cl_sum(i2) .LT. minv(i2) ) cl_sum(i2) = 0.0
            ENDIF
            IF ( i1 .GE. (na(i2)-8) ) THEN
                IF ( v2b .NE. -1 ) THEN
                    sa_sum(i2) = sa_sum(i2) - v2b
                    sa_nave(i2) = sa_nave(i2) - 1
                ENDIF
                IF( sa_sum(i2) .LT. minv(i2) ) sa_sum(i2) = 0.0
            ENDIF
        ENDIF
        ENDDO

        DO J = 1,10
            AVE(J) = 0.0
            INDX(J) = 0
        ENDDO

        ENDDO

        RETURN
        END

```

ARCON96

A.9 RECORD

SUBROUTINE RECORD

```
C*****
C
C SUBROUTINE RECORD
C
C J. V. Ramsdell, Jr.
C Pacific Northwest National Laboratory
C P.O. Box 999
C Richland, WA 99352
C
C Created: December 1994
C Revised: April 26, 1996
C
C Description: Writes a summary of the input data to the ARCON log
C file. The input data are read using the SCENREAD
C subroutine. Data are passed to RECORD in the named
C common blocks.
C
C*****
```

IMPLICIT NONE

```
INCLUDE 'PARAM.INC'
INCLUDE 'MET.INC'
INCLUDE 'SCENARIO.INC'
INCLUDE 'UNITS.INC'
INCLUDE 'XOQ.INC'
```

INTEGER I1

```
WRITE(LOG_UNIT, '(/2X,A)') '***** ARCON INPUT *****'

WRITE(LOG_UNIT, '(/5X,A,I2)') )
+ 'Number of Meteorological Data Files = ', NMETFILE
WRITE(LOG_UNIT, '(5X,A)') 'Meteorological Data File Names'
DO I1 = 1, NMETFILE
  WRITE(LOG_UNIT, '(7X,A)') MET_FILE(I1)
ENDDO
WRITE(LOG_UNIT, '(/5X,A,F8.1)')
+ 'Height of lower wind instrument (m) = ', MHT1
WRITE(LOG_UNIT, '(5X,A,F8.1)')
+ 'Height of upper wind instrument (m) = ', MHT2
SELECT CASE( SPD_TYPE )
  CASE(1)
    WRITE(LOG_UNIT, '(5X,A)')
+ 'Wind speeds entered as meters/second'
  CASE(2)
    WRITE(LOG_UNIT, '(5X,A)')
+ 'Wind speeds entered as miles per hour'
  CASE(3)
```

```

        WRITE(LOG_UNIT,'(5X,A)')
+       'Wind speeds entered as knots'
      CASE DEFAULT
        WRITE(LOG_UNIT,'(5X,A)')
+       'Wind speeds entered in unknown units'
      END SELECT

      SELECT CASE( RTYPE )
        CASE(1)
          WRITE(LOG_UNIT,'(/5X,A)')
+         'Ground-level release'
        CASE(2)
          WRITE(LOG_UNIT,'(/5X,A)')
+         'Vent release'
        CASE(3)
          WRITE(LOG_UNIT,'(/5X,A)')
+         'Elevated release'
        CASE DEFAULT
          WRITE(LOG_UNIT,'(/5X,A)')
+         'Unknown release type'
      END SELECT
      WRITE(LOG_UNIT,'(5X,A,F8.1)')
+       'Release height (m)                = ', RHT
      WRITE(LOG_UNIT,'(5X,A,F8.1)')
+       'Building Area (m^2)                = ', BAREA
      WRITE(LOG_UNIT,'(5X,A,F9.2)')
+       'Effluent vertical velocity (m/s)    = ', WO
      WRITE(LOG_UNIT,'(5X,A,F9.2)')
+       'Vent or stack flow (m^3/s)         = ', FO
      WRITE(LOG_UNIT,'(5X,A,F9.2)')
+       'Vent or stack radius (m)           = ', SRAD

      WRITE(LOG_UNIT,'(/5X,A,5x,I3.3)')
+       'Direction .. intake to source (deg) = ', wind_dir
      WRITE(LOG_UNIT,'(5X,A,5x,I3)')
+       'Wind direction sector width (deg)   = ', window
      WRITE(LOG_UNIT,'(5X,A,2x,i3.3,A,I3.3)')
+       'Wind direction window (deg)        = ', DIR1,
+       ' - ', DIR2
      WRITE(LOG_UNIT,'(5X,A,F8.1)')
+       'Distance to intake (m)              = ', DIST
      WRITE(LOG_UNIT,'(5X,A,F8.1)')
+       'Intake height (m)                   = ', RECHT
      WRITE(LOG_UNIT,'(5X,A,F8.1)')
+       'Terrain elevation difference (m)     = ', T_DIFF

      WRITE(LOG_UNIT,'(/5X,A)') 'Output file names '
      WRITE(LOG_UNIT,'(7X,A)') LOG_FILE
      WRITE(LOG_UNIT,'(7X,A)') CFD_FILE

      WRITE(LOG_UNIT,'(/5X,A,F8.1)')
+       'Minimum Wind Speed (m/s)           = ', umin

```

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```
WRITE(LOG_UNIT, '(5X,A,F9.2)')
+   'Surface roughness length (m)           = ', Z0
WRITE(LOG_UNIT, '(5X,A,F8.1)')
+   'Sector averaging constant             = ', SW_CNST

WRITE(LOG_UNIT, '(/5X,A,F9.2)')
+   'Initial value of sigma y             = ', sigy0
WRITE(LOG_UNIT, '(5X,A,F9.2)')
+   'Initial value of sigma z             = ', sigz0

IF( TEST_FLG ) THEN
  WRITE(LOG_UNIT, '(/5X,A)')
+   'Expanded output for code testing selected'
  WRITE(LOG_UNIT, '(5X,A,A)')
&   'QA output file = ', qa_file
ELSE
  WRITE(LOG_UNIT, '(/5X,A)')
+   'Expanded output for code testing not selected'
ENDIF

RETURN

END
```


A.10 SCENREAD

SUBROUTINE SCENREAD

```

C*****
C
C   SCENREAD
C
C   J. V. Ramsdell, Jr., C. A. Simonen
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Created:      April 1993
C   Revised:     April 24, 1996
C
C   Description:  Read data (except meteorological) from a user
C                 created file for ARCON96. Run specification file
C                 name should be included as a command line argument
C                 for ARCON96. If the QA (expanded) output option is
C                 selected, the user will be prompted for a QA output
C                 file name.
C
C*****

```

IMPLICIT NONE

```

INCLUDE      'PARAM.INC'
INCLUDE      'MET.INC'
INCLUDE      'SCENARIO.INC'
INCLUDE      'UNITS.INC'
INCLUDE      'XOQ.INC'

```

INTEGER*2 I1

CHARACTER*1 YN

C ***** METEOROLOGICAL INFORMATION *****

C --- Read: number of meteorological data files
C and meteorological data file names

```

READ(SCENUNIT,'(I5)') NMETFILE
DO I1 = 1,NMETFILE
  READ(SCENUNIT,'(A)') MET_FILE(I1)
ENDDO

```

C --- Read height of lower level meteorological data (m)

```

READ(SCENUNIT,'(F10.0)') MHT1

```

C --- Read height of upper level met data (m)

ARCON96

```
      READ(SCENUNIT,'(F10.0)') MHT2

C --- Read wind speed data type -- 1 = m/s; 2 = mph; 3 = kt

      READ(SCENUNIT,'(I5)') SPD_TYPE

C ***  RELEASE INFORMATION  *****

C --- release type -- 1 = ground level; 2 = roof top; 3 = elevated

      READ(SCENUNIT,'(I5)') RTYPE

C --- release height (m)

      READ(SCENUNIT,'(F10.0)') RHT

C --- building area for ground release (m**2)

      READ(SCENUNIT,'(F10.0)') BAREA

C --- vertical velocity of vent exhaust, m/s (elevated release)

      READ(SCENUNIT,'(F10.0)') W0

C --- Read stack or vent flow (m**3/s), it may be zero

      READ(SCENUNIT,'(F10.0)') F0

C --- Read stack radius (m), it may be zero except for elevated releases
C      (Rtype = 3)

      READ( SCENUNIT, '(F10.0)') SRAD

C *** RECEPTOR INFORMATION

C --- Read wind direction and window

      READ(SCENUNIT,'(2I5)') wind_dir, window

C ***  calculate the upper and lower limits of the wind direction
C      window... note integer arithmetic... if window is even the
C      window width is actually window + 1 degrees wide; if window is
C      odd the window width is window - 1 degrees wide.

      DIR1 = wind_dir - window / 2
      DIR2 = wind_dir + window / 2

C *** put dir1 and dir2 into 0 to 360 degrees range

      IF( dir1 .LT. 0 ) dir1 = dir1 + 360
      IF( dir2 .GT. 360 ) dir2 = dir2 - 360

C --- Read distance from release point to intake (m)
```

```

        READ(SCENUNIT,'(F10.0)') DIST
C --- Read receptor height
        READ(SCENUNIT,'(F10.0)') RECHT
C --- Read difference in plant grade between stack and intake
C      Grade at release point - Grade at receptor (m)
        READ( SCENUNIT, '(F10.0)') T_DIFF
C *** INPUT FILE NAMES FOR OUTPUT *****
C --- Read file name for results summary (Log file)
        READ(SCENUNIT,'(A)') LOG_FILE
C --- Read file name for results CDF file
        READ(SCENUNIT,'(A)') CFD_FILE
C **** GET MISCELLANEOUS INFORMATION -- typically default values ****
C --- Read surface roughness length (m)
        READ(SCENUNIT,'(F10.0)') Z0
C --- Read the minimum wind speed
        READ(SCENUNIT,'(F10.0)') umin
C --- Read sector width constant
        READ(SCENUNIT, '(F10.0)') SW_CNST
C --- Read X/Q averaging intervals (hours)
        READ(SCENUNIT,'(10I4)') (NA(I1), I1=1,10)
C --- Read minimum number of hours for each averaging interval
        READ(SCENUNIT,'(10I4)') (NAVMIN(I1), I1=1,10)
c --- Read sigma y 0 and sigma z 0 for area source... this read differentiates
c      ARCON96 input file from ARCON95 input file
        Read( scenunit,'(2f10.0)' ) sigy0, sigz0
C ***** EXPANDED OUTPUT FOR TEST PURPOSES *****
C --- Read test output: Yes or No ----

```

ARCON96

```
READ(SCENUNIT,'(A)') YN
TEST_FLG = .FALSE.
IF( (YN .EQ. 'Y') .OR. (YN .EQ. 'y') ) TEST_FLG = .TRUE.

IF( TEST_FLG ) THEN
  WRITE(*,'(2X,A\)' ) 'Enter a name for the QA output file: '
  READ(*,'(A)') QA_File
ENDIF

RETURN
END
```

A.11 SHIFT

SUBROUTINE SHIFT

```

C*****
C
C   SHIFT
C
C   J. V. Ramsdell, Jr., C. A. Simonen
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, Washington  99352
C
C   Created:   May 1993
C   Revised:
C
C   Description:  Subroutine to shift meteorological data and hourly
C                 X/Q values from the end of the storage arrays to the
C                 beginning before reading the next set of meteorological
C                 data.
C
C   Other modules required:  None
C
C*****

```

IMPLICIT NONE

```

INCLUDE 'PARAM.INC'
INCLUDE 'MET.INC'
INCLUDE 'UNITS.INC'
INCLUDE 'XOQ.INC'

```

INTEGER I1, J0, J1, MET_SHIFT

C Move residual met. data AND X/Q's to front of data arrays

```

MET_SHIFT = NA(10) - 1
J0 = MAXHOURS - MET_SHIFT

```

```

DO I1 = 1, MET_SHIFT
  J1 = J0 + I1
  STAB(I1) = STAB(J1)
  DIRL(I1) = DIRL(J1)
  SPDL(I1) = SPDL(J1)
  DIRU(I1) = DIRU(J1)
  SPDU(I1) = SPDU(J1)
  CLXOQ(I1) = CLXOQ(J1)
  SAXOQ(I1) = SAXOQ(J1)
ENDDO

```

FIRST_MET = MET_SHIFT + 1

ARCON96

```
IF( TEST_FLG)  
+ WRITE(LOG_UNIT, '(5X,A,I6)') ' FIRST_MET: ', FIRST_MET
```

RETURN

END

A.12 SUMMARY

SUBROUTINE SUMMARY

```

C*****
C
C   SUMMARY
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Created: April 1993
C   Revised: November 8, 1995
C
C   Description: Subroutine summarizes the X/Q data for control room
C                 habitability assessments.
C
C   Other modules required: XOQ95
C
C*****

```

```

IMPLICIT NONE

```

```

INCLUDE 'PARAM.INC'
INCLUDE 'SCENARIO.INC'
INCLUDE 'UNITS.INC'
INCLUDE 'XOQ.INC'

```

```

INTEGER I1, I2, I3

```

```

REAL T1(10), T2(10), SECTOR_F(10), CLIM, SLIM, VAL95(10),
&   std_xoq, xoq95_2

```

```

C   Total the distributions for check against total hours of data

```

```

DO I1 = 1,10
  DO I2 = 2,101
    T1(I1) = T1(I1) + DISTR(I2,I1)
  ENDDO
  T2(I1) = T1(I1) + DISTR(1,I1) + DISTR(102,I1) + ZERO(I1)
  IF( T2(I1) .GT. 0.0) SECTOR_F(I1) = 1.0 - ZERO(I1) / T2(I1)
ENDDO

```

```

WRITE(LOG_UNIT,3) TOT_XOQ, MISS_XOQ, in_sect, elevated, calm_xoq,
+   out_sect
3 FORMAT(/5X,'Total number of hours of data processed = ', I6,/
+   5X,'Hours of missing data = ', I6,/
+   5X,'Hours direction in window = ', I6,/
+   5X,'Hours elevated plume w/ dir. in window = ', I6,/
+   5X,'Hours of calm winds = ', I6,/

```

ARCON96

```
+          5x, 'Hours direction not in window or calm = ', I6 /)

WRITE(LOG_UNIT,4)
4 FORMAT(5X, 'DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL')

WRITE(LOG_UNIT,5) NA, (10**UPLIM(I1),I1=1,10),
+ (10**LOWLIM(I1),I1=1,10), (DISTR(102,I1),I1=1,10), T1,
+ (DISTR(1,I1),I1=1,10), ZERO, T2, SECTOR_F*100.
5 FORMAT(
+ 3X, ' AVER. PER.', 2X, 10(6X,I4,1X),
+ /3X, ' UPPER LIM.', 2X, 10(1PE10.2,1X),
+ /3X, '  LOW LIM.', 2X, 10(1PE10.2,1X),
+ /3X, 'ABOVE RANGE', 2X, 10(4X,OPF6.0,1X),
+ /3X, '  IN RANGE', 2X, 10(4X,F6.0,1X),
+ /3X, 'BELOW RANGE', 2X, 10(4X,F6.0,1X),
+ /3X, '      ZERO', 2X, 10(4X,F6.0,1X),
+ /3X, ' TOTAL X/Qs', 2X, 10(4X,F6.0,1X),
+ /3X, ' % NON ZERO', 2X, 10(4X,F6.2,1X) )

IF( TEST_FLG ) THEN
WRITE(qa_unit,'(/2x,a/)') 'Subroutine SUMMARY'
WRITE(qa_UNIT,7) 'X/Q FREQUENCY DISTRIBUTIONS',
+ 'XOQ', (NA(I3),I3=1,4), 'XOQ', (NA(I3),I3=5,10)
7 FORMAT( 2X,A27,/6X,A3,5X,4(I3,4X),7X,A3,2X,6(3X,I3,3X) )

WRITE(qa_UNIT,'(1X, A10,4(OPF7.0),3X,A10,6(OPF9.0))')
+ ' Abv. Lim.', (DISTR(102,I3), I3 = 1,4),
+ ' Abv. Lim.', (DISTR(102,I3), I3 = 5,10)

DO I1 = 1,100
I2 = 102 - I1
CLIM = 10**(LOWLIM(1) + (I2-2)/25.)
SLIM = 10**(LOWLIM(3) + (I2-2)/25.)
WRITE(QA_UNIT,8) CLIM, (DISTR(I2,I3),I3=1,4), SLIM,
+ (DISTR(I2,I3),I3 = 5,10)
8 FORMAT(1X,1PE10.3,4(OPF7.0),3X,1PE10.3,6(OPF9.0))
ENDDO

WRITE(qa_UNIT,'(1X, A10,4(OPF7.0),3X,A10,6(OPF9.0))')
+ 'Belw. Lim.', (DISTR(1,I3), I3 = 1,4),
+ 'Belw. Lim.', (DISTR(1,I3), I3 = 5,10)
ENDIF

OPEN( CFD_UNIT, FILE=CFD_FILE, STATUS='NEW', ERR=999)

WRITE(CFD_UNIT,9) 'X/Q CUMULATIVE FREQUENCY DISTRIBUTIONS',
+ 'XOQ', (NA(I3),I3=1,4), 'XOQ', (NA(I3),I3=5,10)
9 FORMAT( /2X,A39,/6X,A3,5X,4(I3,4X),7X,A3,2X,6(3X,I3,3X) )

WRITE(CFD_UNIT,'(1X, A10,4(OPF7.0),3X,A10,6(OPF9.0))')
+ ' Abv. Lim.', (DISTR(102,I3), I3 = 1,4),
+ ' Abv. Lim.', (DISTR(102,I3), I3 = 5,10)
```



```

DO I1 = 1,100
  I2 = 102 - I1
  CLIM = 10**(LOWLIM(1) + (I2-2)/25.)
  SLIM = 10**(LOWLIM(3) + (I2-2)/25.)
  IF( I1 .GE. 2 ) THEN
    DO I3 = 1,10
      DISTR(I2,I3) = DISTR(I2,I3) + DISTR(I2+1,I3)
    ENDDO
  ENDIF
  WRITE(CFD_UNIT,8) CLIM, (DISTR(I2,I3),I3=1,4), SLIM,
+      (DISTR(I2,I3),I3 = 5,10)
  ENDDO

  WRITE(CFD_UNIT,'(1X, A10, 4(OPF7.0),3X,A10,6(OPF9.0))')
+      'Belw. Lim.', (DISTR(1,I3), I3 = 1,4),
+      'Belw. Lim.', (DISTR(1,I3), I3 = 5,10)

  CLOSE(CFD_UNIT)

  CALL XOQ95( LOWLIM, T2, DISTR, VAL95 )

  WRITE(LOG_UNIT, '(/5X, A26, /16X, 10(1PE10.2,1X))' )
+      '95th PERCENTILE X/Q VALUES', (VAL95(I3), I3 = 1,10)

C      calculate the 95% X/Q values for standard averaging intervals...
C      0 - 2 hours (1 hour X/Q), 2 - 8 hours, etc.... The calculations
C      are based on the 95% concentrations above and the exposures
C      required to go from one value to the next. IF statement check
C      to see if the averaging periods were changed.

  WRITE(log_unit, '(/5x,a)')
+      '95% X/Q for standard averaging intervals'

C      0 to 2 hour X/Q ... select larger of the 1 and 2 hr values...
C      normally the 1 hr value, but with elevated release it can be the
C      2 hr value if there aren't sufficient 1 hr values.

  xoq95_2 = amax1( val95(1), val95(2) )

  IF( NA(1) .EQ. 1 )
+      WRITE(log_unit, '(/5x,a16,2x,1pe10.2)')
+      '0 to 2 hours      ', xoq95_2

C      2 to 8 hour X/Q

  IF( (NA(1) .EQ. 1) .AND. (NA(4) .EQ. 8) ) THEN
    std_xoq = (8.0 * val95(4) - 2.0 * xoq95_2) / 6.0
    IF( std_xoq .LT. 0.0 ) std_xoq = 0.0
    WRITE(log_unit, '(5x,a16,2x,1pe10.2)')
+      '2 to 8 hours      ', std_xoq
  ENDIF

```

ARCON96

C 8 to 24 hour X/Q

```
IF( (NA(4) .EQ. 8) .AND. (NA(6) .EQ. 24) ) THEN
  std_xoq = (24.0 * val95(6) - 8.0 * val95(4)) / 16.0
  IF( std_xoq .LT. 0.0 ) std_xoq = 0.0
  WRITE(log_unit, '(5x,a16,2x,1pe10.2)')
+ '8 to 24 hours ', std_xoq
ENDIF
```

C 1 to 4 day X/Q

```
IF( (NA(6) .EQ. 24) .AND. (NA(7) .EQ. 96) ) THEN
  std_xoq = (4.0 * val95(7) - 1.0 * val95(6)) / 3.0
  IF( std_xoq .LT. 0.0 ) std_xoq = 0.0
  WRITE(log_unit, '(5x,a16,2x,1pe10.2)')
+ '1 to 4 days ', std_xoq
ENDIF
```

C 4 to 30 day X/Q

```
IF( (NA(7) .EQ. 96) .AND. (NA(10) .EQ. 720) ) THEN
  std_xoq = (30.0 * val95(10) - 4.0 * val95(7)) / 26.0
  IF( std_xoq .LT. 0.0 ) std_xoq = 0.0
  WRITE(log_unit, '(5x,a16,2x,1pe10.2)')
+ '4 to 30 days ' std_xoq
ENDIF
```

```
WRITE(LOG_UNIT,6) CLMAX, CLMIN, SAMAX, SAMIN
6 FORMAT(/32X 'HOURLY VALUE RANGE ',/
+ 27X, ' MAX X/Q ',10X, ' MIN X/Q ',/ 10X, 'CENTERLINE',
+ 5X,1PE12.2,10X,1PE12.2/,10X, 'SECTOR-AVERAGE',1X,1PE12.2,
+ 10X,1PE12.2)
```

RETURN

```
999 WRITE( LOG_UNIT, '(/2X,A,A)' )
+ 'UNABLE TO OPEN CUM. DISTRIBUTION FILE = ', CFD_FILE
STOP 'UNABLE TO OPEN CDF FILE... CHECK FOR EXISTING NAME'
```

END

A.13 WAKECORR

SUBROUTINE WAKECORR(area, dist, ubar, dsy, dsz)

```

C*****
C
C   WAKECORR
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA  99352
C
C   Created:      December 16, 1994
C   Revised:
C
C   Description:  WAKECORR computes adjustments to the NRC diffusion
C                 coefficients to account for building wakes.  These
C                 adjustments, described in PNL-10286 (Ramsdell 1995),
C                 are most significant in high wind speed conditions.
C                 The numerical coefficients in the model are based on
C                 turbulence and wake diffusion data.
C
C   Input:       area   ==> building cross-sectional area (m^2)
C                dist   ==> "slant range" distance from
C                        release point to the receptor (m)
C                ubar   ==> release height wind speed (m/s)
C
C   Output:      dsy    ==> adjustment to the NRC lateral diffusion
C                        coefficient to account for the wake (m)
C                dsz    ==> adjustment to the NRC vertical diffusion
C                        coefficient to account for the wake (m)
C
C*****

      IMPLICIT  None

      REAL     area, dist, ubar, dsy, dsz, hts, vts, tt

C   time scale for diffusion, in seconds ==> hts, vts

      hts = 10 * SQRT( area ) / ubar
      vts = hts

C   Travel time = dist / ubar ==> tt

      tt = dist / ubar

C   Compute adjustments to NRC diffusion coefficients

      dsy =
+   SQRT(5.24E-2 * ubar**2 * area * (1.0-(1.0+tt/hts)*EXP(-tt/hts)))

```

ARCON96

```
    dsz =  
+   SQRT(1.17E-2 * ubar**2 * area * (1.0-(1.0+tt/vts)*EXP(-tt/vts)))
```

RETURN

END

A.14 WINDYXOQ

```

SUBROUTINE WINDYXOQ( rtype, area, dist, eff_ht, stab, ubar, sigy,
+                 sigz, sigz0, sigy0, flow, w0, sw_const, clxoq, saxoq )

```

```

C*****
C
C   WINDYXOQ
C
C   J.V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Created:  January 29, 1995
C   Revised:  April 24, 1996
C
C   Description:  WINDYXOQ computes X/Q in windy conditions.  For elevated
C                 releases it uses the standard Gaussian model.  For
C                 releases in the vicinity of buildings it uses the model
C                 described in PNL-10286 (Ramsdell and Fosmire 1995).
C                 For elevated vent releases (RTYPE = 2), the model uses
C                 the split-H approach of Reg. Guide 1.111.
C
C   Input:       rtype    ==>  release type 1 = ground, 2 = vent,
C                 area    ==>  building cross-sectional area (m^2)
C                 dist    ==>  distance from release point to
C                 intake (m)
C                 eff_ht  ==>  effective release height (m)
C                 stab    ==>  stability class
C                 ubar    ==>  wind speed at release height (m)
C                 sigy    ==>  NRC lateral diffusion coefficient
C                 for the stability class and
C                 distance (m)
C                 sigz    ==>  NRC vertical diffusion coefficient
C                 for the stability class and
C                 distance (m)
C                 flow    ==>  release flow rate (m^3/s)
C                 w0      ==>  stack effluent velocity (m/s)
C                 sw_const ==>  assumed width of plume in units of
C                 the adjusted sigma y (dimensionless)
C
C   Output:      clxoq    ==>  normalized concentration at center
C                 line of plume (s/m^3)
C                 saxoq    ==>  normalized concentration in a
C                 sector-average plume
C
C   Other modules required:  CURVEFIX, WAKECORR, NSIGMA1
C
C*****

```

ARCON96

```
      IMPLICIT      NONE

      INTEGER*2     rtype

      INTEGER       stab

      REAL          area, dist, dsy1, dsz1, dsy2, dsz2, flow, pi, sigy,
+                sigz, tsigy, tsigz, ubar, max_wide, eff_ht, w0, wr, wf

      REAL          clxoq, saxoq, pwidth, sw_const, sqrt2pi, clxoqw,
&                clxoqs, saxoqw, saxoqs, maxsigy, srange, nsy, nsz,
&                sigz0, sigy0

      pi = 3.14159
      sqrt2pi = SQRT( 2 * pi )

      IF( rtype .GE. 2 ) THEN

C      calculate the normalized concentration at plume centerline
C      for a stack release

          clxoqs = exp(-0.5 * (eff_ht / sigz)**2) /
&                (pi * ubar * sigy * sigz)

C      adjust for finite flow

          IF( (clxoqs .GT. 1.0e-10) .AND. (flow .GT. 0.0) )
&          clxoqs = 1.0 / ( 1.0 / clxoqs + flow )

C      determine plume width for sector average... 0.3927 = (2 pi) / 16

          max_wide = AMIN1( (2*pi * dist), (sw_const * sigy) )
          pwidth = AMAX1( max_wide, (0.3927 * dist) )

C      calculate the normalized sector average concentration

          saxoqs = 2.0 * exp( -0.5 *(eff_ht/sigz)**2) /
&                (sqrt2pi * pwidth * sigz * ubar)

C      adjust for finite flow

          IF( (saxoqs .GT. 1.0e-10) .AND. (flow .GT. 0.0) )
&          saxoqs = 1.0 / ( 1.0 / saxoqs + flow )

      ENDIF

      IF( rtype .LE. 2 ) THEN

C      calculate slant range between release point and receptor

          srange = SQRT( dist**2 + eff_ht**2 )

c      check to see if slant range is < 1% greater than dist.  If it is
```

```

c   use existing NRC diffusion coefficients.

      IF( srange .LT. 1.01 * dist ) THEN
          nsy = sigy
          nsz = sigz
      ELSE

c   calculate NRC diffusion coefficients for slant range

          CALL NSIGMA1( srange, stab, sigz0, sigy0, nsz, nsy )

      ENDIF

c   get low wind speed correction for the NRC diffusion coefficients

          CALL CURVEFIX( srange, ubar, dsy1, dsz1 )

c   get the building wake correction

          CALL WAKECORR( area, srange, ubar, dsy2, dsz2 )

c   calculate the adjusted diffusion coefficients

          tsigy = SQRT( nsy**2 + dsy1**2 + dsy2**2 )
          tsigz = SQRT( nsz**2 + dsz1**2 + dsz2**2 )

c   limit tsigy so that tsigy <= 2pi srange / sqrt(12)  (sigma y for
c   a uniform distribution across a line perpendicular to the plume
c   axis with length equal to the circumference of a circle with
c   radius srange

          maxsigy = 2.0 * pi * srange / SQRT( 12 )
          tsigy = AMIN1( tsigy, maxsigy )

c   calculate the normalized concentration at plume centerline
c   for the entrained portion of the plume

          clxoqw = 1.0 / ( pi * ubar * tsigy * tsigz )

c   adjust for finite flow

          IF( (clxoqw .GT. 1e-10) .AND. (flow .GT. 0.0) )
&      clxoqw = 1.0 / ( 1.0 / clxoqw + flow )

c   determine plume width for sector average... 0.3927 = (2 pi) / 16

          max_wide = AMIN1( (2*pi * srange), (sw_const * tsigy) )
          pwidth = AMAX1( max_wide, (0.3927 * srange) )

c   calculate the normalized sector average concentration

```

ARCON96

saxoqw = 2.0 / (sqrt2pi * pwidth * tsigz * ubar)

C adjust for finite flow

IF((saxoqw .GT. 1e-10) .AND. (flow .GT. 0.0))
& saxoqw = 1.0 / (1.0 / saxoqw + flow)

ENDIF

IF(rtype .EQ. 1) THEN ! Ground-Level Release

clxoq = clxoqw
saxoq = saxoqw

ELSE IF(rtype .EQ. 3) THEN ! Stack Release

clxoq = clxoqs
saxoq = saxoqs

ELSE IF(rtype .EQ. 2) THEN ! Elevated Vent Release

C vent release... calculate fraction entrained in the building
C wake using Regulatory Guide 1.111 method.

wr = w0 / ubar

IF(wr .LE. 1.0) THEN
wf = 1.0
ELSE IF(wr .LE. 1.5) THEN
wf = 2.58 - 1.58 * wr
ELSE IF(wr .LT. 5.0) THEN
wf = 0.3 - 0.06 * wr
ELSE
wf = 0.0
ENDIF

C calculate X/Q using entrained fraction

clxoq = (1.0 - wf) * clxoqs + wf * clxoqw
saxoq = (1.0 - wf) * saxoqs + wf * saxoqw

ELSE ! Unknown Release

Stop 'Unknown release type'

ENDIF

RETURN

END

A.15 XOQ95

SUBROUTINE XOQ95(LOWLIM, T2, DISTR, VAL95)

```

C*****
C
C   XOQ95
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Created: May 1993
C   Revised: January 1995
C
C   Description: Calculate the 95% X/Q from the cumulative frequency
C                distributions for each averaging interval.
C
C   Other modules required: None
C
C*****

```

IMPLICIT NONE

INCLUDE 'PARAM.INC'
INCLUDE 'UNITS.INC'

INTEGER IB, J

REAL LOWLIM(10), T2(10), DISTR(102,10),
+ LLIM, UPLIM, HRS95, VAL95(10)

DO J = 1,10

IF(T2(J) .LT. 20.) THEN

```

C ** Insufficient averages for averaging period J to calculate 95%
C value

```

```

    VAL95(J) = 0.0
    CYCLE
ENDIF

```

```

C ** determine 95% of total possible averaging periods

```

HRS95 = 0.05 * T2(J)

```

C ** First Check to see if 95th percentile is above range
C (PATHOLOGICAL CASE)

```

IF(HRS95 .LE. DISTR(102,J)) THEN

```

ARCON96
      WRITE( LOG_UNIT, '(/2X,A,I2,A)' )
+      '95th percentile value for averaging interval ', J,
+      ' is out of range'

C **      Return negative value

      VAL95(J) = -99999

      ELSE IF( HRS95 .GT. DISTR(2,J) ) THEN

C **      95th percentile value is below range... assume lower end of range

      VAL95(J) = 10**LOWLIM(J)

      ELSE

C **      95% value is in expected range
C **      Find the bin containing the 95% value

      IB = 99
      DO WHILE( (DISTR(IB+2,J) .LE. HRS95) .AND. (IB .GE. 1) )
        IB = IB - 1
      ENDDO

C **      Convert IB to the upper and lower limits of band containing
C      the 95% value

      LLIM = 10**(LOWLIM(J) + IB/25.)
      UPLIM = 10**(LOWLIM(J) + (IB+1)/25.)

      IF( DISTR(IB+2,J) .GT. HRS95 ) THEN
        VAL95(J) = LLIM + (UPLIM - LLIM) * (DISTR(IB+2,J) - HRS95)
+      / (DISTR(IB+2,J) - DISTR(IB+3,J))
      ELSE
        VAL95(J) = LLIM
      ENDIF

      ENDIF

      ENDDO

      RETURN
      END

```

A.16 XOQCALC5

SUBROUTINE XOQCALC5

```

C*****
C
C   XOQCALC5
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Created: December 16, 1994
C   Revised: April 24, 1996
C
C   Description: Computes hourly centerline and sector-average X/Q
C                 for control room habitability assessments using the
C                 final version of the 1995 model for diffusion in
C                 the vicinity of buildings.
C
C   Other modules required:
C
C       Calls:      WINDYXOQ, CURVEFIX, WAKECORR
C
C*****

```

```

IMPLICIT NONE

```

```

INCLUDE 'PARAM.INC'
INCLUDE 'MET.INC'
INCLUDE 'SCENARIO.INC'
INCLUDE 'UNITS.INC'
INCLUDE 'XOQ.INC'

```

```

INTEGER*2 I1, DIR

```

```

REAL      PI, RHU, U10, TESTHT, cxoq, sxoq, eff_ht, dwash

```

```

PI = 3.141593

```

```

C ** Add space to QA file if QA output selected

```

```

IF( TEST_FLG ) WRITE(QA_UNIT,'(/2X,A/)') 'Subroutine XOQCALC5'

```

```

DO I1 = FIRST_MET, LAST_MET

```

```

C ** Set Rhu and U10 to missing

```

```

    u10 = 999.0

```

```

    rhu = 999.0

```

ARCON96

C ** See if stability class missing ... if it is skip X/Q calculations

IF((STAB(I1) .LT. 1) .OR. (STAB(I1) .GT. 7)) THEN

C ** Stability class missing

CLXOQ(I1) = -1.0
SAXOQ(I1) = -1.0
MISS_XOQ = MISS_XOQ + 1

C ** if QA output selected write out status

IF(TEST_FLG) THEN
WRITE(QA_UNIT, '(2X,I5,2X,I2,30X,2(1PE10.2))') i1, stab(i1),
& clxoq(i1), saxoq(i1)
ENDIF

CYCLE
ENDIF

C ** Check for missing wind speeds

IF((SPDL(I1) .EQ. 9999) .AND. (SPDU(I1) .EQ. 9999)) THEN

C ** Wind speeds both missing no X/Q calculations possible

CLXOQ(I1) = -1.0
SAXOQ(I1) = -1.0
MISS_XOQ = MISS_XOQ + 1

C ** if QA output selected write out status

IF(TEST_FLG) THEN
WRITE(QA_UNIT, '(2X,I5,2X,I2,2X,2F6.2,16X,2(1PE10.2))')
& i1, stab(i1), u10, rhu, clxoq(i1), saxoq(i1)
ENDIF

CYCLE

ELSE IF((SPDL(I1) .NE. 9999) .AND. (SPDU(I1) .NE. 9999)) THEN

C ** both wind speeds good convert speed entries to m/s

U10 = (SPDL(I1) / 10.0) * CF(SPD_TYPE) * C1(STAB(I1))

C ** Convert upper speed

TESTHT = (MHT1 + MHT2) / 2.0
IF(RHT .LE. TESTHT) THEN
RHU = (SPDL(I1) / 10.0) * CF(SPD_TYPE) * C2(STAB(I1))
ELSE
RHU = (SPDU(I1) / 10.0) * CF(SPD_TYPE) * C4(STAB(I1))
ENDIF

```

ELSE IF( SPDL(I1) .NE. 9999 ) THEN

C **      Lower level good but not upper level

      U10 = (SPDL(I1) / 10.0) * CF( SPD_TYPE ) * C1(STAB(I1))
      RHU = (SPDL(I1) / 10.0) * CF( SPD_TYPE ) * C2(STAB(I1))

ELSE IF( SPDU(I1) .NE. 9999 ) THEN

C **      Upper speed good but not lower speed

      U10 = (SPDU(I1) / 10.0) * CF( SPD_TYPE ) * C3(STAB(I1))
      RHU = (SPDU(I1) / 10.0) * CF( SPD_TYPE ) * C4(STAB(I1))

ENDIF

C **      Check to see if calm

      IF( ((RTYPE .LE. 2) .AND. (U10 .LT. UMIN )) .OR.
+        ((RTYPE .GE. 2) .AND. (RHU .LT. UMIN )) )
+        THEN

C **      Calm winds

      u10 = 0.0
      rhu = 0.0

C **      See if wind directions both missing ... if they are skip

      ELSE IF( (DIRL(I1) .EQ. 999) .AND. (DIRU(I1) .EQ. 999) ) THEN

C **      Wind directions both missing

      CLXOQ(I1) = -1.0
      SAXOQ(I1) = -1.0
      MISS_XOQ = MISS_XOQ + 1

C **      if QA output selected write out status

      IF( TEST_FLG ) THEN
        WRITE(QA_UNIT, '(2X,I5,2X,I2,2X,2f6.2,2x,2i6, 2x,
&          2(1PE10.2))')  i1, stab(i1), u10, rhu, dirl(i1),
&          diru(i1), clxoq(i1), saxoq(i1)
      ENDIF

      CYCLE

C **      Establish wind direction

      ELSE IF( (DIRL(I1) .EQ. 999) .OR. (DIRU(I1).EQ.999) ) THEN
        DIR = MIN(DIRL(I1),DIRU(I1))

```

ARCON96

```
      ELSE
        IF( RHT .LT. TESTHT ) THEN
          DIR = DIRL(I1)
        ELSE
          DIR = DIRU(I1)
        ENDIF
      ENDIF

C ** calculate downwash (negative if w0 < 1.5 rhu)

      IF( rhu .GE. UMIN ) THEN
        dwash = AMIN1( 4.0 * srad * (w0 / rhu - 1.5), 0.0)
      ELSE
        dwash = 0.0
      ENDIF

C ** calculate effective release height

      IF( rtype .EQ. 1 ) THEN
        eff_ht = rht - recht + t_diff
      ELSE
        eff_ht = AMAX1(rht + dwash, 0.0) - recht + t_diff
      ENDIF

C ** do X/Q calculation

      IF( ((RTYPE .LE. 2) .AND. (U10 .LT. UMIN) ) .OR.
        & ((RTYPE .GE. 2) .AND. (RHU .LT. UMIN) ) ) THEN

C ** calm call windyxoq with umin

        calm_xoq = calm_xoq + 1

        CALL WINDYXOQ( rtype, barea, dist, eff_ht, stab(i1), umin,
          & nsigy(stab(i1)), nsigz(stab(i1)), sigz0, sigy0,
          & f0, w0, sw_cnst, cxoq, sxoq )
        clxoq(i1) = cxoq
        saxoq(i1) = sxoq

C ** Determine if wind blowing from release point to receptor

        ELSE IF( DIR1 .LE. DIR2 ) THEN

C ** Direction window doesn't straddle north

          IF( (DIR1 .LE. DIR) .AND. (DIR .LE. DIR2) ) THEN

C ** Wind direction is in window -- calculate X/Q

            in_sect = in_sect + 1

            CALL WINDYXOQ( rtype, barea, dist, eff_ht, stab(i1), rhu,
              + nsigy(stab(i1)), nsigz(stab(i1)), sigz0,
```

```

&                sigy0, f0, w0, sw_cnst, cxoq, sxoq)

      CLXOQ(I1) = cxoq
      SAXOQ(I1) = sxoq

      ELSE

C  **      Wind direction is outside window

      out_sect = out_sect + 1

      CLXOQ(I1) = 0.0
      SAXOQ(I1) = 0.0

      ENDIF

      ELSE

C  **      Wind direction window straddles north

      IF( (DIR .LE. DIR2) .OR. (DIR .GE. DIR1) ) THEN

C  **      Wind direction is in window -- calculate X/Q

      in_sect = in_sect + 1

      CALL WINDYXOQ( rtype, barea, dist, eff_ht, stab(i1), rhu,
+                 nsigy(stab(i1)), nsigz(stab(i1)), sigz0,
+                 sigy0, f0, w0, sw_cnst, cxoq, sxoq)

      CLXOQ(I1) = cxoq
      SAXOQ(I1) = sxoq

      ELSE

C  **      Wind direction is outside of the window

      out_sect = out_sect + 1

      CLXOQ(I1) = 0.0
      SAXOQ(I1) = 0.0
      ENDIF

      ENDIF      ! end of X/Q calculations

C  **      if QA output selected write out status

      IF( TEST_FLG ) THEN
        WRITE(QA_UNIT, '(2X,I5,2X,I2,2X,2f6.2,2x,i6,8x,
&                2(1PE10.2))') i1, stab(i1), u10, rhu, dir,
&                clxoq(i1), saxoq(i1)
      ENDIF

```

ARCON96

ENDDO ! met data do loop

C ** Update maximum and minimum values

```
DO I1=FIRST_MET, LAST_MET
  IF( CLXOQ(I1) .GT. 0.0 ) THEN
    CLMAX = AMAX1( CLMAX, CLXOQ(I1) )
    CLMIN = AMIN1( CLMIN, CLXOQ(I1) )
    SAMAX = AMAX1( SAMAX, SAXOQ(I1) )
    SAMIN = AMIN1( SAMIN, SAXOQ(I1) )
  ENDIF
ENDDO

FIRST_XOQ = FIRST_MET
LAST_XOQ = LAST_MET
TOT_XOQ = TOT_XOQ + (LAST_XOQ - FIRST_XOQ) + 1

RETURN
END
```


A.17 MET

```

C*****
C
C   MET.INC
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Meteorological Data Type and Common Block Definitions
C
C   Created: May 1991
C   Revised: April 24, 1996
C
C   Included In: ARCON96, BLOCKDATA, INIT, METREAD, RECORD, SCENREAD,
C               SHIFT, XOQCALC5
C*****

```

```

LOGICAL*1 END_MET

INTEGER NMETFILE, SPD_TYPE, STAB(MAXHOURS)

INTEGER*2 DURL(MAXHOURS), DIRU(MAXHOURS), SPDL(MAXHOURS),
+         SPDU(MAXHOURS), JULDAY(MAXHOURS), CHOUR(MAXHOURS)

INTEGER   FIRST_MET, LAST_MET, NEXT_MET, TOT_MET

REAL     C1(7), C2(7), C3(7), C4(7) ,CF(3), NSIGY(7), NSIGZ(7),
+         NSIGY2(7), NSIGZ2(7), TSIGY, TSIGZ, USTAR, ZOL(7), UMIN,
+         sigy0, sigz0

COMMON   /METDATA/ END_MET, NMETFILE, SPD_TYPE, STAB, DURL, DIRU,
+         SPDL, SPDU, JULDAY, FIRST_MET, LAST_MET,
+         NEXT_MET, TOT_MET, UMIN, C1, C2, C3, C4, CF,
+         NSIGY, NSIGZ, NSIGY2, NSIGZ2, TSIGY, TSIGZ,
+         USTAR, ZOL, CHOUR, sigy0, sigz0

```

ARCON96

A.18 PARAM

```
C*****
C
C   PARAM.INC
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Parameter definitions
C
C   Created: May 1991
C   Revised: January 1995
C
C   Included In: ARCON96, BLOCKDATA, INIT, METREAD, PROC, RECORD,
C               SCENREAD, SHIFT, SUMMARY, XOQCALC5, XOQ95
C
C*****
```

INTEGER MAXFILES, MAXHOURS

PARAMETER (MAXFILES = 10, MAXHOURS = 10000)

A.19 SCENARIO

```
C*****
C
C   SCENARIO.INC
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   Scenario description and common block definitions
C
C   Created: May 1991
C   Revised: February 16, 1995
C
C   Included In: ARCON95, BLOCKDATA, INIT, PROC, RECORD, SCENREAD,
C               SUMMARY, XOQCALC5
C
C*****
```

INTEGER*2 DIR1, DIR2, RTYPE, WIND_DIR, WINDOW

REAL BAREA, DIST, FO, MHT1, MHT2, RECHT, RHT, WO,
+ Z0, SW_CNST, T_DIFF, SRAD

Include Files

```
COMMON /SCENARIO/ DIR1, DIR2, RTYPE, WIND_DIR, WINDOW,  
+ BAREA, DIST, FO, MHT1, MHT2, RECHT, RHT, WO,  
+ ZO, SW_CNST, T_DIFF, SRAD
```

ARCON96

A.20 UNITS

```
C*****
C
C   UNITS.INC
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest National Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   File Name and Unit Designations
C
C   Created:  May 1993
C   Revised:  January 1995
C
C   Included In:  ARCON96, BLOCKDATA, INIT, METREAD, PROC, RECORD,
C                 SCENREAD, SHIFT, SUMMARY, XOQCALC5, XOQ95
C
C*****
```

```
LOGICAL*1    TEST_FLG

INTEGER*1    LOG_UNIT, MET_UNIT, SCENUNIT, CFD_UNIT, QA_UNIT

CHARACTER*40 LOG_FILE, MET_FILE(MAXFILES), SCENFILE, CFD_FILE,
&            QA_FILE

COMMON /FILES/ LOG_FILE, MET_FILE, SCENFILE, CFD_FILE, QA_FILE

COMMON /FUNITS/ LOG_UNIT, MET_UNIT, SCENUNIT, CFD_UNIT, QA_UNIT,
&              TEST_FLG
```

A.21 XOQ

```

C*****
C
C   XOQ.INC
C
C   J. V. Ramsdell, Jr.
C   Pacific Northwest Laboratory
C   P.O. Box 999
C   Richland, WA 99352
C
C   X/Q realted variables and common block definitions
C
C   Created: May 1991
C   Revised: April 1995
C
C   Included In: ARCON96, BLOCKDATA, METREAD, PROC, RECORD, SCENREAD
C                SHIFT, SUMMARY, XOQCALC5
C*****

```

LOGICAL LIMITS

```

INTEGER FIRST_XOQ, LAST_XOQ, TOT_XOQ, MISS_XOQ, NA(10),
+ NAVMIN(10), calm_xoq, in_sect, out_sect, elevated

```

```

REAL CLMAX, CLMIN, CLXOQ(MAXHOURS), SAMAX, SAMIN,
+ SAXOQ(MAXHOURS), LOWLIM(10), UPLIM(10),
+ DISTR(102,10), SUM(10), ZERO(10)

```

```

COMMON /XOQ1/ NA, NAVMIN, FIRST_XOQ, LAST_XOQ, TOT_XOQ,
+ MISS_XOQ, CLMAX, CLMIN, CLXOQ, LIMITS, calm_xoq,
+ in_sect, out_sect, elevated

```

```

COMMON /XOQ2/ SAMAX, SAMIN, SAXOQ, LOWLIM, UPLIM, DISTR, ZERO, SUM

```


Appendix B Glossary

| VARIABLE | TYPE | INCLUDE BLOCK | DEFINITION |
|-----------------|------|---------------|---|
| AREA | R*4 | | Building cross-sectional area (m ²) in subroutine WINDYXOQ |
| BAREA | R*4 | SCENARIO | Building cross-sectional area (m ²) |
| C1(7) | R*4 | MET | Factor to adjust the lower wind speed to represent the wind at 10 meters |
| C2(7) | R*4 | MET | Factor to adjust the lower wind speed to represent the wind at the release height |
| C3(7) | R*4 | MET | Factor to adjust the upper wind speed to represent the wind at 10 meters |
| C4(7) | R*4 | MET | Factor to adjust the upper wind speed to represent the wind at the release height |
| CALM_XOQ | I*4 | XOQ | Counter for the number of hours of wind is calm (less than U _{min}) |
| CF(3) | R*4 | MET | Wind speed unit conversion factor |
| CFD_FILE | A*40 | UNITS | Name of cumulative frequency distribution file, including path |
| CFD_UNIT | I*1 | UNITS | Logical unit assigned to cumulative distribution file |
| CHOUR(MAXHOURS) | I*2 | MET | Hour of the meteorological observation 00 = midnight, 23 = 11 pm |
| CLMAX | R*4 | XOQ | Maximum one-hour centerline X/Q (s/m ³) |
| CLMIN | R*4 | XOQ | Minimum one-hour sector-average X/Q (s/m ³) |
| CLXOQ | R*4 | | One-hour centerline X/Q (s/m ³) in subroutine WINDYXOQ |
| CLXOQ(MAXHOURS) | R*4 | XOQ | Vector containing one-hour centerline X/Qs (s/m ³) |
| DIR1 | I*2 | SCENARIO | Lower limit of the wind direction window (farthest counter-clockwise looking into the wind) |
| DIR2 | I*2 | SCENARIO | Upper limit of the wind direction window (farthest counter-clockwise looking into the wind) |
| DIRL(MAXHOURS) | I*2 | MET | Vector of hourly wind directions at the lower measurement level |
| DIRU(MAXHOURS) | I*2 | MET | Vector of hourly wind directions at the upper measurement level |

ARCON96

| VARIABLE | TYPE | INCLUDE BLOCK | DEFINITION |
|------------------|------|---------------|--|
| DIST | R*4 | SCENARIO | Horizontal distance between the release point and the receptor (m) |
| DISTR(102,10) | R*4 | XOQ | Frequency distribution array prior to subroutine SUMMARY; cumulative frequency distribution array following subroutine SUMMARY |
| DSY | R*4 | | Corrections to σ_y in subroutines CURVEFIX and WAKECORR (m) |
| DSZ | R*4 | | Corrections to σ_z in subroutines CURVEFIX and WAKECORR (m) |
| EFF_HT | R*4 | | Vertical distance between the release point and the receptor (m) |
| ELEVATED | I*4 | XOQ | Counter for the number of hours that the wind direction is in window, but the X/Q is > 5 orders of magnitude below the upper bound of the bins |
| END_MET | L*1 | MET | Logical flag signalling that the end of the meteorological data has been reached (no more files) |
| FLOW | R*4 | | Flow of the effluent release (m^3/s) in subroutine WINDYXOQ |
| F0 | R*4 | SCENARIO | Flow of the effluent release (m^3/s) |
| FIRST MET | I*4 | MET | Index of the first new meteorological data |
| FIRST XOQ | I*4 | XOQ | Index of the first new hourly X/Q values |
| IN_SECT | I*4 | XOQ | Counter for the number of hours that the wind direction is in window and wind is > U_{min} |
| JULDAY(MAXHOURS) | I*2 | MET | Day of the year; 1 = Jan 1, 365 or 366 = Dec 31. |
| LAST MET | I*4 | MET | Index of the last meteorological data |
| LAST XOQ | I*4 | XOQ | Index of the last hourly X/Q values |
| LIMITS | L*4 | XOQ | Logical flag enabling calculation of the range of bins for the X/Q frequency distributions |
| LOG FILE | A*40 | UNITS | Name of log file and path |
| LOG UNIT | I*1 | UNITS | Logical unit assigned to the log file |
| LOWLIM(10) | R*4 | XOQ | Vector of lower limits for the X/Q bins |
| MAXFILES | I*4 | PARAM | Maximum number of meteorological data files |
| MAXHOURS | I*4 | PARAM | Maximum number of hours of data that can be stored in memory at one time |

| VARIABLE | TYPE | INCLUDE BLOCK | DEFINITION |
|--------------------|------|---------------|---|
| MET FILE(MAXFILES) | A*40 | UNITS | Vector of meteorological file names and paths |
| MET UNIT | I*1 | UNITS | Logical unit assigned to the meteorological files |
| MHT1 | R*4 | SCENARIO | Measurement height for the lower level of wind direction and wind speed (m) |
| MHT2 | R*4 | SCENARIO | Measurement height for the upper level of wind direction and wind speed (m) |
| MISS_XOQ | I*4 | XOQ | Number of hours for which X/Q could not be calculated |
| NA(10) | I*4 | XOQ | Vector with nominal number of hours for X/Q averaging periods |
| NAVMIN(10) | I*4 | XOQ | Vector with minimum number of hours for each X/Q averaging period |
| NEXT MET | I*4 | MET | Number of the next meteorological data file |
| NMETFILE | I*4 | MET | Number of meteorological data files |
| NSIGY(7) | R*4 | MET | Vector of normal (PAVAN) σ_y by stability class (m) |
| NSIGY2(7) | R*4 | MET | Vector of normal (PAVAN) σ_y^2 by stability class (m ²) |
| NSIGZ(7) | R*4 | MET | Vector of normal (PAVAN) σ_z by stability class (m) |
| NSIGZ2(7) | R*4 | MET | Vector of normal (PAVAN) σ_z^2 by stability class (m ²) |
| OUT_SECT | I*4 | XOQ | Counter for the number of hours wind is not in window, calm, or missing |
| QA_FILE | A*40 | UNITS | Name and path for the file containing the expanded output |
| QA UNIT | I*1 | UNITS | Logical unit assigned to the expanded output file |
| RECHT | R*4 | SCENARIO | Receptor (intake) height above grade (m) |
| RHT | R*4 | SCENARIO | Release height above grade (m) |
| RTYPE | I*2 | SCENARIO | Release type; 1 = ground, 2 = vent, 3 = stack |
| SAMAX | R*4 | XOQ | Maximum one-hour, sector-average X/Q (m/s ³) |
| SAMIN | R*4 | XOQ | Minimum one-hour, sector-average X/Q (m/s ³) |

| VARIABLE | TYPE | INCLUDE BLOCK | DEFINITION |
|-----------------|------|---------------|--|
| SAXOQ | R*4 | | One-hour sector-average X/Q (s/m^3) in subroutine WINDYXOQ |
| SAXOQ(MAXHOURS) | R*4 | XOQ | Vector containing the one-hour, sector-average X/Qs (s/m^3) |
| SCENFILE | A*40 | UNITS | Run specification file name and path |
| SCENUNIT | I*1 | UNITS | Logical unit assigned to the run specification file |
| SIGMAY | R*4 | | σ_y calculated in subroutine NSIGMA1 |
| SIGMAZ | R*4 | | σ_z calculated in subroutine NSIGMA1 |
| SIGY | R*4 | | σ_y from subroutine NSIGMA1 in subroutine WINDYXOQ |
| SIGY0 | R*4 | MET | σ_{y0} (initial value) input to NSIGMA1 |
| SIGZ | R*4 | | σ_z from subroutine NSIGMA1 in subroutine WINDYXOQ |
| SIGZ0 | R*4 | MET | σ_{z0} (initial value) input to NSIGMA1 |
| SPDL(MAXHOURS) | I*2 | MET | Vector containing the hourly, lower-level wind speeds (original measurement units) |
| SPDU(MAXHOURS) | I*2 | MET | Vector containing the hourly, upper-level wind speeds (original measurement units) |
| SPD_TYPE | I*4 | MET | Wind speed measurement units; 1 = m/s, 2 = mph, 3 = knots |
| SRAD | R*4 | SCENARIO | Inside radius of vent or stack (m) |
| STAB(MAXHOURS) | I*4 | MET | Vector containing the hourly stability classes |
| SUM(10) | R*4 | XOQ | Vector containing the running sum of hourly X/Qs (s/m^3) |
| SW_CNST | R*4 | SCENARIO | Sector-width averaging constant |
| T2(10) | R*4 | | Total number of X/Q averages considered in subroutine SUMMARY |
| TEST_FLG | L*1 | UNITS | Logical flag used to control expanded output |
| TOT_MET | I*4 | MET | Total number of hours of meteorological data read by subroutine METREAD |
| TOT_XOQ | I*4 | XOQ | Total number of hours considered in X/Q calculations... includes hours of missing data |

| VARIABLE | TYPE | INCLUDE BLOCK | DEFINITION |
|-----------|------|---------------|--|
| TSIGY | R*4 | MET | Horizontal diffusion coefficient following adjustments to account for low wind speed and building wake |
| TSIGZ | R*4 | MET | Vertical diffusion coefficient following adjustments to account for low wind speed and building wake |
| T_DIFF | R*4 | SCENARIO | Difference in grade elevation between release point and receptor ($T_DIFF = Grade_{RPT} - Grade_{RECTR}$) |
| UBAR | R*4 | | Release height wind speed used in subroutines WINDYXOQ, CURVEFIX, and WAKECORR |
| UMIN | R*4 | MET | Nominal minimum wind speed (m/s) below which wind is assumed to carry effluent from release point to receptor regardless of reported direction |
| UPLIM(10) | R*4 | XOQ | Upper limit of the X/Q bins (s/m^3) |
| USTAR | R*4 | MET | Scaling velocity for wind speed in the boundary layer (m/s) |
| VAL95(10) | R*4 | | Vector containing the 95th percentile X/Q values |
| W0 | R*4 | SCENARIO | Vent or stack effluent vertical velocity (m/s) |
| WIND_DIR | I*2 | SCENARIO | Wind direction carrying effluent from release point directly to receptor (direction of the release point from the receptor) |
| WINDOW | I*2 | SCENARIO | Nominal width of the wind direction window for which effluent is carried to receptor (degrees) |
| Z0 | R*4 | SCENARIO | Surface roughness length (m) |
| ZOL(7) | R*4 | MET | Normalized height in the atmospheric boundary layer |
| ZERO(10) | R*4 | XOQ | Vector containing the number of periods with $X/Q = 0$ for each averaging interval |

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
*(Assigned by NRC. Add Vol., Supp., Rev.,
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11. ABSTRACT *(200 words or less)*

This report documents the ARCON96 computer code developed for the U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation for use in control room habitability assessments. It includes a user's guide to the code, a description of the technical basis for the code, and a programmer's guide to the code. The ARCON96 code uses hourly meteorological data and recently developed methods for estimating dispersion in the vicinity of buildings to calculate relative concentrations at control room air intakes that would be exceeded no more than five percent of the time. These concentrations are calculated for averaging periods ranging from one hour to 30 days in duration.

ARCON96 is a revised version of ARCON95, which was developed for the NRC Office of Nuclear Regulatory Research. Changes in the code permit users to simulate releases from area sources as well as point sources. The method of averaging concentrations for periods longer than 2 hours has also been changed. The change in averaging procedures increases relative concentrations for these averaging periods. In general, the increase in concentrations is less than a factor of two. The increase is greatest for relatively short averaging periods, for example 0 to 8 hours and diminishes as the duration of the averaging period increases.

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