

# Software Integration for Environmental Radiological Release Assessments (SIERRA)

## Atmospheric Transport and Diffusion Module User's Guide

December 2023

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BATTELLE  
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UNITED STATES DEPARTMENT OF ENERGY  
*under Contract DE-AC05-76RL01830*

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Richland, Washington 99354

## Acronyms and Abbreviations

ARCON	computer code for Atmospheric Relative CONcentration in Building Wakes
ATD	atmospheric transport and diffusion
CFR	<i>Code of Federal Regulations</i>
DBA	design basis accident
DOE	U.S. Department of Energy
EAB	exclusion area boundary
EPA	U.S. Environmental Protection Agency
Fortran	FORmula TRANslator
HA	High Quality Assurance grading level
ISC	Industrial Source Complex Dispersion Model
JSON	JavaScript Object Notation
LPZ	outer boundary of the low population zone
NNW	North-Northwest
NPP	nuclear power plants
NPUF	non-power production or utilization facility
NQA-1	Nuclear Quality Assurance-1
NRC	U.S. Nuclear Regulatory Commission
PAVAN	computer code for ground-level $\chi/Q$ for accidental release
P-G	Pasquill-Gifford diffusion coefficients
PNNL	Pacific Northwest National Laboratory
XOQDOQ	computer code for evaluation of routine effluent releases at commercial nuclear power stations
RAMP	Radiation Protection Computer Code Analysis and Maintenance Program
RG	Regulatory Guide
SIERRA	Software Integration for Environmental Radiological Release Assessments
TSC	Technical Support Center
WSW	West-Southwest

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# 1.0 SIERRA Atmospheric Transport and Diffusion Module User's Guide

## 1.1 Introduction

The Software Integration for Environmental Radiological Release Assessments (SIERRA) application is intended to provide a consolidated framework for separate “functional engines” that can be used, individually or in certain combinations, for dose assessment to support licensing of nuclear power plants (NPPs) and non-power production or utilization facilities (NPUFs). The software will consolidate and modernize various existing codes within the U.S. Nuclear Regulatory Commission’s (NRC’s) Radiation Protection Computer Code Analysis and Maintenance Program (RAMP). RAMP develops, maintains, improves, distributes, and provides training on NRC-sponsored radiation protection and dose assessment computer codes. The SIERRA software will be custom created based upon existing RAMP codes and incorporate scientific methods for environmental (e.g., air or water) transport, diffusion, and dose assessment of radionuclides.

This document provides a brief overview of the Atmospheric Transport and Diffusion Module (ATD) software and installation steps. Section 2.0 describes the user interface for SIERRA while Section 3.0 describes the ATD module user interface. Quality assurance applied for this effort is described in Section 4.0.

In this document the SIERRA application and the ATD module are nearly synonymous. The SIERRA application is a developed user interface which currently is home to only the ATD module and user interface for the ATD module. Currently the SIERRA application only holds the atmospheric engine. However, in the future, SIERRA will allow users to access multiple modules (e.g., source term, river/lake dispersion, dose). The ATD module and interface are a part of the larger SIERRA application.

### 1.1.1 Getting Started

This section contains basic information about computer requirements for the SIERRA software application, as well as a brief overview of the software installation process.

#### 1.1.1.1 Computer Requirements

The following are computer requirements to run the SIERRA software.

- Windows 10 or later operating system
- .NET Framework
- 64-bit system
- For optimal user interface display, it is recommended that the computer display scale be set to 125 percent.



### 1.1.1.2 Installation Instructions

Note: If a previous version of SIERRA is already installed, users may need to use the “Apps & Features” tool within “Windows Settings” to remove the “Sierra\_Install” application from the computer.

The basic steps required to install the SIERRA software are as follows:

1. Navigate to and open the “SIERRA\_Install” folder.
2. Double click on the “SIERRA\_Install\_V\_0.exe” file in the folder.
3. Upon start up the installation software may display a license agreement for installation of the .NET framework (Figure 1-1). Click on the “Accept” button to continue the installation and follow the subsequent window prompts.

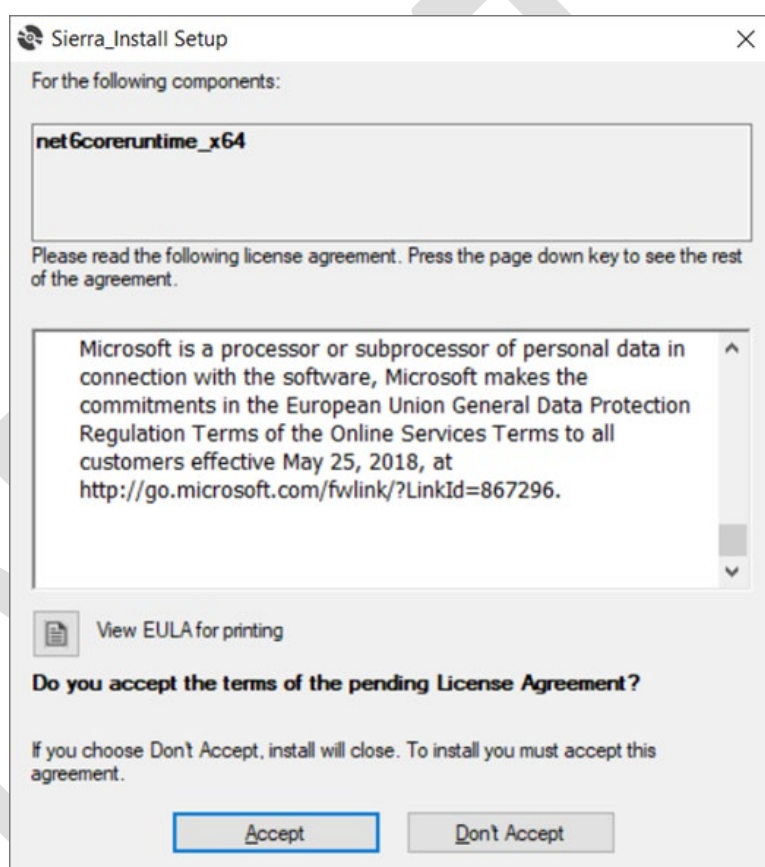


Figure 1-1. SIERRA Install Setup Screen to install .NET

4. Once the .NET framework installation is complete, an “Installation was successful” dialog will be displayed. Click on the “Close” button to continue to the SIERRA installation.
5. The SIERRA installation “Welcome” screen is displayed as shown in Figure 1-2. Click on the “Next” button to continue the installation and proceed through the subsequent window prompts.

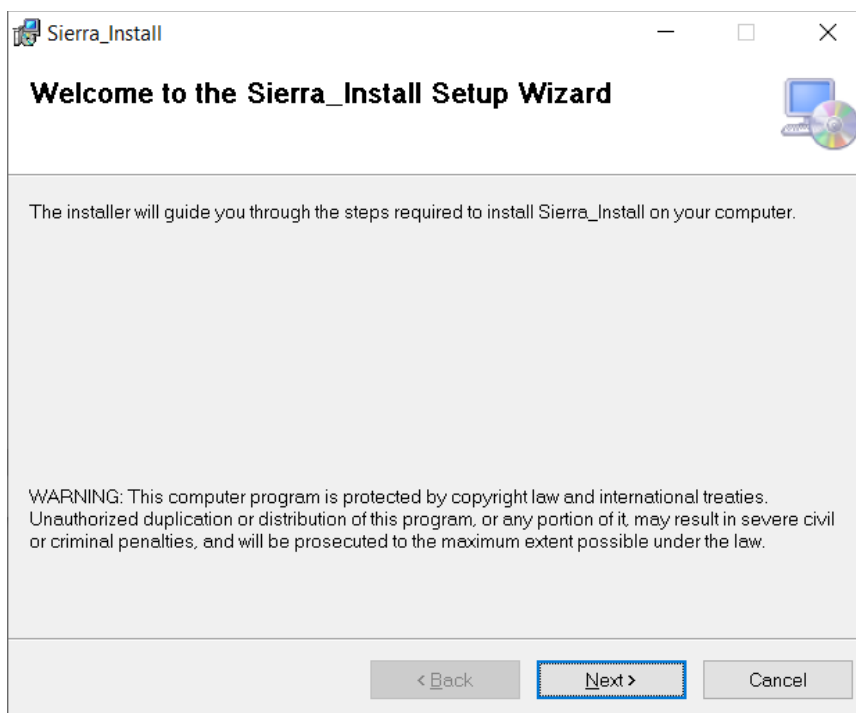


Figure 1-2 Install Select Installation Folder Screen

6. Once the software is successfully installed, an "Installation Complete" screen will be displayed, as shown in Figure 1-3. Click the "Close" button to close the installation program.

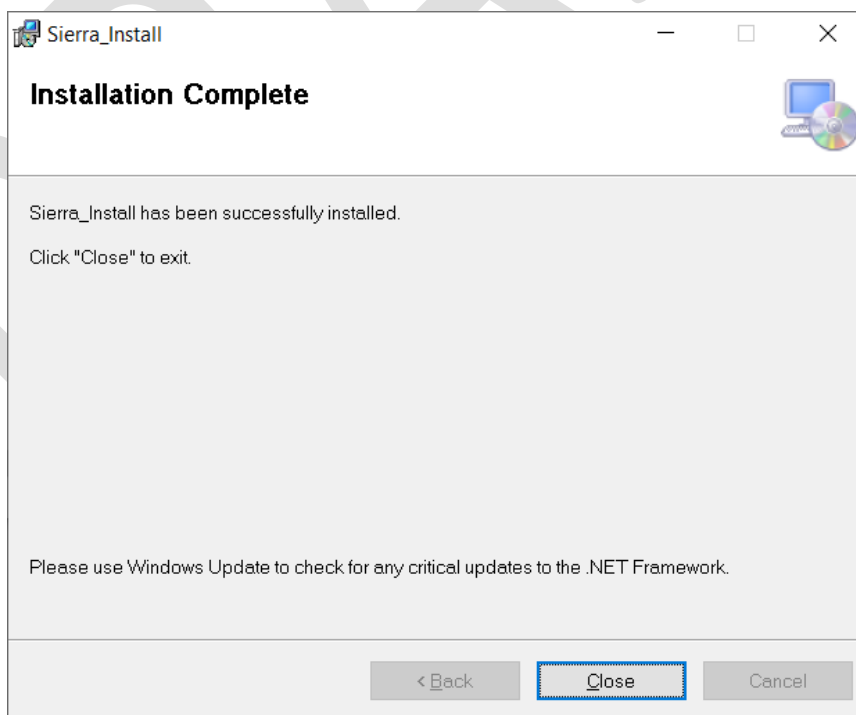


Figure 1-3. Installation Complete Screen

7. The SIERRA software can then be started by double clicking the “SIERRA” shortcut that has been created on the computer’s desktop.

See Appendix A for a description of the directory structure for the SIERRA software, and Appendix B for brief descriptions of the simulation input and output files. Appendix C contains an example with steps for how to run the SIERRA application. Appendix D contains brief descriptions of the example test cases that are included within the SIERRA directory, which may be used to confirm the success of the software install.

DRAFT

## 2.0 SIERRA User Interface Guide

The SIERRA user interface application provides the ability to enter information characterizing the overall simulation that the user intends to run. Through this interface, the user will select the assessment type (Regulatory or Research) and the analysis type (currently Control Room Analysis, Design Basis Accidents, and Routine Analysis) to be simulated along with providing a name for the simulation. Once the user has made their selections, the “Overview” panel of the interface is then used to start an “Atmospheric Dispersion” simulation.

Selections made using the SIERRA interface will be used to control which modules are available to the user and the order in which the modules (e.g., Source Term, Atmospheric Dispersion, River/Lake Dispersion, Dose) will be executed. Current development has focused on the ATD module. Future development will incorporate source terms, river/lake dispersion, environmental accumulation, non-human biota exposure, human exposure, and dose modules. Sections 2.1 through 2.5 provide a description of each of the current SIERRA interface panels along with the controls present on each panel.

### 2.1 Splash Screen

Once the SIERRA application has been started, a splash screen (Figure 2-1) with information about the software will be displayed while the main SIERRA user interface is loading. Once the SIERRA user interface has completed loading, the splash screen will automatically close.



Figure 2-1. SIERRA Splash Screen

When the splash screen closes, the Disclaimer page will be present on the screen. Users may review the disclaimer content and either “Exit” the software or “Continue” to the next step in the software.

## 2.2 Assessment Type Selection Panel

This panel is used to select the type of assessment that the user intends to perform (Figure 2-2). There are two options available: “Regulatory” and “Research.” Each option is defined in the following sections.

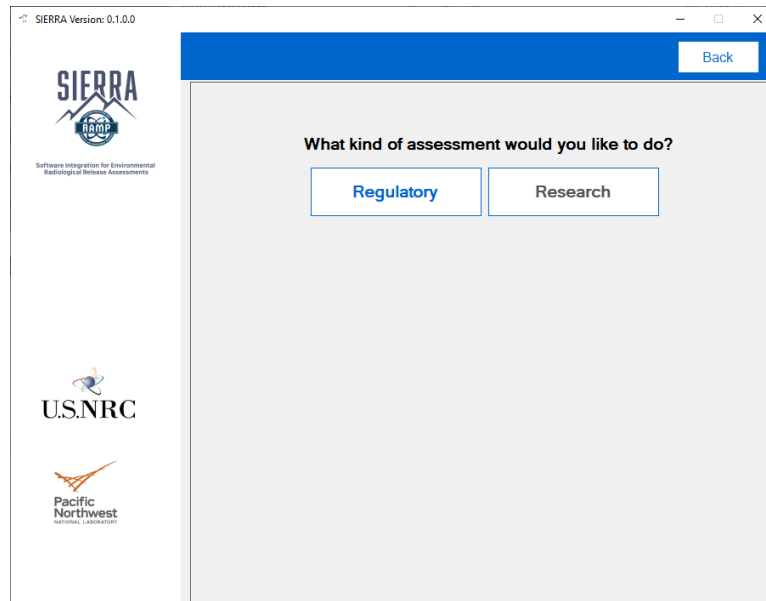


Figure 2-2. SIERRA Assessment Panel

### 2.2.1 Regulatory

The regulatory option, when selected, results in a simulation that uses predefined modules and follows a specific execution path through various modules, when those modules are developed. While the ATD module is the only module available with this version of SIERRA, this is currently the only option available to the user.

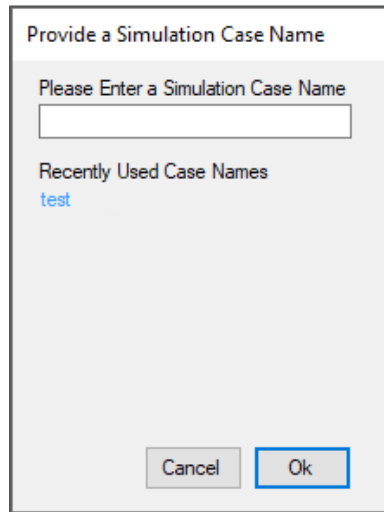
### 2.2.2 Research

The research option is intended to provide the user more freedom in selecting the modules to be used in the simulation and how they are to be executed. This option is currently not available in this version of the software.

## 2.3 Simulation Case Name

Once the assessment type has been selected, a dialog window will be displayed prompting the user to enter a name for the simulation case that is to be executed (Figure 2-3). Alternatively, users may select from a list of recently used case names from a list below the text entry box. Selecting a recent case name will populate that name in the box so users may modify the name. The list of recently used case names will be populated with up to ten unique names. Case names must not contain spaces or any special characters and are limited to 50 characters. This simulation name will be used to create the appropriate directories that store the input and output files used and generated by the simulation modules. The directory structure used by the

SIERRA software to store input and output files generated during a simulation run are defined in Appendix A.

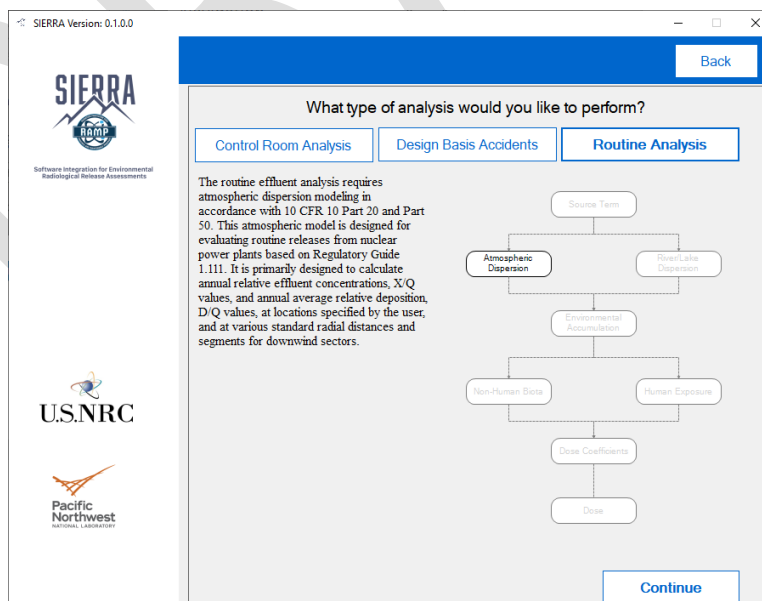


The dialog box is titled "Provide a Simulation Case Name". It contains a text input field with the placeholder text "Please Enter a Simulation Case Name". Below the input field, there is a section titled "Recently Used Case Names" which lists "test" in blue text. At the bottom of the dialog, there are two buttons: "Cancel" and "Ok".

Figure 2-3. SIERRA Simulation Name Dialog

## 2.4 Analysis Type Selection Panel

Following the entry of a simulation name, the software will then display the panel (Figure 2-4) which will be used to select the type of analysis the user wants to simulate. Currently, there are three types of analyses available to select from. They are designated as control room analysis, design basis accidents, and routine analysis. The three different options are further clarified in the following sections. Selecting the button corresponding to each of the analysis types will result in a description of the analysis type being displayed in the center of the panel.



The panel is titled "What type of analysis would you like to perform?". It features three buttons: "Control Room Analysis", "Design Basis Accidents", and "Routine Analysis". The "Routine Analysis" button is selected. Below the buttons, there is a text block describing the routine effluent analysis: "The routine effluent analysis requires atmospheric dispersion modeling in accordance with 10 CFR 10 Part 20 and Part 50. This atmospheric model is designed for evaluating routine releases from nuclear power plants based on Regulatory Guide 1.111. It is primarily designed to calculate annual relative effluent concentrations, X/Q values, and annual average relative deposition, D/Q values, at locations specified by the user, and at various standard radial distances and segments for downwind sectors." To the right of the text is a flowchart showing the analysis process: "Source Term" leads to "Atmospheric Dispersion" and "River/Lake Dispersion", which both lead to "Environmental Accumulation". "Environmental Accumulation" leads to "Non-Human Biota" and "Human Exposure", which both lead to "Dose Coefficients", which finally leads to "Dose". At the bottom right, there is a "Continue" button. The left sidebar of the panel displays the SIERRA logo, the text "Software Integration for Environmental Radiological Release Assessments", the U.S.NRC logo, and the Pacific Northwest National Laboratory logo.

Figure 2-4. SIERRA Analysis Select Panel

### 2.4.1 Control Room Analysis

This analysis type is used to calculate onsite, design basis accident atmospheric relative concentrations ( $\chi/Qs$ ) in support of control room habitability assessments required by Title 10 *Code of Federal Regulations* (10 CFR) Part 50, Appendix A, General Design Criterion 19. It uses hourly meteorological data and the atmosphere's influence (i.e., transport and diffusion) in the vicinity of buildings to calculate the  $\chi/Qs$  at the control room normal and/or emergency air intakes and at points of ingress and egress (e.g., directly to the control room, control building, personnel and equipment hatches). These relative concentrations cannot exceed the set level more than 5 percent of the time and are calculated for moving averaging periods that range from one hour to 30 days in duration.

### 2.4.2 Design Basis Accidents Analysis

The design basis accidents for license applications and renewals requires applicants to estimate  $\chi/Qs$  for specific averaging time periods at specified offsite distances. The modeling approach is based on the guidance in Regulatory Guide (RG) 1.145. These assessments are required by 10 CFR Part 50 and 10 CFR Part 100. The averaging periods range from one hour to 30 days in duration. The distances usually correspond to the shortest distance to the exclusion area boundary (EAB) and the outer boundary of the low population zone (LPZ) for each of the sixteen standard 22.5 ° directional sectors and as specified in the guidance.

### 2.4.3 Routine Analysis

The routine effluent analysis requires ATD modeling in accordance with 10 CFR 10 Part 20 and Part 50. This atmospheric model is designed for evaluating routine releases from NPPs based on RG 1.111. It is primarily designed to calculate annual relative effluent concentrations,  $\chi/Q$  values, and annual average relative deposition,  $D/Q$  values, at locations specified by the user, and at various standard radial distances and segments for downwind sectors.

### 2.4.4 Modules Display

The diagram displayed on the right side of the analysis selection panel in Figure 2-4 shows what modules are available for use in the simulation as well as the active connections for simulations between modules. Modules that are not available for use in a simulation are grayed out and connections that are not available are displayed as dashed lines. Connections that are active will be displayed as solid black lines.

### 2.4.5 Back Button

Located on the upper right corner of the analysis type selection panel, the "Back" button can be used to step back to a prior panel of the interface.

### 2.4.6 Continue Button

Located at the lower right corner of the analysis type selection panel, the "Continue" button, when clicked, will advance the user interface to the "Overview" panel. One of the three analysis options (Control Room Analysis, Design Basis Accidents, or Routine Analysis) must be selected to continue.

## 2.5 Module Overview Panel

The “Module Overview” panel of the SIERRA user interface (Figure 2-5) provides a listing of the modules that are available for use in the simulation. The listing shows a set of buttons that can be used to start the applicable module. Buttons representing modules that are not available for use are disabled and grayed out. Clicking on an active button in the list will start the module’s user interface application. Once a module’s application is started, the SIERRA interface software is locked and only becomes active again after the previously selected module application ends.

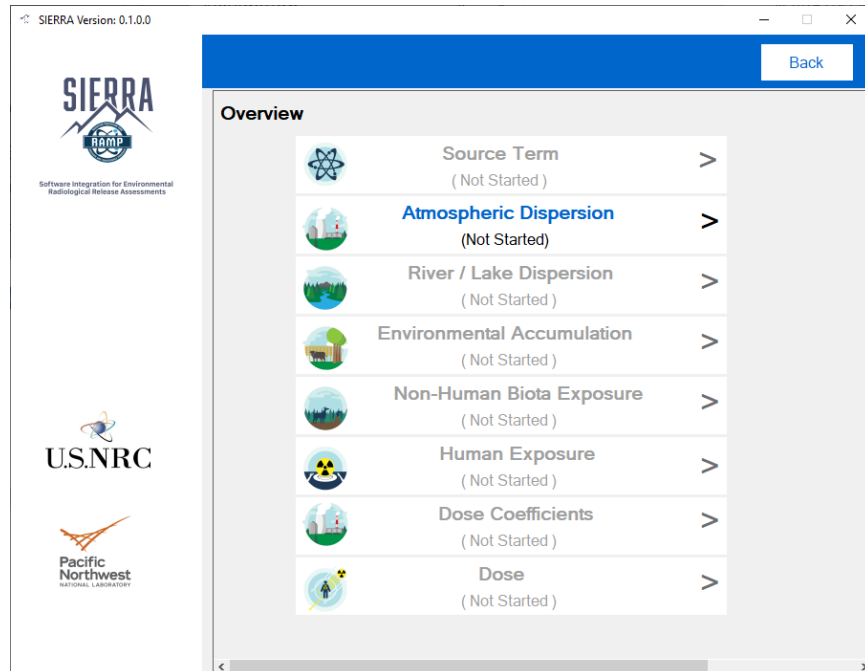


Figure 2-5. SIERRA Module Overview Panel



## 3.0 Atmospheric Transport and Diffusion Module Interface User Guide

This section provides an overview of the atmospheric transport and diffusion module user interface. The primary objective of this section is to document the various panels used for simulation entries. A description of the technical basis of the atmospheric transport and diffusion model is presented in Appendix E.

### 3.1 Overview Panel

Located on the left side of the ATD module user interface, the “Overview” panel (Figure 3-1) displays simulation information such as the analysis type and a graphic showing the module’s place in the simulation’s execution. The panel also contains a set of buttons which can be used to navigate through the interface, access and change module default options, load or save user inputs, and view outputs after the analysis is run. The following define the controls and functionality presented in this panel.

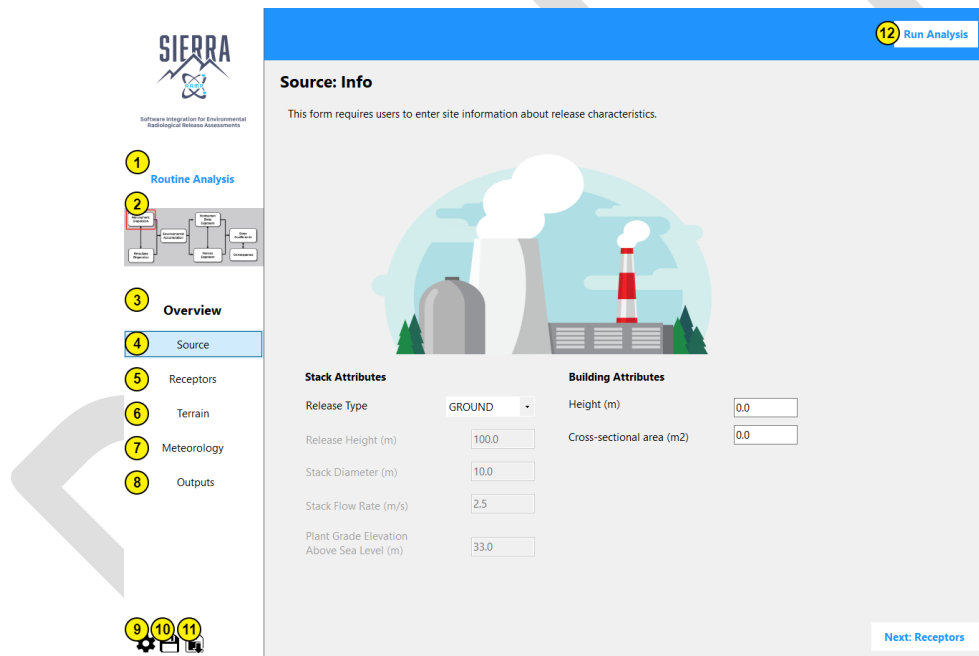


Figure 3-1. ATD Overview Panel. Yellow Circular Numbered Markers Have Been Added to Label Areas of The Overview Panel.

The list below briefly describes the numbered items shown in Figure 3-1.

1. Analysis Type - Indicates which module is currently selected.
2. Module Map - An image to indicate which module is being run. Currently, only the ATD module is available.
3. Overview Section - Provides navigation buttons for the ATD application.
4. Source Button - Initial page seen when ATD application is loaded. Navigates the ATD application to the “Source” panel.

5. Receptor Button - Navigates the ATD application to the “Receptor” panel.
6. Terrain Button - Navigates the ATD application to the “Terrain” panel.
7. Meteorology Button - Navigates the ATD application to the “Meteorology” panel.
8. Outputs Button - Navigates the ATD application to the “Outputs” panel.
9. Module Default Settings – Opens a new window to set defaults for the simulation. The window that is opened depends upon the analysis type selected.
10. Save Module Input Button - Opens a Windows dialog to allow user to select the location to save their current inputs and name that input file. Files are saved in JSON format.
11. Load Module Input Button - Opens a Windows dialog to allow user to select a saved input JSON file to be loaded into the ATD application.
12. Run Analysis Button - Runs the analysis.

### 3.1.1 Module Default Settings

Located in the lower left corner of the “Overview” panel, the “Module Default Settings” button can be selected to display the default settings dialog window for the analysis. Each analysis type has its own set of default values that can be changed for the simulation. Only the default values that apply to the selected analysis type will be displayed in the “Settings” dialog window. The following sections list the default values that are available for each of the analysis types.

#### 3.1.1.1 Control Room Analysis

Figure 3-2. Control Room Analysis Module Defaults

The list below briefly describes the module defaults as numbered in Figure 3-2.

1. Plume Rise - User checks this box if calculating Plume Rise
2. Diffusion - User selects diffusion scheme. Options are NRC, USEPA Industrial Source Complex (ISC), BRIGGS\_RURAL, BRIGGS\_URBAN, DESERT\_SIGMA.

3. Sigma Y - User provides an initial diffusion coefficient of Sigma Y for a diffused source.
4. Sigma Z - User provides an initial diffusion coefficient of Sigma Z for a diffused source.
5. Missing Data Criterion - User provides value that specifies the acceptable missing data criterion when calculating average values. Range 0–30.
6. User Defined Percentile - User provides value to calculate additional statistic. Range 0–100.
7. Cancel Button - Closes the module defaults dialog.
8. Ok Button - Saves the current module default settings and closes the dialog window for the Module Defaults.

### 3.1.1.2 Design Basis Accidents Analyses

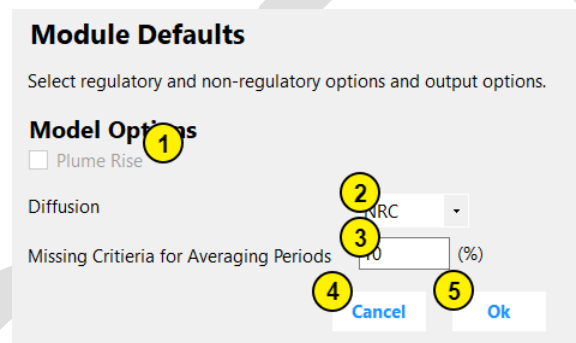


Figure 3-3. ATD Design Basis Accidents Analyses Module Defaults

The list below briefly describes the module defaults as numbered in Figure 3-3.

1. Plume Rise - User checks this box if calculating plume rise
2. Diffusion - User selects diffusion scheme. Options are NRC, ISC, BRIGGS\_RURAL, BRIGGS\_URBAN, DESERT\_SIGMA.
3. Missing Criteria for Averaging Periods - User provides value that specifies the acceptable missing data criterion when calculating average values. Range 0–30.
4. Cancel Button - Closes the module defaults dialog.
5. Ok Button - Saves the current module default settings and closes the dialog window for the Module Defaults.

### 3.1.1.3 Routine Analysis

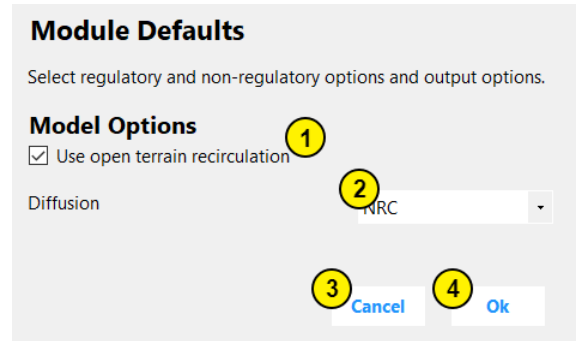


Figure 3-4. ATD Routine Analysis Module Defaults

The list below briefly describes the module defaults as shown in Figure 3-4.

1. Use open terrain recirculation - User checks box for using open terrain recirculation factors to correct  $\chi/Q$  and  $D/Q$ .
2. Diffusion - User selects diffusion scheme. Options are NRC, ISC, BRIGGS\_RURAL, BRIGGS\_URBAN, DESERT\_SIGMA.
3. Cancel Button - Closes the module defaults dialog.
4. Ok Button - Saves the current module default settings and closes the dialog window for the Module Defaults.

## 3.2 Control Room Analysis Panels

This analysis type should be selected to calculate atmospheric relative concentrations ( $\chi/Q$ s) in support of onsite control room habitability assessments required by 10 CFR Part 50, Appendix A, General Design Criterion 19. Habitability assessments are also called for by NUREG-0696 and NUREG-0737, as indicated in Section 2.4.1, when a technical support center (TSC) is located onsite. These concentrations cannot exceed the set level more than 5 percent of the time and are calculated for five averaging periods – that is, 0 to 2 hours, 2 to 8 hours, 8 to 24 hours, 24 to 96 hours (or 1 to 4 days), and 96 to 720 hours (or 4 to 30 days).

The dispersion model for these calculations uses hourly meteorological data. The model accounts for the atmosphere's influence (i.e., transport and diffusion) in the vicinity of buildings. The  $\chi/Q$  values are estimated at the normal and/or emergency air intakes and at various points of ingress and egress to the control room, control building, and at personnel and equipment hatches. When the "Control Room Analysis" option is selected, the ATD user interface automatically configures itself to only present the appropriate input parameters. The following sections define the controls and functionality presented in this set of input panels.

### 3.2.1 Source Panel

**Source: Info**

This form requires users to enter site information about release characteristics.

**Stack Attributes**

Release Type: 1 GROUND

Release Height (m): 2 0

Stack Diameter (m): 3 0

Stack Flow Rate (m3/s): 4 0

Plant Grade Elevation Above Sea Level (m): 5 0

**Building Attributes**

Height (m): 6 0

Cross-sectional area (m2): 7 0

8 Next: Receptors

Figure 3-5. ATD Control Room Analysis Source Panel

The list below briefly describes the source-related inputs as numbered in Figure 3-5.

1. Release Type Selection - User selects the release type as either GROUND or ELEVATED.
2. Release Height - User provides the release height. Range 0–300.
3. Stack Diameter - User provides the stack diameter. Range 0–20. This parameter is disabled when Release Type is set to GROUND.
4. Stack Flow Rate - User provides the flow rate. Range 0–100.
5. Plant Grade Elevation Above Sea Level - User provides the base elevation. Range 0–1000.
6. Height - User provides the building height. Range 0–300. This parameter is disabled when Release Type is set to GROUND.
7. Cross-sectional Area – User provides the building area if structural wake is to be included in the dispersion analysis. Range 0–10,000. This parameter is disabled when Release Type is set to ELEVATED.
8. Next: Receptors Button - When clicked, the ATD application will navigate to the “Receptors” panel.

### 3.2.2 Receptors Panel

**Receptors**

Input the receptor(s) where X/Q should be calculated. Terrain data specific to the site can also be entered.

**Receptor Attributes**

Receptor Distance (m)  (m)

Intake Height  (m)

Terrain Height of Receptor  (m)

**Wind Direction Window**

N  
W E  
S

Figure 3-6. ATD Control Room Analysis Receptor Panel

The list below briefly describes the receptor-related inputs as numbered in Figure 3-6.

1. Receptor Distance - User provides the distance of the receptor from the release point. Range 0–10000.
2. Intake Height - User provides the intake height of the receptor. Range 0–100.
3. Terrain Height of Receptor - User provides the terrain height at the receptor location. Range 0–1000.
4. Direction Window - Visually displays the direction to the source, based on the direction selected in the “Direction Select” portion of the panel.
5. Direction Select - User provides the direction from the receptor to the release point. Range 1–360.
6. Back Button - When clicked, the ATD application will navigate back to the “Source” panel.
7. Next: Meteorology Button - When clicked, the ATD application will navigate to the “Meteorology” panel.

### 3.2.3 Meteorology Panel

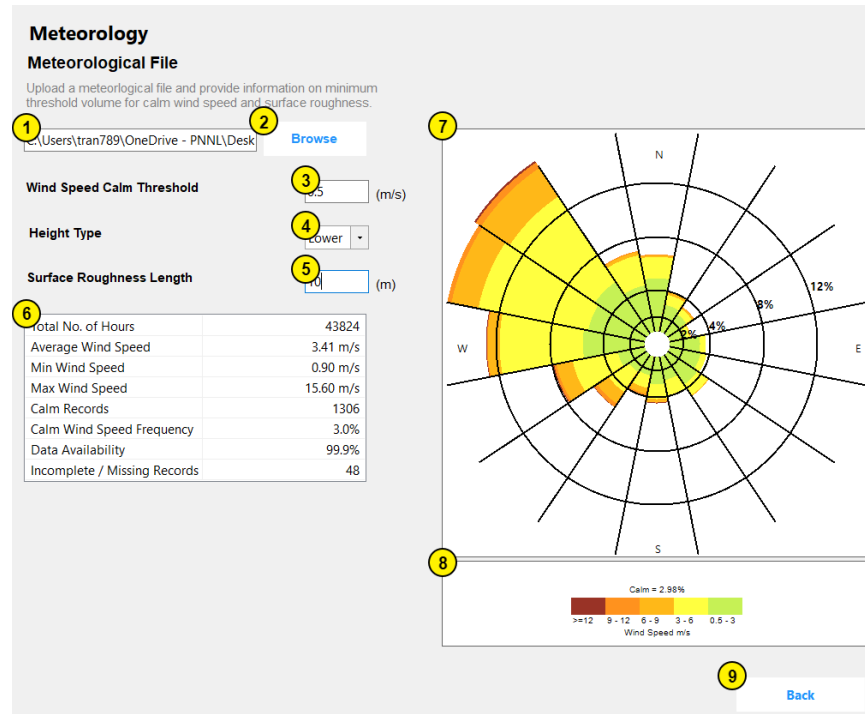


Figure 3-7. ATD Control Room Analysis Meteorology Panel

The list below briefly describes the meteorology-related inputs as numbered in Figure 3-7.

1. Meteorology File Textbox - Displays the path to a selected meteorological data file. An error text will display below the input window if current selected file is invalid.
2. Browse Button - Opens a window dialog which allows users to select their own file.
3. Wind Speed Calm Threshold - Wind speeds below the value entered here are considered calm in the dispersion calculation. Range 0–1. An error text will display below if the current value is invalid.
4. Height Type - User can select a value from the choices provided: Lower, Upper.
5. Surface Roughness Length - User provides a value for the surface roughness length at the meteorological measurement location. Range 0–10.
6. Meteorological Statistics View - Shows the meteorological data generated from an NRC-formatted file.
7. Wind Rose Plot - Displays a wind rose generated from the NRC-formatted file.
8. Legend - Shows the calm wind speed frequency and the colors associated with the wind speed categories.
9. Back Button - When clicked, the ATD application will navigate back to the “Receptors” panel.

### 3.2.4 Outputs Panel

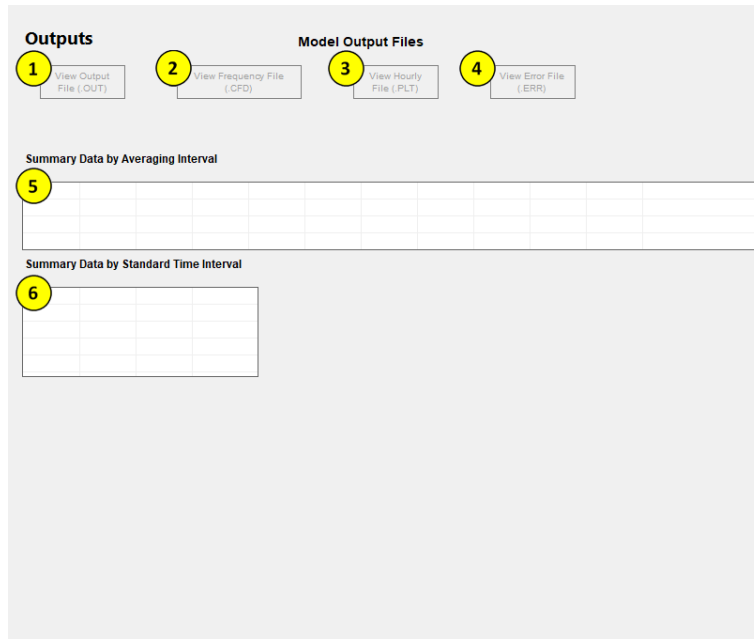


Figure 3-8. ATD Control Room Analysis Outputs Panel

The list below briefly describes the various dispersion model outputs available as numbered in Figure 3-8.

1. View Output File Button - Opens the ATD Output Viewer that displays the OUT file.
2. View Frequency File Button - Opens the ATD Output Viewer that displays the cumulative frequency distribution (CFD) file.
3. View Hourly File Button - Opens the ATD Output Viewer that displays the PLT file.
4. View Error File Button - Opens the ATD Output Viewer that displays the ERR file.
5. Summary Data by Averaging Interval Grid - Displays the Summary Data by the averaging intervals generated by the analysis.
6. Summary Data by Standard Time Interval Grid - Displays the Summary Data by Standard Time interval generated by the analysis.

### 3.3 Design Basis Accidents Analyses Panels

Design basis accident analyses are used to estimate relative ground-level  $\chi/Q_s$  for assessing potential airborne releases of radioactive material from nuclear facilities. The results are direct inputs to accident safety- and environmental-related dose calculations. These assessments are required by 10 CFR Part 50 and 10 CFR Part 100.

The dispersion model for these calculations uses hourly meteorological data. The averaging time periods range from one hour to 30 days in duration – that is, 0 to 2 hours, 0 to 8 hours, 8 to 24 hours, 24 to 96 hours (or 1 to 4 days), and 96 to 720 hours (or 4 to 30 days) consistent with RG 1.145. The receptor distances usually correspond to the EAB and the outer boundary of the



LPZ. When the “Design Basis Accidents” option is selected as the analysis type, the ATD user interface automatically configures itself to only present the appropriate input parameters. The following sections define the controls and functionality presented in this set of input panels.

### 3.3.1 Source Panel

Figure 3-9. ATD Design Basis Accidents Analysis Source Panel

The list below briefly describes the source-related inputs as numbered in Figure 3-9.

1. Release Type Selection - User selects the Release Type as either GROUND or ELEVATED.
2. Release Height - User provides the release height above plant grade. Range 0–300.
3. Stack Diameter - User provides the stack diameter. Range 0–20. This parameter is disabled when Release Type is set to ELEVATED unless Plume Rise is checked in the module defaults panel.
4. Stack Flow Rate - User provides the flow rate. Range 0–100. This parameter is disabled when Release Type is set to ELEVATED unless Plume Rise is checked in the module defaults panel.
5. Plant Grade Elevation Above Sea Level - User provides the base elevation. Range 0–1000.
6. Height - User provides the building height. Range 0–300.
7. Cross-sectional Area - User provides the building area if structural wake is to be included in the dispersion analysis. Range 0–10,000.
8. Site Type Selection - User indicates whether a site is located near a large body of water (i.e., within 2 miles) or farther inland and not subject to fumigation conditions.

Fumigation typically applies to elevated stack releases but may also apply to extremely buoyant low-level releases. Options are Inland, Coastal. This parameter is disabled when Release Type is set to GROUND.

9. Next: Terrain Button - When clicked, the ATD application will navigate to the “Terrain” panel.

### 3.3.2 Terrain Panel

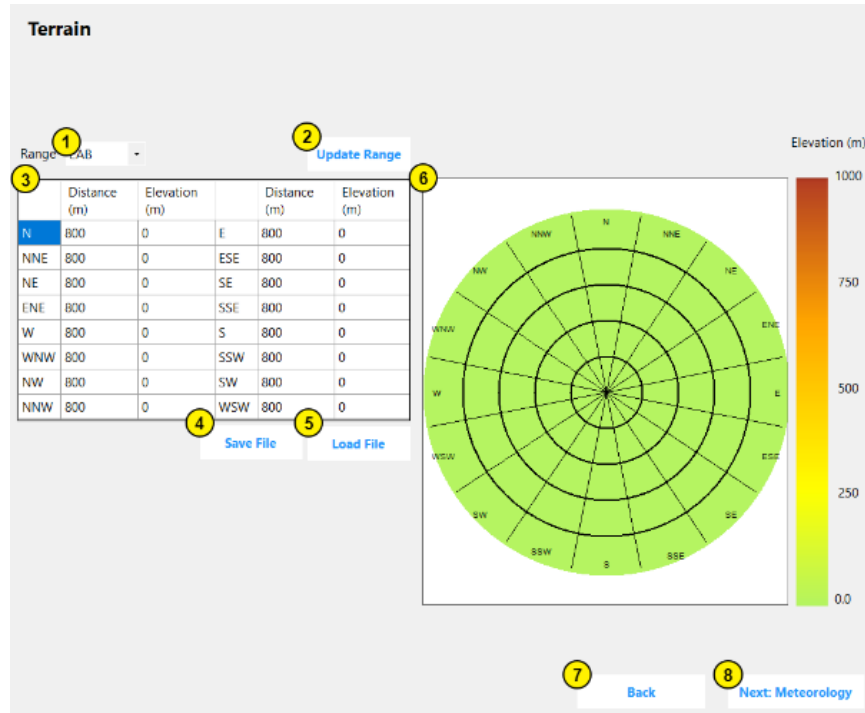


Figure 3-10. ATD Design Basis Accidents Analysis Terrain Panel

The list below briefly describes the terrain-related inputs as numbered in Figure 3-10.

1. Range Selection - User can select a range to edit. Range [EAB or LPZ].
2. Update Range Button - When clicked, it updates the distances and elevation polar grid.
3. Sectors, Distances, and Elevations Grid - User can enter the Distance and Elevation for a sector.
4. Save File Button - User can save the current sector-specific terrain settings to a JSON file.
5. Load File Button - User can load a JSON file that contains sector-specific terrain data.
6. Distances and Elevations Polar Grid Display - Displays the current data from the Distances and Elevations grid.
7. Back Button - When clicked, the ATD application will navigate back to the “Source” panel.

8. Next: Meteorology Button - When clicked, the ATD application will navigate to the “Meteorology” panel.

### 3.3.3 Meteorology Panel

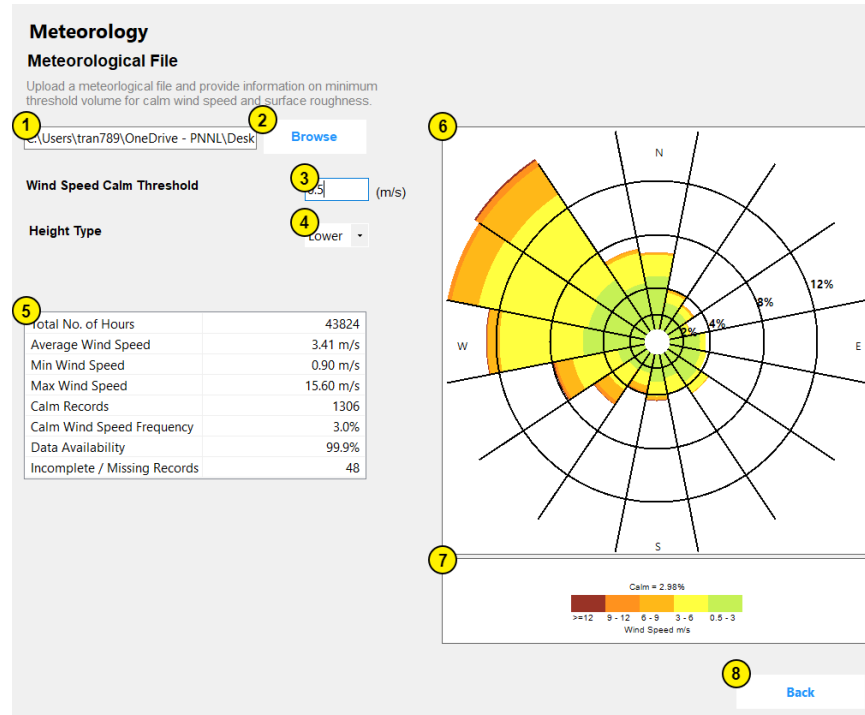


Figure 3-11. ATD Design Basis Accidents Analysis Meteorology Panel

The list below briefly describes the meteorology-related inputs as numbered in Figure 3-11.

1. **Meteorology File Textbox** - Displays the path to a selected meteorological data file. An error text will display below if current selected file is invalid.
2. **Browse Button** - Opens a window dialog to allow users to select their own file.
3. **Wind Speed Calm Threshold** – Wind speeds below the value entered here are considered calm in the dispersion calculation. Range 0–1. An error text will display below if current value is invalid.
4. **Height Type** - User can select a value from the choices provided: Lower, Upper.
5. **Meteorological Statistics View** - Shows the meteorological data generated from an NRC-formatted file.
6. **Wind Rose Plot** - Displays a wind rose generated from the NRC-formatted file.
7. **Legend** - Shows the calm wind speed frequency and the colors associated with the wind speed categories.
8. **Back Button** - When clicked, the ATD application will navigate back to the “Terrain” panel.

### 3.3.4 Outputs Panel

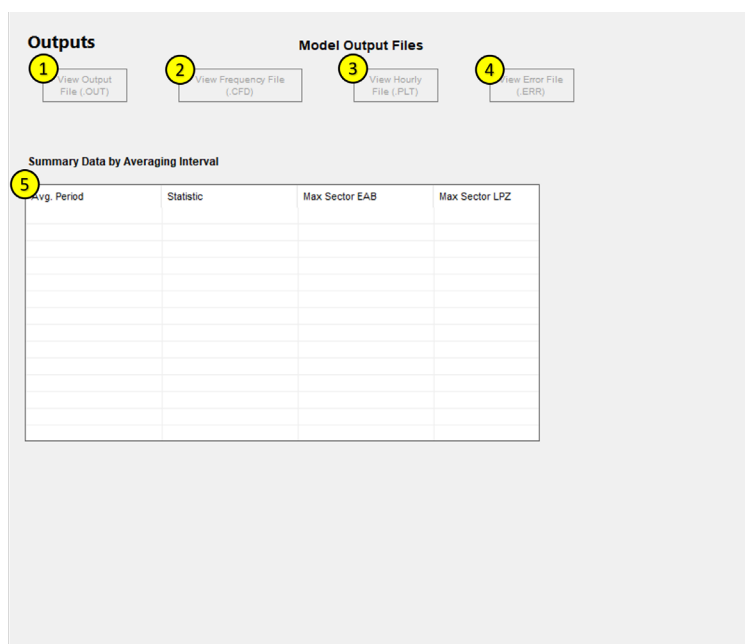


Figure 3-12. ATD Design Basis Accidents Analysis Outputs Panel

The list below briefly describes the various ATD model outputs available as numbered in Figure 3-12.

1. View Output File Button - Opens the ATD Output Viewer that displays the OUT file.
2. View Frequency File Button - Opens the ATD Output Viewer that displays the CFD file.
3. View Hourly File Button - Opens the ATD Output Viewer that displays the PLT file.
4. View Error File Button - Opens the ATD Output Viewer that displays the ERR file.
5. Summary Data by Averaging Interval Grid - Displays the Summary Data by the averaging intervals generated by the analysis.

## 3.4 Routine Analysis Panels

Routine effluent release analyses require ATD modeling in accordance with 10 CFR Part 20 and Part 50. This atmospheric model is designed for evaluating routine releases from NPPs based on RG 1.111. It is primarily designed to calculate annual relative effluent concentrations,  $\chi/Q$  values, and annual average relative deposition,  $D/Q$  values, at locations specified by the user, and at various standard radial distances and segments for downwind sectors. When the “Routine Analysis” option is selected as the analysis type, the ATD user interface automatically configures itself to only present the appropriate input parameters to the user. The following sections define the controls and functionality presented in this set of input panels.

### 3.4.1 Source Panel

**Source: Info**

This form requires users to enter site information about release characteristics.

**Stack Attributes**

Release Type  1

Release Height (m)  2

Stack Diameter (m)  3

Stack Flow Rate (m/s)  4

Plant Grade Elevation Above Sea Level (m)  5

**Building Attributes**

Height (m)  6

Cross-sectional area (m2)  7

8

Figure 3-13. ATD Routine Analysis Source Panel

The list below briefly describes the source-related inputs as numbered in Figure 3-13.

1. Release Type Selection - User selects the Release Type as either GROUND, VENT, or ELEVATED.
2. Release Height - User provides the release height above plant grade. Range 0–300.
3. Stack Diameter - User provides the stack inside diameter. Range 0–20.
4. Stack Flow Rate - User provides the flow rate. Range 0–100.
5. Plant Grade Elevation Above Sea Level - User provides the base elevation. Range 0–1000.
6. Height - User provides the building height. Range 0–300.
7. Cross-sectional Area – User provides the building area if structural wake is to be included in the dispersion analysis. Range 0–10000.
8. Next: Receptors Button - When clicked, the ATD application will navigate to the “Receptors” panel.

### 3.4.2 Receptors Panel

**Receptors**

Input the receptor(s) where X/Q should be calculated. Terrain data specific to the site can also be entered.

Discrete Receptors

Receptor Label	Receptor Type	Receptor Sector	Receptor Distance (m)	Icon Color

80.47 km  
64.37 km  
48.28 km  
32.19 km  
16.09 km  
0.00 m

Back Next: Terrain

Figure 3-14. ATD Routine Analysis Receptors Panel

The list below briefly describes the receptor-related inputs as numbered in Figure 3-14.

1. Discrete Receptors Data Grid - Displays the discrete receptors that are to be used in the analysis.
2. Discrete Receptors Polar Grid - Displays the polar grid of where the discrete receptors are located. User can select a row to highlight a specific discrete receptor.
3. Add Button - The ATD application opens the Add Receptor Interface which allows users to add their own receptors for the analysis.
4. Delete Button - Deletes the currently selected receptor.
5. Load File Button - The user can load a JSON file that contains receptor data.
6. Save Button - The user can save the Discrete Receptors data grid to a JSON file.
7. Back Button - When clicked, the ATD application will navigate back to the “Source” panel.
8. Next Button - When clicked, the ATD application will navigate to the “Terrain” panel.

### 3.4.2.1 Add Receptor Interface

Figure 3-15. ATD Routine Analysis Add Receptor Panel

The list below briefly describes the addition of receptor-related inputs as numbered in Figure 3-15.

1. Label - The name for the receptor.
2. Type Selection - User can select the attribute type for the receptor. Options are milk cow, milk goat, meat animal, residence, vegetable garden, and site boundary.
3. Sector Selection - The user can select the receptor location's sector.
4. Distance - The distance from the source to the receptor.
5. Cancel Button - When clicked, the "Receptors" panel will hide the Add Receptor Panel. Any entries made by the user in the Add Receptor Panel will be lost.
6. Ok Button - When clicked, the "Receptors" panel will hide the Add Receptor Panel and add the new receptor to the Discrete Receptors data grid.

Note that the user interface will allow a simulation to run without any receptors entered but the model will not generate any output data. If a simulation is attempted without any receptors being entered, the user interface will display a warning dialog stating that no results will be generated and asks the user if they would like to continue with the simulation. Figure 3-16 shows an example of the warning dialog that will be displayed.

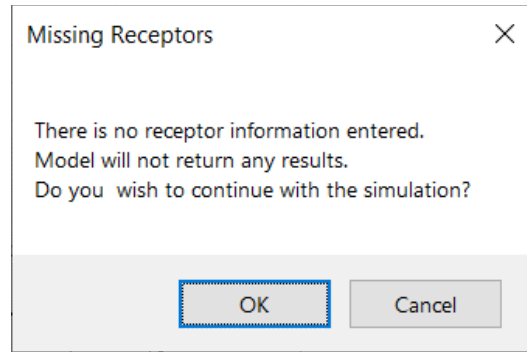


Figure 3-16. Warning Dialog Box When a Simulation Run Is Attempted without Receptor Data

### 3.4.3 Terrain Panel

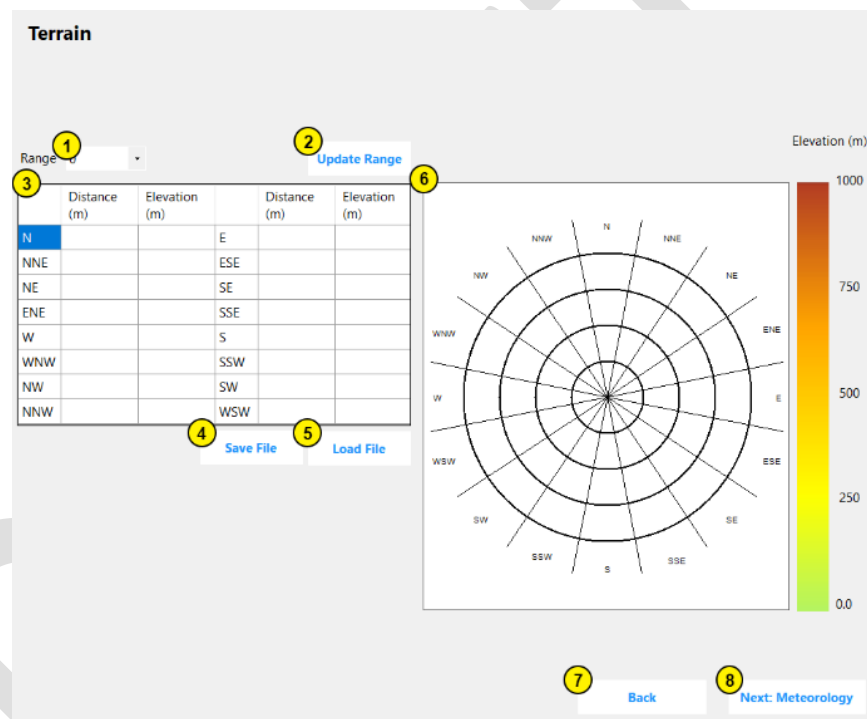


Figure 3-17. ATD Routine Analysis Terrain Panel

The list below briefly describes the terrain-related inputs as numbered in Figure 3-17.

1. Range Selection - User can select a range to edit. Range 0–10.
2. Update Range Button - When clicked, it updates the distances and elevation polar grid.
3. Terrain Distances and Elevations Grid - User can enter the Distance and Elevation for a sector.
4. Save File Button - User can save the current sector-specific terrain settings to a JSON file.



5. Load File Button - User can load a JSON file that contains sector-specific terrain data.
6. Distances and Elevations Polar Grid Display - Displays the current data from the Distances and Elevations grid.
7. Back Button - When clicked, the ATD application will navigate back to the "Receptors" panel.
8. Next: Meteorology Button - When clicked, the ATD application will navigate to the "Meteorology" panel.

Note that the user interface will allow a simulation to run without any terrain data being entered but the model will not generate any output data. If a simulation is attempted without any terrain data being entered, the user interface will display a warning dialog stating that no results will be generated and asks the user if they would like to continue with the simulation. Figure 3-18 shows an example of the warning dialog that will be displayed.

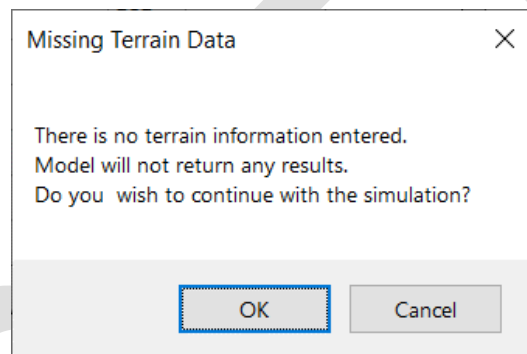


Figure 3-18. Warning Dialog Box When a Simulation Run Is Attempted without Receptor Data

### 3.4.4 Meteorology Panel

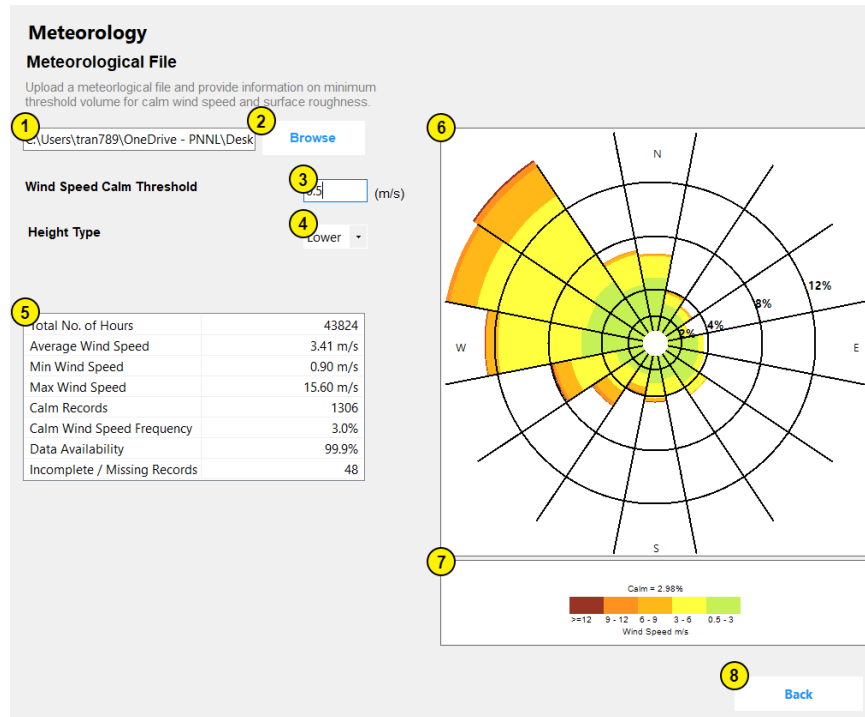


Figure 3-19. ATD Routine Analysis Meteorology Panel

The list below briefly describes the meteorology-related inputs as numbered in Figure 3-19.

1. **Meteorology File Textbox** - Displays the path to a selected meteorological data file. An error text will display below if current selected file is invalid.
2. **Browse Button** - Opens a window dialog to allow users to select their own file.
3. **Wind Speed Calm Threshold** - Wind speeds below the value entered here are considered calm in the dispersion calculation. Range 0–1. An error text will display below if current value is invalid.
4. **Height Type** - User can select a value from the choices provided: Lower, Upper.
5. **Meteorological Statistics View** - Shows the meteorological data generated from an NRC-formatted file.
6. **Wind Rose Plot** - Displays a wind rose generated from the NRC-formatted file.
7. **Legend** - Shows the calm wind speed frequency and the colors associated with the wind speed categories.
8. **Back Button** - When clicked, the ATD application will navigate back to the “Terrain” panel.

### 3.4.5 Outputs Panel

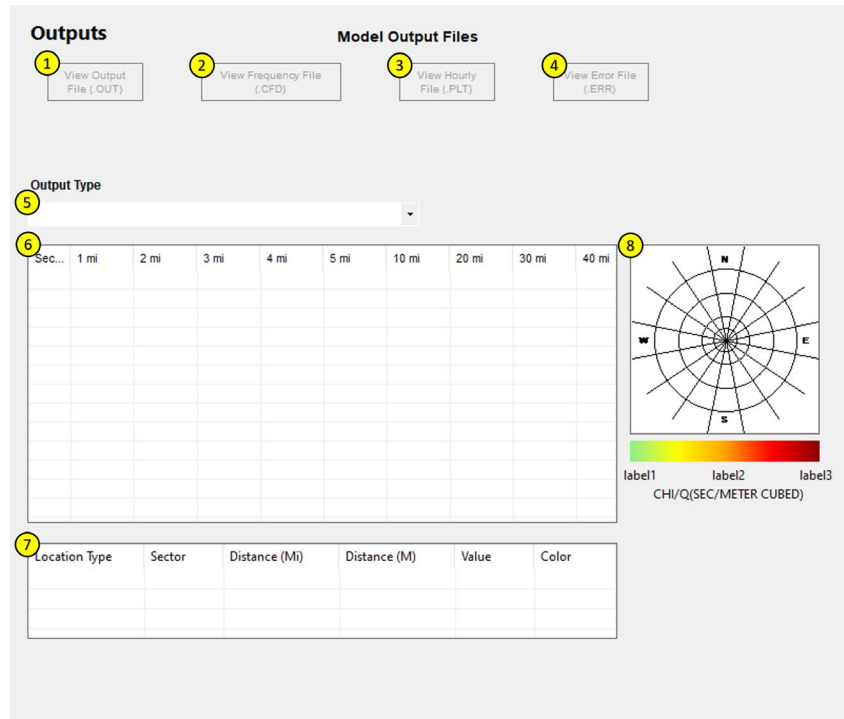


Figure 3-20. ATD Routine Analysis Outputs Panel

The list below briefly describes the various dispersion model outputs available as numbered in Figure 3-20.

1. View Output File Button - Opens the ATD Output Viewer that displays the OUT file.
2. View Frequency File Button - Opens the ATD Output Viewer that displays the CFD file.
3. View Hourly File Button - Opens the ATD Output Viewer that displays the PLT file.
4. View Error File Button - Opens the ATD Output Viewer that displays the ERR file.
5. Output Type Selection - User selects which output type to view: NO DECAY/UNDEPLETED, 2.260 DAY DECAY/UNDEPLETED, 8.000 DAY DECAY/DEPLETED, RELATIVE DEPOSITION PER UNIT AREA (PER METER SQUARED)
6. Output Type Summary Data Grid - Displays the selected output type summary data.
7. Discrete Receptors Summary Data Grid - Displays the output summary data for the grid of Discrete Receptors.
8. Polar Grid Display - Displays the Polar Grid.

## 4.0 Quality Assurance

### 4.1 Quality Assurance Approach – Graded as High Assurance

The SIERRA software will be used by NRC as a confirmatory tool for making independent safety- and environmental-related atmospheric dispersion, dose, and consequence projections for NPP licensing submittals, emergency response analyses, and site decommissioning. A similar dose assessment software called GENII is a RAMP code and part of the U.S. Department of Energy's (DOE's) safety toolbox with Nuclear Quality Assurance-1 (NQA-1) standard compliance. GENII has been classified as Safety and Hazard Analysis Software and Design Software based on DOE's intended use of that software application. However, the current consolidated software will only be used as a confirmatory tool by NRC and its clients and therefore it is not considered safety software. Any other usage of the software beyond its intended use should require additional quality assurance evaluation.

The software has been developed to meet the High Quality Assurance (HA) standards as outlined in the PNNL HDI Develop Software for Delivery workflow. The following risks were identified for the intended use of the software which led to a HA grading:

- Software results could have a significant impact on PNNL's customer (i.e., NRC) decisions, and therefore data quality is a key parameter for the intended use.
- Software failure or performance other than as intended could result in violation of NRC's regulatory limits.

### 4.2 Software Testing

Software testing to meet the Software Quality Assurance Plan for the SIERRA software has been conducted. The project software verification and validation methodology was used to perform testing to demonstrate that the software correctly performs all intended functions. For this software, tests of the mathematical model and the user interface are performed. A brief description of software testing is described in the sections below. For more information of software testing for SIERRA see the Software Quality Assurance Plan.

#### 4.2.1 Mathematical Model Testing

Tests are implemented to determine whether the codes executing the mathematical models are performing as expected. This testing falls into two general categories: unit testing and integrated testing (or functional testing). Unit testing is performed upon the methods and functions in the software codes that either generate or modify data values. This testing is done against the individual function code separate from the testing performed against the software. Unit testing on a function is done by running function code using a set of predefined input values and comparing the results against the expected result values. Unit testing is focused on the smallest separable functions of the underlying coding.

Following unit testing, integrated testing is implemented on the executable to test that the mathematical models are performing as executed together (i.e., at a level above unit testing). Integrated testing of the mathematical model involved numerous cases with varying input

parameters performed with a set of meteorological data. These cases were replicated, to the extent possible, with the corresponding legacy software. The results of these simulations were acceptable if the SIERRA ATD output was largely within a factor of 10 of the legacy output.

#### 4.2.2 User Interface Testing

The user interface testing is performed to determine that the user experience is performing as expected as a user interacts with the interface (i.e., buttons function, screens progressing, etc.). This testing must identify that the user interface performs as expected, and that it will also provide the correct error message or restrict the user if an input falls outside of an acceptable range. Unit tests of the user interface have been performed to assess the performance of the navigation between screens and data input. Functional testing of SIERRA and the ATD Model user interfaces was performed using several different types of tests including:

- invalid input (i.e., string instead of number);
- out-of-range input (i.e., 1001 in the field that has an upper limit of 1000);
- valid input and running the analysis;
- control testing (the functionality of buttons, checkboxes, drop-down lists, etc.);
- input values with a large number of decimal places (i.e., 0.1111111111);
- form navigation (“Next” buttons and left navigation menu);
- saving and loading input (JSON) files; and
- application logic (i.e., does clicking on “Run Analysis” run the model).

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DRAFT

## Appendix A — SIERRA ATD Directory Structure

To standardize the implementation of additional modules into the Radiation Protection Computer Code Analysis and Maintenance Program (RAMP) modeling framework, a well-defined and standardized directory structure is necessary to manage the files required to run a simulation. This directory structure must be defined in such a manner that it allows for file paths to be created during simulations without additional user input. The directory structure needs to be easily accessible by users who wish to review simulation files for audit or debugging purposes. The following provides a description of the different directories contained within the directory structure to be used by the modeling framework.

### A.1 SIERRA Parent Directory

By default, the SIERRA parent directory is installed on the C: drive when the Software Integration for Environmental Radiological Release Assessments (SIERRA) software is installed. This directory acts as the main directory for the modeling framework. All files and directories needed to run a simulation will be managed from within this parent directory. Files that reside at this level are the executables for the system interface and the backend system software as well as all libraries, dlls, and configuration information required by the executables. The directory also contains the Models and Users sub-directories.

#### A.1.1 Models Sub-Directory

The “Models” directory stores the files required for the individual modules (e.g., Atmospheric Transport and Diffusion, Source Term) to execute properly. This directory will contain a sub-directory for each model integrated with the modeling platform.

These sub-directories contain all files required for the model to execute properly when called from the modeling platform’s backend system. Files that reside at this level include the executable files as well as all libraries, dlls, and configuration information required by the executables. There is one sub-directory present in the Models directory for each model integrated with the modeling platform and will be labeled using the official name of the model.

#### A.1.2 Users Sub-Directory

This directory stores simulation data for each user that has run simulations using the modeling framework. Within this directory resides a set of sub-directories each identified by the appropriate User ID. Each user sub-directory (names according to the User’s ID) contains a set of directories representing data and information from simulation runs that will be labeled with the case name assigned to that simulation. User IDs will be automatically pulled from the machine’s operating system.

While creating a new simulation, the modeling framework prompts the user to provide a name for the simulation case. This case name is used to label the scenario case directories stored in the user sub-directory. This directory contains a date/time labeled sub-directory for each of the simulation runs performed by the user.

For every simulation performed by the modeling platform, there is a simulation date sub-directory created in the appropriate scenario directory. Directories are labeled based upon the system date and time that the simulation was run. The format to be used for the naming of



these directories will be yyyy\_mm\_dy\_hr\_mn\_ss where yyyy is the four-digit year, mm is the two-digit month, dy is the two-digit day of the month, hr is the hour in 24-hour format, mn is the two-digit minute, and ss is the two-digit second. This folder will contain all data generated by the simulation with the data being stored in sub-directories labeled Input, Output, and Logs.

The Input directory located within a simulation date directory will be used to store all data files that are used as input files for the modeling platform and simulation models.

The Output directory located within a simulation date directory will be used to store all data files that are generated by the modeling platform and simulation models.

The following figure shows an example directory structure that makes use of the structure described above.

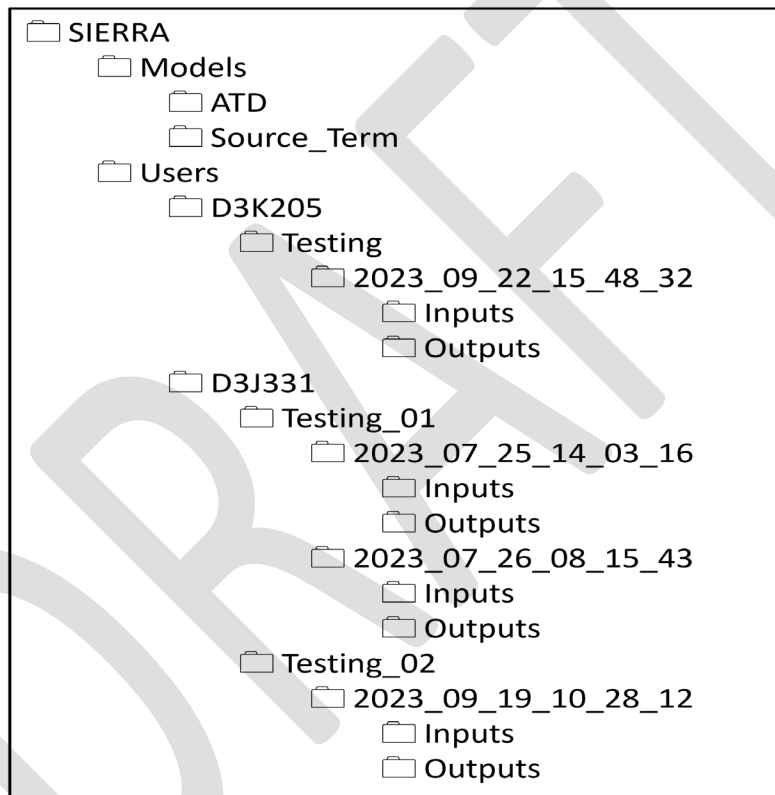


Figure A-1. Example SIERRA Directory Structure

## Appendix B — Input and Output Files

### B.1 JSON Input Structure

The JavaScript Object Notation, JSON, is an open standard file format for storing and sharing electronic data. JSON is human readable, lightweight and can be transferred between different programming languages and operating systems. Data are written in JSON objects which is a combination of key/value pairs condensed in curly braces ({ }). Key/value pairs have a colon between them as in “key”:“value”. Each key/value pair is separated by a comma. A “key” is provided on the left side of the colon with double quotation marks. It is a field name with “string” data type. On the right side of colon, a JSON value is provided which can be string, numbers, objects, arrays or booleans. Arrays are provided in square brackets ([ ]). A JSON format file can store nested objects and nested arrays. These objects and arrays will be passed as values assigned to keys, and may be comprised of key/value pairs as well. An example JSON format file that can be provided as input to the ATD engine for control room analyses is shown in Figure \_. Users can validate their JSON files with tools available online.

The atmospheric transport and diffusion (ATD) input file in JSON format contains the following primary keys:

- control\_info – setup the modeling scenario with user provided string.
- model\_info – provides model or assessment type. Options are 1) “arcon”, 2) “pavan”, 3) “xoqdoq”.
- source\_info – provides release information such as Release Type, stack characteristics, and nearby building information. Release type can be “GROUND”, “VENT”, or “ELEVATED”.
- receptor\_info – provides receptor information such as distance and terrain within arrays. For control room assessment (similar to computer code for Atmospheric Relative CONcentration in Building Wakes [ARCON]) specific receptor information, such as receptor height, wind direction window, and direction of receptor from source. For routine release assessment (similar to computer code for evaluation of routine effluent releases at commercial nuclear power stations [XOQDOQ]), distances for fixed radial receptors are not required. A default 22 distances on 16 radial sectors from 0.5 to 50 miles is used internally. The “receptor\_info” key can be used by the user to provide any terrain information for the site.
- discrete\_info – optional key that can provide information on discrete receptors for routine release analyses similar to existing XOQDOQ model with NRCDose.
- met\_info – provides pathname to the meteorological file formatted according to specification in Regulatory Guide (RG) 1.23. Also, user can set the minimum threshold for calm wind speed below which wind data will be treated as calms.
- prog\_defaults\_info – provides defaults for models that users can choose to modify such as Plume Rise calculations, accounting recirculation factor for routine release, diffusion coefficients calculation methods, missing criteria for averaging for different time periods.

```

{
  "control_info": {
    "scenario": "control_room_ground",
  },

  "model_info": "arcon" ,

  "source_info": {
    "release_type": "GROUND",
    "stack_height": 10,
    "stack_dia": 0,
    "stack_flow": 0,
    "stack_terrain": 0,
    "building_area": 1900} ,

  "receptor_info": {
    "arcon":{"intake_ht": 15,"wd_window":90,"dir2source":230},
    "distance": [45] ,
    "terrain " : [0]
      } ,

  "met_info": {
    "met_file": "met\\metfileXXXX.nrc",
    "ws_calm_threshold": 0.5,
    "surface_roughness": 0.2
      } ,

  "prog_defaults_info": {
    "arcon":{"sigY0": 0,"sigZ0":0},
    "diffusion_option": "NRC",
    "plume_rise": false,
    "missing_criteria":10.,
    "additional_percentile": 99.5
      }
}

```

Figure B-1. Example JSON Input File with a Scenario for Control Room Analysis of a Ground-Level Source

## B.2 Output Files

The ATD engine generates seven output files as described below:

- ATD\_ENGINE.OUT – Summary output text file containing information about inputs, summary of meteorological data, and statistical outputs specific to assessment.

- ATD\_ENGINE.PLT – Hourly values of centerline and sector average  $\chi/Q$  along with windspeed at measurement height, wind speed adjusted for release height, wind direction, flags for calm and missing, stability class, and diffusion coefficients (without corrections for building wake).
- ATD\_ENGINE.CFD – Cumulative frequency distributions of running  $\chi/Q$  averages for specific time periods. No output for routine release analysis.
- ATD\_ENGINE.JFD – Joint frequency distribution summary of meteorological input data. This dataset is not used in calculations and provided only for reference.
- ATD\_ENGINE.ERR – Text file to provide warning and error messages.
- ATD\_ENGINE\_ERR.JSON – JSON format file for warning and error messages.
- ATD\_ENGINE\_OUT.JSON – JSON format file with statistical outputs.

## Appendix C — Running the Application

The following is an example of a regulatory routine analysis simulated using the Software Integration for Environmental Radiological Release Assessments (SIERRA) software. The following steps can be used to set up and run the simulation example.

1. Double click the SIERRA desktop shortcut to start the SIERRA application.
2. The SIERRA splash screen (Figure C-1) will be displayed while the SIERRA application loads.

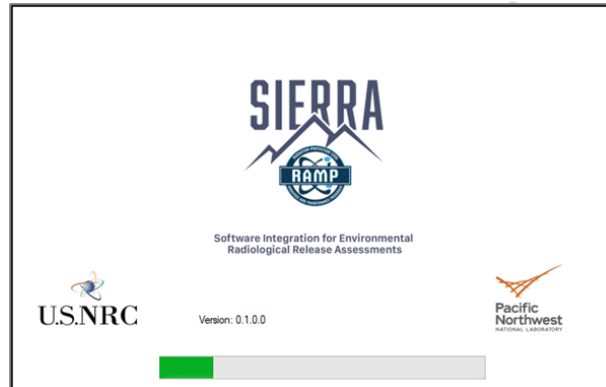


Figure C-1. SIERRA Splash Screen

3. Once the splash screen has closed, a disclaimer page will appear, and if the user selects the “Continue” button, the SIERRA application user interface will be displayed with the assessment type (Figure C-2).

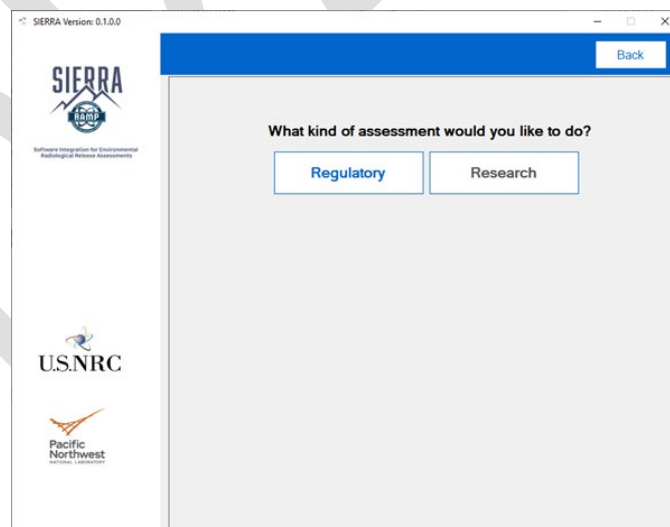
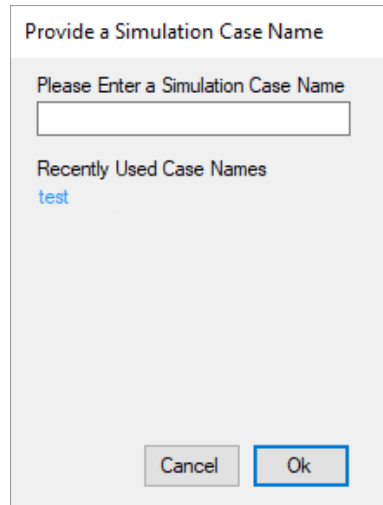


Figure C-2. SIERRA Assessment Selection

4. Click on the “Regulatory” button to select the regulatory assessment simulation option.
5. After the “Regulatory” button is clicked, a dialog window will be displayed prompting for the entry of simulation name (Figure C-3).



Provide a Simulation Case Name

Please Enter a Simulation Case Name

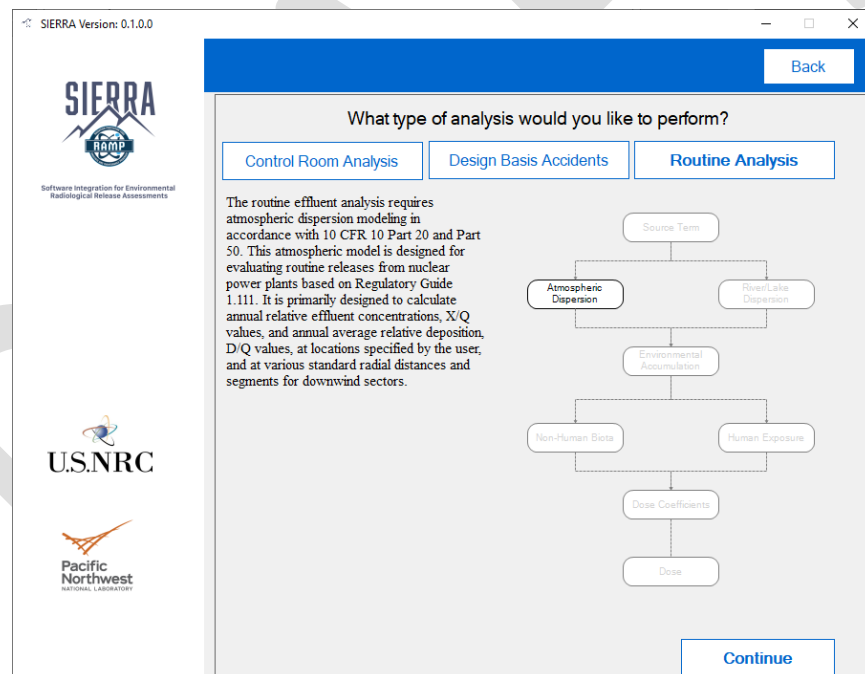
Recently Used Case Names

test

Cancel Ok

Figure C-3. SIERRA Simulation Name

6. Type the desired name into the dialog window text box or select an existing name and then click on the “Ok” button.
7. The interface will then advance to the analysis type selection panel (Figure C-4).



SIERRA Version: 0.1.0.0

Back

What type of analysis would you like to perform?

Control Room Analysis Design Basis Accidents Routine Analysis

The routine effluent analysis requires atmospheric dispersion modeling in accordance with 10 CFR 10 Part 20 and Part 50. This atmospheric model is designed for evaluating routine releases from nuclear power plants based on Regulatory Guide 1.111. It is primarily designed to calculate annual relative effluent concentrations, X/Q values, and annual average relative deposition, D/Q values, at locations specified by the user, and at various standard radial distances and segments for downwind sectors.

Source Term

Atmospheric Dispersion River/Lake Dispersion

Environmental Accumulation

Non-Human Biota Human Exposure

Dose Coefficients

Dose

Continue

SIERRA  
Software Integration for Environmental  
Radiological Release Assessments

U.S. NRC

Pacific Northwest  
National Laboratory

Figure C-4. SIERRA Analysis Select

8. Once displayed, click on the “Routine Analysis” button to select the routine analysis type.
9. With the routine analysis type selected, click the “Continue” button to advance the interface to the simulation “Overview” panel (Figure C-5).

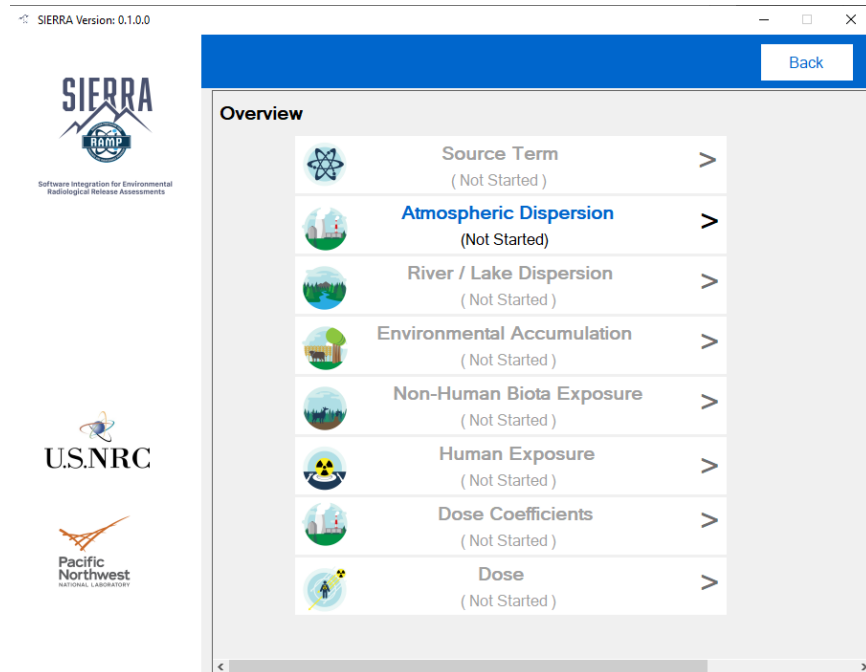


Figure C-5. SIERRA Overview

10. Click on the “Atmospheric Dispersion” button to start the atmospheric transport and diffusion (ATD) module interface.
11. With the interface of the “Atmospheric Dispersion” module now displayed, the left panel of the interface should show the “Source” option highlighted and the “Source” input panel displayed on the right of the interface (Figure C-6).

Atmospheric Dispersion

SIERRA  
Software Integration for Environmental  
Radiological Release Assessments

Routine Analysis

Overview

Source

Receptors

Terrain

Meteorology

Outputs

Settings Save Print

Run Analysis

**Source: Info**

This form requires users to enter site information about release characteristics.

**Stack Attributes**

Release Type: ELEVATED

Release Height (m): 45.0

Stack Diameter (m): 2.0

Stack Flow Rate (m/s): 10.0

Plant Grade Elevation Above Sea Level (m): 0.0

**Building Attributes**

Height (m): 0.0

Cross-sectional area (m2): 0.0

Next: Receptors

Figure C-6. Completed ATD Source Panel

11. Under the “Stack Attributes” section, select the “ELEVATED” Release Type using the “Release Type” drop-down list control.
12. Enter a release height of 45.0 m in the “Release Height” text box.
13. Enter 2.0 in the “Stack Diameter” text box.
14. Enter 10.0 in the “Stack Flow Rate” text box.
15. Retain the 0.0 value pre-populated in the “Plant Grade Elevation Above Sea Level” text box.
16. The “Height” and “Cross-sectional area” text boxes under the “Building Attributes” section should be disabled and will not be used for this simulation.
17. Click on the “Next: Receptors” button at the lower right corner of the panel to advance the interface to the “Receptors” panel (Figure C-7).



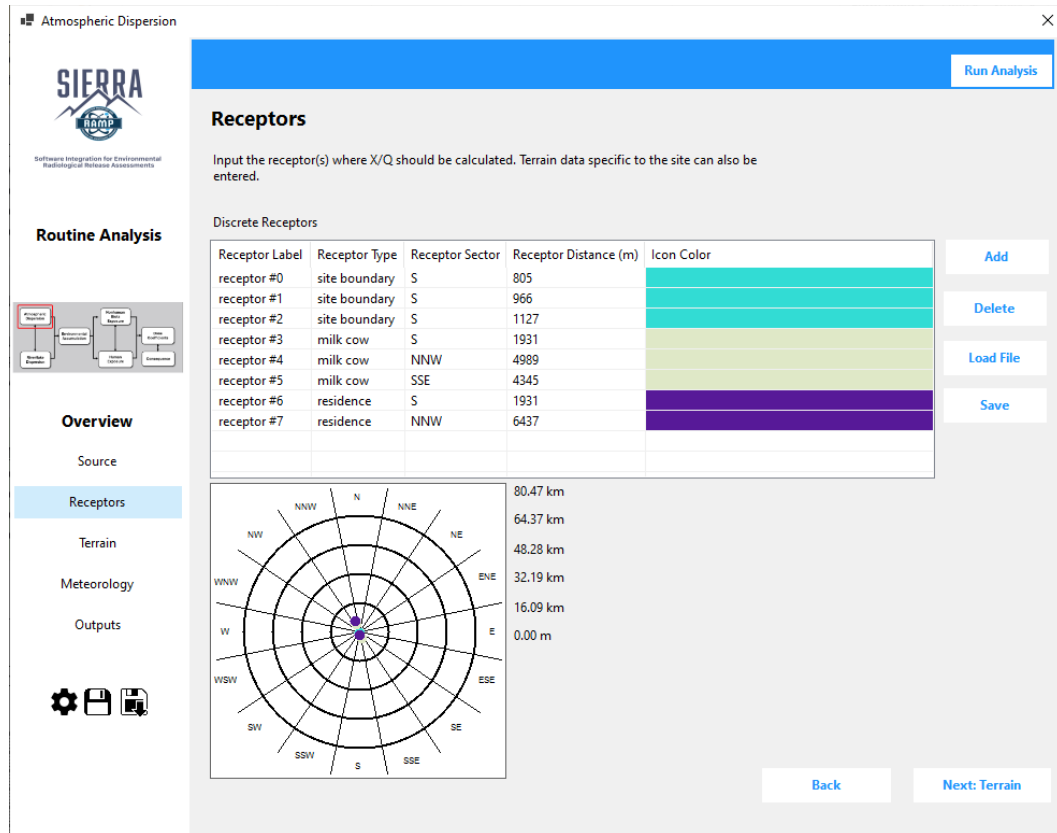


Figure C-7. Completed ATD Receptors Panel

16. With the “Receptors” panel displayed, click on the “Add” button to start the process of adding a new receptor to the simulation.
17. Using the “Receptor Attributes” panel that is displayed, enter a label for the new receptor into the “Label” text box (e.g., “receptor#0”).
18. Select the “site boundary” option for the receptor type using the “Type” drop-down list box.
19. Select the South (“S”) option for the sector using the “Sector” drop-down list box.
20. Enter a distance of “805” in the “Distance (m)” text box.
21. Click on the “Ok” button to add the new receptor to the receptor list.
22. Because there has not been a site boundary receptor added previously, a color select dialog will be displayed. Select a color for the receptor icon that will be displayed in the receptor display, then click on the “OK” button in the dialog window.
  - If a receptor of the same type has already been entered, the color select dialog will not be displayed and the color assigned to the prior receptor will be set to the new receptor being added.
23. Once the icon color has been selected the receptor display will update showing the location of the added receptor.
24. Repeat this process to add seven additional receptors.
  - (a) Label: receptor#1, Type: site boundary, Distance: 966 m, Sector: South (S).

- (b) Label: receptor#2, Type: site boundary, Distance: 1127 m, Sector: S.
  - (c) Label: receptor#3, Type: milk cow, Distance: 1931 m, Sector: S.
  - (d) Label: receptor#4, Type: milk cow, Distance: 4989 m, Sector: North-Northwest (NNW).
  - (e) Label: receptor#5, Type: milk cow, Distance: 4345 m, Sector: South-Southeast (SSE).
  - (f) Label: receptor#6, Type: residence, Distance: 1931 m, Sector: S.
  - (g) Label: receptor#7, Type: residence, Distance: 6437 m, Sector: NNW.
25. Click on the “Next: Terrain” button in the lower right corner of the panel to advance the interface to the “Terrain” panel (Figure C-8).

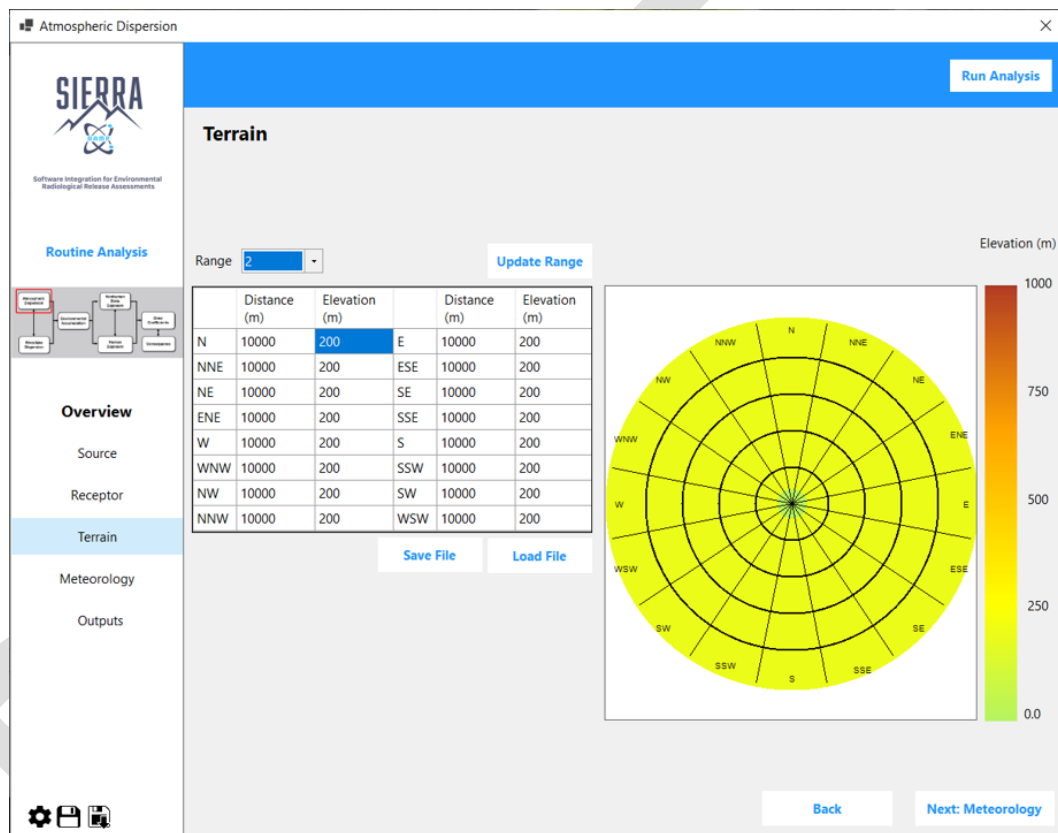


Figure C-8. Completed ATD Terrain Panel

26. Using the “Range” drop-down list box, select the “0” option.
27. In the row labeled “N” enter 100 in the “Distance” cell and 0 in the “Elevation” cell.
- a. To ensure the next two steps are executed correctly, users must enter the distance and elevation value sequentially, or otherwise ensure that the entries are considered “completed” by the software by selecting another cell or clicking a separate space from the entry itself. Entries are not considered “completed” if the cursor in the box is flashing.
28. Using the right button of the mouse click on the “Distance” cell containing the value 100 and then select the “Fill all distances” option from the drop-down menu that is displayed. This will fill in all distance cells with the value of 100.

29. Using the right button of the mouse click on the “Elevation” cell containing the value 0 and then select the “Fill all elevations” option from the drop-down menu that is displayed. This will fill in all elevation cells with the value of 0.
30. Click on the “Update Range” button to enter the Distance and Elevation data.
31. The distance/elevation diagram will automatically update to show the changes to the data.
32. Follow the same directions to add two more sets of range data to the interface. Be sure to click on the “Update Range” button to enter each of the ranges once the data has been entered.
  - (a) Range 1 Distance: 800 m, Elevation: 16 m.
  - (b) Range 2 Distance: 10000 m, Elevation: 200 m.
31. Click on the “Next: Meteorology” button in the lower right corner of the panel to advance the interface to the “Meteorology” panel.
32. With the “Meteorology” panel displayed (Figure C-9), click on the “Browse” next to the “Meteorological File” text box to display an “Open” file dialog window that can be used to select the meteorology file that will be used in the simulation. The meteorological data must be hourly data in Regulatory Guide (RG) 1.123 format.
33. Enter a “Wind Speed Calm Threshold” value of 0.1 m/s into the corresponding text box.
34. Select the “Lower” option from the “Height Type” drop-down list box. This selection impacts the data displayed in the table and the polar plot but does not impact the simulation.

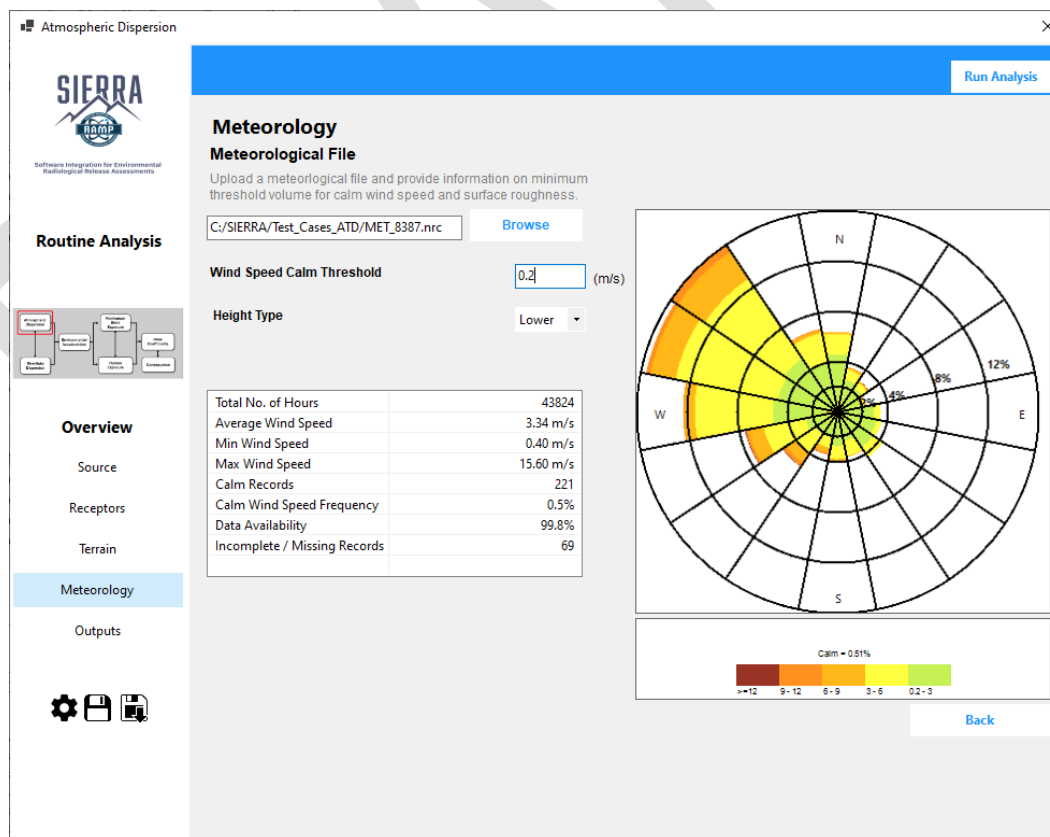


Figure C-9. Completed ATD Meteorology Panel

35. The wind rose diagram and the summary table displayed on the panel will both be automatically updated to reflect data inputs.
36. Click on the “Run Analysis” button located in the upper right corner of the interface to start the ATD simulation engine.
37. Once the simulation engine has finished its execution, the results of the simulation will be processed by the Atmospheric Transport and Diffusion module, and the “Outputs” panel (Figure C-10) will be displayed showing the results of the simulation.

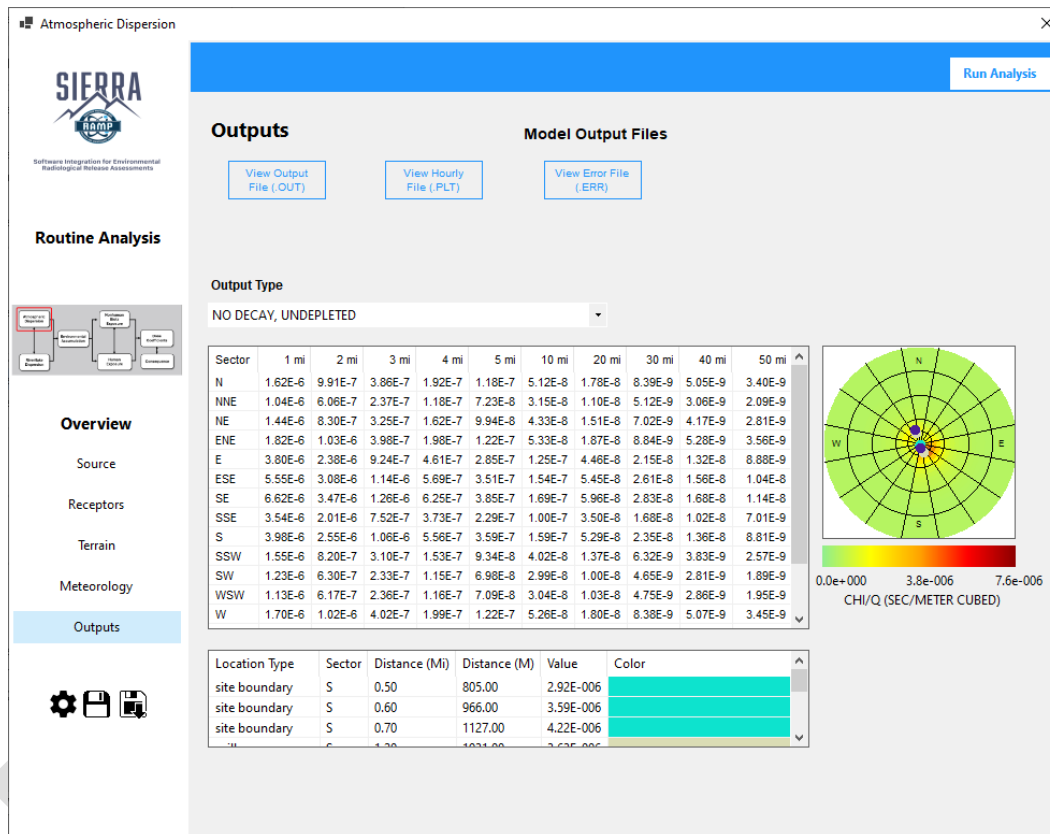


Figure C-10. Completed ATD Model Output Panel

## Appendix D — Example Test Cases

Test cases for each of the atmospheric transport and diffusion modules (Control Room Analysis, Design Basis Accidents, and Routine Analysis), which may be performed by users to confirm their installation are presented here. In many cases, test cases presented here are modeled after the test cases from the legacy software documentation. The JavaScript Object Notation (JSON) input files, along with the corresponding output files, are included with the SIERRA installation and may be found in sub-folders to the SIERRA\Test\_Cases\_ATD folder. While the JSON input files may be used, brief descriptions of the cases are presented below. After loading the JSON input file, users will need to navigate to the Meteorology panel to set the file path for the meteorological data file, which is located in SIERRA\Test\_Cases\_ATD\MET\_8387.nrc.

### D.1 Control Room Analysis Test Cases

#### D.1.1 Control Room Analysis Elevated Test Case

- Source Values
  - Elevated Release Type
  - Release height of 65 m
  - Stack diameter of 1.0 m
  - Stack flow rate of 10.0 m<sup>3</sup>/s
  - Plant Grade Elevation of 0.0 m
  - Building Height of 0 m
- Receptor Values
  - Receptor distance of 210 m from source
  - Intake height of 25 m
  - Terrain height 0.0 m
  - Wind Direction Window 90.0 degrees
  - Direction to receptor from the source is 284 degrees
- Meteorology Values
  - 5 years of a Meteorological Station data from 1983 through 1987
  - Calm wind speed threshold of 0.1 m/s
  - Height Type of Lower
  - Surface roughness of 0.2 m
- Module Defaults
  - NRC Diffusion
  - No initial diffusion Coefficients
  - Missing Data Criterion 10 percent
  - User defined percentile of 99.5th

### D.1.2 Control Room Analysis Ground Test Case

- Source Values
  - Ground-level Release Type
  - Release height of 10 m (default)
  - Stack flow rate of 0.0 m<sup>3</sup>/s
  - Plant Grade Elevation of 0.0 m
  - Building cross-sectional area of 1900 m<sup>2</sup>
- Receptor Values
  - Receptor distance of 45 m from source
  - Intake height of 15 m
  - Terrain height 0.0 m
  - Wind Direction Window 90.0 degrees
  - Direction to receptor from the source is 326 degrees
- Meteorology Values
  - 5 years of a Meteorological Station data from 1983 through 1987
  - Calm wind speed threshold of 0.1 m/s
  - Height Type of Lower
  - Surface roughness of 0.2 m
- Module Defaults
  - NRC Diffusion
  - No initial diffusion Coefficients
  - Missing Data Criterion 10 percent
  - User defined percentile of 99.5th

## D.2 Design Basis Accidents Test Cases

### D.2.1 Design Basis Accidents Elevated Test Case

- Source Values
  - Elevated Release Type
  - Release Height of 45 m
  - Plant Grade Elevation of 0.0 m
  - Site Type of Inland
- Terrain Values
  - Exclusion area boundary (EAB) distance at 800 m, Elevation of 0 m
  - Low population zone (LPZ) distance at 3000 m, Elevation of 0 m

- Meteorology Values
  - 5 years of a Meteorological Station data from 1983 through 1987
  - Calm wind speed threshold of 0.1 m/s
  - Height Type of Lower
- Module Defaults
  - No Plume Rise
  - NRC Diffusion
  - Missing Data Criterion 10 percent

## **D.2.2 Design Basis Accidents Ground Test Case**

- Source Values
  - Ground-level Release Type
  - Release Height of 10 m (default)
  - Building height of 25 m
  - Building Cross-sectional area of 900m<sup>2</sup>
- Terrain Values
  - EAB distance at 800 m, Elevation of 0 m
  - LPZ distance at 3000 m, Elevation of 0 m
- Meteorology Values
  - 5 years of a Meteorological Station data from 1983 through 1987
  - Calm wind speed threshold of 0.1 m/s
  - Height Type of Lower
- Module Defaults
  - No Plume Rise
  - NRC Diffusion
  - Missing Data Criterion 10 percent

## **D.3 Routine Analysis Test Cases**

### **D.3.1 Routine Analysis Elevated Test Case**

- Source Values
  - Elevated Release Type
  - Release height of 45 m
  - Stack diameter of 2 m
  - Stack Flow Rate of 10.0 m/s
  - Plant Grade Elevation of 0 m

- Receptor Values
  - Site Boundary – 805 m at S sector
  - Site Boundary – 966 m at S sector
  - Site Boundary – 1127 m at S sector
  - Milk Cow – 1931 m at S sector
  - Milk Cow – 4989 m at NNW sector
  - Milk Cow – 4345 m at SSE sector
  - Residence – 1931 m at S sector
  - Residence – 6437 m at NNW sector
- Terrain Values
  - Range 0 distance at 100 m, Elevation of 0 m
  - Range 1 distance at 800 m, Elevation of 16 m
  - Range 2 distance at 10000 m, Elevation of 200 m
- Meteorology Values
  - 5 years of a Meteorological Station data from 1983 through 1987
  - Calm wind speed threshold of 0.1 m/s
  - Height Type of Lower
- Module Defaults
  - Use open terrain recirculation – TRUE
  - Diffusion: NRC

### **D.3.2 Routine Analysis Ground Test Case**

- Source Values
  - Ground Release Type
  - Release Height of 10 m (default)
  - Building height at 0 m
  - Building cross-sectional area of 0 m<sup>2</sup>
- Receptor Values
  - Site Boundary - 805 m at S sector
  - Site Boundary - 966 m at S sector
  - Site Boundary - 1127 m at S sector
  - Milk Cow - 1931 m at S sector
  - Milk Cow - 4989 m at NNW sector
  - Milk Cow – 4345 m at SSE sector
  - Residence - 1931 m at S sector



- Residence - 6437 m at NNW sector
- Terrain Values
  - Range 0 distance at 100 m, Elevation of 0 m
  - Range 1 distance at 800 m, Elevation of 16 m
  - Range 2 distance at 10000 m, Elevation of 200 m
- Meteorology Values
  - 5 years of a Meteorological Station data from 1983 through 1987
  - Calm wind speed threshold of 0.1 m/s
  - Height Type of Lower
- Module Defaults
  - Use open terrain recirculation - TRUE
  - Diffusion: NRC

### **D.3.3 Routine Analysis Vent Test Case**

- Source Values
  - Vent Release Type
  - Release Height of 10 m
  - Stack diameter of 2 m
  - Stack Flow Rate of 10.0 m/s
  - Plant Grade Elevation of 0 m
  - Building height of 40 m
  - Building cross-sectional area of 2000 m<sup>2</sup>
- Receptor Values
  - Site Boundary - 805 m at S sector
  - Site Boundary - 966 m at S sector
  - Site Boundary - 1127 m at S sector
  - Milk Cow - 1931 m at S sector
  - Milk Cow - 4989 m at NNW sector
  - Milk Cow - 4345 m at SSE sector
  - Residence - 1931 m at S sector
  - Residence - 6437 m at NNW sector
- Terrain Values
  - Range 0 distance at 100 m, Elevation of 0 m
  - Range 1 distance at 800 m, Elevation of 16 m
  - Range 2 distance at 10000 m, Elevation of 200 m

- Meteorology Values
  - 5 years of a Meteorological Station data from 1983 through 1987
  - Calm wind speed threshold of 0.1 m/s
  - Height Type of Lower
- Module Defaults
  - Use open terrain recirculation – TRUE
  - Diffusion: NRC

DRAFT

## Appendix E — Atmospheric Transport and Dispersion Module Technical Bases

The atmospheric transport and diffusion (ATD) module within Software Integration for Environmental Radiological Release Assessments (SIERRA) is a unified code in FORMula TRANslator (Fortran) 90 that allows computation of  $\chi/Q$  for three different assessments – 1) control room habitability, 2) offsite design basis accidents (DBAs), and 3) routine release accidents. Historically, NRC staff and RAMP users employed ARCON2 (earlier ARCON96) for short-term consequence assessment in control room; PAVAN for nuclear power plant licensing; and XOQDOQ for long-term consequence assessment of routine releases from nuclear power plants (NPPs). A summary of these assessments is described below, and their respective regulatory bases are provided in Table E-1.

Table E-1. Regulations and NRC Guidance Documents Related to Assessment Types

Assessment/Model Type	Legacy Model	NRC Guidance Document	Regulations	Applicability
Control room habitability assessment	ARCON	RG 1.194	10 CFR 50, Appendix A, General Design Criteria 19	Evaluate personnel exposures inside the control room during accidents
		SRP 2.3.4		
Design basis accident analyses	PAVAN	SRP 15.0.3	10 CFR Part 50, Paragraph IV.E.8 of Appendix E	Protection against radiation inside the onsite technical support center
		RG 1.145	10 CFR 50.34(a)(1)(ii)(d)	Offsite consequence at EAB and LPZ for plant design
		SRP2.3.4	10 CFR 52.47(a)(2)(iv)	Offsite consequence at EAB and LPZ for plant design
			10 CFR 52.17(a)(1)(ix)	Offsite consequence at EAB and LPZ for safety assessment
			10 CFR 52.79(a)(1)(vi)	Offsite consequence at EAB and LPZ for safety assessment
			10 CFR 100.11(a)	Determine acceptable EAB and LPZ for siting
Routine release analysis	XOQDOQ	RG 1.111	10 CFR 100.21(c)(2)	Offsite consequence at EAB and LPZ for postulated accidents
		SRP 2.3.5	10 CFR Part 20 Subpart D	Annual dose assessment to ensure below threshold limit during operations

Assessment/Model Type	Legacy Model	NRC Guidance Document	Regulations	Applicability
			10 CFR Part 50, Appendix I	Annual dose assessment to meet as low as is reasonably achievable (ALARA) criterion during preliminary plant design

ARCON = computer code for Atmospheric Relative CONcentration in Building Wakes, RG = Regulatory Guide, SRP = standard review plans, CFR = *Code of Federal Regulations*, PAVAN = computer code for ground-level  $\chi/Q$  for accidental release, EAB = exclusion area boundary, LPZ = limited population zone, XOQDOQ = computer code for atmospheric transport and diffusion modeling for routine releases.

A summary of the control room habitability assessment is provided below:

- General Design Criterion 19 of 10 CFR 50, Appendix A 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 >5 rem whole body, or its equivalent to any part of the body, for the duration of the accident.”
- Regulatory Guide (RG) 1.194, “Atmospheric Relative Concentrations for Control room.”
- “Radiological Habitability Assessments at Nuclear Power Plants,” presents criteria for characterizing atmospheric transport and diffusion conditions for evaluating the consequences of radiological releases to the control room.
- RG 1.94 requires determination of 95th percentile  $\chi/Q$  (exceeded no more than 5 percent of the assessment period) for each of the source to receptor combinations.
- Currently, RG 1.94 prescribes ARCON as an acceptable methodology for assessing control room  $\chi/Q$  values.
- ARCON is designed to estimate concentrations for sources and receptors in the vicinity of buildings. The model includes explicit treatment of low wind speed dispersion and building wakes. The stability based Pasquill-Gifford diffusion coefficients were modified based on field experimental data as described in Ramsdell and Fosmire (1998). These dispersion coefficients are valid only for distances within few hundred meters from the source.
- ARCON currently considers ground-level releases, vent releases, or elevated releases. However, Regulatory Position C.3.2.3 states that the vent release mode within ARCON should not be used for DBA.

A summary of the offsite DBA analyses is provided next:

- 10 CFR 100.11 requires that an applicant to determine the following for siting considerations:
  - An individual at an exclusion area boundary (EAB) does not receive a total whole body radiation dose over 25 rem over the first two hours of exposure.

- An individual at a low population zone (LPZ) such does not receive a total radiation dose over 25 rem over the entire period of the plume passage.
- RG 1.45 provides guidance on ATD models for potential accident consequence assessment at NPPs.
  - This guide provides specific  $\chi/Q$  calculation methods for ground-level release and elevated releases that were implemented in PAVAN. The sector averaged Gaussian plume equation is modified with corrections for building wake and meander for ground-level release.
- RG 1.145 requires calculation of 2-hour  $\chi/Q$  at EAB that is exceeded 0.5 percent for each of the 16 directions (22.5° each)
- RG 1.145 requires calculation of  $\geq 8$ -hour  $\chi/Q$  at LPZ that is exceeded 0.5 percent for each of the 16 directions and 5 percent for overall site (all directions)

Finally, a summary of the routine release analyses is provided:

- 10 CFR 50, Appendix I requires that a nuclear facility be operated to meet the criterion “as low as is reasonably achievable” (ALARA).
- 10 CFR 20.1301 sets radiational dose limits to public from routine release of radioactive effluents from a nuclear facility and thus regulates the amount of annual releases.
- RG 1.111 provides the acceptable methods for estimation of atmospheric transport and dispersion of gaseous effluents in routine releases.
- XOQDOQ implements the long-term dispersion and deposition calculation for routine releases based on Sagendorf (1994).
- Unlike the legacy models for control room analysis and design basis analysis, XOQDOQ accounts for removal processes due to dry deposition and radioactive decay.
- This analysis considers ground-level releases, vent releases, or elevated releases.

Table E-2 highlights the differences in dispersion methods among these three types of assessments.

**Table E-2. Summary of Differences in Parameters Considered in the Three Modeling Assessment Types**

Parameter	Control room Analyses	Offsite Design Basis Accident	Routine Release Analyses
Building wake	Ramsdell and Fostmire (1995)	Slade (1968)	Slade (1968)
Low wind speed (meander) effects	Ramsdell and Fostmire (1995)	RG 1.145	RG 1.145

Parameter	Control room Analyses	Offsite Design Basis Accident	Routine Release Analyses
Plume rise (default)	No	No	Yes
Downwash	Yes	No	Yes
Recirculation factor	No	No	Yes
Finite flow corrections	Yes	No	No
Fumigation	No	Yes	No
Iteration for max $\chi/Q$ (elevated)	No	Yes	No
Terrain	Yes	Yes	Yes
Intake Height	Yes	No	No
Slant Height	Yes	No	No

Although the objectives of these three assessments are different, the underlying technical basis is based on a simple near-field straight-line Gaussian plume model that takes a common input of meteorological fields of wind speed, wind direction, and atmospheric stability for a site. Therefore, for the SIERRA software, these three different codes were reengineered and consolidated with a common input of hourly meteorological data based on RG 1.23 format.

## E.1 Meteorological Data Processing

Meteorological data in a Fortran format provided in the RG 1.23 guidance document is used as model input. The meteorological reader routine within the ATD engine reads the wind speed, wind direction collected at lower and upper air measurement heights, and the temperature difference between these two heights. There are other variables (e.g., sigma theta) that can be provided by the user as described in RG 1.23. However, the reading routine ignores these values and treats them as blank space. The Fortran format used in this routine is described in Table E-3.

Table E-3. Fortran Format Implemented in the Meteorological Reader Routine

Fortran Specification	Variable Description
A4	Identifier
I4	Year
I3	Julian day
I4	Hour (01 to 24)
F5.1	Upper measurement height (m)
F5.1	Wind direction (degrees) at upper air height
F5.1	Wind speed (m/s) at upper air height
55X	Not used as a variable
F5.1	Lower measurement height (m)

Fortran Specification	Variable Description
F5.1	Wind direction (degrees) at lower air height
F5.1	Wind speed (m/s) at lower air height
20X	Not used as a variable
F5.1	Temp. Diff. (Upper-Lower) (degree C/100 meters)

Thereafter, the meteorological processor routine selects the measurement height that will be used for diffusion calculations. The selection is based on the model/assessment type using the following criterion:

- Control room assessment - If the stack height is greater than the average of lower and upper air measurement heights, then the height of upper air measurement is chosen, otherwise the lower measurement height is chosen.
- Offsite DBA or Routine Release - If the stack is elevated, then the upper air measurement height is chosen, otherwise the lower measurement height is chosen.

Once a measurement height is selected, the routine determines the “calm” wind from the hourly data for the selected height using the following criteria:

- Wind direction or wind speed fields with values “77777” as prescribed in RG 1.23 to indicate calm.
- Less than or equal to minimum calm threshold provided by user in JSON input.

The missing data is determined based on following criteria:

- Any field with values “99999” as prescribed in RG 1.23 for a lost record.
- Wind direction greater than 360 °.

A “calm” hour with any missing field is treated as missing data and not included in calculations.  $\chi/Q$  is not computed for hours with missing data and also excluded from statistical averages during post-processing.

The atmospheric stability (A through G) for each hour is then determined from the temperature difference (dt/dz) value using the classification in Table 1 of RG 1.23. The wind speed at the measurement height is corrected for the stack (release) height using Monin-Obukhov length similarity theory for control room assessment (ARCON96 user manual). A simple power law relationship (PAVAN user guide) is used to adjust the wind speed for the other two assessments.

Effective stack height is determined for elevated sources from a combination of stack (release) height, Plume Rise, downwash and terrain. The effective height is also adjusted for surrounding terrain heights and receptor height (control room) to adjust for the difference between the plume centerline and receptor heights.

$$H_{eff} = H_{stack} + \Delta H_{rise} + \Delta H_d + (T_{stack} - T_{rec}) - H_{intake} \quad \text{Equation 1}$$

Where:

$H_{\text{eff}}$	effective stack height used in computation of relative concentrations,
$H_{\text{stack}}$	physical height of the stack,
$\Delta H_{\text{rise}}$	increase in plume height due to Plume Rise,
$\Delta H_d$	stack downwash (control room analysis only),
$T_{\text{stack}}$	terrain height at the stack location,
$T_{\text{rec}}$	terrain height at the receptor location,
$H_{\text{intake}}$	height of intake (control room analysis only).

The terrain height ( $T_{\text{rec}}$ ) for a single receptor is directly retrieved from JSON input for control room analyses. This value is interpolated from a range of user inputs within the JSON file for the other two assessments which may have terrain information at different distances for each directional sector. The ATD engine currently allows user to enter terrain data as a function of two or more distances and 16 directions. The ATD engine interpolates the terrain data at a particular hour for a receptor of certain distance and a directional sector where the concentration is being computed.

Plume rise ( $\Delta H_{\text{rise}}$ ) is calculated for elevated releases using exit velocity ( $w_0$ ) based on formulations outlined in Sagendorf et. al. (1982). It is calculated separately for stable conditions and neutral/unstable conditions. If the exit velocity is less than 1.5 times the wind speed, a correction for downwash is made. The ATD engine calculates the exit velocity using the user inputs of stack flow rate and stack diameter.

$$w_0 = \frac{F}{\pi \left(\frac{D}{2}\right)^2} \quad \text{Equation 2}$$

Where:

$w_0$	exit velocity,
$F$	stack flow rate ( $\text{m}^3/\text{s}$ ),
$D$	stack diameter (m)

Plume rise is calculated by default for routine release analyses in compliance with RG 1.111, while it is a user option for control room analyses and offsite DBA analyses. If Plume Rise calculation is not selected, then a stack tip downwash is computed for control room assessment as shown below:

$$\Delta H_d = 4 \frac{D}{2} \left[ \frac{w_0}{U} - 1.5 \right] \quad \text{Equation 3}$$

Where,  $U$  is the wind speed in m/s.

## E.2 The Gaussian Plume Model

Concentrations (and deposition) at receptor distances are computed for each hour using the inputs of adjusted wind speed and atmospheric stability for a source with effective height. The atmospheric engine implements a straight-line Gaussian plume model. The complete straight-line Gaussian plume model (including ground reflection) is:



$$\frac{\chi}{Q} = \frac{1}{2\pi U \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[ \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right] \quad \text{Equation 4}$$

Where:

- $\chi$  concentration (Ci/m<sup>3</sup>) at downwind distance  $x$ , crosswind distance  $y$ , and height  $z$  in a plume with axis at effective stack height  $H$ ,
- $Q$  release rate (Ci/s),
- $\chi/Q$  relative concentration (s/m<sup>3</sup>),
- $U$  mean wind speed (m/s)
- $x$  downwind distance (m),
- $y$  crosswind distance (m),
- $z$  height in the plume (m),
- $H$  effective stack height (m), and
- $\sigma_y, \sigma_z$  diffusion coefficients in horizontal and vertical directions, respectively (m).

### E.2.1 Centerline Plume Model

The Gaussian plume model in Equation 1 can be simplified for ground-level ( $z=0$ ) centerline ( $y=0$ ) concentrations as:

$$\frac{\chi}{Q} = \frac{1}{\pi U \sigma_y \sigma_z} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) \quad \text{Equation 5}$$

This equation provides the centerline relative concentrations for an elevated release with effective stack height  $H$  (m). For ground-level sources,  $H$  is equal to zero and the equation is further simplified to:

$$\frac{\chi}{Q} = \frac{1}{\pi U \sigma_y \sigma_z} \quad \text{Equation 6}$$

### E.2.2 Sector Average Plume Model

The centerline relative concentrations in Equations 2 and 3 are appropriate for short averaging periods. It is unlikely that the plume position will remain constant at the same direction for long periods. Therefore, a sector average model is used to estimate relative concentrations for averaging periods longer than 8 h. The sector average plume model is derived by integrating the concentration across the normal plume model and dividing the result by the sector width,  $W$  (m). The ground-level, centerline, sector average concentration is given by:

$$\frac{\chi}{Q} = \frac{2}{\sqrt{2\pi} U \sigma_z W} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) \quad \text{Equation 7}$$

Further, for ground-level sources, the sector average plume model is:

$$\frac{\chi}{Q} = \frac{2}{\sqrt{2\pi} U \sigma_z W} \quad \text{Equation 8}$$

Where,  $W$  is the width of a 22.5 ° wind direction sector, which is a function of the downwind distance (m). It can be calculated from the circumference of a circle with radius equal to the downwind distance  $x$  divided by number of wind direction sectors (conventionally 16 directions, which are each 22.5 ° wide).

$$W = \frac{2\pi x}{16} \quad \text{Equation 9}$$

Using this value of  $W$ , the sector averaged normalized concentration for elevated and ground-level sources can be expressed as:

$$\frac{\chi}{Q} = \frac{2.0318}{U\sigma_z x} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) \quad \text{Equation 10}$$

$$\frac{\chi}{Q} = \frac{2.0318}{U\sigma_z x} \quad \text{Equation 11}$$

These two equations for concentrations based on distance-based sector width are used for calculations within the atmospheric engine that mimic the functionality of PAVAN and XOQDOQ. It should be noted that NRC codes of PAVAN (Bander, 1982) and XOQDOQ (Sagendorf et. al., 1982) also utilized a factor for joint frequency distribution of meteorological data in the sector average model. The atmospheric engine is based on hourly simulations; therefore, the equations implemented here do not incorporate the frequency factor. All the hourly  $\chi/Q$  are collected in an array and long-term averages (including annual averages) are computed during post-processing.

### E.2.3 Calculations for Control Room Analysis

For control room analysis, the sector width  $W$  is calculated assuming that 95 percent of the Gaussian plume is generally within  $\pm 2\sigma_y$  of the plume centerline (Ramsdell & Simonen, 1997).

$$W = 4.3\sigma_y \quad \text{Equation 12}$$

If the Release Type is a ground-level source, a slant path is used as the distance to receptor for control room analyses of  $\chi/Q$  in lieu of the perpendicular distance between the control room and the source of release. The slant path is computed using the Pythagorean theorem from the effective release height (difference between stack and receptor heights) and distance of the control room receptor.

$$X_{slant} = \sqrt{(X)^2 + (H)^2} \quad \text{Equation 13}$$

The relative concentration is corrected for the stack flow rate as prescribed in RG 1.94:

$$\left(\frac{\chi}{Q}\right)^* = \frac{1}{\frac{1}{\chi/Q} + F} \quad \text{Equation 14}$$

Where  $F$  is the stack flow rate ( $\text{m}^3/\text{s}$ ).

### E.2.4 Calculations for Design Basis Accidents Analysis

The relative concentrations for elevated releases are calculated at various pre-determined distances up to a maximum of 90,000 meters. The  $\chi/Q$  values at given boundary distances (EAB and LPZ) are compared to concentrations at various distances beyond the boundary to assure that the maximum  $\chi/Q$  does not occur outside the boundary. For EAB values, maximum values are not searched beyond the LPZ boundary. For LPZ values, comparisons are made with iterations till 12.8 km beyond LPZ boundary. Thus, the maximum  $\chi/Q$  values at or beyond the boundary are used like that for PAVAN (Bander, 1982).

Fumigation conditions are determined at each hour based on the stable atmospheric conditions (E, F, or G classes) at that hour and unstable conditions (A, B, or C classes) at the next hour. For hours with fumigation conditions, the following equation is used to determine the centerline relative concentrations based on RG1.145:

$$\frac{\chi}{Q} = \frac{1}{\sqrt{2\pi}U\sigma_yH} \quad \text{Equation 15}$$

The wind speed used in this equation is representative of the fumigation layer. A value of 2 m/s is used as a reasonably conservative assumption for an effective stack height of about 1000 m (RG 1.145). The lateral plume spread at given distances are based on a moderately stable atmosphere (Pasquill stability class F).

The “fumigation  $\chi/Q$ ” from can approach unrealistically large values, as the effective stack height becomes small (on the order of 10 m). To limit the “fumigation  $\chi/Q$ ” value, the ATD routine assumes F stability, a wind speed of 2 m/s, and an effective height of 0 m. The  $\chi/Q$  values calculated using both equations are compared, and the lower value is selected as the “fumigation  $\chi/Q$ ”. Furthermore, a maximum of the “fumigation  $\chi/Q$ ” and non-fumigant  $\chi/Q$  (using normal atmospheric conditions) is selected for coastal sites. An average value of the “fumigation  $\chi/Q$ ” and non-fumigant  $\chi/Q$  is used for inland sites. The method for determination of  $\chi/Q$  during fumigation conditions is described in RG 1.145.

## E.2.5 Calculations for Routine Release Analysis

The annual average is processed from hourly normalized concentrations (sector averaged only) and deposition in the post-processing routine. Hourly normalized concentration values are calculated using modified forms of the elevated and ground-level release equations. RG 1.111 requires calculations of radionuclide transport for long durations/distances. Therefore, open terrain recirculation and removal mechanisms due to radioactive decay and dry deposition are accounted in the routine release analysis. Standard multiplicative factors as function of distance are provided for these processes in RG1.111. The sector averaged  $\chi/Q$  in is multiplied with these factors as in Sagendorf et. al. (1982).

$$\frac{\chi}{Q} = \frac{2.0318}{U\sigma_zx} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) \times RF(x) \times DEC(x, U) \times DEPL(x, stab, H) \quad \text{Equation 16}$$

$$\frac{\chi}{Q} = \frac{2.0318}{U\sigma_zx} \times RF(x) \times DEC(x, U) \times DEPL(x, stab) \quad \text{Equation 17}$$

Where:

- stab stability condition,
- RF open terrain recirculation factor at distance x,
- DEC reduction factor due to radioactive decay at distance x, and wind speed, U
- DEPL reduction factor due to plume depletion at distance x, stability (stab), and Height (H, for elevated sources).

The correction factor for open terrain recirculation is calculated using polynomial equations (function of x) based on Figure 3.2 within the XOQDOQ user manual (Sagendorf et. al., 1982). If the user does not select the option of recirculation factor, then RF is equal to 1. The factor DEC is computed using simple first order radioactive decay based on a predefined half-life.

$$DEC(x) = \exp\left(\frac{-0.693 \times t}{24 \times T_{1/2}}\right) \quad \text{Equation 18}$$

$$t = \frac{x}{3600 \times U} \quad \text{Equation 19}$$

Where:

- t travel time in hours calculated from hourly wind speed U (m/s), and
- $T_{1/2}$  half-life of the radioactive material (days).

Three different values for relative concentrations are calculated based on three half-life values that have been predefined in RG 1.111 and implemented in XOQDOQ (Sagendorf et. al., 1982):

- No decay, undepleted
- An overall half-life of 2.26 days for short-lived noble gases (undepleted)
- 8 days half-life for all iodines (depleted)

The plume depletion factor is also calculated using polynomial equations based on Figures 3 through 6 of RG 1.111. The plume depletion is a function of the release height (H) and downwind distance (x). For releases >15 m, the depletion factor also varies for stability conditions (stab).

Relative deposition is calculated as:

$$\frac{D}{Q} = \frac{F(x,stab,H)}{(2\pi/16)x} \times RF \quad \text{Equation 20}$$

Where:

D/Q relative deposition

F polynomial equation from XOQDOQ.

The function F is a polynomial equation from XOQDOQ based on distance, stability condition, and release height. These polynomials were derived from Figures 7 through 10 of RG 1.111. For release heights ≤15 m, the deposition is only function of downwind distance, like depletion factors. The function plots for recirculation factor, plume depletion, and relative deposition are shown in Figure 4-1 through Figure 4-7.

The routine analyses also calculate relative concentration and deposition for vent releases in addition to ground-level and elevated sources. An entrainment coefficient is calculated based on the ratio of the plume exit velocity ( $w_0$ ) to the hourly wind speed at the release height. If the ratio is <1 (i.e., exit velocity less than wind speed), then it is treated as a ground-level source. If the ratio is >5, then the plume is treated as an elevated source. For cases where the ratio of exit velocity to wind speed is between one and five, a mixed release model is assumed, in which the plume is considered as an elevated release during a part of the time and as a ground-level release during remainder of the time. The entrainment coefficient ( $E_t$ ) is determined for these cases as shown below:

$$E_t = 1 \quad \text{for } \frac{w_0}{U} \geq 1 \quad \text{Equation 21}$$

$$E_t = 2.58 - 1.58 \left( \frac{w_0}{U} \right) \quad \text{for } 1 < \frac{w_0}{U} \leq 1.5 \quad \text{Equation 22}$$

$$E_t = 0.3 - 0.06 \left( \frac{w_0}{U} \right) \quad \text{for } 1.5 < \frac{w_0}{U} < 5 \quad \text{Equation 23}$$

$$E_t = 0 \quad \text{for } \frac{w_0}{U} \geq 5 \quad \text{Equation 24}$$

The release is considered to occur as an elevated release during  $(1-E_t)$  time fraction and as a ground release during  $E_t$  time fraction as shown below. For mixed-mode calculations during vent release, relative concentrations and deposition rates are calculated using Gaussian equations for both elevated and ground releases.

$$\left(\frac{\chi}{Q}\right)_{vent} = (1 - E_t) \left(\frac{\chi}{Q}\right)_{ground} + E_t \left(\frac{\chi}{Q}\right)_{elevated}$$

Equation 25

$$\left(\frac{D}{Q}\right)_{vent} = (1 - E_t) \left(\frac{D}{Q}\right)_{ground} + E_t \left(\frac{D}{Q}\right)_{elevated}$$

Equation 26

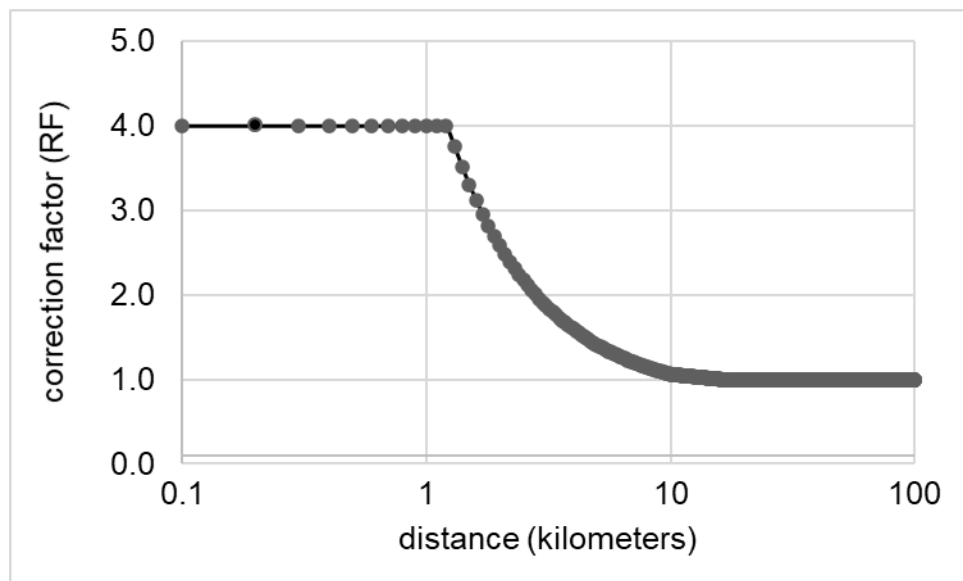


Figure E-1. Open Terrain Correction Factor

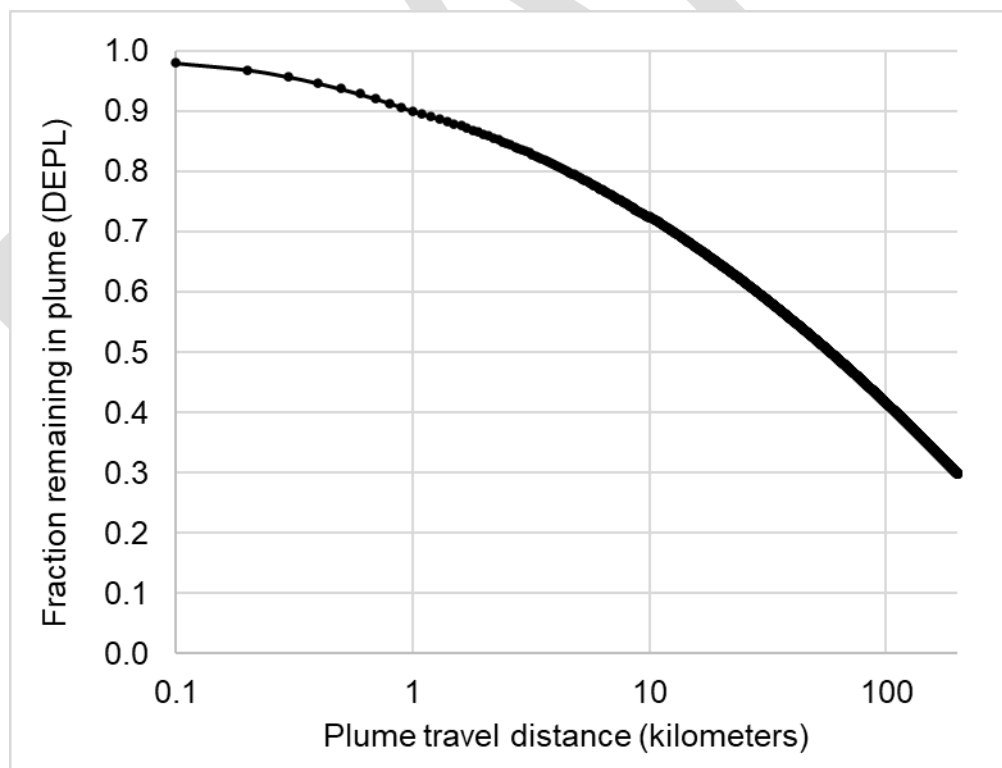


Figure E-2. Plume Depletion Effect for Ground-Level Releases (All Atmospheric Stability Classes)

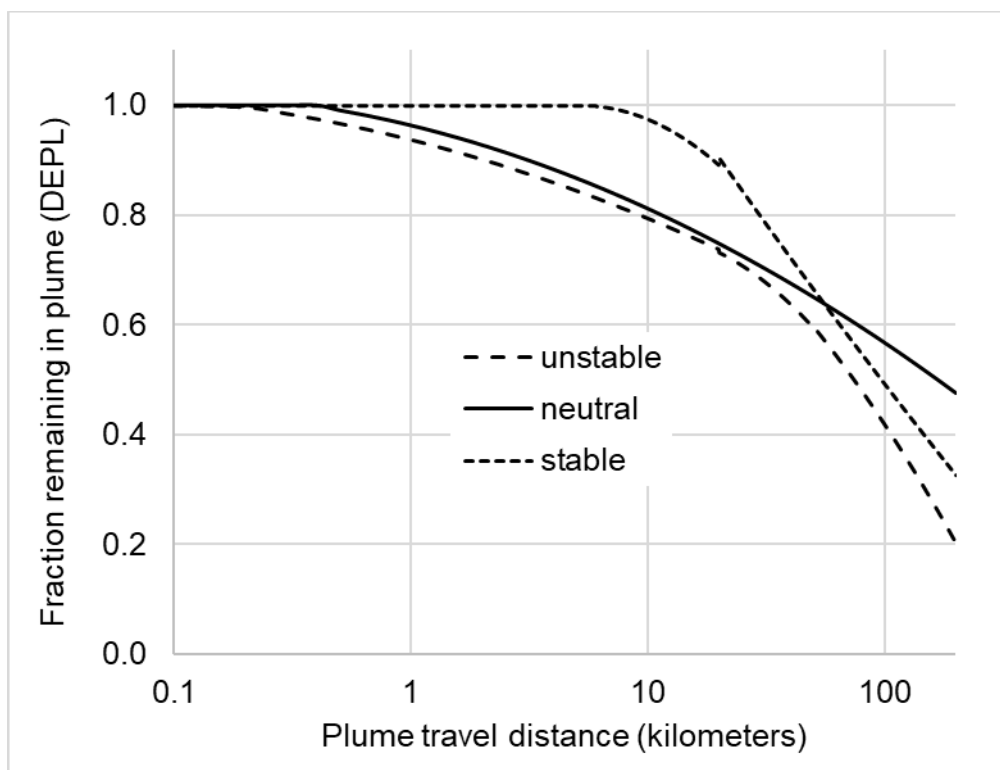


Figure E-3. Plume Depletion Effect For 30 m Releases and Atmospheric Stability Classes

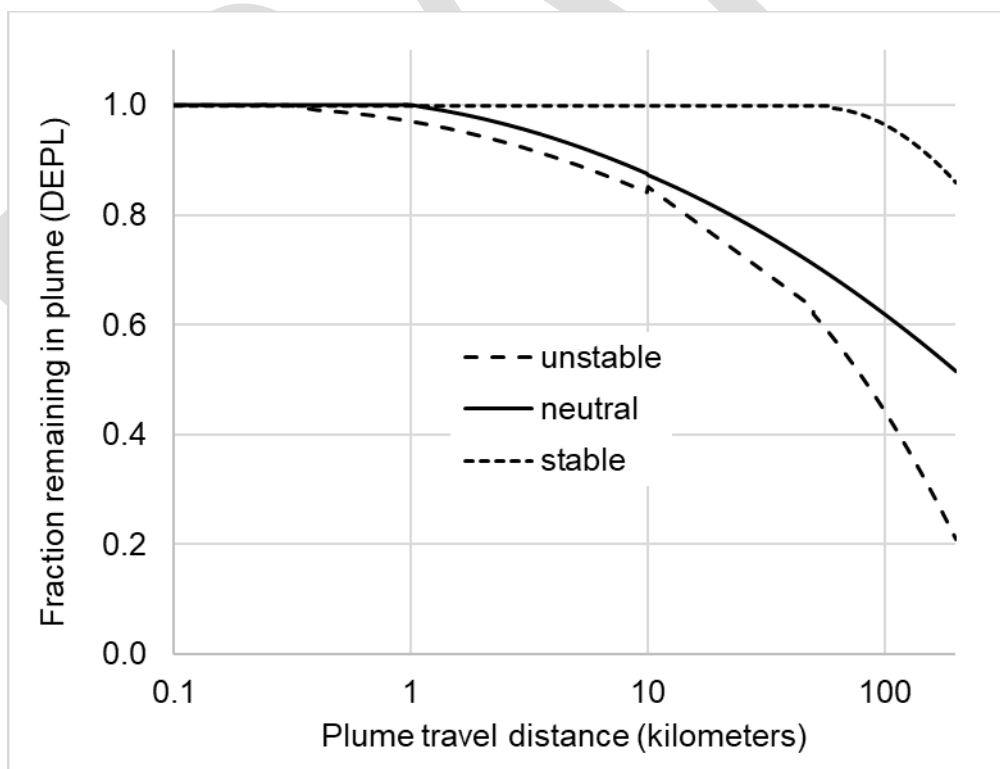


Figure E-4. Plume Depletion Effect for 60 m Releases and Atmospheric Stability Classes

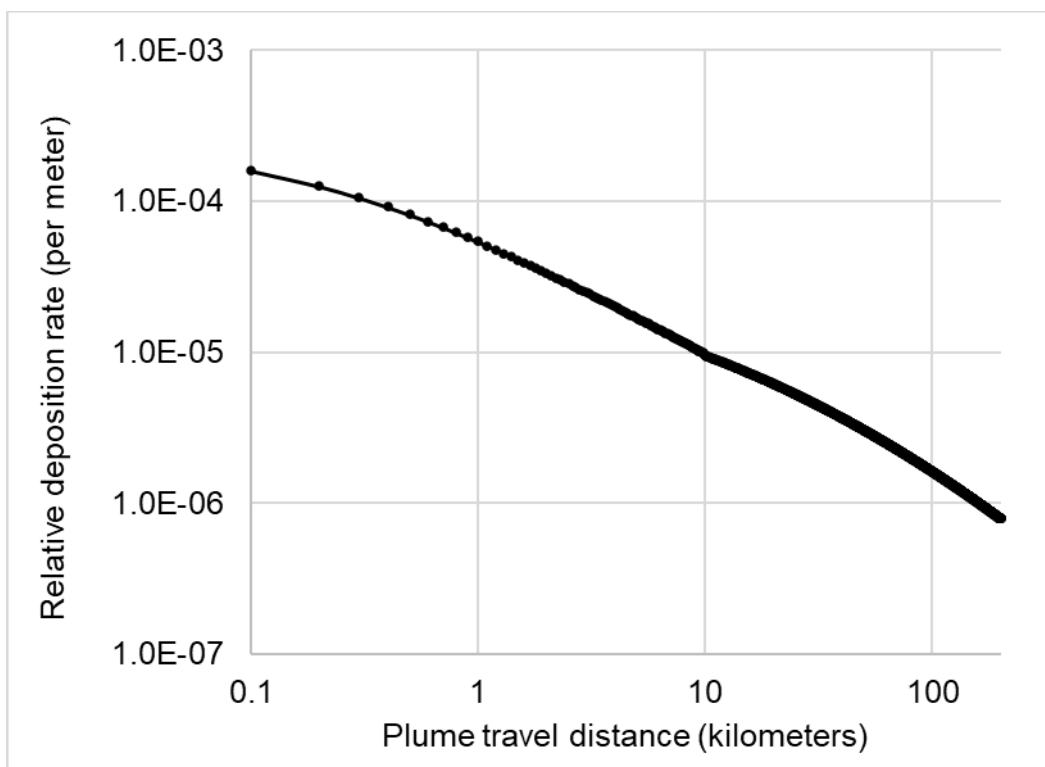


Figure E-5. Relative Deposition for Ground-Level Releases (All Atmospheric Stability Classes)

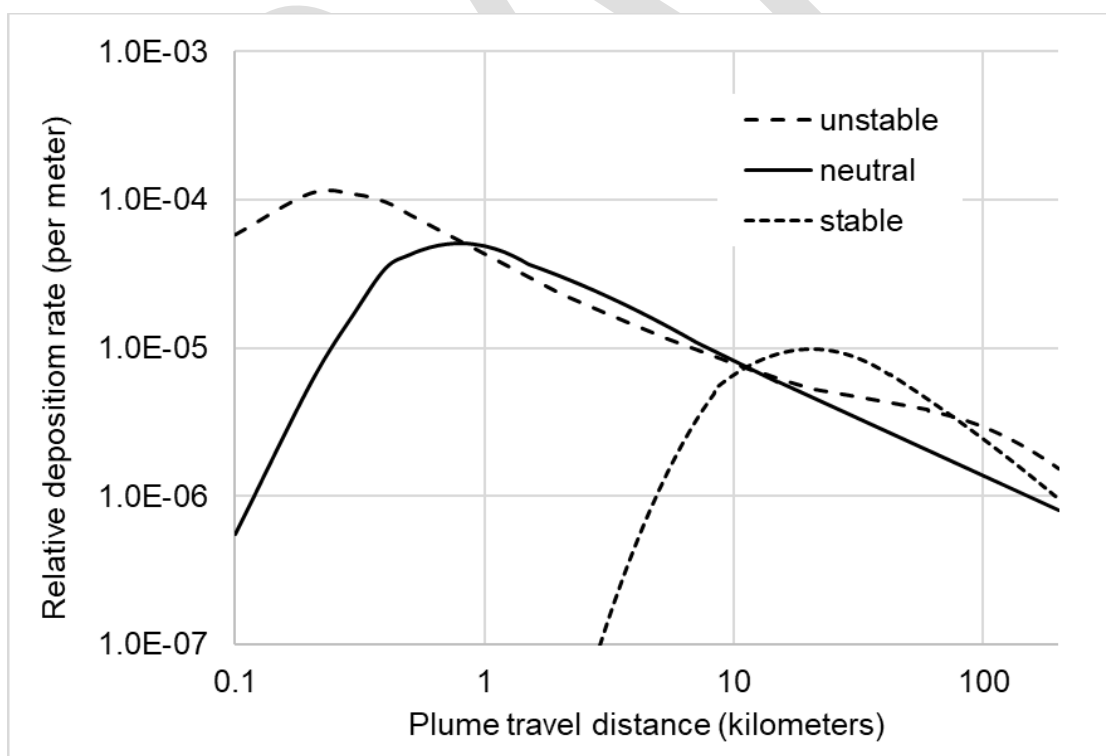


Figure E-6. Relative Deposition for 30 m Releases and Different Atmospheric Stability Classes

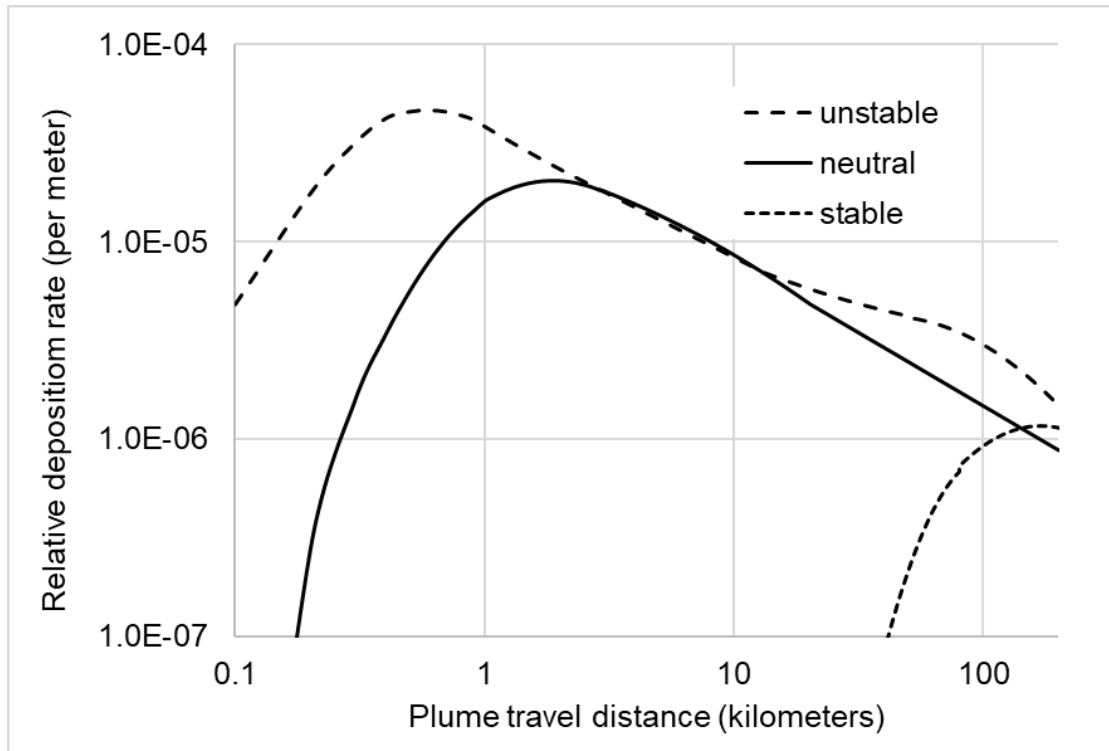


Figure E-7. Relative Deposition for 60 m Releases and Different Atmospheric Stability Classes

## E.2.6 Diffusion Coefficients

The spread of the plume at a prescribed downwind distance is described by diffusion coefficients. These coefficients are standard deviations of the Gaussian plume distribution and are related to atmospheric stability and downwind distance. There are many schemes of estimating these coefficients based on empirical data. The diffusion coefficients have the general form (Ramsdell & Simonen, 1997):

$$\sigma = ax^b + c \quad \text{Equation 27}$$

Where:

- $\sigma$  diffusion coefficients (m),
- $x$  downwind distance (m), and
- $a, b, c$  parameters as functions of atmospheric stability.

The most widely used stability classification is based on Pasquill-Gifford (referred as P-G hereafter) diffusion coefficients. It should be noted that P-G diffusion coefficients has been established by NRC for seven stability categories (A-G) while U.S. Environmental Protection Agency (EPA) defines them for six stability categories only (A-F). The atmospheric stability at each hour is calculated using vertical temperature gradient (dTdZ) from meteorological data in RG 1.23 format based on guidance provided in Table 1 of RG 1.23 (NRC 2007).

The atmospheric engine allows five empirical methods for calculating dispersion coefficients:

- Pasquill-Gifford relationships implemented in NRC models (default method).
- Pasquill-Gifford relationships implemented in EPA ISC3 model.



- Briggs open country conditions.
- Briggs urban conditions
- Desert diffusion curves by Markee implemented in XOQDOQ (Sagendorf et. al., 1982)

These empirical relationships are elaborated in a report by Napier (2011). NRC P-G coefficients and Markee's desert diffusion curves are also provided in PAVAN (Bander, 1982) and XOQDOQ (Sagendorf et. al., 1982) user guides.

The airflow over and around buildings create a complex dispersion pattern for plumes. Recirculation air flow near the edge of the building create enhanced turbulence and accelerated diffusion of the plume. Such "building wake" effects near buildings are accounted for through simple statistical modification of the diffusion coefficients in the Gaussian plume model.

#### E.2.6.1 Diffusion Coefficients Adjustments for Control Room Analysis

A building wake model based on work by Ramsdell and Fosmire (1998) is used for near-field calculations similar to ARCON2 and ARCON96. The modified diffusion coefficients are calculated as:

$$\Sigma_y = (\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2)^{1/2} \quad \text{Equation 28}$$

$$\Sigma_z = (\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2)^{1/2} \quad \text{Equation 29}$$

Where:

$\Sigma_y, \Sigma_z$  Modified diffusion coefficients,  
 $\sigma_y, \sigma_z$  diffusion coefficients in specified direction (m),  
 $\Delta\sigma_{y1}, \Delta\sigma_{z1}$  low wind speed corrections, and  
 $\Delta\sigma_{y2}, \Delta\sigma_{z2}$  the building wake corrections.

These corrections used in Equation 11 and Equation 12 are described in ARCON96 user manual (Ramsdell and Simonen, 1997).

#### E.2.6.2 Diffusion Coefficients Adjustments for Design Basis Accident and Routine Release Analysis

The building wake model implementation for mid-field and far-field analyses are based on equations provided in NRC RG 1.145, and PAVAN and XODOQ user manuals. RG 1.145 recommends two classifications based on meteorological conditions: (i) neutral (class D) or stable (E, F, or G classes) or (ii) unstable (A, B, or C classes). The following three equations are simultaneously calculated for centerline relative concentrations:

$$\frac{\chi}{Q} = \frac{1}{U(\pi\sigma_y\sigma_z + C \cdot A)} \quad \text{Equation 30}$$

$$\frac{\chi}{Q} = \frac{1}{U(3\pi\sigma_y\sigma_z)} \quad \text{Equation 31}$$

$$\frac{\chi}{Q} = \frac{1}{U(\pi\Sigma_M\sigma_y\sigma_z)} \quad \text{Equation 32}$$

Where:

A minimum cross-sectional area of the building,  
C mixing volume coefficient in the building wake term (internally set to 0.5),

$\Sigma_{My}$  meander factor for lateral plume spread as a function of stability and wind speed.

The product of meander factor and horizontal diffusion coefficient ( $\sigma_y$ ) is adjusted as shown below:

$$\Sigma_{My}\sigma_y = \sigma_y + [\Sigma_{My} - 1]\sigma_{y,800m} \quad \text{Equation 33}$$

Where:

$\sigma_{y,800m}$  horizontal diffusion coefficient at 800 m distance for the particular stability class.

For determination of  $\Sigma_{My}$  and a complete discussion on plume meander, refer to Appendix A and Figure 3 of RG 1.145. For unstable conditions, the higher concentration between the results of Equations 13 and 14 is used and Equation 15 is not used. For neutral and stable conditions, the higher concentration between the results of Equations 13 and 14 is compared with the result from Equation 15 and the minimum is selected.

Simpkins (2007) compared the building wake calculations using equations and parameters from ARCON and RG1.145. This investigative study showed that the ARCON wake corrections generated much lower values compared to a Gaussian plume model simulation without any building (about 100 times lower) for F stability category. While RG1.145 method showed slightly lower than no-building simulations for F stability (less than a factor of 10).

The building wake corrections for sector average concentrations are based on RG 1.111 and applicable for long-term averages (>8 h) in DBA and routine analyses.

The vertical diffusion coefficient ( $\sigma_z$ ) in Equation 5 is modified by calculating the minimum value from the following equation:

$$\Sigma_z = \text{MIN} \left[ (\sigma_z^2 + C \cdot D^2 / \pi)^{1/2}, \sqrt{3}\sigma_z \right] \quad \text{Equation 34}$$

Where:

$\Sigma_z$  Modified diffusion coefficients,  
D the minimum adjacent building height either up- or downwind from the release point.

## E.3 Statistical Calculations

Although the consolidated ATD code calculates hourly normalized concentration and deposition values, regulatory guides require different statistical outputs for different model assessments. Post-processing generates statistics and output as required by the regulatory guides – RG 1.94 for control room analysis; RG 1.145 for DBAs; and RG 1.111 for routine analyses.

### E.3.1 Statistical Calculations for Control Room Analysis

For control room analyses,  $\chi/Q$  is computed for all calm hours and any non-missing hour when the wind is within the wind direction window i.e., direction to source  $\pm 45^\circ$ . For other times when the wind direction is outside of this window or not calm, the  $\chi/Q$  value for that hour is assigned as zero. The intention is to assess the frequency of  $\chi/Q$  at the receptor site (control room) during the entire period of meteorological data.

Time averaged values of relative concentrations are computed as running mean values of the hourly concentrations. Time averages are calculated for 1, 2, 4, 8, 12, 24, 96, 168, 360, and

720 h. For averaging time periods of  $\leq 8$  h in duration, the running average is calculated using the centerline concentrations.

$$\bar{\chi} = \frac{1}{N} \sum_{i=1}^N \left( \frac{\chi}{Q} \right) \bigg|_{i_{centerline}} \quad \text{Equation 35}$$

Where, N is 1, 2, 4, or 8 h for averaging period.

For periods longer than 8 h, time averages include both centerline and sector average concentrations.

$$\bar{\chi} = \frac{1}{N} \left[ \sum_{i=1}^8 \left( \frac{\chi}{Q} \right) \bigg|_{i_{centerline}} + \sum_{i=8}^N \left( \frac{\chi}{Q} \right) \bigg|_{i_{sector-average}} \right] \quad \text{Equation 36}$$

Where N is 12, 24, 96, 168, 360 or 720 h.

Cumulative frequency distributions are then computed for each averaging interval. The 95th percentile values and user provided customized percentile values (e.g., 99.5th) are then calculated from these frequency distributions. In addition to calculating percentile values for each averaging period, the algorithm determines the percentile values for standard averaging intervals: 0–2 h, 2–8 h, 8–24 h, 1–4 days, and 4–30 days. Average 95th relative concentrations for the 2–8 h period are calculated as:

$$\left( \frac{\chi}{Q} \right)_{95} \bigg|_{2 \text{ to } 8 \text{ hr}} = \frac{8 \times \left( \frac{\chi}{Q} \right)_{95} \big|_{0 \text{ to } 8 \text{ hr}} - 2 \times \left( \frac{\chi}{Q} \right)_{95} \big|_{0 \text{ to } 2 \text{ hr}}}{8 - 2} \quad \text{Equation 37}$$

Relative concentrations for the other standard time intervals are calculated in a similar manner.

Missing data are accounted by deleting hours with missing data from the calculation of the running average relative concentrations. Missing data tolerance criteria are used to determine when the number of hours with missing data make a specific average unacceptable. This tolerance criterion is a user input which is generally 0.1 (or 10 percent). Time averages are not calculated for periods in which the number of hours with missing data exceed the tolerance criteria.

### E.3.2 Statistical Calculations for Design Basis Accident Analysis

This algorithm calculates relative concentrations at two sets of distances, labeled EAB and LPZ. For both sets of boundaries, two different procedures are utilized for statistical calculations:

- Direction-dependent approach described in RG 1.145. Time averaged values and consequent exceedance values are calculated for each direction sector. For example, the relative concentration in each sector that is exceeded 0.5 percent of the total time is calculated which is similar to 99.5th percentile.
- Direction-independent approach described in Standard Review Plan (SRP) 2.3.4. In this procedure, the averages and exceedance values are computed for all 16 direction sectors.

The following averaging time periods are considered: 0–2 h (maximum of 1 h and 2 h), 0–8 h, 8–24 h (16 h), 1–4 days (72 h), 4–30 days (624 h), and annual average. Relative concentrations for short periods ( $\leq 8$  h) are calculated using centerline values and for longer periods ( $> 8$  h) are calculated using both center line and sector average values. Exceedance values of 0.5%, 5%, and 50% are calculated for both direction-dependent and direction-independent relative

concentrations. The calm hours are accounted during the entire modeling period for each direction sector to generate a conservative estimate for the direction-dependent approach. Annual average is calculated from the sum of all values in each wind direction sector and dividing the total simulation hours (i.e., total number of hours in meteorological data — number of hours with missing data). For direction-independent approach, the annual average is calculated from the sum of the simulated values for all 16 wind sectors.

### E.3.3 Statistical Calculations for Routine Analysis

For routine analysis, the algorithm calculates annual averaged relative concentrations ( $\chi/Q$ ) and deposition values ( $D/Q$ ) at user specified discrete locations, at 22 standard radial distances and 10 distance segments for 16 downwind sectors. Annual averages are computed from the hourly values. The algorithm internally sets 22 fixed distances between 0.25 and 50 mi from the site to compute values at the radial distances.

Additionally, average values bounded by the segment boundaries are computed from the values at these fixed distances. The following method is used to compute the average values for distance segments:

$$\overline{\chi/Q}_{seg}(K) = \frac{R_1 \times \overline{\chi/Q}(R_1, K) + r_1 \times \overline{\chi/Q}(r_1, K) + \dots + r_n \times \overline{\chi/Q}(r_n, K) + R_2 \times \overline{\chi/Q}(R_2, K)}{R_1 + r_1 + \dots + r_n + R_2} \quad \text{Equation 38}$$

Where:

- $\chi/Q_{seg}(K)$  average value for the segment for the directional sector K,
- $\chi/Q(R_1, K)$  value at downwind distance  $R_1$  for the directional sector K,
- $R_1, R_2$  downwind distance of the segment boundaries, and
- $R_1 \dots r_n$  selected radii between  $R_1$  and  $R_2$ .

For example, an average  $\chi/Q$  value for the segment 10–20 mi in the North sector represents an average value for any point north of the site between 10 and 20 mi north of the site.

The algorithm additionally calculates relative concentrations and deposition factors for user provided discrete receptor locations (e.g., cow, garden, site boundary). As mentioned earlier in the document, the routine analysis algorithm performs calculations for three decay and depletion scenarios – 1) no decay (101 days half-life) with no depletion 2) 2.26 days half-life with no depletion 3) 8 days half-life with depletion. The algorithm generates three sets of  $\chi/Q$  values for these three scenarios, and one set of relative deposition at 22 distances, 10 segment boundaries and receptor locations.

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