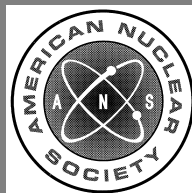


American Nuclear Society

**criteria for modeling and calculating
atmospheric dispersion of routine radiological
releases from nuclear facilities**

an American National Standard



**published by the
American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60526 USA**

**American National Standard
Criteria for Modeling and Calculating Atmospheric
Dispersion of Routine Radiological Releases
from Nuclear Facilities**

Secretariat
American Nuclear Society

Prepared by the
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Working Group ANS-2.15**

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Foreword

(This Foreword is not a part of American National Standard “Criteria for Modeling and Calculating Atmospheric Dispersion of Routine Radiological Releases from Nuclear Facilities,” ANSI/ANS-2.15-2013.)

Atmospheric dispersion modeling is the mathematical simulation of atmospheric processes involving the release, transport, diffusion, and fate of airborne pollutants. Computer programs and systems that implement atmospheric dispersion modeling have been in widespread use for decades. As a result, there are many common practices among model users. However, a national standard does not exist that provides criteria for model selection and use for different types of modeling applications (e.g., assessment of annual releases, accidental release events) or for different types of modeling domains (e.g., flat terrain, mountain/valley areas, water/land environments). Instead, atmospheric dispersion modeling practices are often based on a diverse set of regulatory guidance and other documents that date from the 1970s and 1980s.

Since the publication of these guidance documents, considerable advances have occurred in our understanding of the atmospheric processes that govern the transport, diffusion, and deposition of atmospheric pollutants. Dramatic improvements in computer technologies have resulted in the significant increase in computational processing speeds and information sharing capabilities of available models. Also, technological advances have occurred in the areas of meteorological monitoring, data collection, and data sharing that can greatly expand the capabilities of atmospheric dispersion models. As a result of these changes, atmospheric dispersion modeling selection and usage practices need to be updated to incorporate the scientific and technological enhancements, improve modeling results, and support greater consistency among model users.

Subject matter experts from the Nuclear Utilities Meteorological Data User’s Group, the U.S. Department of Energy’s Meteorological Coordinating Council, and other organizations began working together in 2004 to define and standardize practices that can be used to address the atmospheric dispersion modeling of radiological releases from nuclear facilities. The working group decided that several standards were needed, based on end-use considerations:

- ANS-2.15, addressing atmospheric dispersion modeling of routine releases;
- ANS-2.16, addressing atmospheric dispersion modeling of design-basis accidents;
- ANS-3.8.10, addressing atmospheric dispersion modeling of accidental releases for emergency response.

This document, on the modeling of routine releases, is the first of these dispersion modeling standards. The working group decided to create all three standards in sequence to take advantage of their similarities, to achieve consistency among the standards, and to incorporate the lessons learned from one in preparing the next.

This standard might reference documents and other standards that have been superseded or withdrawn at the time the standard is applied. A statement has been included in the references section that provides guidance on the use of references.

This standard does not incorporate the concepts of generating risk-informed insights, performance-based requirements, or a graded approach to quality assurance. The user is advised that one or more of these techniques could enhance the application of this standard.

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Criteria for Modeling and Calculating Atmospheric Dispersion of Routine Radiological Releases from Nuclear Facilities

1 Introduction and scope

In the decades prior to this standard, significant enhancements have been made in the area of atmospheric dispersion modeling. Considerable advances have occurred in our understanding of atmospheric processes that play a key role in the transport, dispersion, and deposition of atmospheric contaminants. In addition, dramatic advances in computer technologies have resulted in a significant increase in computational processing speeds and capabilities. Calculations that would have taken days or weeks of computation resources on a mainframe computer can now be completed in minutes on an inexpensive personal computer. Graphical displays of information that required hand drawing by graphics specialists are now available through the use of geographical information system (GIS) software.

In addition to the advances in modeling, technological advances have occurred in the areas of meteorological monitoring and data sharing. New digital instrumentation allows for the measurement of atmospheric parameters that were not previously measurable on a routine and widespread basis (e.g., direct measurements of turbulence). Remote monitoring, satellite measurements, and numerical modeling of meteorological parameters provide new suites of data for atmospheric dispersion modeling. More data are available in real time or close to real time from meteorological monitoring stations that were not accessible in the past. Radiotelemetry, cellular networks, and the Internet provide routine access to new sources of data.

The purpose of this document is thus to establish criteria for evaluating the atmospheric effects of routine radioactive releases at or beyond the facility site boundary. The criteria incorpo-

rate the numerous advances in technical capabilities, computer technology, data access, and information sharing.

This document begins by describing a common modeling process that explicitly defines requirements and quality assurance (QA) elements and then examines the need for more complex, variable-trajectory modeling. Ensuing document sections contain criteria for the selection of dispersion model types, relevant timescales, release modes, and removal mechanisms. The remaining sections contain criteria for geospatial data, meteorological data, meteorological networks, and finally QA. Several appendices provide additional information to help the reader choose modeling parameters.

2 Acronyms and definitions

2.1 List of acronyms¹⁾

BPIPPRM: Building Profile Input Program for PRIME

DEM: Digital Elevation Model

EPA: U.S. Environmental Protection Agency

GEP: Good Engineering Practice

GIS: geographical information system

MCF: model correction factor

NRC: U.S. Nuclear Regulatory Commission

NWS: National Weather Service

PG: Pasquill-Gifford

QA: quality assurance

¹⁾ This listing of acronyms applies to the standard and to the appendices.

RF: recirculation factor

RG: Regulatory Guide

SRDT: solar radiation and delta temperature

USGS: U.S. Geological Survey

2.2 Definitions

area source: A two-dimensional array of pollutant sources so widely dispersed and uniform in strength that they can be treated in a dispersion model as an aggregate pollutant release from a defined area at a uniform rate.

complex flow: A nonuniform atmospheric flow field.

complex terrain: Variations in terrain elevation within the study region that generate flow features that significantly influence the transport and diffusion of pollutants in the air.

diagnostic models: Models that map multiple observations taken all at the same time onto a field that spans the geographical location of the observations. Diagnostic models are not able to forecast conditions into the future except by persistence.

diffusion: The spreading of gaseous and/or particulate matter caused by turbulent motions in the atmosphere [1].²⁾

dispersion: The sum of the processes of transport and diffusion.

domain: The geographical region of interest for a modeling study.

Eulerian method: A method of studying atmospheric motions in which one considers volume elements at fixed locations in space across which material flows [2].

Gaussian plume model: An atmospheric dispersion model where the effluent is assumed to have a Gaussian mass distribution vertically and horizontally across the plume centerline.

Lagrangian method: A method of studying atmospheric motions in which one considers

volume elements that are carried along within the atmosphere and across whose boundaries material does not flow [2].

land-water circulation: Coastal winds that flow from land to large bodies of water and vice-versa caused by differential heating of the two areas.

line source: A one-dimensional source of emissions that is defined by its length. Line sources are often used to model emissions from roadways and railroads. Alternatively, an array of pollutant sources along a defined path that can be treated in dispersion models as an aggregate uniform release of pollutants along a line.

meteorological network: A collection of meteorological observations from multiple sites and sources.

mixing depth: The vertical distance between the ground and the altitude to which pollutants are mixed by turbulence caused by convective currents, vertical shear in the horizontal wind, or mechanical mixing.

mountain-valley circulation: Diurnal winds that form in a complex terrain area, consisting of mountain-plain, along-valley, cross-valley, and slope wind systems. Differential heating and cooling of the terrain causes the pressure gradients that create the flow fields.

plume meander: Plume spreading from the centerline due to large low-frequency oscillations of the horizontal wind direction.

point source: A single, identifiable, stationary source of emission that can be elevated or ground level. A point source has no geometric dimension and is often used to represent the geographic location of a plume's origin.

prognostic models: Models that explicitly forecast conditions into the future based on an initial state and time-dependent equations of motion.

real-time measurements: Observations that are available on the order of a reading's averaging time.

²⁾ Numbers in brackets refer to corresponding numbers in Sec. 12, "References."

recirculation: Plume movement by vertical or horizontal eddies where material follows a curved path through the atmosphere back to regions previously impacted.

routine releases: Releases of pollutants that occur as part of normal facility operation and are not associated with unplanned events.

shall, should, and may: The word “shall” is used to denote a requirement; the word “should” is used to denote a recommendation; and the word “may” is used to denote permission, neither a requirement nor a recommendation.

simple terrain: Any site where terrain effects on meteorological measurements are nonsignificant.

sodar: A wind profiling system that employs sound to probe the atmosphere.

stability: A measure of the degree of resistance of a layer of air to vertical motion. It is used to define the amount of turbulent mixing in the atmosphere, which directly influences atmospheric dispersion.

stagnation: An atmospheric condition that suppresses the dispersion of airborne material.

transport: The movement of gaseous and/or particulate matter through the atmosphere.

turbulence: Atmospheric motions in which local velocities and pressures fluctuate irregularly, in a random manner, to form swirling eddies that can cause rapid mixing [2].

variable-trajectory model: An atmospheric dispersion model where plumes follow complex flow fields usually in three or four dimensions.

volume source: The initial configuration of a plume or puff of material within a dispersion model that represents a three-dimensional volume.

3 The modeling process

When modeling the airborne impacts from routine releases of radiological material, the process depicted in Fig. 1—which explicitly considers requirements, QA practices, and the potential for complex flow effects—shall be followed.

Requirements bound the scope of the modeling project and provide a metric for determining

successful completion. Quality assurance processes reduce errors in the course of the modeling effort. Complex atmospheric effects, such as recirculation and stagnation, can significantly increase the consequences from routine airborne releases of radiological material (see Appendix A). Therefore, if consequences from a straight-line Gaussian model are >10% of regulatory limits and the site resides in a domain that experiences complex flow >15% of the year, the complex effects shall be explicitly treated using variable-trajectory models.

Sections 3.1 through 3.12 contain instructions for navigating the flowchart contained in Fig. 1.

3.1 Step 1: Determine requirements.

The first step in any modeling project is to specify requirements for the project. Requirements shall be written and shall include clearly achievable actions that can be objectively tested at the end of the project to demonstrate successful completion of work. Requirements shall be uniquely identified and tracked throughout the modeling process to allow for verification of completion. Requirements may come from outside regulatory agencies or from internal sources.

At a minimum, the following shall be included when specifying requirements:

- regulatory agencies governing atmospheric modeling studies for the site;
- applicable regulatory limits associated with the modeling process;
- model selection requirements (see Sec. 3.12);
- timescale requirements (see Sec. 5);
- release mode requirements (see Sec. 6);
- removal mechanism requirements (see Sec. 7);
- input data requirements (see Secs. 8, 9, and 10);
- definition of the modeling domain to be studied;
- modeling objectives;
- QA requirements (see Sec. 11).

3.2 Step 2: Determine QA components.

A formal QA program shall be incorporated as part of the modeling process. Since not all components of a QA program are relevant to all processes, the components that are relevant to

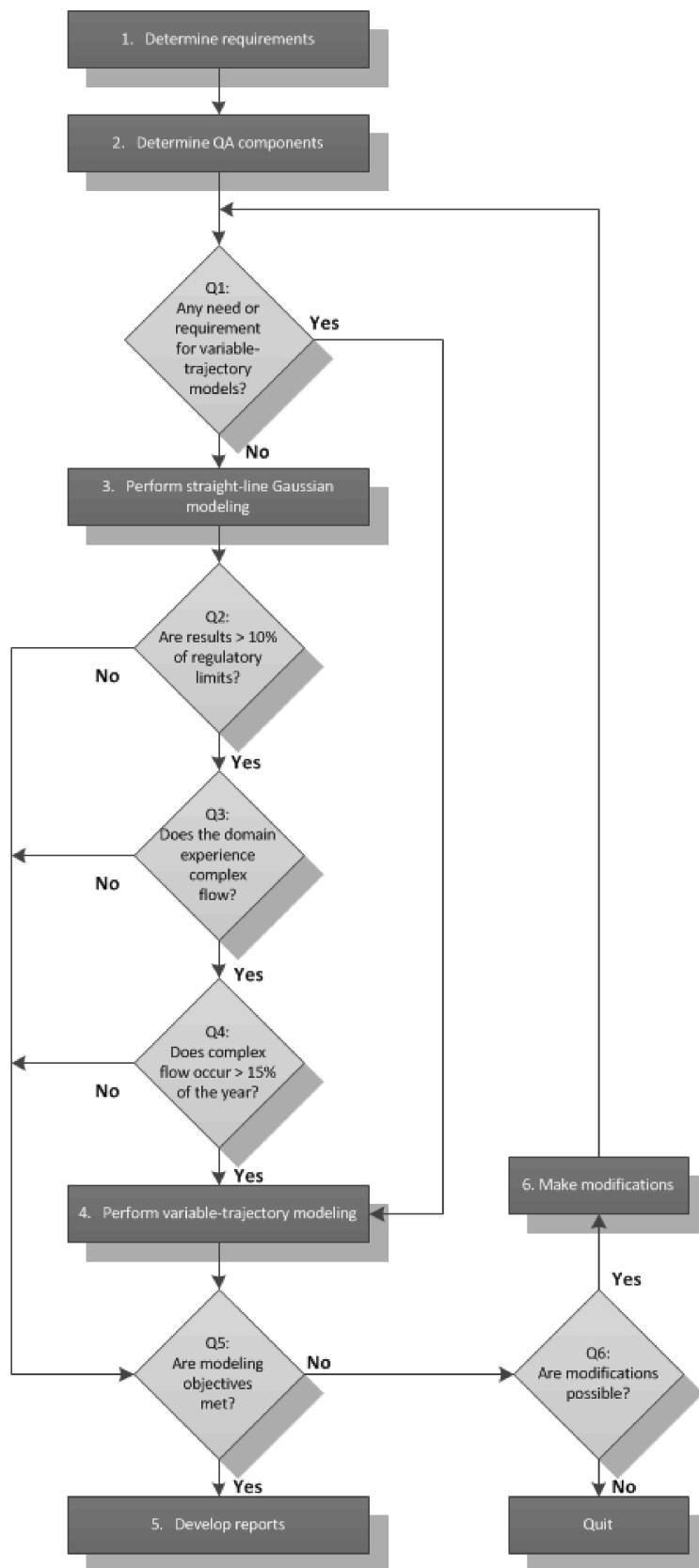


Figure 1 – Modeling process for routine releases of radiological material

the modeling process shall be explicitly identified. The QA components that are determined to be relevant shall be completed. Section 11 provides more instructions on QA.

3.3 Question 1: Any need or requirement for variable-trajectory models?

If project requirements specify use of variable-trajectory models, the user shall proceed to step 4 (Sec. 3.8).

3.4 Step 3: Perform straight-line Gaussian modeling.

If there are no explicit requirements to use variable-trajectory models from step 1 (Sec. 3.1), then a straight-line Gaussian model may be used to assess routine releases. However, at the completion of the modeling effort, it shall be determined if use of more complex variable-trajectory models is required by proceeding through the flowchart depicted in Fig. 1, which considers the severity of projected impacts and the existence and frequency of complex flow within the region. Straight-line Gaussian models shall incorporate the effects of radiological decay and deposition, since these processes are important when comparing modeling results against regulatory limits.

3.5 Question 2: Are results >10% of regulatory limits?

Results of straight-line Gaussian model output shall be compared to applicable regulatory limits defined in step 1 (Sec. 3.1). If results of the straight-line Gaussian modeling process in step 3 (Sec. 3.4) produce off-site impacts that are >10% of regulatory limits, it shall be determined if complex flow occurs within that domain by proceeding to question 3 (Sec. 3.6). If off-site modeling results do not exceed 10% of regulatory limits, the next question to answer should be question 5 (Sec. 3.9).

3.6 Question 3: Does the domain experience complex flow?

If output from straight-line Gaussian models is >10% of regulatory limits off-site, then the presence of complex flow within the domain shall be determined by one of two acceptable ways:

(1) *Documented flow*: A meteorologist or other individual with equivalent knowledge of re-

gional flow features should identify complex flow regimes within the domain;

(2) *Topographical features*: It should be determined if the domain is subject to complex flow based on the existence of any of the following topographical features within the domain:

(a) *Large bodies of water*: If the modeling domain contains any portion of a body of water with a surface area >500 km², the domain is subject to complex flow (see Appendix A),

(b) *Mountains*: If the domain contains a mountain or mountain range, the domain is subject to complex flow. Mountains <150 m (493 ft) tall (relative to the domain) need not be considered unless they are within 2 km (1.2 miles) of the release location,

(c) *Valleys*: If the domain is within a valley, it is subject to complex flow. Shallow valleys <50 m (<164 ft) deep (relative to the domain) that do not have steep side walls are not typically considered to have the potential for complex flow.

The rationale behind the determination shall be documented. If the domain does experience complex flow, the frequency of complex flow shall be determined with question 4 (Sec. 3.7). Otherwise, completion of modeling objectives should be determined with question 5 (Sec. 3.9).

3.7 Question 4: Does complex flow occur >15% of the year?

If the answers to questions 2 and 3 are “yes” and the domain experiences complex flow >15% of a year, then variable-trajectory modeling shall be performed in step 4 (Sec. 3.8).

To determine if complex flow occurs more frequently than 15% of the year, the complex flow features should first be identified, and then a way to quantify the frequency of occurrence of those features should be determined and carried out. The recirculation and stagnation potential mechanism defined by Allwine and Whiteman [3] is acceptable for determining the frequency of occurrence of complex flow. Regardless of the method used, the frequency of complex flow shall be determined and documented.

3.8 Step 4: Perform variable-trajectory modeling.

To perform variable-trajectory modeling, a variable-trajectory model shall be employed. Sections 4 through 10 contain instructions on the use of such models, including considerations for varying terrain, land cover, and meteorological data sources.

3.9 Question 5: Are modeling objectives met?

When all modeling activities have been completed, a determination shall be made as to whether the objectives defined in step 1 (Sec. 3.1) have been achieved. If modeling objectives have not been met, the process shall proceed to question 6 (Sec. 3.10). If modeling objectives have been met, the modeling study shall be completed by going to step 5 (Sec. 3.11).

3.10 Question 6: Are modifications possible?

If any of the following can be modified in such a way that the modeling objectives can be met, then the modeling study shall proceed to step 6:

- modeling objectives;
- input data;
- requirements;
- modeling components;
- domain.

The modifications shall be defensible within the scientific community, shall not conflict with requirements stated within this standard, and shall be fully documented.

3.11 Step 5: Develop reports.

The final step in the modeling process is to develop all required reports. In this step, documentation of all work performed in the modeling process shall be assembled, including the rationale behind all decisions, relevant input data used, and resulting output data.

3.12 Step 6: Make modifications.

In this step, any modifications identified in question 6 (Sec. 3.10) that will alter the modeling results and still meet the modeling objectives and requirements shall be implemented. All changes shall be fully documented, including the reasons for making the modifications. After performing the modifications and docu-

menting the changes, the modeling study shall proceed back to question 1 (Sec. 3.3).

4 Models

Atmospheric dispersion modeling is the mathematical simulation of how air pollutants disperse in the atmosphere. It is typically performed with computer programs that solve the mathematical equations and algorithms that simulate the pollutant dispersion. Dispersion models require the input of data including the following:

- meteorological conditions such as wind speed and direction, the amount of atmospheric turbulence (or stability class), the ambient air temperature, and the height to the bottom of any inversion aloft that may be present;
- source configuration parameters such as source location and height, source vent stack diameter and exit velocity, exit temperature, and mass flow rate;
- terrain elevations at the source location, at receptor locations, and within the domain;
- the location, height, and width of obstructions (such as buildings or other structures) in the path of the emitted plume.

Dispersion models shall be configured to include the effects of relevant atmospheric phenomena defined by the project requirements (see step 1, Sec. 3.1). Specific phenomena may include plume rise, plume meandering, fumigation, stack downwash, building wakes, calms, radioactive decay, wet and dry deposition, resuspension, molecular weight differences, surface roughness, land-water circulations, and complex terrain.

Numerous dispersion models have been developed over the years to calculate atmospheric transport, diffusion, and deposition. Several different approaches may be used to support assessments of the potential environmental and human health impacts of routine releases of radiological material using these models. The appropriate model and modeling assumptions to use for a particular application often are dictated by the characteristics and requirements of the assessment. Among these key items are the following:

- the length of time that needs to be modeled;
- the amount of meteorological data available to support the assessment;