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USE OF ARCON METHODOLOGY FOR CALCULATION OF ACCIDENT-RELATED OFFSITE ATMOSPHERIC DISPERSION FACTORS

A. INTRODUCTION

Purpose

This regulatory guide (RG) describes an approach that is acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) to meet the NRC requirements for determining atmospheric relative concentration (χ/Q) values in support of modeling onsite releases to offsite boundaries from a design-basis accident (DBA). This guidance provides procedures for using the ARCON code to estimate χ/Qs at the exclusion area boundary (EAB) and the outer boundary of the low-population zone (LPZ) out to distances of 1,200 meters (m) (3,937 feet (ft)) from the nearest edge of a building within the powerblock area (PBA).

Additionally, this guidance implements the methodology in RG 1.194, "Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants" (Ref. 1) for offsite dose locations at boundaries out to distances of 1200 meters (m) (3,937 ft). Also, this RG provides new guidance on plausible alternate meteorological monitoring approaches.

Applicability

This RG applies to reactor applicants and licensees subject to Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities" (Ref. 2); 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 3); and 10 CFR Part 100, "Reactor Site Criteria" (Ref. 4). The relevance of this guidance will likely be applicable to plants with limited distances associated with the EAB and LPZ boundaries.

Applicable Regulations

The NRC regulations related to siting and licensing of stationary nuclear power facilities require

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This RG is being issued in draft form to involve the public in the development of regulatory guidance in this area. It has not received final staff review or approval and does not represent an NRC final staff position. Public comments are being solicited on this DG and its associated regulatory analysis. Comments should be accompanied by appropriate supporting data. Comments may be submitted through the Federal rulemaking Web site, http://www.regulations.gov, by searching for draft regulatory guide DG-4030. Alternatively, comments may be submitted to the Office of Administration, Mailstop: TWFN 7A-06M, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, ATTN: Program Management, Announcements and Editing Staff. Comments must be submitted by the date indicated in the *Federal Register* notice.

Electronic copies of this DG, previous versions of DGs, and other recently issued guides are available through the NRC's public Web site under the Regulatory Guides document collection of the NRC Library at https://nrcweb.nrc.gov/reading-rm/doc-collections/reg-guides/. The DG is also available through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html, under Accession No. ML21165A005. The regulatory analysis may be found in ADAMS under Accession No. ML21165A007.

that applicants provide an analysis and evaluation of the facility's siting and the design and performance of structures, systems, and components (SSCs) of the facility with the objective of assessing the risk to public health and safety resulting from facility operation. These regulations are the following:

- 10 CFR Part 50 provides regulations for licensing production and utilization facilities.
  - 10 CFR 50.34(a)(1)(ii)(D) requires an applicant for a construction permit to include a safety assessment of the site, including consideration of major SSCs of the facility and site meteorology, to evaluate the offsite radiological consequences at the EAB and LPZ.
  - 10 CFR 50.34(b)(11)(ii) requires an applicant for an operating license for a stationary power reactor to include a safety assessment of the site as in 10 CFR 50.34(a)(1)(ii).
- 10 CFR Part 52 governs the issuance of early site permits, standard design certifications, combined licenses, standard design approvals, and manufacturing licenses for nuclear power facilities.
  - 10 CFR 52.17, "Contents of applications; technical information," for early site permit applications, requires a safety assessment of the site, including consideration of major SSCs of the facility and site meteorology, to evaluate the offsite radiological consequences at the EAB and LPZ.
  - 10 CFR 52.47, "Contents of applications; technical information," for design certification applications, requires an assessment of the plant design features intended to mitigate the radiological consequences of accidents, which includes consideration of postulated site parameters such as site meteorology, to evaluate the offsite radiological consequences at the EAB and LPZ.
  - 10 CFR 52.79, "Contents of applications; technical information in final safety analysis report," for combined license applications, requires a safety assessment of the site, including consideration of major SSCs of the facility and site meteorology, to evaluate the offsite radiological consequences at the EAB and LPZ.
  - 10 CFR 52.137, "Contents of applications; technical information," for standard design approval applications, requires a safety assessment of the site, including consideration of major SSCs of the facility and site meteorology, to evaluate the offsite radiological consequences at the EAB and LPZ.
  - 10 CFR 52.157, "Contents of applications; technical information in final safety analysis report," for manufacturing license applications, requires a safety assessment of the site, including consideration of major SSCs of the facility and site meteorology, to evaluate the offsite radiological consequences at the EAB and LPZ.
- 10 CFR Part 100 establishes approval requirements for proposed sites for stationary power and testing reactors subject to 10 CFR Part 50 and 10 CFR Part 52.
  - 10 CFR 100.21, "Non-seismic siting criteria," includes siting requirements related to the atmospheric dispersion characteristics used in the evaluation of EAB and LPZ radiological dose consequences for postulated accidents.

Related Guidance

- NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (Ref. 5), presents criteria that could affect the safe design and siting of the plant.
    - Section 2.3.3, "Onsite Meteorological Measurements Program," discusses the meteorological data to be used for atmospheric dispersion assessments.
    - Section 2.3.4, "Short-Term Atmospheric Dispersion Estimates for Accident Releases," discusses the characteristics that could affect the safe design and siting of a plant.
- RG 1.23, "Meteorological Monitoring Programs for Nuclear Power Plants" (Ref. 6), presents criteria for an acceptable onsite meteorological monitoring program and the resulting meteorological database that may be used as input to the atmospheric dispersion estimates.
- RG 1.194 is an acceptable method to meet the regulations concerning the determination of atmospheric relative concentration (χ/Q) values in support of design-basis control room habitability assessments at nuclear power plants.
- RG 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants" (Ref. 7), presents criteria for characterizing atmospheric dispersion conditions for evaluating the consequences of radiological releases to the EAB and LPZ.

Purpose of Regulatory Guides

The NRC issues RGs to describe methods that are acceptable to the staff for implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific issues or postulated events, and to describe information that the staff needs in its review of applications for permits and licenses. RGs are not NRC regulations and compliance with them is not required. Methods and solutions that differ from those set forth in RGs are acceptable if supported by a basis for the issuance or continuance of a permit or license by the Commission.

Paperwork Reduction Act

This RG provides voluntary guidance for implementing the mandatory information collections in 10 CFR Parts 50, 52, and 100 that are subject to the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et. seq.). These information collections were approved by the Office of Management and Budget (OMB), approval numbers 3150-0011, 3150-0151, and 3150-0093, respectively. Send comments regarding this information collection to the FOIA, Library, and Information Collections Branch (T6-A10M), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by e-mail to Infocollects.Resource@nrc.gov, and to the OMB reviewer at: OMB Office of Information and Regulatory Affairs (3150-0011, 3150-0151, 3150-0093), Attn: Desk Officer for the Nuclear Regulatory Commission, 725 17th Street, NW Washington, DC 20503; e-mail: oira_submission@omb.eop.gov.

Public Protection Notification

The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless the document requesting or requiring the collection displays a currently valid OMB control number.

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B. DISCUSSION

Reason for Issuance

This RG provides guidance to industry for complying with and implementing the NRC requirements by endorsing the use of the ARCON computer code (as referenced in RG 1.194 and NUREG/CR-6331) to calculate offsite dispersion values at the EAB and LPZ out to distances of 1,200 m (3,937 ft). ARCON refers to both the ARCON96 and ARCON 2.0 versions of the code. For consistency across versions of the code, and because the updated ARCON 2.0 version only updated the user interface and not the underlying dispersion algorithms, this RG will refer to the code simply as ARCON when the discussion is applicable to either version.

RG 1.194 also endorses the use of the ARCON96 computer code however, it is intended for calculating accident-related onsite (control room and technical support center (TSC)) atmospheric dispersion values, which are direct inputs to habitability dose assessments. In addition, RG 1.145 describes the present methodology incorporated into the PAVAN computer code (Ref. 8), as reviewed by the staff using NUREG-0800, Section 2.3.4, for calculating accident-related, offsite atmospheric dispersion values.

Background

NRC RGs provide approaches that the staff considers acceptable for meeting the regulatory requirements addressed by the specific guide. At the same time, an applicant has the flexibility to propose alternate approaches to the guidance so long as it demonstrates that the applicable regulatory requirements are still met. The PAVAN code has been approved for calculating offsite χ/Q values at the EAB and outer boundary of the LPZ. ARCON96 has been previously approved for calculating onsite χ/Q values to support control room and technical support center habitability dose assessments.

Some of the regulatory positions in this RG represent procedures acceptable to the staff beyond those previously found acceptable to determine χ/Q values. The NRC recently updated the ARCON96 user interface to improve its functionality on modern personal computers and renamed the latest version of the code as ARCON 2.0. As described in RG 1.194, the ARCON96 code uses an improved building wake dispersion algorithm; assessment of ground-level, elevated, and diffuse source release modes; hour-by-hour meteorological observations; sector averaging; and directional dependence of dispersion conditions. ARCON was initially developed and has historically only been used for determining onsite χ/Q values at air intakes and points of ingress and egress to the control room and technical support center.

In the mid-1980s, the NRC staff determined that its DBA atmospheric dispersion modeling guidance, which included RG 1.145 and PAVAN, significantly overpredicted concentrations during light winds in the vicinity of buildings and embarked on a series of studies that ultimately resulted in the ARCON96 model. The ARCON model is based on field measurements taken at seven reactor sites. The downwind distances of the field measurements ranged from locations on and adjacent to buildings out to distances of 1,200 m (3937 ft). The results were a set of revised diffusion coefficients that had low wind speed and building wake corrections. The resulting dispersion algorithms improved model performance by reducing overpredictions without significantly increasing underpredictions. The staff subsequently endorsed, in large part, ARCON96 in RG 1.194 as a method for determining atmospheric relative concentrations in support of design-basis radiological habitability assessments for the control room

Both the ARCON96 and ARCON 2.0 versions of the model calculate χ/Q values using hourly meteorological data. The hourly χ/Q values are then combined to estimate relative concentration averages for periods ranging from 2 hours to 30 days. With the default averaging periods, the χ/Q values for 1, 2, 4, and 8 hours are centerline values. Average χ/Q values for periods longer than 8 hours consist of centerline χ/Q values for the first 8 hours and sector-average χ/Q values for the remainder of the period. For example, each 24-hour average χ/Q is made up of an average of 8 one-hour centerline χ/Q values followed by 16 one-hour sector-average χ/Q values. This is consistent with NRC guidance on the use of centerline and sector-average χ/Q values found in Regulatory Guides 1.111 and 1.145. Because wind direction is considered as the averages are formed, the averages account for persistence in both diffusion conditions and wind direction. Cumulative frequency distributions are prepared from the average relative concentrations, and relative concentrations that are exceeded no more than 5 percent of the time (95th-percentile concentrations) are determined for the cumulative frequency distributions for each averaging period.

As described in RG 1.194, the ARCON96 code implements an improved building wake dispersion algorithm; assessment of ground-level, elevated, and diffuse source release modes; use of hour-by-hour meteorological observations; sector averaging; and directional dependence of dispersion conditions. This guidance provides procedures for using the ARCON code to estimate χ/Q values out to distances of 1200-meters (m) from the PBA, which could include the EAB and the outer boundary of the LPZ.

Large light-water nuclear power plants typically have EAB and LPZ distances that range from 800 to 6,000 m (2,625 to 19,685 ft), whereas expected small modular reactor and advanced reactor designs are postulated to include EAB and LPZ distances in the range of 80 to 400 m (262.5 to 1,312.3 ft). The NRC has determined that the ARCON computer code, which was developed to model shorter distances in the vicinity of buildings typical of control room habitability dose evaluations, is acceptable for modeling EAB and LPZ χ/Q values at relatively short distances. The ARCON dispersion algorithms are based on field measurements taken out to distances of 1,200 m (3,937 ft) (Ramsdell et. al, 1998) (Ref. 10). Therefore, this guidance is applicable to EAB and LPZ distances from the PBA to a distance of 1,200 m (3,937 ft).

Consideration of International Standards

The International Atomic Energy Agency (IAEA) works with member states and other partners to promote the safe, secure, and peaceful use of nuclear technologies. The IAEA develops Safety Requirements and Safety Guides for protecting people and the environment from harmful effects of ionizing radiation. This system of safety fundamentals, safety requirements, safety guides, and other relevant reports reflects an international perspective on what constitutes a high level of safety. To inform its development of this RG, the NRC considered IAEA Safety Requirements and Safety Guides pursuant to the Commission's "International Policy Statement," published in the *Federal Register* on July 10, 2014 (Ref. 11), and Management Directive and Handbook 6.6, "Regulatory Guides," dated May 2, 2016 (Ref. 12). The NRC staff did not identify any IAEA Safety Requirements or Guides with information related to the topic of this RG.

C. STAFF REGULATORY GUIDANCE

1. General Considerations

ARCON96, as described in NUREG/CR-6331, "Atmospheric Relative Concentrations in Building Wakes," Revision 1, issued May 1997 (Ref. 13), and ARCON 2.0 that was recently updated by the NRC, provide an acceptable methodology for calculating offsite atmospheric dispersion factors (χ/Q values), subject to the positions in this guide.

ARCON χ/Q values are generally determined for each of the following averaging periods: 0–8 hours (or 0–2 hours and 2–8 hours), 8–24 hours, 24–96 hours, and 96–720 hours. The period of the most adverse release of radioactive materials to the environment should be assumed to occur coincident with the period of most unfavorable atmospheric dispersion. If the 0–2-hour χ/Q is calculated, this value should be used coincident with the limiting portion of the release to the environment. The 2–8-hour χ/Q value is used for the remaining 6 hours of the first 8-hour time period. Part of this 6-hour interval may occur before or after the limiting 2-hour period. The 8–24, 24–96, and 96–720-hour χ/Q values should similarly be used for the remainder of the release duration. Applicants and licensees for certain designs, or the siting of such units that may have different release characteristics, such that averaging periods other than the standard intervals apply, should identify those intervals and may have to modify their use of the ARCON model further. These modifications should be documented and submitted to the NRC as part of the applicant's licensing action.

2. Calculation of χ/Q Using ARCON

This section addresses the use of the ARCON code for calculating χ/Q values for offsite atmospheric dispersion at receptors located at the EAB and LPZ. The ARCON code should be obtained and maintained under an appropriate software quality assurance program that complies with the applicable criteria of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 and applicable industry consensus standards to which the licensee has committed. Certain locations are affected by atmospheric transport and diffusion conditions that may be more restrictive than assumed in the contiguous 48 states, including effects caused by variations in the duration of daylight and darkness (e.g., limited inversion depths, extended persistence of various conditions). If a given design may be deployed in locations characterized by extreme and persistent restrictive dispersion conditions (e.g., in Alaska) the applicability of the dispersion algorithms in ARCON may not apply or may require further modification.

2.1 Meteorological Data Input

This section addresses the meteorological data used as input to ARCON for dispersion estimates to the EAB and LPZ. Meteorological data are input into ARCON using meteorological data files. Appendix A to RG 1.194 provides information on the structure and content of the meteorological data set and input parameters used by the ARCON code. If meteorological data are not needed to support dispersion modeling but only to develop summaries (potentially for design certification, standard design approval, and manufacturing license applications), then an applicant may consider it unnecessary to establish an onsite monitoring program. NUREG-0800 affords an applicant some flexibility in the approach used for meteorological monitoring (i.e., alternative approaches may be used if an applicant provides sufficient justification for doing so and the relevant requirements in the applicable regulations are met).

2.1.1. Onsite Meteorological Data

The meteorological data needed for χ/Q calculations using ARCON or PAVAN include wind speed, wind direction, and a measure of atmospheric stability. For construction permit, operating license, early site permit, and combined license applications, these data should be obtained from an onsite meteorological measurement program based on the guidance of RG 1.23. The meteorological data set used in these assessments should represent hourly averages as defined in RG 1.23. Data should be representative of the overall site conditions and be free from local effects such as building and cooling tower wakes, brush and vegetation, or terrain. Collected data should be reviewed on a regular basis to identify instrumentation problems and missing or anomalous observations, and the data should meet the 90-percent recovery criterion for individual and composite parameters. The size of the data set used in the χ/Q assessments should be sufficiently large such that it is representative of long-term meteorological trends at the site. The minimum amount of onsite meteorological data to be provided at the time of application (1) for a construction permit is a representative consecutive 12-month period, (2) for an operating license is a representative consecutive 24-month period, including the most recent 1-year period, and (3) for an early site permit or a combined license that does not reference an early site permit is a consecutive 24-month period of data that is defendable, representative, and complete, but not older than 10 years from the date of the application. However, three or more years of data are preferable and, if available, should be submitted with the application.

Wind direction should be expressed as the direction from which the wind is blowing (i.e., the upwind direction from the center of the site) referenced to true north.

Atmospheric stability should be determined by the vertical temperature difference (ΔT) measured over the difference in height appropriate for the projected release height, including plume rise as applicable. RG 1.23 gives a table of ΔT values in units of degrees Celsius per 100 meters (°C/100m) versus stability class. If other well-documented methodologies are used to estimate atmospheric stability with appropriate justification, the ARCON model referred to in this RG may require modification. A well-documented methodology is one that is substantiated by diffusion data for conditions similar to those at the nuclear power plant site or design involved.

2.1.2 Alternative Meteorological Data

This section of the RG presents examples of plausible alternate meteorological monitoring approaches for use with ARCON that have not been previously provided in recent NRC guidance.

Offsite (in lieu of, or in addition to, onsite) meteorological data may be acquired by an applicant from one or more measurement locations. These may include data obtained from National Weather Service (NWS) stations, Federal Aviation Administration stations, U.S. Environmental Protection Agency (EPA)-endorsed measurement programs, other sources such as at U.S. Department of Defense or U.S. Department of Energy facilities, or from other non-NWS or non-EPA-endorsed measurement programs. If these data are not able to be directly input to ARCON, then additional processing, and additional justification, by an applicant will be necessary before the data can be used.

Some technical issues that might be associated with a given data source are listed below. These are not intended to be an all-inclusive list. Additional issues may be identified by an applicant or the NRC staff during pre-application meetings, subsequent agency review of any application submittals, or project execution. Use of alternative meteorological data should include the following technical details, as applicable:

a. identification and rationale for the selection of each offsite meteorological monitoring location to be used (including station name and type and, for applications where a proposed site is known, the distance and direction of the station from the site, as well as differences in ground elevation at the site and each station);

b. how a modeling analysis will be performed if meteorological data from more than one offsite or onsite station will be used;

c. listing of pertinent measurements made at each offsite location and associated information (e.g., details pertaining to tower siting, tower and measurement heights, instrument types and performance specifications, instrument exposure, sampling frequency and recording of output, data reduction and processing, data averaging (if applicable) and methods, instrument and system surveillance frequency, and other quality assurance activities);

d. guidance followed in conducting the offsite monitoring program(s), for example:

    (1) RG 1.23

    (2) American National Standards Institute (ANSI)/American Nuclear Society (ANS) ANSI/ANS-3.11-2015, "Determining Meteorological Information at Nuclear Facilities" (Ref. 14)

    (3) EPA-454/R-99-005, "Meteorological Monitoring Guidance for Regulatory Modeling Applications," issued February 2000 (Ref. 15)

    (4) EPA-454/B-08-002, "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements," Version 2.0, issued March 2008 (Ref. 16)

    (5) Interagency Council for Advancing Meteorological Services, Federal Meteorological Handbook(s) (Ref. 17)

e. identification and explanation of any departures between the meteorological monitoring guidance used at each offsite location and the monitoring guidance in RG 1.23 with regard to data quality in general and to potential implications of the dispersion modeling in particular;

f. representativeness of the offsite meteorological measurements with respect to the characteristics of the potential accident releases;

g. representativeness of the offsite meteorological data to conditions at a given site; and

h. for each monitoring location, the period of record to be used and the annual data recoveries for individual model input parameters, as well as the composite recovery of wind speed, wind direction, and atmospheric stability class by year and for the period of record.

The values and assumptions associated with the technical issues listed above may be affected for a reactor design deployed in areas with persistent limited atmospheric transport and diffusion conditions. Meteorological monitoring programs that support the modeling analyses, using data acquired either through an alternate approach or a conventional onsite monitoring program, may also be affected by deployment in such areas. These issues include, but may not be limited to, the following:

a. applicability of the dispersion algorithms (curves or values, or both) in ARCON;

b. characteristics of accident releases (e.g., buoyancy, momentum) depending on ambient conditions at the time of release;

c. transport and diffusion conditions possibly being significantly different or more restrictive than assumed, including effects caused by variations in the duration of daylight and darkness (e.g., limited inversion depths, extended persistence of various conditions);

d. seasonal variation of dispersion and meteorological conditions such that separate modeling approaches and models may be necessary at certain times of the year; and

e. the possible need for field studies to characterize and model dispersion conditions.

The staff considers 5 years of hourly offsite observations to be representative of the conditions at a proposed or existing site, for the purposes of estimating χ/Q values at the EAB and LPZ. However, given this relatively short time scale, added attention should be given to the comparison between the offsite station(s) and the conditions at the site, as discussed above in Sections 2.1.2 (6) and 2.1.2 (7) of this RG.

2.2 Source-Receptor Pair Distances and Directions

2.2.1 Distance from Source to Receptor

Figure 2-1 depicts an example of how an applicant may use the building locations within the powerblock area to determine the most limiting distance from the edge of the building to the EAB or LPZ. Analysts only need to consider the buildings from which radioactive material could potentially be released. Other buildings, such as support buildings and cooling towers, do not need to be considered when calculating the distance to the EAB or LPZ. The preferred, and most conservative, method is to use the limiting distance from the nearest building edge and apply that distance over all 16 sectors, thus creating a uniform circle around the powerblock area. Using the limiting distance over all 16 directional sectors would ensure that the most conservative χ/Q value is calculated for each given sector. When used in conjunction with the preferred release characteristics discussed in Section 2.3, this method would ensure that the 95th-percentile overall site χ/Q is conservatively determined.

The source to receptor distance is the shortest horizontal distance between the release point and the receptor location. ARCON will use this distance and the elevations of the source and receptor to calculate the slant path.[1] For an area source such as a building surface, the shortest horizontal distance from the building surface to the EAB or LPZ is used as the source to receptor distance. If the distance to the receptor is less than about 10 m (32.8 ft), the ARCON code should not be used to assess χ/Q values. These situations will need to be addressed on a case-by-case basis. Should the facility be sited on a military or other government facility, where the EAB and/or LPZ boundary falls within a larger controlled area, the applicant will need to clearly identify the locations or areas considered to be onsite and offsite. These cases will also need to be addressed on a case-by-case basis.

1 ARCON calculates the shortest line-of-sight distance from the release point to the receptor location, based on the differences in elevation and the horizontal intervening distance, and uses it used as the source-to-receptor distance. N

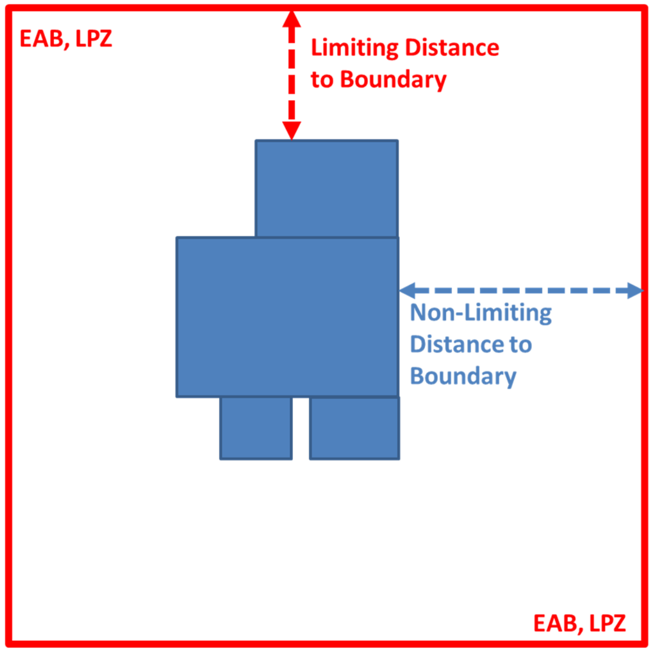

Figure 2-1. Example of limiting and nonlimiting distances from buildings within the PBA to the EAB/LPZ boundaries

An alternative method for determining the distance for each source-receptor pair in each 22.5-degree sector is to use the closest point of an applicable building in that sector to the EAB, as shown in Figure 2-2. As with the preferred method, analysts only need to consider the buildings from which radioactive material could potentially be released. Other buildings, such as support buildings and cooling towers, do not need to be used when calculating the distance to the EAB or LPZ. Using the closest point on an applicable building for each sector would create a less conservative but potentially more realistic set of χ/Q values than the preferred method described above. Figures 2-1 and 2-2 depict a square EAB/LPZ boundary; however, the same principles would apply to EAB and LPZ boundaries of any other shape.

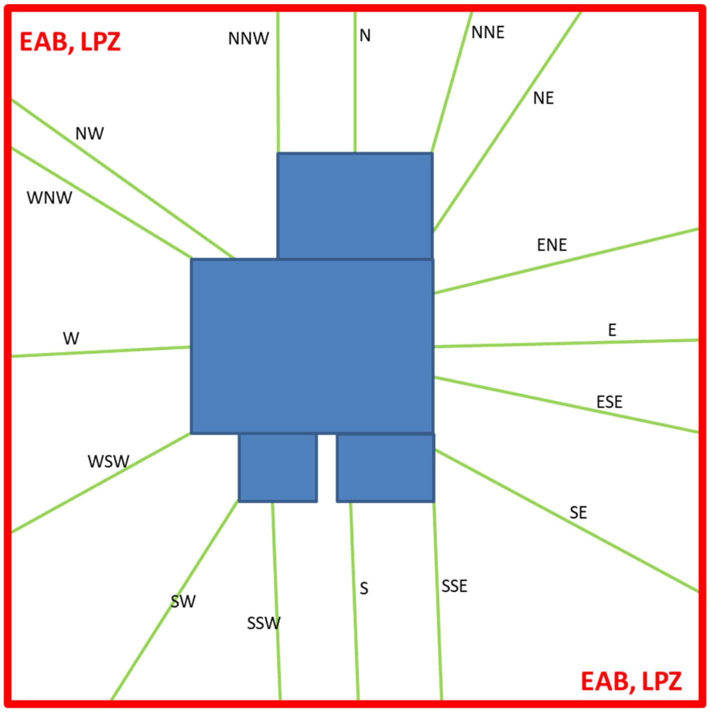

Figure 2-2. Example of how to use the closest point of a building withing each of the 16 directional sectors from the PBA to the EAB/LPZ boundaries

2.2.2 Direction from Source to Receptor

Traditionally, the ARCON code has been run by calculating a relative concentration for only one specific direction per code execution or, put otherwise, one source-receptor pair. This source -receptor pair, within the existing code, assumes a release point from a location within or near the plant boundary. Analysts only need to consider the buildings from which radioactive material could potentially be released. Other buildings, such as support buildings and cooling towers, do not need to be used when calculating the direction from the nearest building edge to the EAB or LPZ.

When the combinations of source (release point) and receptor pairs have been identified, the direction and distance between the release point and the receptor location should be determined. Wind direction data are recorded as the direction from which the wind blows (e.g., a north wind blows from the north, a wind blowing out of the west is recorded with a direction of 270 degrees). The direction input to ARCON is the wind direction (in degrees) that would carry the plume from the release point to the receptor location.[2] For example, an analyst standing at the receptor location facing west to the release point would enter 270 degrees; an analyst facing north would enter 360 degrees.

2.3 Release Characteristics

A 95th-percentile overall site χ/Q value, or a 99.5th-percentile relative concentration for each sector, should be determined for each analysis. In determining the bounding combinations, it will be

2 The site meteorological tower wind direction sensors are generally calibrated with reference to true north (360 degrees). Analysts should use caution in measuring directions on site engineering drawings since these drawings typically incorporate a plant grid and a plant “north” that may not align with true north. The source-to-receptor direction input to ARCON must use the same north reference as the wind direction observations.

necessary to consider the distance, direction, release mode, and height of the release location(s) to the various EAB and LPZ receptor locations.

The ARCON code provides options that allow an analyst to model ground-level, elevated stack, and vent-point source releases. In addition, the analyst can model diffuse area sources as a sub-mode of the ground-level release type. The positions that follow discuss these modes and limitations on their use.

2.3.1 Ground-Level Releases

The ground-level release mode is recommended for the majority of the estimates from the powerblock area to the EAB or LPZ. If the release type is ground-level, then ARCON ignores all user inputs related to release velocity and radius. Due the limited applicable distance assumed in this RG, ground-level releases are highly recommended. Use of elevated (stack) and vent releases may be appropriate, depending on the design of the plant and with appropriate justification.

2.3.2 Elevated (Stack) Releases

The stack release mode is appropriate for releases from a freestanding, vertical, uncapped stack that is outside the directionally dependent zone of influence of adjacent structures. Such a stack should be more than 2.5 times the height of the adjacent structures or be located as follows:

a. more than 5L downwind of the trailing edge of upwind buildings, and
b. more than 2L upwind of the leading edge of downwind buildings, and
c. more than 0.5L crosswind of the closest edge of crosswind buildings,

where L is the lesser of the height or width of the building creating the downwind, upwind, or crosswind wake. Since L will be dependent on wind direction for most building clusters, it will generally be necessary to assess the zone of influence for all directions within the 90 degree wind direction sector centered on the line of sight between the stack and the EAB or LPZ receptor location. As shown in Figure 1 of RG 1.194, if multiple receptors are involved such that upwind, downwind, and crosswind orientations are confounded, 5L could be used for each orientation. ARCON does not calculate the plume rise from buoyancy or mechanical jet effects. The analyst may determine plume rise and add the amount of rise to the physical height of the stack to obtain an effective plume height, as described in Regulatory Position 6 of RG 1.194. Although ARCON does not determine plume rise, it uses the input values of stack flow, radius, and vertical velocity to assess downwash and to estimate a limiting χ/Q value.

If the EAB and LPZ receptor locations are close to the base of a tall stack, the elevated release model in ARCON generates negligibly low χ/Q values. Although perhaps numerically correct, these model results may not be sufficiently conservative for a design-basis assessment since the model does not adequately address meteorological conditions that could result in higher χ/Qs. Concentrations greater than those predicted by ARCON could result from diurnal wind direction changes, meander, or stagnation. Therefore, the procedure in the following paragraphs, as well as equations (1) and (2), should be used to assess whether a particular stack-to-receptor configuration is subject to this concern and to determine the appropriate χ/Q values. For stack releases, the maximum ground-level concentration in a sector may occur beyond the EAB or LPZ boundary distance. Therefore, for stack releases, χ/Q calculations should be made in each sector at each minimum boundary distance and at various distances beyond the EAB / LPZ boundary distance to determine the maximum relative concentration for consideration in subsequent calculations.

In addition to running ARCON to determine the elevated stack χ/Q values for the EAB or LPZ assessment, the analyst should calculate the maximum elevated stack χ/Q value using the methodology of RG 1.145 to determine the maximum χ/Q value at ground-level for the 0–2-hour interval and for the 24–96-hour and 96–720-hour intervals. The NRC-sponsored code PAVAN, is acceptable to the staff for this assessment, as discussed in RG 1.145 and NUREG/CR-2858 (Ref. 8). For this assessment, the input parameters should be adjusted such that the effective release height is measured from the elevation of the EAB or LPZ receptor. The same release point characterization and meteorological data sets used in ARCON should be used to determine the χ/Q values for several distances in each wind direction sector with the objective of identifying the maximum χ/Q value. The maximum χ/Q value obtained for the 0–2-hour interval should be compared to the corresponding χ/Q value generated by ARCON and the higher value determined through the use of PAVAN. The χ/Q values generated by ARCON for the 2–8-hour and the 8–24-hour intervals may be used without adjustment.

For the 24–96-hour and 96–20-hour intervals, the following expressions may be used to determine the effective χ/Q. This deterministic approach assumes that the stack plume reverses direction for 1 hour of each day for the duration of the event. The plume is assumed to fold over itself such that the ground-level concentration is at its maximum value at the receptor location.

$$\left(\frac{\chi}{Q}\right)_{24\rightarrow 96hr} = \frac{1\cdot\left(\frac{\chi}{Q}\right)_{24\rightarrow 96\,hr}^{PAVAN} + 23\cdot\left(\frac{\chi}{Q}\right)_{24\rightarrow 96\,hr}^{ARCON}}{24} \qquad (1)$$

$$\left(\frac{\chi}{Q}\right)_{96\rightarrow 720hr} = \frac{1\cdot\left(\frac{\chi}{Q}\right)_{96\rightarrow 720\,hr}^{PAVAN} + 23\cdot\left(\frac{\chi}{Q}\right)_{96\rightarrow 720\,hr}^{ARCON}}{24} \qquad (2)$$

Fumigation is an atmospheric effect that occurs when a plume, initially embedded in an elevated relatively non-turbulent layer of the atmosphere, encounters a turbulent mixing layer. As described in NUREG/CR- 3352, “Fumigation Potential at Inland and Coastal Power Plant Sites”, issued October 1983 (Ref. 18), this fumigation effect can lead to ground-level concentrations, when and where the plume comes to the ground, that are higher than the concentrations before or after the fumigation episode. Therefore, at sites where fumigation is a potential concern, this effect will be addressed on a case-by-case basis.

2.3.3 Vent Releases

The ARCON calculation of vent releases includes an algorithm to model mixed-mode releases as described in RG 1.111, “Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors” (Ref. 19), which addresses χ/Q values used in the assessment of routine effluent releases. The development of this algorithm was based in part on limited field experiments. Given the limited experiment set, the results obtained with this algorithm may not be sufficiently conservative for accident evaluations. For this reason, the vent-release mode should not be used in design-basis assessments. This position is consistent with the guidance of RG 1.145 for offsite χ/Q values. These releases should be treated as a ground-level release (Section 2.3.1 of this RG) or as an elevated release (Section 2.3.2 of this RG).

2.3.4 Point Source

Use of a ground-level point source from a building periphery is the preferred method for determining the atmospheric concentrations at the EAB or LPZ. Use of this method will produce the most conservative estimates, since there will be no plume rise for buoyancy or mechanical jet effects, as well as no credit given for diffuse area sources. The point source should be the closest point, along the edge of an applicable building, to the EAB or LPZ following the guidance in Section 2.2.1 and depicted in Figures 2-1 and 2-2.

2.3.5 Diffuse Source—Point Receptor

ARCON allows users to enter initial diffusion coefficients that may approximate dimensions of diffuse area sources. The diffusion models in ARCON are based on point source formulations. However, some release sources may be better characterized as area sources. Assessments that deem diffuse area sources to be appropriate should follow the guidance in Section 2.2.1 of this RG and use the shortest distance between the building boundary and the EAB or LPZ. Section 2.5.7, "Example 6—Diffuse Source Release," of NUREG/CR-6331, Revision 1, shows an example of how to model a diffuse area source.

When considering the use of a diffuse area source, analysts should consider the following:

a. Diffuse source modeling should be used only for those situations in which the activity being released is homogeneously throughout the building and when the assumed release rate from the building surface would be reasonably constant over the surface of the building.

b. ARCON uses two initial diffusion coefficients entered by the user to represent the area source. There are insufficient field measurements to mechanistically model these initial diffusion coefficients. The following deterministic equations should be used in the absence of site-specific empirical data:

$$\sigma_{Y_0} = \frac{Width_{\,area\ source}}{6}$$

$$\sigma_{Z_0} = \frac{Height_{\,area\ source}}{6}$$

c. The height and width of the area source (e.g., the building surface) are taken as the maximum vertical and horizontal dimensions of the above-grade building cross-sectional area perpendicular to the line of sight from the building center to the EAB or LPZ boundary. These dimensions are projected onto a vertical plane perpendicular to the line of sight and located at the closest point on the building surface to the EAB or LPZ boundary. The release height is set at the vertical center of the projected plane but may also be considered as a ground-level source to reduce the distance to the EAB or LPZ. The source to receptor distance (slant path) is measured from this point to the receptor location.

Section 3.2.4, "Diffuse Area Sources," of RG 1.194, describes other scenarios, primarily for large light-water reactors requiring the use of a diffuse area source can be found in Section 3.2.4, "Diffuse Area Sources," of RG 1.194.

2.4 Determining the 95-Percentile and 99.5-Percentile χ/Q Values

This RG provides a method for applicants and licensees to use ARCON for offsite (EAB and LPZ) χ/Q estimates. For each of the 16 downwind direction sectors (e.g., N, NNE, NE, ENE), ARCON calculates the 95th-percentile χ/Q values for each source-receptor combination for various time-averaged periods ranging from 2 hours to 30 days. ARCON does not calculate a maximum sector 99.5th percentile, as performed by PAVAN and stated in Regulatory Position 2 of RG 1.145.

Using the methods described in Sections 2.4.1 and 2.4.2 of this RG, the user can calculate the 99.5th-percentile χ/Q value for each sector and should select the larger of the two χ/Q values, either the 99.5-percent maximum sector value or the 95-percent overall site value to represent the χ/Q value for the 0-2 hour time interval. If the applicant or licensee uses other methodologies to determine the maximum 99.5th-percentile χ/Q value, the methodologies should be well documented and provided with appropriate justification.

2.4.1 Determination of 95th-Percentile Overall Site χ/Q

ARCON provides time-averaged directional χ/Q values for the 95th percentile. To determine the overall site χ/Q, analysts should apply a "wind direction window" width of 360 degrees. This will effectively include all the hours in the dataset and will therefore represent each wind direction, regardless of sector.

Each of the other ARCON inputs should be entered as appropriate for the design of the plant.

2.4.2 Determination of 99.5-Percentile Maximum Sector χ/Q

A 99.5th-percentile χ/Q value should be calculated for each of the 16 downwind sectors, and the maximum 99.5th-percentile χ/Q value out of all the 16 sectors is selected for each time interval. The maximum χ/Q value from the 16 sectors becomes the 0–2 hour "maximum sector χ/Q value."

Since ARCON calculates a relative concentration for only one specified direction per code execution, each of the 16 direction sectors needs to be calculated individually. ARCON allows the user to specify the width of the wind direction window in degrees. As such the wind direction window width for each sector should be 45 degrees centered on the compass direction of interest.

The following steps can be used as an acceptable method to calculate the 99.5th-percentile χ/Q for any given sector. Each ARCON run produces a "Frequency File" output file with the extension "Cumulative Frequency Distribution (CFD" (cumulative frequency distribution).)". The ARCON 2.0 User's Guide (Ref. 9) states that the "Frequency File (.CFD)" name and directory path are the same as for "Input File (.RSF)." The "Frequency File (.CFD)" contains the cumulative frequency distributions of the concentrations calculated for 10 averaging intervals and is designed to be imported into a spreadsheet for further data analysis and display. The distributions may be used to determine concentrations at percentiles other than the 95th percentile. Using the number of hours for a given averaging period from the .LOG file, along with the data provided in the .CFD file, a user can calculate the frequency that any given χ/Q is exceeded in that ARCON run.

Appendix A to this RG provides an example of how a user may determine the 99.5th-percentile χ/Q value from the standard ARCON output.

D. IMPLEMENTATION

The NRC staff may use this RG as a reference in its regulatory processes, such as licensing, inspection, or enforcement. However, the NRC staff does not intend to use the guidance in this RG to support NRC staff actions in a manner that would constitute backfitting as that term is defined in 10 CFR 50.109, "Backfitting," and as described in NRC Management Directive 8.4, "Management of Backfitting, Forward Fitting, Issue Finality, and Information Requests" (Ref. 20), nor does the NRC staff intend to use the guidance to affect the issue finality of an approval under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." The staff also does not intend to use the guidance to support NRC staff actions in a manner that constitutes forward fitting as that term is defined and described in Management Directive 8.4. If a licensee believes that the NRC is using this RG in a manner inconsistent with the discussion in this Implementation section, then the licensee may file a backfitting or forward fitting appeal with the NRC in accordance with the process in Management Directive 8.4.

REFERENCES [3]

1. U.S. Nuclear Regulatory Commission (NRC), "Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants," Regulatory Guide (RG) 1.194, Washington, DC.

2. *U.S. Code of Federal Regulations* (CFR), "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy."

3. CFR, "Licenses, Certifications, and Approvals for Nuclear Power Plants," Part 52, Chapter 1, Title 10, "Energy."

4. CFR, "Reactor Site Criteria," Part 100, Chapter 1, Title 10, "Energy."

5. NRC, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," NUREG-0800, Washington, DC.

6. NRC, "Meteorological Monitoring Programs for Nuclear Power Plants," RG 1.23, Washington, DC.

7. NRC, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," RG 1.145, Washington, DC.

8. NRC, "PAVAN: An Atmospheric Dispersion Program for Evaluating Design Basis Accidental Releases of Radioactive Materials from Nuclear Power Plants," NUREG/CR-2858, November 1982. Agencywide Documents Access and Management System (ADAMS) Accession No. ML12045A149.

9. NRC, "ARCON 2.0 User Guide," Radiation Protection Computer Code Analysis and Maintenance Program, Washington, DC, May 24, 2021, ADAMS Accession No. ML21144A062.

10. Ramsdell, J. V. Jr, and C. J. Fosmire, "Estimating Concentrations in Plumes Released in the Vicinity of Buildings: Model Evaluation," *Atmospheric Environment* 32(10), p. 1679-1689, May 1998.

11. NRC, "Nuclear Regulatory Commission International Policy Statement," Federal Register, Vol. 79, No. 132, July 10, 2014, pp. 39415–39418.

12. NRC, "Regulatory Guides," Management Directive 6.6, ADAMS Accession No. ML18073A170.

13. NRC, "Atmospheric Relative Concentrations in Building Wakes," NUREG/CR-6331, Revision 1, Washington, DC, May 1997, Agencywide Documents Access and Management System (ADAMS) Accession No. ML17213A190.

3 Publicly available NRC published documents are available electronically through the NRC Library on the NRC's public Web site at http://www.nrc.gov/reading-rm/doc-collections/ and through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html. The documents can also be viewed on lineonline or printed for a fee in the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD. For problems with ADAMS, contact the PDR staff at 301-415-4737 or (800) 397-4209;
fax (301) 415-3548; or e--mail pdr.resource@nrc.gov.

14. American National Standards Institute (ANSI)/American Nuclear Society (ANS), "Determining Meteorological Information at Nuclear Facilities," ANSI/ANS-3.11-2015, La Grange Park, IL, 2015.[4]

15. U.S. Environmental Protection Agency (EPA), "Meteorological Monitoring Guidance for Regulatory Modeling Applications," EPA-454/R-99-005, Research Triangle Park, NC, February 2000.[5]

16. EPA, "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV: Meteorological Measurements," EPA-454/B-08-002, Version 2.0, Research Triangle Park, NC, March 2008.

17. Interagency Council for Advancing Meteorological Services (ICAMS) Web site, available at https://www.icams-portal.gov/publications/fmh/allfmh2.htm, Federal Meteorological Handbooks (accessed May 21, 2021).

18. NRC, "Fumigation Potential at Inland and Coastal Power Plant Sites," NUREG/CR-3352, Washington, DC, October 1983. ADAMS Accession No. ML20081C313.

19. NRC, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," RG 1.111, Washington, DC.

20. NRC, "Management of Facility-Specific Backfitting and Information Collection," Management Directive 8.4, Washington, DC, October 9, 2013, ADAMS Accession No. ML12059A460.

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4 Copies of American National Standards Institute (ANSI) standards may be purchased from ANSI, 1819 L Street NW, Washington, DC 20036, or through its Web site at http://webstore.ansi.org/; telephone (202) 293-8020; fax (202) 293 9287; or e-mail storemanager@ansi.org.

5 Copies of EPA Library Services may be obtained through their Web site: http://www.epa.gov/libraries/library_services.html

APPENDIX A

EXAMPLE PROCESS FOR CALCULATING 99.5TH-PERCENTILE χ/Q

The assumptions and methods in this appendix are acceptable to the staff of the U.S. Nuclear Regulatory Commission for deriving the 99.5th-percentile atmospheric relative concentration (χ/Q) values from ARCON standard output files. These assumptions and processes supplement the guidance provided in the main body of this regulatory guide (RG).

As discussed in Section 2.4.2 of this RG, ARCON produces standard output files that can be used to analyze the data and produce χ/Q exceedance frequencies not calculated in typical ARCON runs. The standard output files include a "Frequency File" output file with the extension ".CFD" (cumulative frequency distribution). The "Frequency File (.CFD)" contains the cumulative frequency distributions of the concentrations calculated for 10 averaging intervals and is designed to be imported into a spreadsheet for further data analysis and display. Figure A-1 contains a portion of a frequency file output created as part of Example 1 in the ARCON 2.0 example problems (Ref. A-1). The second column in Figure A-1 represents the number of 1-hour averaging intervals that are exceeded by the χ/Q thresholds, or concentrations, provided in the first column (with a header of "XOQ"). The third column (with a header of "2") represents the number of 2-hour averaging intervals that are exceeded by the χ/Q thresholds. This is the case for each of the averaging intervals up to 720 hours, or 30 days. The 2-hour averaging interval should be used to derive the 0-2-hour χ/Q values, as would be consistent with Regulatory Positions 1.3 and 1.4 in RG 1.145 (Ref. A-2). It is noted that RG 1.145 (Ref. A-2) recommends that the time periods used to determine the sector χ/Qs for the LPZ represent appropriate meteorological regimes, e.g., 8 and 16 hours and 3 and 26 days. Some of these durations are not represented in the standard ARCON output, but may be derived from the CFD output file. A second method to estimate χ/Qs for these timeframes is to adjust the ARCON Program Defaults. This can be found in Figure 2.8 of the ARCON 2.0 User's Guide (Ref. A-1).

The frequency file is intended to be imported into a spreadsheet and divided into columns. Once the columns are delimited, the χ/Q exceedance frequencies can be identified. A new column can be created that provides the percent of the time that a given χ/Q value is exceeded. This can be done by identifying the total number of hours in the .LOG file for each averaging interval (in Figure A-2, this would be 8,742 for the 2-hour averaging interval). The user would then subtract the number of hours in the averaging interval column for each χ/Q threshold (from Figure A-1, this would be 2 for the χ/Q threshold of 2.291×10^{-03} seconds per cubic meter (s/m^3), 14 for the χ/Q threshold of 2.089×10^{-03} s/m^3, etc.) from the total number of hours, divide by the total number of hours, and multiply by 100 to calculate the percentage of the time each χ/Q is exceeded in the .CFD file.

X/Q CUMULATIVE FREQUENCY DISTRIBUTIONS

XOQ	1	2	4	8	XOQ	12	24	96	168	360	720
Abv. Lim.	0.	0.	0.	0.	Abv. Lim.	0.	0.	0.	0.	0.	0.
9.120E-03	0.	0.	0.	0.	9.120E-03	0.	0.	0.	0.	0.	0.
...											
2.754E-03	0.	0.	0.	0.	2.754E-03	0.	0.	0.	0.	0.	0.
2.512E-03	0.	0.	0.	0.	2.512E-03	0.	0.	0.	0.	0.	0.
2.291E-03	8.	2.	0.	0.	2.291E-03	0.	0.	0.	0.	0.	0.
2.089E-03	39.	14.	4.	0.	2.089E-03	0.	0.	0.	0.	0.	0.
1.905E-03	109.	60.	26.	10.	1.905E-03	0.	0.	0.	0.	0.	0.
1.738E-03	186.	130.	81.	53.	1.738E-03	0.	0.	0.	0.	0.	0.
1.585E-03	290.	211.	142.	90.	1.585E-03	18.	0.	0.	0.	0.	0.
1.445E-03	421.	294.	217.	154.	1.445E-03	42.	0.	0.	0.	0.	0.
1.318E-03	594.	432.	340.	226.	1.318E-03	81.	1.	0.	0.	0.	0.
1.202E-03	767.	570.	473.	339.	1.202E-03	136.	10.	0.	0.	0.	0.
1.096E-03	962.	721.	598.	497.	1.096E-03	211.	29.	0.	0.	0.	0.
1.000E-03	1087.	897.	758.	677.	1.000E-03	332.	55.	0.	0.	0.	0.
9.120E-04	1324.	1123.	1005.	901.	9.120E-04	490.	115.	0.	0.	0.	0.
8.318E-04	1464.	1309.	1259.	1203.	8.318E-04	701.	186.	0.	0.	0.	0.
7.586E-04	4635.	3946.	3232.	2456.	7.586E-04	961.	323.	0.	0.	0.	0.
6.918E-04	4645.	4026.	3397.	3170.	6.918E-04	1364.	501.	0.	0.	0.	0.
6.310E-04	4663.	4082.	3542.	3435.	6.310E-04	2242.	748.	17.	0.	0.	0.
5.754E-04	4663.	4194.	4383.	4003.	5.754E-04	2911.	1103.	49.	8.	0.	0.
5.248E-04	4663.	4277.	4467.	4171.	5.248E-04	3512.	1657.	250.	54.	0.	0.
4.786E-04	4663.	4352.	4585.	4685.	4.786E-04	3982.	2386.	494.	182.	0.	0.
4.365E-04	4663.	4472.	4711.	4814.	4.365E-04	4368.	3088.	843.	383.	63.	0.
3.981E-04	4663.	4963.	5020.	5140.	3.981E-04	4722.	3749.	1472.	917.	364.	0.
3.631E-04	4663.	5543.	5451.	5433.	3.631E-04	5029.	4408.	2672.	1661.	669.	419.
3.311E-04	4663.	5557.	5483.	5525.	3.311E-04	5347.	4954.	3848.	3104.	2211.	1344.
3.020E-04	4663.	5557.	5537.	5635.	3.020E-04	5611.	5488.	4894.	4638.	4096.	4495.
2.754E-04	4663.	5557.	5600.	6051.	2.754E-04	5822.	5904.	5829.	5702.	5757.	6000.
2.512E-04	4663.	5557.	5630.	6122.	2.512E-04	6065.	6233.	6487.	6652.	7127.	7297.
2.291E-04	4663.	5557.	5694.	6204.	2.291E-04	6256.	6501.	6984.	7363.	7838.	7867.
2.089E-04	4663.	5557.	5759.	6288.	2.089E-04	6442.	6699.	7334.	7750.	8135.	8035.
1.905E-04	4663.	5557.	6403.	6697.	1.905E-04	6636.	6915.	7644.	7949.	8245.	8112.
1.738E-04	4663.	5557.	6413.	6735.	1.738E-04	6766.	7079.	7900.	8127.	8386.	8112.
1.585E-04	4663.	5557.	6423.	6751.	1.585E-04	6866.	7217.	8082.	8284.	8436.	8112.
...											
1.000E-06	4663.	5557.	6423.	7373.	1.000E-06	7922.	8425.	8673.	8608.	8436.	8112.
Belw. Lim.	0.	0.	0.	0.	Belw. Lim.	0.	0.	0.	0.	0.	0.

Figure A-1. Portion of the ARCON 2.0 .CFD File from Example 1 in the ARCON 2.0 User's Guide

As the χ/Q values in the first column get smaller, the more likely it becomes that the χ/Q value is exceeded in the defined wind direction window. Therefore, the number of hours above any given threshold increases as the χ/Q decreases. For χ/Qs associated with an averaging interval value of 0, this indicates that this χ/Q limit is never exceeded, and therefore 100 percent of the hourly χ/Qs are below this threshold. This formula and relationship can be expressed as:

$$\%_{Exceedance} = \left(\frac{H_{total} - H_{avg\_int}}{H_{total}}\right) * 100 \qquad \text{Equation A-1}$$

where,

$\%_{Exceedance}$ = the percentage of the time that each χ/Q threshold is exceeded

H_{Total} = the total number of hours in the .LOG file for a given averaging interval

H_{avg_int} = the number of hours exceeded for each χ/Q threshold

Equation A-1 should be applied to each line in the .CFD file until the exceedance frequency of each χ/Q in the first column is identified. The 99.5th-percentile χ/Q value will most likely be between two χ/Q threshold values. In Figure A-1, third column, the 99.5th-percentile χ/Q value is bounded by the 2.089 x 10^{-03} s/m^3 χ/Q (99.83th percentile) and 1.905E-03 s/m^3 χ/Q (98.31th percentile).

Using the two bounding χ/Q threshold values from Equation A-1, a simple linear interpolation can be used to determine the 99.5th-percentile χ/Q using the following equation:

$$y = y_1 + \left[\left(\frac{x - x_1}{x_2 - x_1}\right) \cdot (y_2 - y_1)\right] \qquad \text{Equation A-2}$$

The expressions in Equation A-2 are:

y	=	the resulting 99.5th-percentile χ/Q value
y_1	=	the lesser of the two bounding χ/Q values
y_2	=	the greater of the two bounding χ/Q values
x	=	99.5
x_1	=	the lesser of the two exceedance frequencies
x_2	=	the greater of the two exceedance frequencies

Based on the χ/Qs in this example, Equation A-2 can be solved as:

$$y = 1.905\ x\ 10^{-03} + \left[\left(\frac{99.5 - 99.31}{99.83 - 99.31}\right) \cdot (2.089\ x\ 10^{-03} - 1.905\ x\ 10^{-03})\right]$$

Therefore,

y= 99.5th-percentile χ/Q = 1.970 x 10^{-03} s/m^3

Note that for some unique modeling scenarios, this methodology may not produce the most conservative χ/Q values from the CFD output file. Those cases may need to be examined on a case-by-case basis and are discussed in the ARCON 2.0 User's Guide.

```
Expanded output for code testing selected
QA output file = C:\ARCON 2.0\arcon2_ex1.EXT

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

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL
 AVER. PER.         1         2         4         8        12        24        96       168       360       720
 UPPER LIM.  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02
   LOW LIM.  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06  1.00E-06
ABOVE RANGE        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
   IN RANGE     4663.     5557.     6423.     7373.     7922.     8425.     8673.     8608.     8436.     8112.
BELOW RANGE        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
       ZERO     4087.     3185.     2303.     1321.      815.      291.        0.        0.        0.        0.
 TOTAL X/Qs     8750.     8742.     8726.     8694.     8737.     8716.     8673.     8608.     8436.     8112.
 % NON ZERO     53.29     63.57     73.61     84.81     90.67     96.66    100.00    100.00    100.00    100.00

95th PERCENTILE X/Q VALUES
             1.43E-03  1.31E-03  1.23E-03  1.14E-03  9.42E-04  7.16E-04  4.90E-04  4.33E-04  3.91E-04  3.64E-04

95% X/Q for standard averaging intervals

0 to 2 hours        1.43E-03
2 to 8 hours        1.04E-03
8 to 24 hours       5.05E-04
1 to 4 days         4.15E-04
4 to 30 days        3.45E-04
```

Figure A-2. Portion of the ARCON 2.0 .LOG File from Example 1 in the ARCON 2.0 User's Guide

REFERENCES

APPENDIX A

A-1 U.S. Nuclear Regulatory Commission, "ARCON 2.0 User Guide," Radiation Protection Computer Code Analysis and Maintenance Program, Washington, DC, May 24, 2021, ADAMS Accession No. ML21144A062.

A-2 NRC, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plant," RG 1.145, Washington, DC.