Use and Application of the ARCON96 Dispersion Model at the Y-12 Complex

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Abstract

The **A**tmospheric **R**elative **Con**centrations in Building Wakes computer code (ARCON96) was developed for the U.S. Nuclear Regulatory Commission (NRC) to calculate normalized concentrations in plumes from nuclear power plants at control room air intakes in the vicinity of hypothetical accidental releases. ARCON96 implements a straight-line Gaussian dispersion model with dispersion coefficients that are modified to account for low-wind-speed meander and building wake effects. These two modifications to the dispersion coefficients were benchmarked and justified in the ARCON96 code documentation. The code calculates χ/Q values (normalized concentrations) consistent with the methodology defined in NRC Regulatory Guide (RG) 1.145, position 3. Based on recent U. S. Department of Energy (DOE) acceptance of NRC RG 1.145, position 3 methodology for performing accident dispersion analyses, BWXT Y-12 L.L.C. evaluated the potential use and application for performing dispersion analyses at the Y-12 Complex. Using site specific meteorology inputs, a generic analysis (assuming ground-level releases) was performed to develop site-wide normalized concentrations for various distances to be used in consequence screening analyses. Additionally, the results were compared to other dispersion analysis models for confirmation of the results.

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Introduction

The **A**tmospheric **R**elative **Con**centrations in Building Wakes computer code (ARCON96) was developed for the U.S. Nuclear Regulatory Commission (NRC) to calculate normalized concentrations in plumes from nuclear power plants at control room air intakes in the vicinity of hypothetical accidental releases. ARCON96 implements a straight-line Gaussian dispersion model with dispersion coefficients that are modified to account for low-wind-speed meander and building wake effects. These two modifications to the dispersion coefficients were benchmarked and justified in the ARCON96 code documentation.[1] The code calculates χ/Q values (normalized concentrations) consistent with the methodology defined in NRC Regulatory Guide (RG) 1.145,[2] position 3. Based on recent U. S. Department of Energy (DOE) acceptance of NRC RG 1.145, position 3 methodology for performing accident dispersion analyses, BWXT Y-12 L.L.C. evaluated the potential use and application for performing dispersion analyses at the Y-12 Complex. Using site specific meteorology inputs, a generic analysis (assuming ground-level releases) was performed to develop normalized concentrations for various distances at the Y-12 Complex to be used in consequence screening analyses.

Recently issued DOE guidance documents (DOE-STD-3009-94, Change Notice 1[3] and DOE G 420.1-1[4]) provide specific guidance for performing dispersion analysis for safety-class equipment determinations. The guidance documents endorse the methodology of NRC RG 1.145, position 3 for guidance with atmospheric dispersion modeling for safety analysis at DOE facilities. Based on the recently issued guidance from DOE, the ARCON96 air dispersion model was selected to calculate χ/Q values (normalized concentrations) for the Y-12 Complex.

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[1] Ramsdell, Jr., J. V. and C. A. Simonen. *Atmospheric Relative Concentrations in Building Wakes*, NUREG/CR-6331, Rev.1, PNNL-10521, Rev.1, (1997) U.S. Nuclear Regulatory Commission, Washington, D.C.
[2] NRC, *Regulatory Guide 1.145, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*, (1982) Office of Nuclear Regulatory Research, Washington, D.C.
[3] DOE, *DOE-STD-3009-94, Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports*, Change Notice No. 1, Appendix A, (2000) Office of Environment, Safety and Health, Washington, D.C.
[4] DOE, *DOE G 420.1-1, Nonreactor Nuclear Safety Design Criteria and Explosives Safety Criteria Guide*, (2000) Office of Environment, Safety and Health, Washington, D.C.

ARCON96 is an NRC-approved code for evaluating normalized concentrations in plumes from nuclear power plants at control room air intakes in the vicinity of hypothetical accidental releases. ARCON96 was selected for a generic analysis because it is approved by NRC, easy to use, and calculates 95th percentile χ/Q values, which is consistent with the DOE requirements. The χ/Q values are calculated as either direction-independent or direction-specific. The results of the code can be used to establish relationships between quantities of hazardous and radioactive materials released from facilities within the Y-12 Complex and downwind concentrations.

The analysis used the ARCON96 code with site-specific meteorological data from Y-12 to determine χ/Q values as a function of distance. The approach consisted of developing the input data for the application of the ARCON96 code to Y-12 and calculating the 95th percentile χ/Q values at 16 distances ranging from 100 m to 1000 m downwind from the point of release. The 95th percentile χ/Q values are defined in RG 1.145 as the values that are exceeded by no more than 5% of the total number of hours in the data set. The meteorological conditions associated with these values were dependent of other input variables such as release height. Various exposure periods ranging from 1 hour to 720 hours were also considered.

A brief summary of the ARCON96 code will be provided along with a discussion of the generic Y-12 analysis. Code limitations will also be discussed along with a comparison of the results with other dispersion codes.

Code Description

This section provides a brief background of the ARCON96 computer code. It discusses the input data, including meteorological data, and also discusses the output from the code. A detailed description of the code and its application is provided with the code documentation.[1]

Model Background

The ARCON96 computer code was developed by Ramsdell and Simonen[1] of Pacific Northwest National Laboratory (PNNL) for the NRC Office of Nuclear Reactor Regulation to calculate normalized concentrations in plumes from nuclear power plants at control room air intakes in the vicinity of hypothetical accidental releases. ARCON96 implements a straight-line Gaussian dispersion model with dispersion coefficients that are modified to account for low-wind-speed meander and building wake effects. The release rate is assumed to be constant for the entire period of release. Values of χ/Q are calculated from hourly meteorological data for averaging periods ranging from 1 hour to 720 hours in duration. The calculated values for each period are used to form cumulative frequency distributions. Normalized concentrations that are exceeded no more than 5% of the time are determined from the cumulative frequency distributions for each averaging period. The computational program is written in FORTRAN, and the user interface is written in VisualBasic for DOS.

Input for the ARCON96 code can be divided into the following five major pieces. The five pieces are:

- default parameters,
- meteorological parameters,
- source information,
- receptor information, and
- output files.

Each of these input sections will be described with additional details provided in the code documentation.[1]

Default Parameters

Default input parameters for the code include:

1. a surface roughness length (0.1 m);
2. an angular width, β (90°);
3. a threshold wind speed, T (0.5 m/s), below which the specified wind direction is considered meaningless, and the input hourly meteorological conditions are routed to a calm-processing subroutine within the program;
4. a sector-averaging width, used only for averaging periods greater than 8 hours, and for which the default value is 4 standard deviation units (2 units wide on each side of the centerline) of a Gaussian plume;
5. initial dispersion parameters in terms of lateral (σ_y) and vertical (σ_z) standard deviations of a Gaussian plume (default values for both are zero), and;
6. a set of averaging periods, ranging from 1 to 720 hours, for which average χ/Q values are to be calculated.

Input for ARCON96 includes a direction, α (see receptor information below), from which the wind is coming toward the receptor, and an angular width, β; both are specified in units of angular degrees. All wind directions within β/2 degrees on either side of α are effectively changed by the code to represent winds coming from direction α; all other non-calm winds are excluded from calculations for the sector. The default value for the angular width in ARCON96 is 90°. Distributions of the χ/Q values for each of several averaging periods ranging from 1 hour to 720 hours may be calculated for n sectors, each of width 360/n degrees, where the position of each sector is defined by the direction of its centerline, α. Direction-independent values of χ/Q (including winds from all directions) may be calculated by setting α = 180° and changing the value of the window (β) to 360°. This feature is not described in the code manual but was determined by analysis to satisfy the requirements of RG 1.145, position 3.

If the wind speed is less than T, it is considered to be calm, and the wind direction is assumed to be from direction α. This is the same procedure as for non-calm winds, except that winds from *every* direction are included in the calculations for each sector, rather than only including those winds from within β/2 degrees of the sector centerline (i.e., wind directions within the window). The calm-processing routine is described in detail in the code documentation.[1] If more than 5%

of the winds are defined as calm, the corresponding χ/Q values (regardless of the specified wind direction) may dominate the top 5% of the χ/Q values calculated for any sector, and the 95^{th} percentile χ/Qs may remain relatively constant from one sector to the next. Lowering T from its default value (0.5 m/s) results in fewer light winds being included in the calculations of χ/Q for each sector, and a greater variability of the 95th percentile χ/Q value from one sector to the next.

Meteorological Parameters

These include the number of meteorological data files the program must read, the heights above ground level at which meteorological data are measured, and the units used for the input wind speeds (knots, miles per hour, or meters per second).

Source Information

Source information includes specification of six parameters. The parameters include the release type (ground level, vent, or stack). For the generic analysis, only ground level releases were used. Other parameters required are the height above ground level of the source, the area of the building from which (or adjacent to which) the pollutant is released (for determining wake parameters), the radius of the stack (or vent), and the velocity and volumetric flow rate of the exiting gas.

Receptor Information

Receptor information includes the height above ground level of the air intake, the elevation difference between the terrain (ground level) at the source and at the receptor, and the distance and direction of the source from the receptor. The direction, α, defines the centerline of a sector of angular width, β (discussed above in the default parameters). Values of χ/Q can be calculated for each of 16 sectors, with their centerlines at 22.5° intervals.

Output Files

These include the names of the summary file and the cumulative frequency distribution file. The summary file includes information about the input, the number of hours for which data are missing, the number of calm hours, the direction of the centerline of the sector being considered, the number of hours processed, the maximum centerline and sector-averaged values of χ/Q, and the 95^{th} percentile χ/Q value for each of several averaging periods ranging from 1 hour to 720 hours. ARCON96 provides centerline values and sector-averaged values; only the (larger) centerline values were used in the generic analysis.

There is also an option for more detailed output, primarily for quality assurance, called a “qa” file. These files are extensive and include a listing of all hourly values of χ/Q (up to 5 years of hourly data). The listing includes hours for which χ/Q was not calculated but was instead set to zero because the wind direction was not within $\beta/2$ degrees of the direction for which the 95^{th} percentile χ/Q was calculated. The range of directions included in the calculation is specified as one of the default parameters. A precise value of the 95^{th} χ/Q may be obtained by ranking the hourly values and counting downward through 5% of them. This process was used to confirm the approach described previously (i.e., setting the angular width to 360° and the direction of α to 180° for performing analyses consistent with RG 1.145, position 3).

Application of ARCON96 to Y-12 Complex

This section discusses the method used to apply the ARCON96 code to the Y-12 Complex. A generic ground-level release from a building was modeled to determine normalized concentrations at various distances from the facility to apply in consequence screening analyses. The code was used to produce direction-independent 95^{th} percentile values of χ/Q for 1-hour and 720-hour averages at 16 downwind distances from the source.

Because the choice of input parameters used is often subjective based on best professional judgment it is useful to perform analyses to evaluate the sensitivity of the model results to varying values of input parameters. A sensitivity analysis of the results was performed by varying the cross-sectional building area.

Data input for the Baseline Case

The standard default parameters for the ARCON96 code were used with the exception of the angular width. The angular width, β, was set to 360º to develop the directional-independent χ/Q's consistent with the approach described in RG 1.145, position 3.

The meteorological data used for the code were obtained from an on-site tower located at the eastern end of the Y-12 Complex. The code can use meteorological data from two levels. For this analysis, data from 10 m above ground level were used for the lower level, and data from 100 m above ground level were used for the upper level. The 10-m level is representative of winds along the Y-12 valley floor (i.e., ground level), and the 100-m level is representative of winds along the ridge tops. For release heights below the lower level of meteorological data, the ARCON96 code uses the lower level only.

For the source information, a ground-level release type was used. Because so-called "ground-level" releases may actually occur somewhat above the surrounding terrain (e.g., in the case of a leaking tank), a non-zero release height is acceptable for "ground-level" releases. The release height was chosen to be 2 m, which is conservative (forms an upper bound) for expected downwind concentrations at receptors 2 m above ground level because the plume centerline and receptor (also set a 2 m above ground level) are at the same elevation. The effluent vertical velocity, vent or stack flow, and vent or stack radius were all assumed to be zero. These assumptions are conservative because an initial vertical velocity would elevate the plume farther from the ground and reduce downwind concentrations near the source at the 2-m level, compared to a release with no initial velocity, and a large initial opening for a release would result in lower initial concentrations at the source and consequently downwind. For the cross-sectional building area (formed within the plane perpendicular to the wind vector), 1500 m^2 was used, which corresponds with a building having a horizontal dimension of 75 m and a height of 20 m. These dimensions were considered representative of a building at Y-12. A sensitivity study indicated that ARCON96 results are not sensitive to building area for the combination of input parameters and downwind distances selected in this analysis.

For the generic ground-level analysis, the receptor information used for the intake height, or height of a receptor above ground, was selected to be 2 m to approximate the height at which an adult human inhales. There was assumed to be no change in elevation due to terrain between the source of the release and the downwind receptor, which again is conservative because the plume moves unimpeded toward the receptor with the plume centerline remaining at the same elevation as the receptor. The wind direction was chosen to be 180º to support the directional independent χ/Q development. Various distances from the source were used (i.e., 16 total) to provide the basis to assess consequence screening values at various distances.

Table 1 provides a summary of the input data used for each portion of the code to develop the direction-independent χ/Q values.

Table 1. Summary of input parameters.

Input parameters		**Value used**
Default parameter	Surface roughness length	0.1 m (default)
	Angular width, β	360º (directional independent value)
	Threshold wind speed, T	0.5 m/s
	Sector-averaging width	4 (default value)
	σ_y and σ_z	0, 0 (default values)
	Averaging periods	default values
Meteorological parameters	Wind speeds, stability class, and units	Y-12 Complex specific data
Source parameter	Release type	Ground
	Release height	2 m
	Building area	1500 m^2
	Vertical velocity	0 m/s
	Stack flow	0 m^3/s
	Stack radius	0 m
Receptor parameter	Distance to receptor	Varied
	Intake height	2 m
	Elevation difference	0 m
	Direction to source	180º (directional independent value)

Results of the Baseline Case

The ARCON96 code was used to generate the χ/Q values for 16 downwind distances using the inputs provided in Table 1. Figure 1 illustrates the direction-independent 95th percentile χ/Q values for a 1-hour average and a 720-hour average. As expected, the values decrease with increasing distance; the rate of decrease is relatively rapid at the shorter distances and relatively slow at the longer distances. Because high 1-hour χ/Q values are smoothed out over a period of 720 hours, the values for the 720-hour average are significantly less than the corresponding values for the 1-hour values.

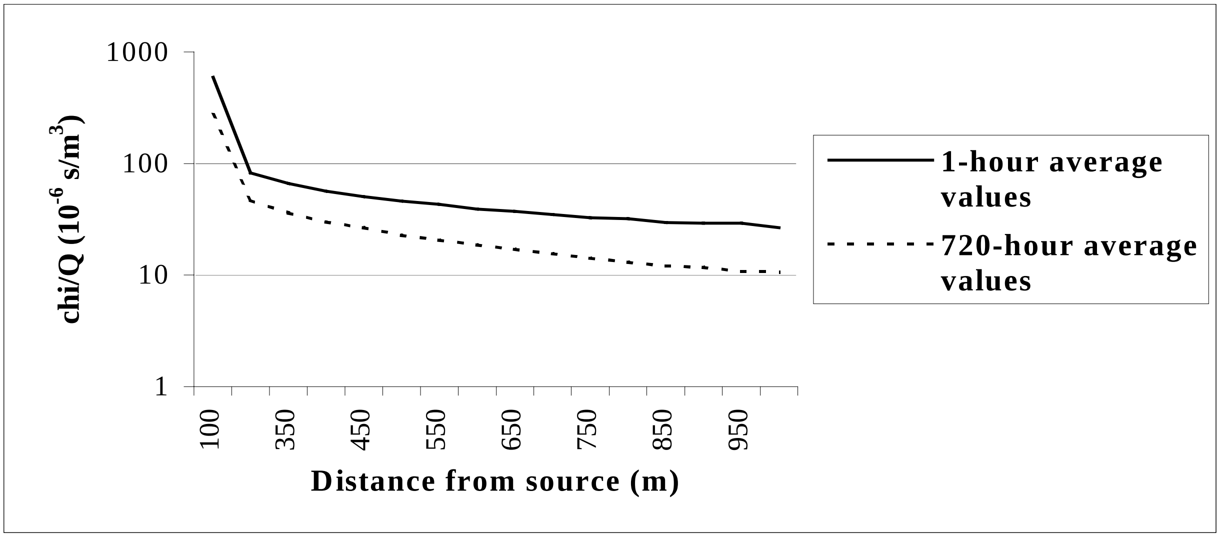

Figure 1. Directional-independent χ/Qs for the Y-12 Complex.

Sensitivity Reviews of the Results

A 1500-m^2 cross-sectional building area (formed within the plane perpendicular to the wind vector) was used for the baseline case, which corresponds with a building having a horizontal dimension of 75 m and a height of 20 m. These dimensions are considered representative of a large building at the Y-12 Complex. A sensitivity study was performed, which indicated that ARCON96 results are not sensitive to the magnitude of the building area for the combination of input parameters selected in the baseline case, even though ARCON96 considers building wake effects from ground-level releases and includes any effects in the results. The reason for the insensitivity is because of the meteorological conditions associated with the 95th percentile χ/Q values. Building wake effects are not pronounced in ARCON96 at relatively low wind speeds.[1] When a comparable sensitivity analysis was performed for a higher wind speed (8 m/s) with less stable conditions (C stability), the building size affected downwind concentrations appreciably, as expected.

Code Limitations

This section discusses some of the limitations of the ARCON96 code and calculated results. Topics discussed include complex terrain, release height and receptor height specifications, downwind distance, release duration, release type, deposition, and building wake associated with building location and size.

Complex Terrain, Release Height, and Receptor Height Specifications

The ARCON96 code allows the input of elevation differences between the release location and downwind receptors to simulate the effects of complex terrain. However, that option was not included in this generic ground-level analysis. Because the release height and the receptors were selected for this analysis to be 2 m above ground level and the initial vertical velocity was assumed to be zero, the results are conservative for expected downwind concentrations should a ground-level release occur. This is because the plume centerline intersects the receptors at 2 m above ground level.

Elevation differences (caused either by terrain or by differences in the release height versus the receptor height) should be evaluated separately due to variations in how the code handles elevated releases and ground releases (e.g., elevated releases do not consider the wake effects of the building).

Downwind Distance

The ARCON96 code was run to obtain results for 16 downwind distances between 100 m and 1000 m. The code can be run for downwind distances up to 10,000 m. The dispersion parameters σ_y and σ_z use coefficients that vary according to 3 distance ranges: 0 m to 100 m, 100 m to 1000 m, and greater than 1000 m. All of the ARCON96 runs were in the middle distance range. Because the Y-12 Complex has a close public boundary for most facilities (i.e., from 300 m to 800 meters), the distances are within the code's limitations.

Release Duration

The ARCON96 code was developed to model continuous release scenarios from nuclear power plants and provides normalized concentrations based on averaged exposure times. The code was not developed to specifically address instantaneous releases and short-term exposures. Caution should be used with any results if an instantaneous release is the source from a facility.

Release Type

The ARCON96 code assumes that the plume moves downwind without reacting chemically and maintains its centerline at the height of the release. As such, buoyant releases (e.g., fires), jet releases with initial upward momentum, heavy gases, and chemical reactions are not specifically considered. Alternately, following a manual calculation of plume rise to estimate an effective stack height to use in ARCON96, the model could simulate buoyant and jet releases.

Although a negatively-buoyant heavy gas plume should behave as a Gaussian plume at downwind distances rather than “slump” as it would initially during the release, the ARCON96 model should not be used for heavy gas modeling because it is not certain that the results would be conservative. Similarly, the model should not be used for hypothetical scenarios involving chemical reactions (e.g., UF_6) because the results may not be conservative.

Deposition

The effects of deposition are not considered in the ARCON96 code. The results should be conservative for a nearly ground-level plume because material that actually has settled out of the plume onto the ground is still considered as being in the air by the model. However, the results may not be conservative for a jet release (that is rising from initial upward momentum) or a buoyant release (that is rising because it is warmer and less dense than the ambient environment, such as during a fire). Gravitational settling of heavier particles from the elevated plume down to near the ground may result in concentrations that are greater than predicted by ARCON96, which assumes a near ground-level plume.

Building Wake Effects

A sensitivity study was performed, which indicated that ARCON96 results are not sensitive to the magnitude of the building area for the combination of input parameters selected in this analysis, even though ARCON96 considers building wake effects from ground-level releases. The reason for the insensitivity is because of the meteorological conditions associated with the 95^{th} percentile χ/Q values. Building wake effects are not pronounced in ARCON96 at relatively low wind speeds. When a comparable sensitivity analysis was performed for a higher wind speed (8 m/s) with less stable conditions (C stability), the building size affected downwind concentrations appreciably.

Software Documentation

Section 4.7 of the code documentation[1] provides a summary of the quality assurance for the code. ARCON95 (revision 0 of the code) was developed and tested in accordance with the requirements of ANSI/ASME NQA-1[5] as interpreted by the PNNL Quality Assurance Program. For the code modification leading to ARCON96, the example problems in NUREG/CR-6331 were rerun to verify that the results were consistent with the changes made to the code, with hand calculations also being performed to verify the results.

Comparison Reviews of the Code Results

A comparison review of the results obtained from running the ARCON96 computer code with those from running the **M**ELCOR **A**ccident **C**onsequence **C**ode **S**ystem for the Calculation of the Health and Economic Consequences of Accidental Atmospheric Radiological Releases (MACCS2)[6] was performed. While MACCS2 has been used extensively for safety analysis calculations at DOE and other federal facilities, the user's manual cautions that the MACCS2 code should not be used for estimating doses at distances less than 500 m from laboratory or industrial-scale facilities because dispersion of material released in the wake of large buildings is subject to a large degree of uncertainty. The comparison identified significant differences between ARCON96 and MACCS2 in the calculated results for χ/Q that can be associated with

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[5] ASME. *Quality Assurance Program Requirements for Nuclear Facilities*, ANSI/ASME NQA1, (1986) American Society of Mechanical Engineers.

[6] Chanin, D. and M. L. Young. *Code Manual for MACCS2: User's Guide*, NUREG/CR-6613, Vol. 1, SAND97-0594, (1998) U.S. Nuclear Regulatory Commission, Washington, D.C.

the treatment of building wakes and plume meander at low-wind speeds. To assist in the interpretation of the calculated results of this code comparison, the WAKE portion of the HGSYSTEM/UF_6 Model[7] was used. The WAKE portion of the HGSYSTEM/UF_6 Model Suite represents the state-of-the-science in the modeling of dispersion in building wakes.

Although ARCON96 and MACCS2 perform similar calculations and can produce similar types of output, they are designed for different purposes. ARCON96 was designed to calculate normalized concentrations in plumes from nuclear power plants at control room air intakes in the vicinity of hypothetical accidental releases. The principal phenomena considered in MACCS2 are atmospheric transport, mitigative actions based on dose projection, dose accumulation by a number of pathways including food and water ingestion, early and latent health effects, and economic costs. MACCS2 can be used for a variety of applications including probabilistic risk assessment of nuclear power plants and other nuclear facilities, sensitivity studies to gain a better understanding of the parameters important to probabilistic risk assessment, and cost benefit analysis. For this model comparison, only the atmospheric transport and diffusion module of MACCS2 was run. MACCS2 also determines normalized concentrations that are exceeded no more than 5% of the time from the cumulative frequency distributions for each averaging period and accounts for the effects of building wakes and low-wind speed meander.

Comparison of Model Input Data

There are several major differences in the input data and algorithms used in ARCON96 and MACCS2 that affect the results. For example, both the building wake and plume meander corrections are built into ARCON96. These corrections are entered as data in MACCS2. In addition, the atmospheric dispersion parameters (σ_y and σ_z) are built into ARCON96, but they are input to MACCS2. For this model comparison, the MACCS2 values provided in sample exercises were used for these parameters. While the input values for the MACCS2 model could have been specified to be the same as the calculated values in ARCON96, this would not have resulted in a legitimate demonstration of the differences between the models. For all other parameters, the MACCS2 and ARCON96 data were matched as closely as possible.

1. Meteorological input data

The meteorological tower data are treated differently in ARCON96 and MACCS2 in several ways. MACCS2 only accepts meteorological data from one height above ground, but ARCON96 accepts two levels. The meteorological data were obtained from the on-site tower located at the eastern end of the Y-12 Complex. Data from 10 m above ground level were input to MACCS2. For ARCON96, data from 10 m above ground level were used for the lower level and data from 100 m above ground level were used for the upper level. Because an ARCON96 run can accept multiple years of meteorological data and MACCS2 can accept a maximum of 1 year for a run, MACCS2 was run separately for each year to compare with the ARCON96 results.

[7] Hanna, S. R. and Chang, J. C. *HGSYSTEM/UF_6 Model Enhancements for Plume and Dispersion Around Buildings, Lift-off of Buoyant Plumes, and Robustness of Numerical Solver*, K/SUB/93-XJ947/2R1, (1997) Earth Technology, Inc., Concord, Mass.

Although the generic threshold ground-level analyses for the Y-12 Complex did not use the upper level meteorological data, analyses of elevated releases from specific Y-12 facilities with specific scenarios in future analysis work are likely to require the use of these data. This added benefit of ARCON96 provides for the selection of the appropriate meteorological conditions depending on the release height and scenario being considered, which is in contrast to MACCS2. MACCS2 makes corrections to the input data to account for elevated releases, which may or may not be caught in a building wake, rather than access the upper level wind data for making such determinations.

ARCON96 also allows for missing meteorological data, but MACCS2 does not. Because there were hours with data missing from the Y-12 eastern meteorological tower at 10 m above ground level, data from the Y-12 western meteorological tower at 10 m above ground level were used to augment the MACCS2 data set, for those hours where data were available. Because 3 hours of data were missing from both tower data sets, these were replaced with the average of the hours before and after each to complete the data set. The largest number of consecutive hours with missing data at both towers was three.

MACCS2 sets all hours with G stability to F stability and sets all hours with wind speeds less than 0.5 m/s to 0.5 m/s. ARCON96 allows G stability and treats calm winds explicitly. For MACCS2, wind directions must be converted from degrees to a sector number (1 to 16). MACCS2 allows several different schemes for sampling the available meteorological data in the annual data set used for input. To most closely match the ARCON96 runs, MACCS2 was set to use all hours in the year. MACCS2 allows for inclusion or exclusion of both wet and dry deposition. Because ARCON96 does not calculate wet or dry deposition, deposition was excluded in the MACCS2 runs for this comparison.

2. Scenario input data

ARCON96 allows entry of both the source and receptor height. MACCS2 allows entry of the source height only. In ARCON96, the source and receptor were set to 2 m. In MACCS2, the source height was set at ground level (0 m) to ensure that the source and receptor were at the same height. A MACCS2 run that was made with the source height at 2 m indicated no significant difference in the results.

MACCS2 requires the user to enter the dispersion parameters (σ_y and σ_z). In the MACCS2 runs, the dispersion parameters used were the default Tadmor-Gur[8] values. ARCON96 uses a diffusion coefficient parameterization from the NRC model PAVAN.[9]

ARCON96 requires only the cross-sectional building area (formed within the plane perpendicular to the wind vector) as input to its building wake algorithm. MACCS2 requires entry of the building height and initial values of σ_y and σ_z for the building wake correction. The MACCS2 manual suggests using the formulas:

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[8] Dobbins, R. A. *Atmospheric Motion and Air Pollution*, (1979) John Wiley & Sons, New York.

[9] Bander, T. J. *PAVAN: An Atmospheric Dispersion Program for Evaluation Design Basis Accidental Releases of Radioactive Materials from Nuclear Power Stations*, NUREG/CR-2858, (1982) U.S. Nuclear Regulatory Commission, Washington, D.C.

σ_y = Building Width / 4.3, and
σ_z = Building Height / 2.15.

For the comparison runs made with ARCON96, a cross-sectional building area of 1500 m^2 was used. This corresponds to a building having a horizontal dimension of 75 m and a height of 20 m. The initial σ_y and σ_z were set to 0.0 m in ARCON96. The corresponding width and height, which are considered representative of a building at the Y-12 Complex, resulted in an initial σ_y of 17.4 m and σ_z of 9.3 m, respectively, for MACCS2.

Surface roughness, Z, is entered directly in ARCON96. In MACCS2, the surface roughness is accounted for by applying a constant scaling factor to σ_z. MACCS2 suggests using the formula

$$(Z_1 / Z_0)^{0.2}$$

for this factor, where Z_0 is 3 cm. Because ARCON96 used a surface roughness of 10 cm, the scaling factor used for MACCS2 was $(10/3)^{0.2} = 1.27$.

Results of Model Comparisons

The comparison of ARCON96 and MACCS2 was made with respect to the numerical results from the codes, the various features of the two codes, and the ease of use. The numerical results are interpreted using similar calculations from the WAKE code.

1. Comparison of numerical results

Figure 2 presents a comparison of the calculated 95^{th} percentile χ/Qs for ARCON96 and MACCS2 for distances from 500 m to 1000 m. The MACCS2 code manual cautions that “The dispersion of a plume of material released in the wake of a large building is subject to a large degree of uncertainty. For that reason, MACCS2 should not be used for estimating doses at distances less that 0.5 km from laboratory or industrial-scale facilities.” Consequently, χ/Q values were not calculated at distances less than 500 m for the MACCS2 model.

The WAKE code was used to provide a comparison of ARCON96 results at less than 500 m. The inputs for WAKE were consistent with the inputs for ARCON96 with one exception. WAKE does not accept meteorological data as input. WAKE requires the specification of stability class and wind speed as input. The 95^{th} percentile meteorological condition determined by ARCON96 for the east tower data at Y-12 for 1995 and 1996 was F stability with 1.7 m/s wind, which was used as input to WAKE. Additionally, WAKE does not have an adjustment for plume meander. ARCON96 treats plume meander with increased dispersion coefficients at low-wind speeds. The effect can be approximated by reducing the χ/Q values at low-wind speeds by a factor of 3. This approximation is presented in NRC Regulatory Guide 1.145, position 1.3.1, equation (2) and is incorporated into ARCON96. The output of WAKE was reduced by a factor of 3 consistent with ARCON96 to account for plume meander.

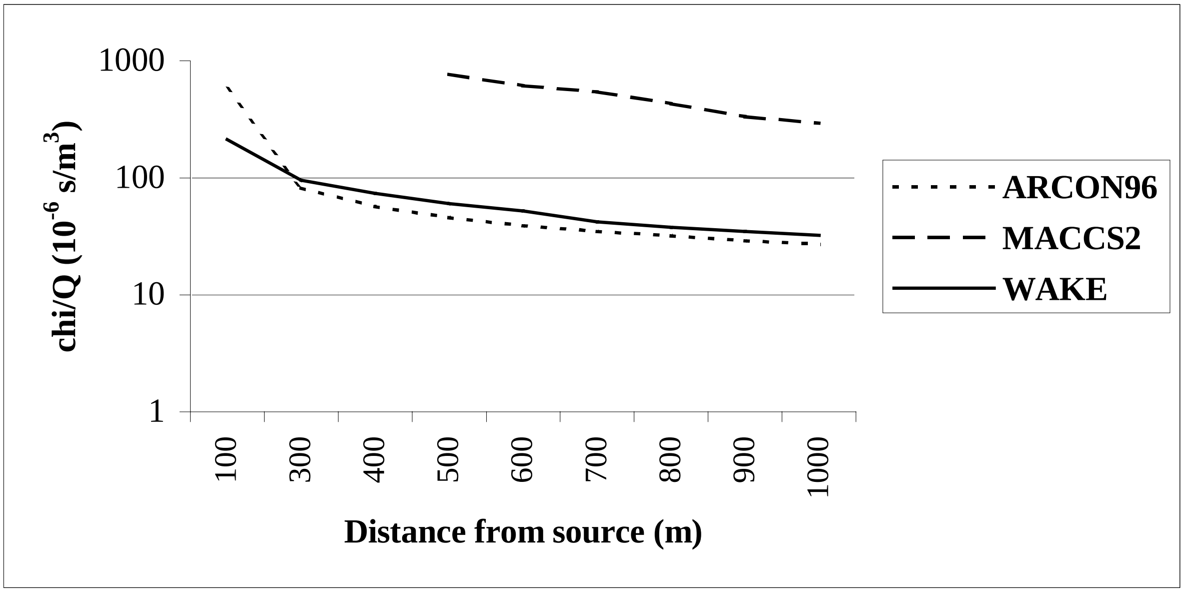

Figure 2. Comparison of 95th percentile χ/Qs.

The χ/Q values calculated by MACCS2 are slightly more than one order of magnitude greater than those calculated by ARCON96 and WAKE. This is not surprising because ARCON96 and WAKE were developed to specifically address releases near buildings while the MACCS2 code specifically discusses the limitations near large buildings. The ARCON96 and WAKE results tracked very closely, with ARCON96 being slightly more conservative at 100 m and slightly less conservative at larger distances. Figure 3 provides a comparison of the ratios between the various code runs to illustrate the relative differences between the modeling tools. As indicated in Figure 3, WAKE and ARCON96 produce almost identical results when WAKE is adjusted for the plume meander. MACCS2 produces consistently higher results when compared to the other two models by slightly more than one order of magnitude for the same distances.

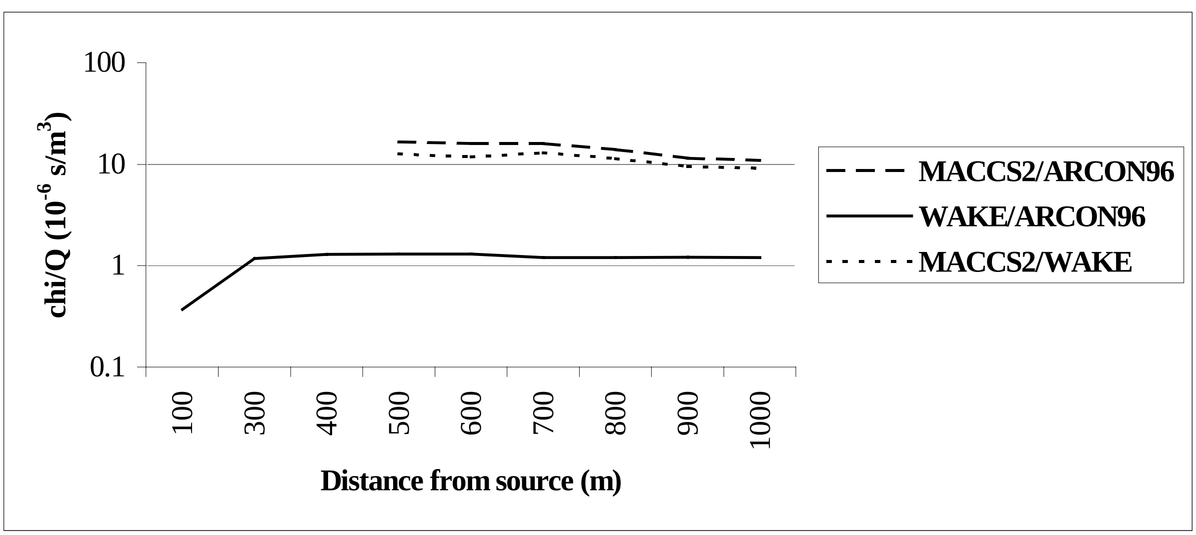

Figure 3. Comparison of 95th percentile χ/Qs ratios.

To understand the differences between the specific models, a more detailed review of the specific methods used to calculate plume meander and building wakes will be evaluated.

As indicated previously, ARCON96 treats plume meander with increased dispersion coefficients at low wind speeds. The effect can be approximated by reducing the χ/Q values at low wind speeds by a factor of 3 (a 67% decrease). MACCS2 also makes an adjustment for plume meander by increasing the "plume segment release duration." This adjustment does not correspond to the approach presented in NRC Regulatory Guide 1.145, position 1.3.1, but is derived from Gifford,[10] and Mueller and Reisinger.[11] As illustrated in Figure 4, the effect is not as pronounced. When the plume segment duration was increased from 600 s (the threshold for the plume meander expansion factor to increase the effective width of the plume) to 10,800 s (a factor of 18 in the plume segment release duration, which is equivalent to a plume meander expansion factor of 2.06), the χ/Q values decreased by about 34% (from 924 to 611) at 500 m and 52% (from 460 to 220) at 1000 m. This is a significantly smaller effect than the approach taken in ARCON96 and indicates that MACCS2 conservatively represents the effects of plume meander at low wind speeds in comparison to ARCON96.

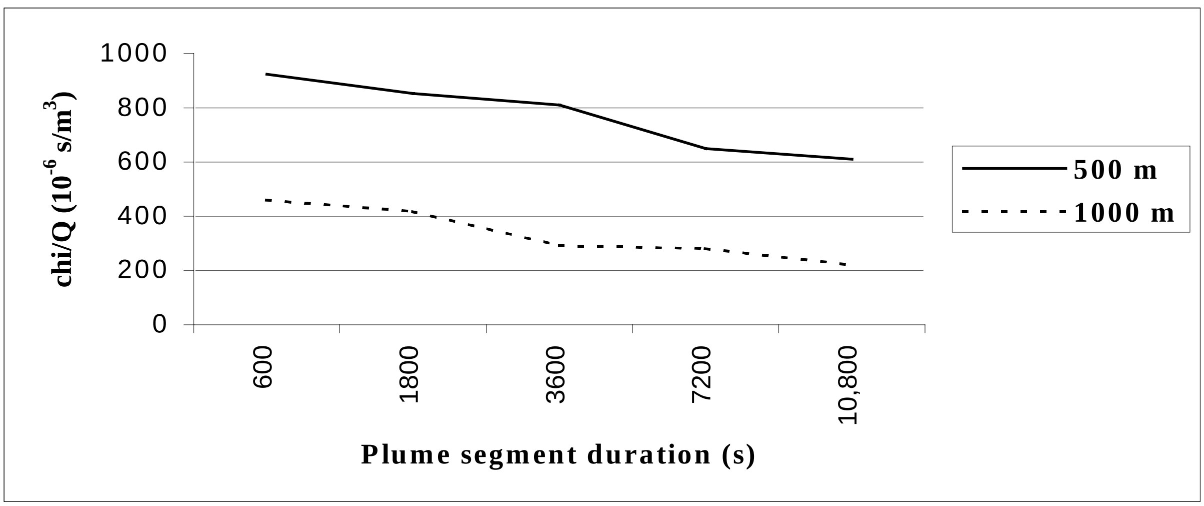

Figure 4. Effect of plume segment release duration on χ/Qs calculated by MACCS2.

Unlike plume meander, there is no direct way to compare the differing approaches to evaluating building wakes in ARCON96 and MACCS2. WAKE calculates plume behavior using the revised lift-off methodology presented in Hanna *et al*.,[7] which differs from the approach in MACCS2 and ARCON96. This approach has been widely reviewed and accepted as being the current state-of-the-science for evaluating building wakes. The results presented in Figure 3 clearly demonstrate that ARCON96 and WAKE have very comparable results when the effect of plume meander is included in WAKE. However, the differences between MACCS2 and WAKE are significant. For dispersion codes to have results that are as comparable as ARCON96 and

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[10] Gifford, F. "Atmospheric Dispersion Models for Environmental Pollution Applications," in *Lectures in Air Pollution and Environmental Impact Analysis*, (1975) D. A. Haugen ed., American Meteorological Association, Boston, Mass.
[11] Mueller, S. F. and L. M. Reissinger. "Measured Plume Width Versus Sampling Time: A Look Beyond 10 Kilometers," (1986) *Atmospheric Environment*, **20**, 895.

WAKE with the substantial differences in code formulation suggests that MACCS2 is substantially more conservative than ARCON96 and WAKE.

As indicated in the sensitivity analysis for ARCON96, the ARCON96 results did not vary significantly by changing building sizes with the 95th percent meteorological conditions calculated. Table 2 presents the results of evaluating the sensitivity of the χ/Q values calculated by MACCS2 to varying building sizes. The χ/Q values are reduced by about 55% (from 1820 to 810) at 500 m and 40% (from 483 to 291) at 1000 m when the building dimensions are increased from a negligible size to the dimensions used for calculating the results in Figure 2 (width of 75 m and height of 20 m). Table 2 demonstrates that MACCS2 is quite sensitive to building size for the 95th percentile meteorological conditions at Y-12, which are a stable meteorology with a low wind speed. Under low wind speeds with stable conditions, the effect of building size would be expected to be relatively small, especially at large distances downwind from a building. A reason for a difference in the χ/Q value of a factor of nearly 8 for differing building sizes at 500 m or of nearly 4 for differing building sizes at 1000 m is not immediately apparent. ARCON96 has been shown to be relatively insensitive to building size at Y-12 under 95th percentile meteorological conditions, which is consistent with what would be expected.

Table 2. Effect of building size on χ/Q (10^{-6} s/m^3) calculated by MACCS2.

Building width (m)	Building height (m)	σ_y	σ_z	χ/Q (500 m)	χ/Q (1000 m)
0.43	0.22	0.1	0.1	1820	483
37.5	10	8.7	4.7	1220	360
75	20	17.4	9.3	810	291
150	40	34.9	18.6	403	192
225	60	52.3	27.9	238	128

Summary

ARCON96 calculates the dispersion of hazardous materials consistent with the requirements set forth in Appendix A of DOE-STD-3009-94[3] relative to 95th percentile meteorological conditions. ARCON96 is an NRC approved code for performing dispersion analysis near control room intakes in nuclear power plants. The ARCON96 code makes adjustments for plume meander at low wind speeds consistent with NRC RG 1.145, position 1.3.1. The other major adjustment made for ground-level releases (i.e., building wake effects) has been shown to produce consistent results with WAKE, which is recognized as using the state-of-the-science for building wakes. The software has a significant level of quality assurance (changes from revision 0 did not receive the full quality assurance review process). However, for the portions of the code used in this analysis, the results were compared to the WAKE results, which do have the appropriate level of quality assurance. The code also has a user-friendly interface for inputting scenario and meteorological data.

ARCON96 produces less conservative results than MACCS2 because of the conceptual differences in modeling low wind speeds and building wakes. The treatment of building wakes by ARCON96 and MACCS2 was examined in detail, and an additional computer code with a building wake routine (WAKE) was used for additional comparison. ARCON96 compared well with WAKE when the effects of plume meander were incorporated into the WAKE results (within 30% except for 100 m, which is within a factor of 3). MACCS2 did not compare as well to the WAKE results (within a factor of 9 to 12 for distances greater than 500 m). Plume meander at low wind speeds is considered in ARCON96 using the methods described in Regulatory Guide 1.145, position 1.3.1. MACCS2 also considers plume meander at low wind speeds but uses a more conservative method.

Both MACCS2 and ARCON96 make use of the 95th percentile meteorological conditions determined from a statistical analysis of meteorological tower data. MACCS2 can only consider one year of data; ARCON96 can consider up to five years of data and automatically handle missing data. The consideration of low wind speeds and building wakes in the dispersion of hazardous materials is included in ARCON96 and MACCS2. These considerations are consistent with the requirements presented in Regulatory Guide 1.145 and are also addressed in Appendix A of DOE-STD-3009[3], which states:

> Accidents with unique dispersion characteristics, such as explosions, may be modeled using phenomenon-specific codes more accurately representing the release conditions. Discussion should be provided justifying the appropriateness of the model to the specific situation.

Since accidents with unique dispersion characteristics are major considerations in consequence analyses of facilities at the Y-12 Complex and the effects of low wind speeds and building wakes are important phenomena for the industrial setting of the Y-12 Complex, these two phenomena are appropriate for consideration in the modeling to be performed in support of the dispersion analysis at the Y-12 Complex.