A Comparison of ARCON96 vs. Murphy & Campe Including Case Study Results

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INTRODUCTION

Control room habitability analyses have been conducted to satisfy the requirements of General Design Criterion 19 (Ref. 1) of Appendix A to 10 CFR 50 for many years primarily using atmospheric relative concentration values (X/Qs) derived from the 1974 Murphy-Campe methodology (Ref. 2). Although other techniques have been proposed and used for this purpose (e.g., Halitsky K values) on a case by case basis, the Murphy-Campe technique has been the only methodology endorsed by the Nuclear Regulatory Commission (NRC) for general use until recently. With the publication of Draft Regulatory Guide DG-1111 in December 2001 (Ref. 3), the NRC is proposing, for the first time, a methodology that is generally acceptable to the staff for calculating control room X/Q values for use in design basis accident (DBA) radiological analyses other than Murphy & Campe. In fact, the Murphy-Campe methodology is referred to in DG-1111 as an alternative procedure.

The new procedure recommended in DG-1111 is described in NUREG/CR-6331 Revision 1, "Atmospheric Relative Concentrations in Building Wakes" (Ref. 4), and is coded as **A**tmospheric **R**elative **CON**centrations (ARCON). It is the result of many years of NRC sponsored studies conducted by Pacific Northwest National Laboratory (PNNL) evaluating the Murphy-Campe models using experimental data and developing alternative approaches. These studies found that the Murphy-Campe models did not reliably characterize the dispersion in the vicinity of buildings, nor accounted for plume meander, and were overly conservative in most cases. The ARCON96 methodology has been shown to provide a more realistic treatment of diffusion in building wakes, particularly under low wind speed conditions, for downwind distances as small as 10 meters.

With the advent of a promising new control room habitability X/Q methodology that provides more realistic results, a number of nuclear power plants have sought to make use of the ARCON96 code to obtain less conservative (i.e., more realistic) X/Qs for dose calculations, mainly associated with power uprate applications to the NRC. In many cases, especially for sites with a high frequency of very stable light wind speed conditions, ARCON96 has provided a marked reduction in X/Q values compared to the Murphy-Campe models. However, some sites saw an increase in X/Q values compared to those calculated using Murphy-Campe for certain release/receptor combinations, due primarily to the meteorological conditions of the site. These sites generally had less restrictive atmospheric dispersion conditions.

Both the ARCON96 and Murphy-Campe methodologies are acceptable to the NRC staff according to DG-1111. The purpose of this paper is provide an overview of the differences in the formulations of the ARCON96 and Murphy-Campe methodologies and to provide a comparison of X/Q values calculated by the two methods using a variety of nuclear power plant on-site meteorological databases. The key factors contributing to the differences in X/Q results are explored along with some insights on the application of ARCON96 to a control room habitability analysis and the aspects of most concern to the NRC.

DESCRIPTION OF ARCON96 METHODOLOGY

ARCON96 is a state-of-the-art computer code whose building wake/cavity algorithms have been validated by numerous wind tunnel measurements and whose lateral plume meander algorithms have been validated by in situ field tracer measurements. The ARCON96 code provides more realistic X/Q values than previous techniques for all of the time periods applicable to control room habitability evaluations, since it contains empirically derived adjustments to the lateral and vertical turbulence parameters, derived from the aforementioned wind tunnel and field tracer data.

The basic dispersion model implemented in ARCON96 is a straight-line Gaussian plume model that assumes the release rate is temporally invariant for the duration of each of the release periods. This is a typical assumption in straight-line steady state Gaussian codes. ARCON96 can be used for ground level, vent, or elevated releases but is not currently recommended by the NRC for vent or elevated release DBA analyses. Draft Regulatory Guide DG-1111 cautions against the use of the mixed mode (i.e., partially entrained/partially elevated) approach that is available for vent releases, and the elevated release model in cases where the receptor is located in close proximity to the stack. For ground-level releases, aerodynamic effects from building structures (e.g., building wake enhancement of vertical turbulence and cavity effects) are considered.

The dispersion coefficients used in ARCON96 have three components. The first component is the commonly used NRC POLYN curves for calculation of lateral (σ_y) and vertical (σ_z) atmospheric turbulence as a function of stability class and downwind distance. The other two components are corrections to account for enhanced dispersion under low wind speed conditions (i.e., plume meander) and in building wakes. Parameter values for the correction factors are based on analysis of diffusion data collected in various wind tunnel experiments. These experiments were conducted under a wide spectrum of meteorological conditions. However, a large number of the experiments that were considered were conducted during low wind speeds, when the effects of building wake vanish. The wake correction model treats diffusion under these conditions much better than any previous model, accounting for both low wind speed lateral turbulence meander and aerodynamic wake effects.

The form of the Gaussian plume model in ARCON96 for a ground-level release is as follows:

$$X/Q = [(u)(\pi)(\Sigma_y)(\Sigma_z)]^{-1} \exp -1/2\ (y/\sigma_y)^2$$

where:

X/Q =	relative concentration for a 1-hour period (sec/m^3)
Σ_y =	$[\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2]^{1/2}$ (m)
Σ_z =	$[\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2]^{1/2}$ (m)
σ_y =	normal atmospheric horizontal dispersion coefficient (m)
σ_z =	normal atmospheric vertical dispersion coefficient (m)
$\Delta\sigma_{y1}, \Delta\sigma_{z1}$ =	low wind speed corrections (m)
$\Delta\sigma_{y1}$ =	9.13E05[1 - (1+(x/1000u))exp(-x/1000u)]
$\Delta\sigma_{z1}$ =	6.67E02[1 - (1+(x/100u))exp(-x/100u)]
$\Delta\sigma_{y2}, \Delta\sigma_{z2}$ =	building wake corrections (m)
$\Delta\sigma_{y2}$ =	5.24E-02u^2A[1 - (1+(x/10$A^{1/2}$))exp(-x/10$A^{1/2}$)]
$\Delta\sigma_{z2}$ =	1.17E-02u^2A[1 - (1+(x/10$A^{1/2}$))exp(-x/10$A^{1/2}$)]
u =	wind speed (m/sec)
x =	downwind distance (m)
y =	horizontal distance from the center of the plume (m)
A =	cross-sectional area of the building (m^2)

The exponential term in the above equation becomes a factor of one for plume centerline concentrations. An upper limit of 1.81x is placed on Σ_y as a conservative measure. A sector-average model is used to estimate X/Q values for averaging periods longer than the 0-8 hour period. The sector width for this purpose is the larger of $\alpha\Sigma_y$ and $\pi x/8$ where α is a numerical constant with a default value of 4 in the ARCON96 code to be conservative.

There are various default options in ARCON96 that can be set by the user including parameters such as the sector averaging constant (α), wind direction sector width applicable to the source/receptor geometry, minimum wind speed, and the surface roughness length. Draft Regulatory Guide DG-1111, Table A-1 contains recommended values for these parameters. There is also a diffuse source option available whereby radiological releases distributed over a large area, such as a containment release, can be treated as a diffuse source rather than a point source. This option allows the user to input values of initial dispersion coefficients based on the dimensions of the diffuse source. Draft Regulatory Guide DG-1111, Table A-1 recommends that these values be based on the source width and height, divided by a factor of 6 for conservatism, for the values of initial horizontal and vertical dispersion coefficients, respectively.

ARCON96 uses hourly-average meteorological data in its calculation routines and then combines the hourly averages to estimate concentrations for averaging periods of up to 30 days. Wind direction is considered as the averages are formed. As a result, the averages account for persistence in both diffusion conditions and wind direction. Cumulative frequency distributions are prepared from the average relative concentrations and 95% values are determined for each averaging period. Finally, the relative concentrations for the five standard averaging periods (i.e., 0-2 hour, 2-8 hour, 8-24 hour, 1-4 day and 4-30 day) are determined from the 95th percentile relative concentrations. As an example, the 2-8 hour X/Q value is calculated as follows:

X/Q_{95} (2-8 hour) = [8 x X/Q_{95} (0-8 hour) - 2 x X/Q_{95} (0-2 hour)] / 6 hours

where X/Q_{95} (0-8 hour) and X/Q_{95} (0-2 hour) are 95^{th} percentile average values for 8 and 2 hours, respectively. The 6 hours is the length of the averaging period.

ARCON96 has been peer reviewed and is endorsed by the NRC for general use in Draft Regulatory Guide DG-1111 subject to the guidance contained in that document. Based on experience in using ARCON96 for power uprate applications, the NRC emphasis in reviewing these analyses has been on the proper application of the code to the given situation. The primary concerns of the NRC with respect to using ARCON96 under any circumstances (i.e., outside its application domain) have included the following:

- Use of ARCON96 for receptor distances of less than 10 meters,
- Use of the vent release (i.e., mixed mode option) for DBA analyses,
- Use of the elevated option in cases where the receptor is close to the stack base,
- Proper use of building wake effect,
- Use of 5 years of on-site data,
- Re-formatting of meteorological data to ARCON96 format and verification that proper wind speed units are used,
- Verification that the meteorological monitoring system has been properly maintained and that there are no new obstructions near the tower that could affect data spatial representativeness.

MURPHY-CAMPE MODELS

The Murphy-Campe models were developed in 1974 (Ref. 2) and, at that time, represented the state-of-the-art for calculating relative concentrations for control room habitability evaluations and thus enjoyed widespread use. Note that the first field studies that characterized the plume meander were not conducted until a year later.

Deleted:

The basic dispersion model implemented in Murphy-Campe is also a straight-line Gaussian plume model. The Murphy-Campe approach recommends the point source - point receptor technique for X/Q calculation from Section V(B)(1)(a) be used when the elevation difference between a point source and a point receptor is less than or equal to 30 percent of the building height. Otherwise, the diffuse source - point receptor technique for X/Q calculation from Section V(B)(1)(b) is recommended for point and diffuse sources.

The X/Q equations are as follows:

$X/Q = [3u\pi\sigma_y\sigma_z]^{-1}$ (point source - point receptor)

$X/Q = [u(\pi\sigma_y\sigma_z + A/(K+2))]^{-1}$ (diffuse source - point receptor)

where:

X/Q is relative concentration (sec/m^3)
σ_y, σ_z are horizontal and vertical dispersion coefficients based on stability class and horizontal distance (m)
u = wind speed at 10-meter elevation (m/sec)
3 = wake factor based on Regulatory Guides 1.3 and 1.4
A = cross-sectional containment structure area (m^2)
$k = 3/(s/d)^{1.4}$
s = source to receptor distance (m)
d = containment structure width (m)

The above relationships are used to calculate the 0 - 2 hour X/Q value based on site meteorological data, selecting the wind speed and stability class combination that represents the 5-percentile dispersion condition at the site. The 5-percentile wind speed and stability class combination is determined from the on-site meteorological data considering only those wind directions resulting in receptor exposure. The number of wind direction sectors to be considered for each source-receptor relationship is determined using Figure 2 of Murphy and Campe which is based on the ratio of the source to receptor distance (s) to the diameter (d) or width of the building from which the release emanates (s/d ratio). The number of possible 22.5-degree sectors ranges from three to ten.

The intermediate averaging time X/Qs (i.e., 8-24 hours, 1-4 days, and 4-30 days) are determined from the calculated 0-2 hour X/Q value multiplying by control room occupancy, wind speed, and wind direction factors in accordance with Ref. 2. These factors are as follows:

Averaging Time	Occupancy Factor	Wind Speed Factor	Wind Direction Factor
0 - 2 Hours	1	1	1
8 - 24 Hours	1	5%/10% wind speed	0.75 + F/4
1 - 4 Days	0.6	5%/20% wind speed	0.50 + F/2
4 - 30 Days	0.4	5%/40% wind speed	F

F is the fraction of time the wind blows the activity toward the receptor.

COMPARISON OF ARCON96 AND MURPHY-CAMPE CONTROL ROOM X/Q RESULTS

The results of a number of case study control room X/Q calculations performed using both the ARCON96 and Murphy-Campe methodologies are presented and compared in this section. A total of nine different sets of on-site meteorological databases were used in these calculations along with a variety of release point types and source to receptor distances. These release point types include diffuse source releases from containment building walls and a number of point source releases from containment tops, vents, main steam relief valves, and main steam line breaks. All of the radiological sources for these calculations were treated as ground-level releases. Elevated release control room X/Q calculations are generally performed using other methods (e.g., Regulatory Guide 1.145, Ref. 5).

The calculations were performed in accordance with the guidance provided for each methodology. This guidance includes the differentiation of diffuse and point sources, the use of applicable building cross-sectional areas to account for wake effects, the use of the wind direction window causing receptor exposure (i.e., 90-degree sector for ARCON96 and variable sector width based on s/d ratio for Murphy-Campe) and the 95th percentile dispersion condition meteorology.

Input data to ARCON 96 consists of:

1) Hourly onsite meteorological data;

2) Release characteristics including height, flow rate, and building area affecting the release; and

3) Receptor information including distance and azimuth direction from the release to the control room air intake and intake height.

It should be noted that the shortest horizontal distance from the release to the receptor is input to ARCON96 but that the program actually calculates a slant range distance to account for differences in release/receptor elevation. The default options in ARCON96, including items such as the sector averaging constant, wind direction sector width applicable to the source/receptor geometry, minimum wind speed, and the surface roughness length, were set in accordance with either direction from the NRC or the DG-1111, Table A-1 recommendations.

The Murphy-Campe calculations require information on the source to receptor distance and direction, source and receptor heights above grade, release point diameter or width, cross-sectional building area, and the 5-percentile dispersion condition (i.e., wind speed and stability class). The 10%, 20% and 40% wind speeds also need to be manually extracted from the meteorological database to determine the wind speed correction factors as well as the frequency of winds blowing in the wind direction window of interest (F).

The comparison of the ARCON96 versus Murphy-Campe X/Q results for the various sites examined (Sites A through I) is provided in Tables 1-4 for sites with relatively low average wind speeds and in Table 5 for sites with moderate average wind speeds. In this context, low-wind speed sites generally have 5-percentile wind speeds of less than 2 meters per second while moderate-wind speed sites have greater than 2 meter per second 5-percentile wind speeds. The tables are divided in this manner as there is a fairly consistent pattern of lower ARCON96 X/Q values compared to the Murphy-Campe values at low wind speed sites. This pattern is generally reversed at moderate wind speed sites but not in all cases. The tables provide the calculated Murphy-Campe and ARCON96 X/Q values (i.e., sec/m^3) for the standard averaging periods along with the ratio of the Murphy-Campe to ARCON96 X/Qs referred to as “credit”. Credit values greater than one indicate the degree of improvement (i.e., less conservative) obtained by using the ARCON96 methodology.

As can be seen from Table 1 showing the X/Q comparisons for Site A, a low-wind speed site, there is generally a significant improvement (i.e., lower values) in X/Q values using ARCON96. The degree of improvement or “credit” tends to maximize in the 8-24 hour averaging period and is generally a minimum in the 4-30 day averaging period. In fact, there are times when there is improvement in the ARCON96 X/Qs for all averaging periods except for the 4-30 day period. The ARCON96 method of calculating averages based on running mean values of X/Qs using the hourly meteorological data versus the Murphy-Campe wind speed and wind direction factors has a tendency to result in higher X/Qs for the longer averaging times (i.e., 1-4 days and 4-30 days). The degree of improvement in ARCON96 X/Q values also appears to be a function of the distance (x) from the release to the receptor where greater distances result in greater improvement.

A similar pattern exists for the Site B (i.e., low wind speed) X/Q comparisons in Table 2 but to a lesser degree in terms of credit obtained in going from Murphy-Campe to ARCON96, presumably due to differences in the meteorological databases. The same averaging time pattern also exists in this case but with a couple of instances of higher 0-2 hour X/Qs being calculated by ARCON96. The Table 3 results for Site C maintain the same pattern discussed above but with no increases in ARCON96 X/Qs for the 4-30 day averaging period. This result is likely due to the low wind speed nature of the site. The Site D results in Table 4 support the consistency of the pattern of lower ARCON96 X/Qs versus Murphy-Campe at low wind speed sites.

Table 5 provides the X/Q comparisons for the higher wind speed sites (Sites E through I) with Sites G through I being marginally moderate wind speed sites. The Site E results show consistently higher ARCON96 X/Q values than those determined using Murphy-Campe (i.e., “credit” values less than 1) due to the higher wind speeds. The same general pattern relative to the effect of averaging time on the X/Q ratios is maintained with the greatest differences occurring in the longer averaging times. The Site F meteorology produces very similar ARCON96 versus Murphy-Campe X/Q values with ratios of nearly one with the exception of the 4-30 day period. The remaining sites (i.e., Sites G through I) show slight improvement in the ARCON96 X/Q values with the exception of the longer averaging times.

The tendency for ARCON96 to produce lower X/Q values than the Murphy-Campe technique at low wind speed sites can be explained primarily from the formulation of the dispersion coefficients. As discussed earlier, ARCON96 addresses both low wind speed lateral turbulence meander and aerodynamic wake effects in its formulations. The ARCON96 dispersion coefficients are essentially dominated by the plume meander component at low wind speeds and by the aerodynamic wake effects at higher wind speeds. Therefore, there is generally a wind speed range within which the contribution of these two phenomena to the dispersion coefficient values are very similar. Under stable atmospheric conditions, this wind speed range is on the order of 3 to 4 meters per second which means that the ARCON96 X/Q values will tend to maximize at these speeds, not at the lowest wind speeds as in Murphy-Campe. Therefore, the performance of ARCON96 versus Murphy-Campe is very much dependent on the characteristic wind speeds of the site.

CONCLUSIONS

This paper has provided an overview of the differences in the formulations of the ARCON96 and Murphy-Campe methodologies and a comparison of Χ/Q values calculated by the two methods for several case studies using a variety of nuclear power plant on-site meteorological databases. Although both methodologies are based on the straight-line steady state Gaussian plume model, there are important differences in formulations relative to the treatment of dispersion near buildings. The ARCON96 wake correction model treats diffusion much better than any previous model, empirically accounting for both low wind speed lateral turbulence meander and aerodynamic wake effects. Parametric values for the correction factors are based on analysis of diffusion data collected in various building wake experiments. Murphy-Campe only generally deals with building wake effect since many of the wind tunnel studies that refined the ARCON96 turbulence coefficients had not yet been conducted.

The comparison of ARCON96 and Murphy-Campe Χ/Q calculations for a number of different sites and release types indicates that ARCON96 does generally provide lower Χ/Q values than Murphy-Campe, sometimes to a significant degree, but that its performance is very much dependent on the meteorology of a given site. The less conservative ARCON96 Χ/Q values are generally associated with low wind speed sites and may actually provide higher Χ/Q values than Murphy-Campe at higher wind speed sites. In addition, the differences in calculated Χ/Q values tend to maximize at the 8-24 hour averaging period with the smallest differences generally occurring at the 4-30 day averaging period. The dominance of the low wind speed plume meander correction to the dispersion coefficients is the primary contributor to the lower ARCON96 Χ/Q values at low wind speeds. The ARCON96 Χ/Q values tend to maximize at some intermediate wind speed (e.g., 3-4 meters per second) rather than at the lowest wind speeds as in Murphy-Campe.

It is also important for the analyst to be aware of the key elements of concern to the NRC in applying ARCON96 to a given situation. These elements include:

1) Proper use of 5 years of representative meteorological data including the re-formatting of the data and use of correct wind speed units;

2) Avoiding inappropriate options such as vent and elevated releases for DBA accident analyses;

3) Not using ARCON96 for distances less than 10 meters; and

4) Proper application of cross-sectional building area for wake effect.

REFERENCES

1. 10 CFR 50, Appendix A, General Design Criterion 19.

2. Murphy, K.G., and Campe, K.M., "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Design Criterion 19", Presented at the 13th Air Cleaning Conference, 1974.

3. U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Draft Regulatory Guide DG-1111, "Atmospheric Relative Concentrations for Control Room Habitability Assessments at Nuclear Power Plants", December 2001.

4. Ramsdell, J. V. Jr. and C. A. Simonen, "Atmospheric Relative Concentrations in Building Wakes". Prepared by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission, PNL-10521, NUREG/CR-6331, Rev. 1, May 1997.

5. U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants", Revision 1, November 1982.

TABLE 1

Comparison of ARCON96 and Murphy-Campe Control Room χ/Q Values for Site A (Low Wind Speed)

95th Percentile χ/Q Values (sec/m^3)

Site A: Unit 1 Containment Edge (x = 75 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	2.88E-03	2.88E-03	1.90E-03	6.62E-04	1.41E-04
ARCON96	4.88E-04	4.07E-04	1.79E-04	1.41E-04	1.22E-04
Credit	5.9	7.1	10.6	4.7	1.2
Site A: Unit 1 Containment Top (x = 94 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	2.51E-03	2.51E-03	1.66E-03	5.77E-04	1.23E-04
ARCON96	5.93E-04	4.63E-04	1.84E-04	1.34E-04	1.16E-04
Credit	4.2	5.4	9.0	4.3	1.1
Site A: Unit 1 Auxiliary Building (x = 28 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	8.24E-03	8.24E-03	6.01E-03	2.32E-03	6.18E-04
ARCON96	6.48E-03	4.91E-03	1.95E-03	1.45E-03	1.19E-03
Credit	1.3	1.7	3.1	1.6	0.5
Site A: Unit 1 Main Steam Line Break (x = 35 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	7.81E-03	7.81E-03	5.55E-03	2.11E-03	7.11E-04
ARCON96	4.24E-03	3.87E-03	1.69E-03	1.18E-03	1.06E-03
Credit	1.8	2.0	3.3	1.8	0.7
Site A: Unit 1 Main Steam Relief Valves (x = 86 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	2.97E-03	2.97E-03	1.94E-03	6.92E-04	1.54E-04
ARCON96	7.46E-04	6.31E-04	2.62E-04	1.98E-04	1.62E-04
Credit	4.0	4.7	7.4	3.5	0.9

TABLE 1: CONTINUED

95th Percentile Χ/Q Values (sec/m^3)

	Site A: Unit 2 Containment Edge (x = 72 m)				
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	4.16E-03	4.16E-03	2.81E-03	1.09E-03	1.58E-04
ARCON96	4.82E-04	3.59E-04	1.55E-04	1.21E-04	9.18E-05
Credit	8.6	11.6	18.1	9.0	1.7
	Site A: Unit 2 Containment Top (x = 93 m)				
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	3.65E-03	3.65E-03	2.47E-03	9.56E-04	1.39E-04
ARCON96	5.56E-04	4.45E-04	1.91E-04	1.39E-04	9.35E-05
Credit	6.6	8.2	12.9	6.9	1.5
	Site A: Unit 2 Auxiliary Building (x = 25 m)				
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	1.33E-02	1.33E-02	9.30E-03	3.94E-03	1.20E-03
ARCON96	4.82E-03	3.20E-03	1.58E-03	1.13E-03	8.07E-04
Credit	2.8	4.2	5.9	3.5	1.5
	Site A: Unit 2 Main Steam Line Break (x = 54 m)				
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	6.46E-03	6.46E-03	4.90E-03	2.00E-03	5.75E-04
ARCON96	1.22E-03	8.69E-04	3.66E-04	2.71E-04	2.02E-04
Credit	5.3	7.4	13.4	7.4	2.9
	Site A: Unit 2 Main Steam Relief Valves (x = 91 m)				
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	7.75E-03	7.75E-03	5.63E-03	1.99E-03	3.26E-04
ARCON96	5.01E-04	3.58E-04	1.61E-04	1.19E-04	8.32E-05
Credit	15.5	21.7	35.0	16.7	3.9

TABLE 2

Comparison of ARCON96 and Murphy-Campe Control Room χ/Q Values for Site B (Low Wind Speed)

95th Percentile χ/Q Values (sec/m^3)

Site B: Unit 1 Containment Edge (x= 46 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	2.10E-03	2.10E-03	1.40E-03	5.20E-04	1.40E-04
ARCON96	1.04E-03	7.60E-04	3.04E-04	2.73E-04	2.14E-04
Credit	2.0	2.8	4.6	1.9	0.7
Site B: Auxiliary Building Stack (x = 59 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	1.70E-03	1.70E-03	1.20E-03	4.00E-04	9.00E-05
ARCON96	1.75E-03	1.25E-03	4.52E-04	3.34E-04	2.91E-04
Credit	1.0	1.4	2.7	1.2	0.3
Site B: Unit 1 Main Steam Relief Valves (x = 45 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	2.10E-03	2.10E-03	1.40E-03	5.20E-04	1.40E-04
ARCON96	2.77E-03	2.02E-03	6.79E-04	5.63E-04	4.65E-04
Credit	0.8	1.0	2.1	0.9	0.3
Site B: Unit 2 Containment Edge (x = 31 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	3.00E-03	3.00E-03	1.90E-03	7.10E-04	1.90E-04
ARCON96	1.34E-03	1.02E-03	3.88E-04	3.04E-04	2.23E-04
Credit	2.2	2.9	4.9	2.3	0.9
	Site B: Unit 2 Main Steam Relief Valves (x = 34 m)				
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	2.70E-03	2.70E-03	1.80E-03	6.50E-04	1.60E-04
ARCON96	3.75E-03	2.58E-03	9.28E-04	7.58E-04	6.91E-04
Credit	0.7	1.1	1.9	0.9	0.2

TABLE 3

Comparison of ARCON96 and Murphy-Campe Control Room X/Q Values for Site C (Low Wind Speed)

95th Percentile X/Q Values (sec/m^3)

Site C: Building Vent to Intake 1					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	3.48E-04	2.94E-04	2.53E-04	2.01E-04	1.44E-04
ARCON96	1.20E-04	9.96E-05	4.85E-05	3.15E-05	2.02E-05
Credit	2.9	3.0	5.2	6.4	7.1
Site C: Building Vent to Intake 2					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	3.48E-04	2.94E-04	2.53E-04	2.01E-04	1.44E-04
ARCON96	2.17E-04	1.64E-04	7.89E-05	4.33E-05	3.35E-05
Credit	1.6	1.8	3.2	4.6	4.3
Site C: Ground-Level Release to Intake 1					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	3.70E-03	2.38E-03	1.91E-03	1.19E-03	5.97E-04
ARCON96	2.00E-04	1.28E-04	5.72E-05	4.05E-05	3.09E-05
Credit	18.5	18.6	33.4	29.4	19.3
Site C: Ground-Level Release to Intake 2					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	1.20E-03	7.91E-04	6.42E-04	4.09E-04	2.14E-04
ARCON96	8.60E-05	6.46E-05	2.80E-05	2.00E-05	1.53E-05
Credit	14.0	12.2	22.9	20.5	14.0

TABLE 4

Comparison of ARCON96 and Murphy-Campe Control Room X/Q Values for Site D (Low Wind Speed)

95th Percentile X/Q Values (sec/m^3)

Site D: Unit 1 Vent to Intake 1					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	3.84E-03	2.03E-03	1.68E-03	1.18E-03	8.89E-04
ARCON96	7.96E-04	4.68E-04	2.23E-04	1.78E-04	1.44E-04
Credit	4.8	4.3	7.5	6.6	6.2
Site D: Unit 1 Vent to Intake 2					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	4.07E-03	2.47E-03	1.97E-03	1.37E-03	9.84E-04
ARCON96	4.03E-03	3.35E-03	1.54E-03	1.05E-03	8.81E-04
Credit	1.0	0.7	1.3	1.3	1.1
Site D: Unit 2 Vent to Intake 1					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	2.53E-03	1.72E-03	1.46E-03	1.04E-03	7.23E-04
ARCON96	2.60E-03	2.16E-03	1.02E-03	6.96E-04	5.71E-04
Credit	1.0	0.8	1.4	1.5	1.3
Site D: Unit 2 Vent to Intake 2					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	1.70E-03	1.10E-03	9.44E-04	6.73E-04	4.64E-04
ARCON96	5.85E-04	3.89E-04	1.93E-04	1.47E-04	1.17E-04
Credit	2.9	2.8	4.9	4.6	4.0

TABLE 5

Comparison of ARCON96 and Murphy-Campe Control Room X/Q Values for Sites E-I (Moderate Wind Speed Sites)

95th Percentile X/Q Values (sec/m^3)

Site E: Unit 1 Containment Edge (x = 31 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	4.05E-03	4.05E-03	1.90E-03	9.55E-04	3.42E-04
ARCON96	6.10E-03	5.30E-03	2.66E-03	2.00E-03	1.52E-03
Credit	0.7	0.8	0.7	0.5	0.2
Site E: Unit 2 Containment Edge (x = 31 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	4.05E-03	4.05E-03	1.90E-03	9.55E-04	3.42E-04
ARCON96	6.04E-03	5.30E-03	2.68E-03	1.98E-03	1.53E-03
Credit	0.7	0.8	0.7	0.5	0.2
Site F: Unit 1 Containment Edge (x = 31 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	6.24E-03	6.24E-03	3.16E-03	1.40E-03	3.50E-04
ARCON96	6.08E-03	5.32E-03	2.79E-03	1.82E-03	1.32E-03
Credit	1.0	1.2	1.1	0.8	0.3
Site F: Unit 2 Containment Edge (x = 31 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	6.24E-03	6.24E-03	3.16E-03	1.40E-03	3.50E-04
ARCON96	6.20E-03	5.37E-03	2.74E-03	1.80E-03	1.31E-03
Credit	1.0	1.2	1.2	0.8	0.3

TABLE 5: CONTINUED

95th Percentile X/Q Values (sec/m^3)

Site G: Main Steam Relief Valves (x = 69 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	1.29E-03	1.29E-03	7.61E-04	4.84E-04	2.13E-04
ARCON96	1.13E-03	9.45E-04	4.54E-04	2.68E-04	1.67E-04
Credit	1.1	1.4	1.7	1.8	1.3
Site H: Main Steam Relief Valves (x = 67 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	1.29E-03	1.29E-03	7.61E-04	4.84E-04	2.13E-04
ARCON96	1.24E-03	1.08E-03	5.29E-04	3.43E-04	2.72E-04
Credit	1.0	1.2	1.4	1.4	0.8
Site I: Main Steam Relief Valves (x = 30 m)					
	0 - 2 hr	**2 - 8 hr**	**8 - 24 hr**	**1 - 4 day**	**4 - 30 day**
Murphy-Campe	3.19E-03	3.19E-03	2.05E-03	7.61E-04	2.13E-04
ARCON96	2.85E-03	2.31E-03	9.84E-04	8.83E-04	7.82E-04
Credit	1.1	1.4	2.1	0.9	0.3