Application of the ARCON96 Atmospheric Dispersion Model to Browns Ferry Nuclear (BFN) CREVS Intake χ/Q Calculations

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REGULATORY BACKGROUND AND NEED FOR ANALYSIS

Since 1992, Nuclear Regulatory Commission (NRC) officials and Browns Ferry Nuclear (BFN) Plant management have discussed the compliance of the design and operation of the Control Room Emergency Ventilation System (CREVS) with General Design Criterion (GDC) 19 of Appendix A to 10 CFR 50 (Reference 1). In July 1992, in support of control room dose calculations, normalized concentrations (i.e., χ/Q values) were calculated, using methodology identified in Regulatory Guide 1.145 (Reference 2) and Regulatory Guide 1.111 (Reference 3) for 4 applicable radiological release scenarios:

1. Top of the stack Standby Gas Treatment System (SGTS) radiological release under inversion breakup fumigation conditions for the 0.0-0.5-hour post-accident period;

2. Top of the stack SGTS radiological release for the remaining 0.5 hour-30-day post-accident period;

3. Bottom of the stack SGTS leakage of 10 cfm for the 0-30 day post-accident period;

4. Main Steam Isolation Valve (MSIV) leakage through the turbine building vents for the 0-30 day post-accident period.

When all of the control room dose calculations were completed, it was determined that the 0-30 day control room doses were within GDC 19 limitations. Over the next 2 years, many additional refinements were made to the Control Room habitability evaluations in response to several NRC Requests for Additional Information (RAI).

In February 1998, NRC issued a new RAI concerning the CREVS during its review of the BFN application for a 5% power uprate. The CREV system was upgraded during the recovery of Unit 2 and Unit 3 in the early 1990's from a redundant 500-cfm pressurization fan system, to a redundant 3,000-cfm pressurization fan system. The upgrade was in response to concerns based on a test that indicated unfiltered in-leakage was much higher than previously expected. There were numerous meetings and correspondence with the NRC during this time period, but a Safety Evaluation Report (SER) was never issued by the NRC. This RAI resulted in another series of meetings and correspondence between TVA and NRC associated with the following major issues and subsequent BFN actions:

1) Concerns regarding the χ/Q methodology used during the 1992-1994 time period and its application to the dual intake configuration for control room ventilation installed during that period. BFN agreed to re-evaluate all χ/Q values and to report the results to the NRC;

2) MSIV leakage was assumed to leak into the secondary containment in the current design and licensing basis. Standard Review Plan 15.6.5, Appendix D, "Radiological Consequences of a Design Basis Loss of Coolant Accident: Leakage from Main Steam Isolation Valve Control System (BWR)" (Reference 4), requires MSIV leakage to bypass secondary containment and be released directly to the atmosphere. BFN agreed to re-evaluate the results of the Design Basis Accident (DBA) Loss of Coolant Accident (LOCA) in accordance with SRP 15.6.5, and report the results to NRC; and,

3) Emergency Core Cooling System (ECCS) leakage was not considered in the current design and licensing basis. SRP 15.6.5, Appendix B: Radiological Consequences of a Design Basis Loss of Coolant Accident: Leakage From Engineered Safety Feature Components" (Reference 5), requires postulated leakage from ECCS components outside containment to be considered in the evaluation of the DBA LOCA. BFN agreed to consider leakage from the ECCS components outside containment in accordance with SRP 15.6.5, in a re-evaluation of the DBA LOCA, and report the results to the NRC.

The control room thyroid doses during a DBA LOCA using χ/Q values from the Murphy & Campe methodology (Reference 6), **without the inclusion of MSIV and ECCS leakage,** were calculated using TVA radiological codes STP (Reference 7) and COROD (Reference 8). These results are presented in Table 1 below:

RELEASE POINT	**UNIT 1 INTAKE (NEAREST)**	**UNIT 3 INTAKE (FARTHEST)**
Bottom of Stack	**12.62**	**4.45**
Top of Stack	**1.71**	**3.43**
TOTAL	**14.33**	**7.88**

Dose = [(Unit 1 Intake + Unit 3 Intake)/2] = [(14.33 + 7.88)/2] = 11.11 rem

Table 1: Thyroid Dose without MSIV and ECCS Leakage.

Since the CREVS air intakes are not designed to be isolated, the total dose is calculated by summing the dose contributions at each intake and dividing by the number of intakes, since 50% of the control room makeup flow is from each intake. This is an extremely conservative approach since it assumes that the centerline of the plume occurs at both intakes simultaneously, when realistically it can occur at only one intake structure at a time. This conservatism was explored and confirmed by a simultaneous contamination analysis, which will be discussed later.

The primary purpose of this paper is to document the results of a relatively recent methodology, as applied to the calculation of control room χ/Q values at the Browns Ferry Nuclear Plant. This methodology is described in NUREG/CR-6331, "Atmospheric Relative Concentrations in Building Wakes" (Reference 9), and is coded as **A**tmospheric **R**elative **CON**centrations (ARCON). The ARCON96 version of the code was developed for the NRC explicitly for control room habitability determinations. It was the result of many years of effort by Pacific Northwest National Laboratories (PNNL), a technical consultant to the NRC.

DESCRIPTION OF ARCON96 CONTROL ROOM HABITABILITY χ/Q MODEL

ARCON96 is an easy-to-use state-of-the-art 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 measurements. The ARCON96 code provides more realistic and defendable χ/Q values for all of the time periods applicable to control room habitability evaluations designed to show compliance to GDC 19. ARCON is described in detail in NUREG/CR-6331.

The ARCON code uses hourly meteorological data and recently-developed methods for estimating dispersion in the vicinity of buildings to calculate relative concentrations (i.e., χ/Q values) at control room air intakes that would be exceeded no more than five percent of the time. These concentrations are calculated for averaging periods ranging from one hour to 30 days in duration. Accordingly, 0-2 hour, 2-8 hour, 8-24 hour, 1-4 day, and 4-30 day period χ/Q values are directly calculated without the need for application of logarithmic interpolation techniques. Only the 0-0.5 hour top of stack release under fumigation conditions was outside of the ARCON96 calculation domain.

As will be shown in the section that addresses the comparison to earlier calculations, the relative concentrations calculated by ARCON96 are significantly lower than concentrations calculated using the combined Regulatory Guide 1.145-Regulatory Guide 1.111-Murphy & Campe technique (or Murphy-Campe for short). From a series of unpublished parametric studies conducted by PNNL when it was alpha- and beta-testing ARCON96, it was concluded that it is generally true that ARCON96 produces lower χ/Q values than the Murphy-Campe when wind speeds are less than 2 meters per second. For wind speeds greater than this 2 meter per second value, the ARCON96 and Murphy-Campe techniques produce converging results. The important difference in the ARCON96 technique is the application of the lateral turbulence plume meander factor, which is a significant component of additional crosswind dispersion that generally occurs at nighttime under light wind speed- very stable atmospheric conditions.

Personal communication with the ARCON96 developer on this matter, without revealing any specific nuclear power plant, confirmed this expectation. The developer indicated that when comparing ARCON96 to Murphy-Campe for numerous nuclear power plants, due to its small roughness length and rural setting, the Browns Ferry Nuclear Plant exhibited the largest difference (Reference 10). This conclusion is reasonable since light wind-very stable conditions occur quite frequently at Browns Ferry. In fact, their frequency is essentially the 95% worst case meteorology.

Recently, the Nuclear Energy Institute (NEI) issued a draft White Paper, "New χ/Q Methodologies and Their Impact on Control Room Habitability" (Reference 11). The draft White Paper, which compared ARCON96 with Murphy-Campe, concluded:

"The ratios of the ARCON96 to Murphy-Campe results indicate that the Murphy-Campe χ/Qs may be overly conservative by more than a factor of 10".

For sites with higher average wind speeds and fewer very stable to extremely stable conditions, the difference between ARCON96 and Murphy-Campe are smaller, and in some cases, vanish.

The basic diffusion model implemented in ARCON96 is a straight-line Eulerian frame of reference Gaussian plume model that assumes that the release rate is temporally invariant for the duration of each of the release periods. This is a typical assumption in straight-line Gaussian codes. ARCON96 is applicable to ground level, vent, or elevated releases. For ground-level releases, aerodynamic effects from building structures (e.g., building wake enhancement of vertical turbulence, cavity effects) are considered.

Vent releases are treated as a mixed-mode, a ground level, or an elevated release, following the guidance of the NRC XOQDOQ code (Reference 12). The mixed-mode release, which was based on field studies conducted at the Millstone Nuclear Power Plant in the late-1970's, use the V_e/u ratio to determine the amount of the plume that remains elevated. V_e, or efflux velocity, can be looked upon as an escape velocity. The larger the efflux velocity, the better the chance that the vent release can escape the aerodynamic (and potential down washing) effects of the building on the wind field and reach the unaffected portion of the atmosphere. Conversely, the wind speed can be looked upon as a capture velocity. The faster that the wind is moving, the better the chance that the plume will not escape the aerodynamic effects of the building. Accordingly, the V_e/u ratio is critical in determining whether the vent release will be either ground level, mixed mode, or elevated.

Elevated releases are treated in the usual manner with correction for stack tip down wash and differences in terrain elevation (i.e., zero-plane adjustment) between the release point and the control room intake.

Diffusion coefficients have three components. The first component is the commonly NRC-used POLYN curves for calculation of lateral and vertical 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 and in building wakes. Derivations of these equations from field and wind tunnel measurements are described in "Atmospheric Dispersion Estimates in the Vicinity of Buildings" (Reference 13). Parameter values for the correction factors are based on analysis of diffusion data collected in various building wake 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 models; accounting for both low wind speed lateral turbulence meander and aerodynamic wake effects.

ARCON96 uses hourly meteorological data in its calculation routines and then combines the hourly averages to estimate concentrations for 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 hr, 2-8 hr, 8-24 hr, 1-4 day and 4-30 day) are calculated from the 95th percentile relative concentrations.

TECHNICAL SUPERIORITY OF ARCON96 VERSUS MURPHY-CAMPE MODEL

The Murphy-Campe model was developed in 1974. At that time, it represented the state-of-the-art for calculating relative concentrations for control room habitability evaluations; and thus enjoyed widespread use. Since its publication, there have been significant field studies and wind tunnel studies that have provided better in situ definition of the building wake and lateral plume meander components. Essentially, the building wake and plume meander "black boxes" were opened after Murphy-Campe was published. In 1975, field studies were conducted nearby St. Francisville, Louisiana, which revealed the magnitude of the lateral meander under light wind speed - stable conditions. After many years of discussion with the NRC, the meander factor was included as part of Regulatory Guide 1.145. However, the Murphy-Campe technique was not updated to include this new knowledge. In 1978, field studies were conducted at the Millstone Nuclear Plant in eastern Connecticut, to determine vent release criteria in the vicinity of buildings. The results of this work, which led to the definition of a mixed mode release, was integrated in Regulatory Guide 1.111, but not Regulatory Guide 1.145 or Murphy-Campe. Lastly, the results of comprehensive wind tunnel studies associated with defining complex wind fields in the Rancho Seco Nuclear Generation Station (Reference 14) were not included in the Murphy-Campe technique.

ARCON96 has been peer reviewed and endorsed by the NRC. It was developed by a researcher in a national laboratory, PNNL, under contract to the NRC. It's primary author, Dr. Van Ramsdell, is well-recognized by his peers relative to his understanding and grasp of planetary boundary layer meteorology.

An examination of the facts leads to the conclusion that ARCON96 has incorporated the most recent research, has been developed by a reputable national laboratory and senior scientist, and has been peer reviewed. In contrast, Murphy-Campe still remains a relatively good 24-year old technique, but suffers from not including recent research in its methodology. In the dispersion modeling community, the operative term is evolve or die. In order for Murphy-Campe to pass technical muster at this point in time, it would have to be upgraded to consider the planetary boundary layer variables that ARCON96 addresses.

APPLICATION OF ARCON96 TO BFN CONTROL ROOM HABITABILITY DETERMINATION

ARCON Input Parameters

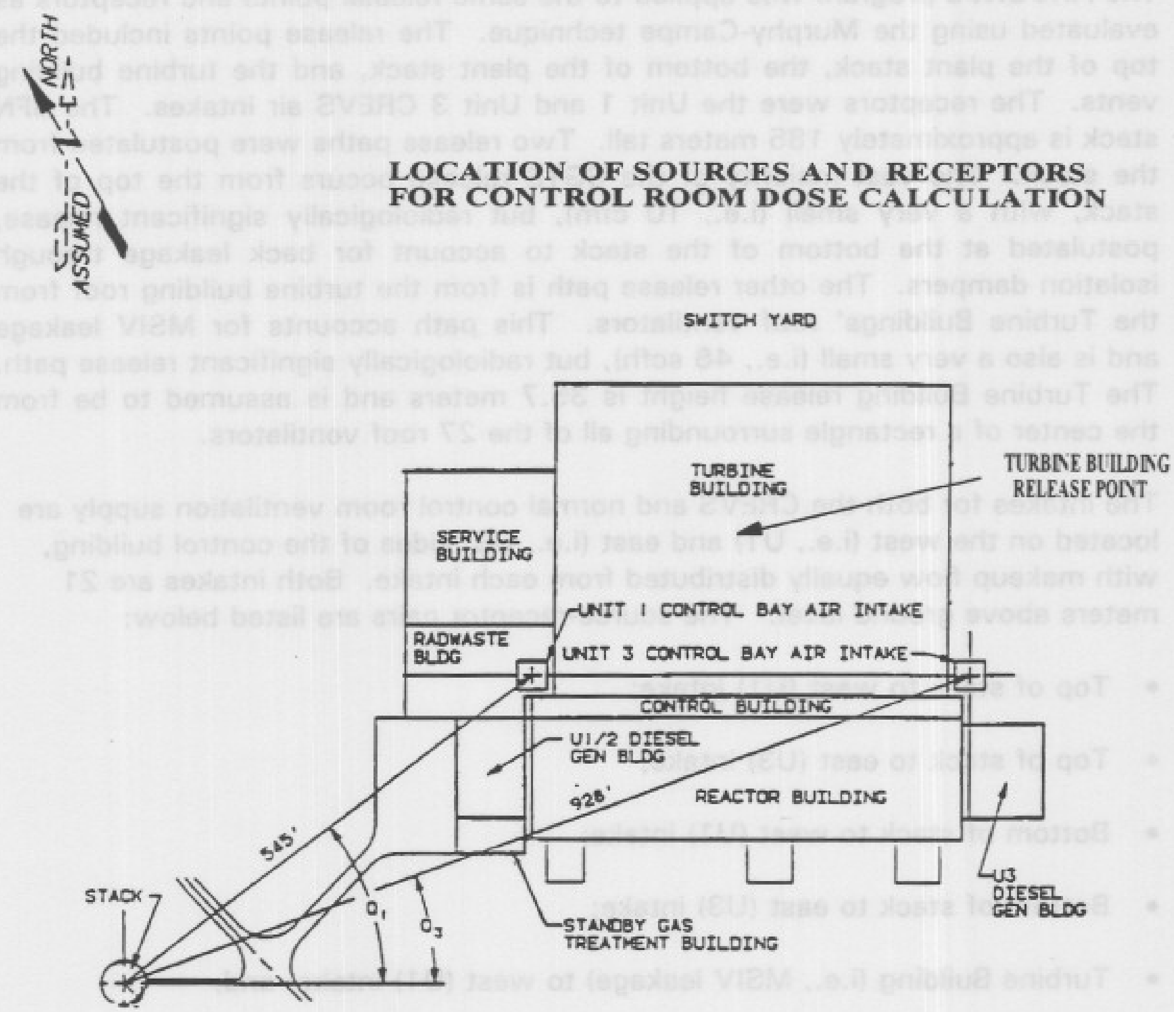
The ARCON96 program was applied to the same release points and receptors as evaluated using the Murphy-Campe technique. The release points included the top of the plant stack, the bottom of the plant stack, and the turbine building vents. The receptors were the Unit 1 and Unit 3 CREVS air intakes. The BFN stack is approximately 185 meters tall. Two release paths were postulated from the stack. The vast majority of the SGTS release occurs from the top of the stack, with a very small (i.e., 10 cfm), but radiologically significant release, postulated at the bottom of the stack to account for back leakage through isolation dampers. The other release path is from the turbine building roof from the Turbine Buildings' roof ventilators. This path accounts for MSIV leakage and is also a very small (i.e., 46 scfh), but radiologically significant release path. The Turbine Building release height is 35.7 meters and is assumed to be from the center of a rectangle surrounding all of the 27 roof ventilators.

The intakes for both the CREVS and normal control room ventilation supply are located on the west (i.e., U1) and east (i.e., U3) sides of the control building, with makeup flow equally distributed from each intake. Both intakes are 21 meters above ground level. The source-receptor pairs are listed below:

- Top of stack to west (U1) intake;
- Top of stack to east (U3) intake;
- Bottom of stack to west (U1) intake;
- Bottom of stack to east (U3) intake;
- Turbine Building (i.e., MSIV leakage) to west (U1) intake; and,
- Turbine Building (i.e., MSIV leakage) to east (U3) intake.

The relative distances and directions from each of the radiological release sources to each of the receptors are shown in Figure 1.

LOCATION OF SOURCES AND RECEPTORS FOR CONTROL ROOM DOSE CALCULATION



STACK TO U1 INTAKE
166 meters @ 083 deg.

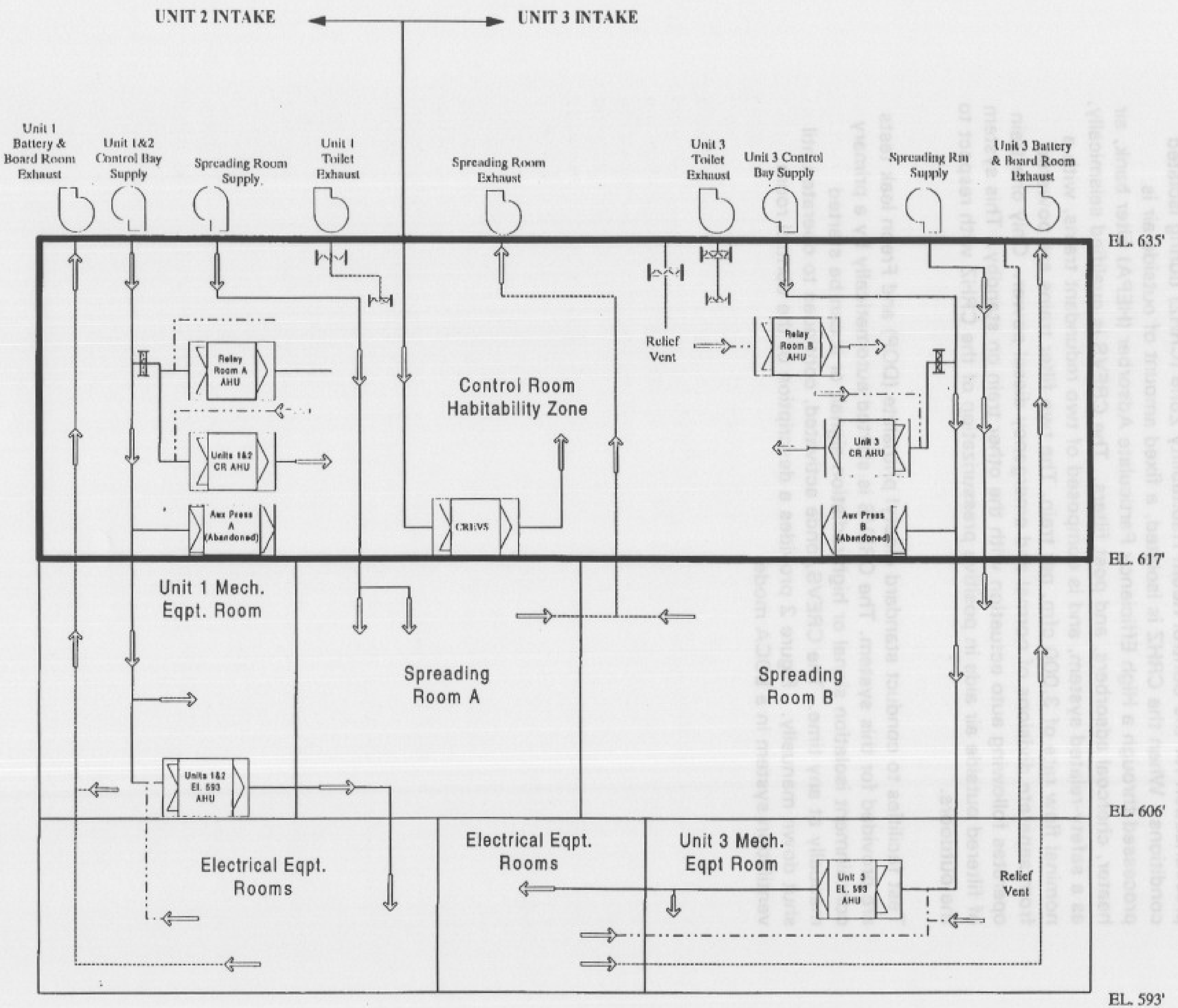
TURBINE BLDG TO U1 INTAKE
81.2 meters @ 266 deg.

STACK TO U3 INTAKE
283 meters @ 100 deg.

TURBINE BLDG TO U1 INTAKE
81.2 meters @155 deg.

The CREVS processes outside air needed to provide ventilation and pressurization for the Control Room Habitability Zone (CRHZ) during isolated conditions. When the CRHZ is isolated, a fixed amount of outside air is processed through a High Efficiency Particulate Adsorber (HEPA) filter bank, air heater, charcoal adsorbers, and post filters. The CREVS is qualified seismically, as a safety-related system, and is composed of two redundant trains, with a nominal flow rate of 3,000 cfm, per train. The two filter trains are powered from separate divisions of normal and emergency diesel power. Only one train operates following auto actuation with the other train on standby. This system of filtered outside air aids in positive pressurization of the CRHZ with respect to the outdoors.

Test facilities to conduct standard dioctyl phthalate (DOP) and Freon leak tests are provided for this system. The CREVS is started automatically by a primary containment isolation signal or high radiation signal, or it can be started manually at any time. The CREVS, once activated, continues to operate until shut down manually. Figure 2 provides a description of the control room ventilation system in a LOCA mode.



Browns Ferry Control Building HVAC (LOCA Configuration)

Input data to ARCON 96 consisted of: hourly onsite meteorological data; release characteristics such as height, radius, exit velocity, flow rate, and building area affecting the release; and receptor information such as distance and azimuth direction from the release to the control room air intake and intake height. A temporally representative continuous 11-year period of hourly data (i.e., January 1, 1987 through December 31, 1997) from the BFN meteorological tower was used in this calculation. Each hour of data, at a minimum, must have a validated wind speed and direction at the upper and lower tower levels and a temperature difference between the upper and lower tower levels. Data from the 45-meter and 10-meter tower levels were used for the bottom of stack and turbine building vent releases while the 93-meter and 10-meter tower levels were used for the top of stack release.

The top of the stack release was treated as a totally elevated release with the input parameters consisting of stack height, stack exit radius, effluent vertical velocity, and volumetric flow rate. The bottom of the stack release was analyzed as a ground level release with the cross-sectional area of the stack base as the only release parameter used in ARCON96. The vent type parameters described for the top of stack release do not apply to ground level releases. The turbine building vent release was evaluated as a vent (i.e., mixed mode) release accounting for the exit velocity from each vent and the total volumetric flow from each of the turbine building fans. The separation of the roof top vents was accounted for in ARCON96 as an area source by providing initial values of the dispersion coefficients based on the area of the rectangle encompassing the vents. Besides the meteorological data, the other inputs to the ARCON96 analyses consisted of the distances and directions to the Unit 1 and Unit 3 CREVS air intakes.

The ARCON96 default wind direction range of 90° azimuth, centered on the direction that transports the gaseous effluents from the release points to either of the intakes, was used in the calculation along with the ARCON96 default calm wind speed of 0.5 m/sec. Other assumptions made for the ARCON96 evaluation were as follows:

- The release points from which distances and directions to each air intake were determined were assumed to be at the center of the stack top and nearest edge of the stack bottom;
- The ARCON96 default value for surface roughness length (i.e., 0.10 meter), is representative of the type of topography in the vicinity of Browns Ferry Nuclear Plant, and the default value for the sector averaging constant (i.e., 4.0) were used in the calculation; and,
- The cross sectional area of the stack base was used as the building area in the calculation.

ARCON96 Modeling Results

ARCON96 calculates χ/Q values using the hourly meteorological data and then combines the hourly averages to estimate χ/Q values for periods ranging from 2 hours to 30 days. Wind direction is considered as the averages are formed. Thus, the averages account for persistence in both diffusion conditions and wind direction. Cumulative frequency distributions are prepared from the average χ/Q values and the values that are exceeded no more than five percent of the time, or the 95th percentile values, are determined from the cumulative frequency distributions for each averaging period. For the top of stack non-fumigation condition release, the ARCON96 χ/Q values applicable to the Unit 1 and Unit 3 air intakes are as shown in Table 2.

	Top of Stack χ/Q Values (sec/m^3)				
Air Intake	**0.5-2 hours**	**2-8 hours**	**8-24 hours**	**1-4 days**	**4-30 days**
Unit 1	1.00E-16	1.00E-16	1.00E-16	1.00E-16	8.76E-16
Unit 3	1.00E-10	1.00E-10	1.00E-10	1.00E-10	4.21E-10

Table 2. Top of Stack ARCON96 χ/Q Values for the Unit 1 and Unit 3 Air Intakes.

Likewise, Table 3 presents the ARCON96 χ/Q values applicable to the Unit 1 and Unit 3 air intakes for the bottom of stack release.

	Bottom of Stack χ/Q Values (sec/m^3)				
Air Intake	**0-2 hours**	**2-8 hours**	**8-24 hours**	**1-4 days**	**4-30 days**
Unit 1	2.00E-04	1.28E-04	5.72E-05	4.05E-05	3.09E-05
Unit 3	8.60E-05	6.46E-05	2.80E-05	2.00E-05	1.53E-05

Table 3. Bottom of Stack ARCON96 χ/Q Values for the Unit 1 and Unit 3 Air Intakes.

Finally, for the turbine building releases, the ARCON96 χ/Q values applicable to the Unit 1 and Unit 3 air intakes are presented in Table 4.

	Turbine Building χ/Q Values (sec/m^3)				
Air Intake	**0-2 hours**	**2-8 hours**	**8-24 hours**	**1-4 days**	**4-30 days**
Unit 1	1.20E-04	9.96E-05	4.85E-05	3.15E-05	2.02E-05
Unit 3	2.17E-04	1.64E-04	7.89E-05	4.33E-05	3.35E-05

Table 4. Turbine Building ARCON96 χ/Q Values for the Unit 1 and Unit 3 Air Intakes.

SIMULTANEOUS CONTAMINATION OF UNIT 1/UNIT 3 CREVS INTAKES

Overview

It was conservatively assumed that the plume centerline from each release point was transported directly over the worst case intake. The dose component was halved since simultaneous contamination of both intakes is not feasible. The following analysis demonstrates the absence of simultaneous contamination of the Unit 1 and Unit 3 intakes for the 0-30 day time period.

Representative Meteorological Conditions

The first step of this analysis was to establish representative meteorological conditions for all time periods encompassed by the control room habitability calculation. Representative meteorological conditions for the short-term period are controlled by the 95%, "worst case", selection criterion in Regulatory Guide 1.145. For the Browns Ferry site, the 95% meteorological condition can be reasonably approximated by the F stability condition for the bottom of stack and turbine building ground level releases and an "A" stability condition for the top of stack elevated release. The top of the stack fumigation meteorological condition is controlled by Regulatory Guide 1.145 as "F" stability at a 2.0 meter per second wind. Examination of the applicable equation immediately precludes any consideration for simultaneous contamination, since the width of the fumigated plume is much smaller than the separation of the CREVS Unit 1 and Unit 3 intakes. Accordingly, simultaneous contamination during fumigation conditions no longer needed to be considered.

Applying the stability class to the χ/Q equation, allows the back-calculation of the representative wind speed. For the short-term periods of the control room dose calculation, the following values, shown in Table 5, identify the representative meteorological conditions for the 0-8 hour period. As previously noted, simultaneous contamination of the CREVS Unit 1 and Unit 3 intakes under a fumigation condition, which is postulated to occur during the 0-0.5-hour period, is impossible.

RELEASE POINT(S)	PERIOD AFTER RELEASE	STABILITY CLASS	WIND SPEED (M/S)
Top of Stack	0.5-2 Hours	A	0.3
	2-8 Hours	A	0.4
Bottom of Stack	0-2 Hours	F	0.9
	2-8 Hours	F	1.3
Turbine Building	0-2 Hours	F	0.9
	2-8 Hours	F	1.3

Table 5. Representative Meteorological Conditions for the 3 Release Points for 0-8-Hours After the Accident.

The meteorological conditions that are representative of the interim-term period are a hybrid of the 95% worst case selection criterion in Regulatory Guide 1.145, and the long-term conditions that are identified in Regulatory Guide 1.111. At Browns Ferry, for the bottom of stack and turbine building ground level releases, the applicable meteorological condition is reasonably approximated by an "E", and "D", stability class, for the 8-24 Hour and 1-4 Day periods, respectively. A "B" and "C" stability condition is applicable to the top of stack elevated release, for the 8-24 Hour and 1-4 Day periods, respectively. However, for the top of the stack release, the "A" Stability Class is so dominant in the determination of the χ/Q value, that it overrode the use of any other stability class. Accordingly, "A" stability class for the top of the stack was used for all periods even if the representative wind speed was higher than what would occur with an "A" stability class.

Applying the stability class to the χ/Q equation, allows the back-calculation to determine the representative wind speed. For the intermediate term periods (i.e., 8 hours to 4 days) of the control room dose calculation, the following values, as displayed in Table 6, identify the representative meteorological conditions.

RELEASE POINT(S)	PERIOD AFTER RELEASE	STABILITY CLASS	WIND SPEED (M/S)
Top of Stack	**8-24 Hours**	**A**	**3.5**
	1-4 Days	**A**	**20.5**
Bottom of Stack	**8-24 Hours**	**E**	**0.7**
	1-4 Days	**D**	**0.6**
Turbine Building	**8-24 Hours**	**E**	**0.7**
	1-4 Days	**D**	**0.6**

Table 6. **Representative Meteorological Conditions for the 3 Release Points for 8-Hours to 4-Days After the Accident.**

The meteorological conditions that are representative of the long-term period (i.e., 4-30 days) are controlled by the 50% average meteorology selection criterion in Regulatory Guide 1.111. At the Browns Ferry site, the 50% meteorological condition can be reasonably approximated by the "D" stability condition for the bottom of stack and turbine building ground level releases and a "D" stability condition for the top of stack elevated release. Similarly, as for the intermediate time periods, for the top of the stack release, the "A" Stability Class is so dominant in the determination of the χ/Q value, that it override the use of any other stability class. Accordingly, "A" stability class for the top of the stack was used for the 4-30 day period even if the representative wind speed was higher than what would occur with an "A" stability class.

Applying the stability class to the χ/Q equation, allows the back-calculation to determine the representative wind speed. For the long-term periods of the control room dose calculation, the following Table 7 values identify the representative meteorological conditions.

RELEASE POINT(S)	PERIOD AFTER RELEASE	STABILITY CLASS	WIND SPEED (M/S)
Top of Stack	4-30 Days	A	25.9
Bottom of Stack	4-30 Days	D	1.2
Turbine Building	4-30 Days	D	1.2

Table 7. **Representative Meteorological Conditions for the 3 Release Points for 4-30-Days After the Accident.**

Simultaneous Contamination Screening Calculations

Table 8 presents the centerline (CL) χ/Q values at both of the Unit 1 and Unit 3 CREVS intakes from a SGTS release from the top of the stack. The first case (CL @ CREVS-3 Intake) represents the χ/Q values at both of the Unit 3 and Unit 1 CREVS intakes when the plume centerline (CL) is at the Unit 3 intake. The second case (CL @ CREVS-1 Intake) represents the χ/Q values at both of the Unit 3 and Unit 1 CREVS intakes when the plume centerline (CL) is at the Unit 1 intake.

The results clearly show that there is no meaningful simultaneous contamination for the top of the stack release combinations for all of the time periods. The CL contribution at either intake essentially represents the entire control room dose. The bolded values represent the χ/Q values that were used in the May 1, 1998 response to the NRC RAI.

PERIOD	CL @ CREVS-3 INTAKE		CL @ CREVS-1 INTAKE	
	UNIT 3 χ/Q	UNIT 1 χ/Q	UNIT 3 χ/Q	UNIT χ/Q
0.5-2 Hour	**9.64 E-07**	2.58 E-15	3.67 E-07	**5.90 E-15**
2-8 Hour	**1.89 E-07**	1.88 E-15	7.20 E-08	**4.29 E-15**
8-24 Hour	**8.37 E-08**	1.60 E-15	3.18 E-08	**3.65 E-15**
1-4 Day	**1.43 E-08**	1.13 E-15	5.40 E-09	**2.58 E-15**
4-30 Day	**1.13 E-08**	6.90 E-16	4.30 E-09	**1.57 E-15**

Table 8. **χ/Q Values at Both the Unit 3 and Unit 1 CREVS Intakes from the SGTS Release from the Top of the Stack.**

Table 9 presents the χ/Q values at both of the Unit 3 and Unit 1 CREVS intakes from the 10 cfm SGTS leakage from the bottom of the stack. The first case (CL @ CREVS-3 Intake) represents the χ/Q values at both of the Unit 3 and Unit 1 CREVS intakes when the plume centerline (CL) is at the Unit 3 intake. The second case (CL @ CREVS-1 Intake) represents the χ/Q values at both of the Unit 3 and Unit 1 CREVS intakes when the plume centerline (CL) is at the Unit 1 intake.

As demonstrated by the top of the stack release scenarios, the results again clearly show that the there is no meaningful simultaneous contamination for all bottom of the stack release combinations for all time periods. The CL contribution at either intake represents essentially the total control room dose. The bolded values again represent the χ/Q values that were used in the May 1, 1998 response to the NRC.

PERIOD	CL @ CREVS-3 INTAKE		CL @ CREVS-1 INTAKE	
	UNIT 3 χ/Q	UNIT 1 χ/Q	UNIT 3 χ/Q	UNIT 1 χ/Q
0-2 Hour	**1.20 E-03**	2.31 E-12	2.11 E-14	**3.70 E-03**
2-8 Hour	**7.91 E-04**	1.48 E-12	1.39 E-14	**2.38 E-03**
8-24 Hour	**6.42 E-04**	7.82 E-08	4.82 E-09	**1.91 E-03**
1-4 Day	**4.09 E-04**	7.21 E-06	1.05 E-06	**1.19 E-03**
4-30 Day	**2.14 E-04**	3.62 E-08	5.48 E-07	**5.97 E-04**

Table 9. χ/Q Values at Both the Unit 3 and Unit 1 CREVS Intakes from10 cfm SGTS Leakage from the Bottom of the Stack.

Examination of the orientation of the Unit 1 and Unit 3 CREVS intakes with the vents, all on the turbine building, it can be reasonably concluded that it is geometrically impossible to simultaneously contaminate both CREVS intakes.

Simultaneous Contamination of Either CREVS Unit 1 and Unit 3 Intakes from More than One Release

There were two scenarios that were evaluated:

- Simultaneous Top of Stack and Turbine Building Releases; and,
- Simultaneous Bottom of Stack and Turbine Building Releases.

Inspection of Figure 1 clearly shows that any stack release will have to come from a direction that transports a turbine building release away from both intakes. It is therefore concluded that simultaneous contamination of either CREVS intake from more than one release is not geometrically plausible and can be dismissed outright.

COMPARISON OF ARCON-SIMULANTEOUS CONTAMINATION ANALTYICAL RESULTS TO EARLIER CALCULATIONS

Tables 10 through 12 show the comparison to the present licensing position (i.e., earlier χ/Q values), and the credit received from the ARCON96 technique (i.e., ARCON96 χ/Q). All χ/Q values are presented in units of sec/m^3. At both the CREVS Unit 1 and Unit 3 intakes, the χ/Q values were significantly lower for each of the release points (i.e., top of stack, bottom of stack, and turbine building), with the most credit for the top of the stack release. This result was expected due to the preponderance of light wind - stable meteorological conditions at the Browns Ferry Nuclear Plant.

MSIV RELEASE FROM TURBINE BUILDING VENT/UNIT 1 CREVS INTAKE

Time Period (hr)	Earlier χ/Q	ARCON96 χ/Q	Credit
0-2	3.48 E - 04	1.20 E - 04	2.90
2-8	2.94 E - 04	9.96 E - 05	2.95
8-24	2.53 E - 04	4.85 E - 05	5.21
24-96	2.01 E - 04	3.15 E - 05	6.38
96-720	1.44 E - 04	2.02 E - 05	7.13

MSIV RELEASE FROM TURBINE BUILDING VENT/UNIT 3 CREVS INTAKE

Time Period (hr)	Earlier χ/Q	ARCON96 χ/Q	Credit
0-2	3.48 E - 04	2.17 E - 04	1.60
2-8	2.94 E - 04	1.64 E - 04	1.79
8-24	2.53 E - 04	7.89 E - 05	3.21
24-96	2.01 E - 04	4.33 E - 05	4.64
96-720	1.44 E - 04	3.35 E - 05	4.30

Table 10. Comparison of ARCON96 and Present Licensing Position χ/Q Values for MSIV Releases from the Turbine Building Vents.

BOTTOM OF STACK RELEASE/UNIT 1 CREVS INTAKE

Time Period (hr)	Earlier χ/Q	ARCON96 χ/Q	Credit
0-2	3.70 E - 03	2.00 E - 04	18.5
2-8	2.38 E - 03	1.28 E - 04	18.6
8-24	1.91 E - 03	5.72 E - 05	33.4
24-96	1.19 E - 03	4.05 E - 05	29.4
96-720	5.97 E - 04	3.09 E - 05	19.3

BOTTOM OF STACK RELEASE/UNIT 3 CREVS INTAKE

Time Period (hr)	Earlier χ/Q	ARCON96 χ/Q	Credit
0-2	1.20 E - 03	8.60 E - 05	14.0
2-8	7.91 E - 04	6.46 E - 05	12.2
8-24	6.42 E - 04	2.80 E - 05	22.9
24-96	4.09 E - 04	2.00 E - 05	20.5
96-720	2.14 E - 04	1.53 E - 05	14.0

Table 11. Comparison of ARCON96 and Present Licensing Position χ/Q Values for 10 cfm SGTS Releases from the Bottom of the Stack.

TOP OF STACK RELEASE/UNIT 1 CREVS INTAKE

Time Period (hr)	Earlier χ/Q	ARCON96 χ/Q	Credit
0.5-2	5.90 E - 15	1.00 E - 16	59.0
2-8	4.29 E - 15	1.00 E - 16	42.9
8-24	3.65 E - 15	1.00 E - 16	36.5
24-96	2.58 E - 15	1.00 E - 16	25.8
96-720	1.57 E - 15	8.76 E - 16	1.79

TOP OF STACK RELEASE/UNIT 3 CREVS INTAKE

Time Period (hr)	Earlier χ/Q	ARCON96 χ/Q	Credit
0.5-2	9.64 E - 07	1.00 E - 10	9640
2-8	1.89 E - 07	1.00 E - 10	1890
8-24	8.37 E - 08	1.00 E - 10	837
24-96	1.43 E - 08	1.00 E - 10	143
96-720	1.13 E - 09	4.21 E - 10	2.68

Table 12. Comparison of ARCON96 and Present Licensing Position χ/Q Values for SGTS Releases from the Top of the Stack.

The ARCON96 χ/Q values were then used as input to the COROD code to calculate control room doses at both the Unit 1 and Unit 3 CREVS intakes. The results are shown in Table 13.

	Control Room Thyroid Dose (rem)			
	Base of Stack	Top of Stack	MSIV	Total/2
Unit 1 Intake	**0.858**	**3.272**	**3.200**	**3.665**
Unit 3 Intake	**0.424**	**2.938**	**4.756**	**4.059**

Table 13. Thyroid Doses Including Leakage from the MSIV and the ECCS.

Since simultaneous contamination of both intakes has been determined to be impossible, the worst case intake dose is taken, and the result is divided by a factor of two to account for the 50% flow component from the non-contaminated intake.

This ARCON96 control room thyroid dose of 4.059 rem includes both the MSIV and ECCS leakage. As Table 13 indicates, the MSIV leakage dose component is larger than the sum of the base of stack and top of stack contributions. Since the Murphy-Campe dose results of 11.11 rem represented an earlier evaluation that did not include MSIV and ECCS leakage, a direct one-to-one dose comparison between it and ARCON was not possible. In other words, the factor of 2.74 reduction in dose is obfuscated by the inclusion of the MSIV and ECCS leakage in the ARCON96 analysis. Notwithstanding the differences in the dose calculation techniques, examination of the control room dose results from both evaluations lead to the conclusion that a significant improvement in the control room dose can be realized when the more technically defensible ARCON96 position is applied. This improvement likely approaches a full order of magnitude in dose.

CONCLUSIONS

The application of the ARCON96 model to the Browns Ferry Nuclear Plant control room habitability evaluation resulted in significantly lower χ/Q values than the modeling techniques used to support the existing licensing position. Moreover, the ARCON96 χ/Q values are more technically defensible, while representing the present state-of-the-art in control habitability relative concentration methodology. This ARCON96 methodology exposes the conservatism in the Murphy-Campe technique.

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