Recent Developments Regarding NRC Guidance on Control Room Habitability Assessment

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1. Introduction

Concerns regarding the adequacy and maintenance of control room (CR) designs for nuclear power plants began to emerge during the mid-1980's when numerous NRC reviews revealed deficiencies in the areas of CR boundary maintenance, knowledge of station personnel concerning CR habitability, treatment of CR habitability as a low priority item, and testing of CR boundary. In the 1990's, roughly a quarter of the CRs measured their unfiltered in-leakage and, in nearly all cases, the measured values were greater than those assumed in the CR radiological habitability analyses.

In response to this heightened awareness, the industry advocacy group Nuclear Energy Institute (NEI) published their Control Room Habitability Assessment Guidance Document NEI 99-03 in June 2001 (Reference 1). This industry guidance document was developed after considerable discussion with the NRC, with the intent of eventually obtaining NRC endorsement. While the NRC concluded that the final draft of NEI 99-03 contained useful guidance on CR habitability issues, the NRC could not endorse NEI 99-03 in its entirety because of continuing technical and licensing differences between industry and the NRC staff on several items.

Consequently, the NRC is currently in the process of issuing a draft generic letter[1] on CR habitability and several associated regulatory guides[2] for public comment. Much of this regulatory guidance is expected to make extensive use of NEI 99-03. Two of these regulatory guides concern performing atmospheric dispersion analyses in support of CR habitability analyses: draft Regulatory Guide DG-1111 (*Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants*, Reference 2) and Revision 1 to Regulatory Guide 1.78 (*Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release*, Reference 3).

This presentation will review the atmospheric dispersion guidance presented in draft Regulatory Guide DG-1111 and Revision 1 to Regulatory Guide 1.78, with an emphasis on identifying changes in methodology from previous guidance documents.

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[1] Generic Letters are used by the NRC to communicate a common need or resolution approach to an issue or provide guidance on issues pertaining to a matter of regulatory interest. They generally impose mandatory requirements or actions.

[2] Regulatory Guides are issued by the NRC to describe methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, to explain techniques used by the staff in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory Guides are not substitutes for regulations and compliance with Regulatory Guides is not required.

2. CR *Radiological* Habitability Assessments: Draft Regulatory Guide DG-1111

The NRC issued draft Regulatory Guide DG-1111 (Reference 2) for public comment in December 2001 to provide guidance on determining atmospheric relative concentration (χ/Q) values in support of design basis CR radiological habitability assessments at nuclear power plants. Prior to issuing DG-1111, the NRC staff had never issued a regulatory guide providing guidance for generating χ/Q values for CR habitability evaluations. Consequently, licensees and the staff have historically used a variety of models for determining CR habitability χ/Q values. The primary model used by the staff is documented in a CR habitability assessment procedure developed by Murphy and Campe (Reference 4) and its implementation is discussed in Section 6.4, "Control Room Habitability System" of the Standard Review Plan (Reference 5). The Murphy-Campe procedure addresses several ground level release source-receptor geometries but did not address elevated (stack) releases.

DG-1111 presents two different methods for determining χ/Q values for CR radiological habitability assessments: the Murphy-Campe methodology (as discussed above) and a new computer code called ARCON96 (Reference 6). ARCON96 was developed from a number of NRC sponsored studies conducted during the 1980s. The intent of these studies was to evaluate the Murphy-Campe model against experimental testing in the environment and in wind tunnels in order to assess the potential for developing alternative approaches. These studies indicated that the Murphy-Campe model did not reliably predict concentrations in the vicinity of buildings. A statistical model was developed from the data resulting from these studies. The resulting model, ARCON96, claims to make significantly more reliable predictions in building wakes.

A comparison of the Murphy-Campe versus ARCON96 methodologies is provided in Table 1. The major difference between the two methodologies is ARCON96 is a computer code requiring at least one year of hourly meteorological data as input whereas the Murphy-Campe methodology can be implemented as a hand calculation. The ARCON96 methodology also models both ground level as well as stack releases whereas the Murphy-Campe methodology only addresses ground-level releases.

In implementing the Murphy-Campe and ARCON96 methodologies, the intent is to select a χ/Q value that is not exceeded more than five percent of the total hours in the meteorological data set (DG-1111 refers to this value as the 95-percentile χ/Q). Both methodologies determine control Room χ/Q values for each of the following averaging periods: 0-8 hours (or 0-2 and 2-8 hours for ARCON96), 8-24 hours, 24-96 hours, and 96-720 hours. The period of the most adverse release of radioactive materials to the environment should be assumed to occur coincident with the period of most unfavorable atmospheric dispersion. For example, for facilities using the traditional TID-14844 source term (Reference 7), the 0-2 hour period will generally coincide with the start of the accident; for facilities using the alternative Regulatory Guide 1.183 source term (Reference 8), the 0-2 hour period will often coincide with the onset of the in-vessel release phase.

DG-1111 also provides additional guidance for modeling release scenarios that are not adequately addressed by either Murphy-Campe or ARCON96. These release scenarios involve flow reveral effects for stack releases[3] as well as plume rise effects for stack and vent releases as follows:

[3] Elevated releases are defined as releases from an isolated, free-standing, uncapped stack, the top of which is at least 2½ times the height of adjacent solid structures.

- *Flow Reversal Effects for Stack Releases:* The elevated release model in ARCON96 may generate negligibly low χ/Q values if the control room air intake is located close to the base of a tall stack. Although numerically correct, ARCON96 may not be sufficiently conservative for a design basis assessment since the model does not adequately address flow reversal conditions (such as diurnal wind direct changes, plume meander and stagnation) that could result in higher χ/Q values.[4] In this situation, the maximum downwind 0-2 hour χ/Q value at ground level should be determined using the methodology of Regulatory Guide 1.145 (Reference 9).[5] The resulting 0-2 hour χ/Q value should be compared to the 0-2 hour ARCON96 χ/Q value and the higher value should be used. The χ/Q values for the 24-96 and 96-720 hour intervals should then be the averages of the χ/Q values determined with ARCON96 and the maximum χ/Q value at ground level for each of the respective periods, weighted on the basis of one hour of the maximum 0-2 hour χ/Q value for each day in the interval.

- *Plume Rise Effects for Stack and Vent Releases:* Although ARCON96 does not calculate plume rise from buoyancy or mechanical jet effects, licensees can determine plume rise and add the amount of rise to the physical height of the stack to obtain an effective plume height. Plume rise may be considered for isolated, freestanding stacks and for vents located on plant buildings. The Briggs plume rise equations as presented in Hanna et al (Reference 11) are presented for use.[6] In order to credit these adjustments, the licensee must be able to demonstrate that the buoyancy and/or vertical velocity of the plume will be maintained throughout the time intervals that the plume rise is credited.

Note that appropriately structure site-specific atmospheric diffusion tests may be considered as an alternative to the analytical methods presented above. Such tests (e.g., field, wind tunnel) may be accepted on a case-by-case basis. They must encompass a significant range of meteorological and, if appropriate, modeling conditions applicable to the site to ensure the limiting cases (e.g., resulting in the 95 percentile χ/Q value) have been evaluated. The testing and results should be verified and validated.

3. CR *Hazardous* Chemical Habitability Assessments: Rev. 1 to Regulatory Guide 1.78

Regulatory Guide 1.78 was originally issued in June 1974 to describe assumptions acceptable to the NRC for use in assessing the habitability of the control room during and following a postulated external release of hazardous chemicals from mobile or stationary sources, offsite or onsite. Revision 1 to Regulatory Guide 1.78 (Reference 3) was issued in December 2001 to update certain regulatory positions based on more current knowledge of the subject. Revision 1 also incorporated and withdrew Regulatory Guide 1.95 (Reference 12), which provided guidance on the protection of control room operators against an accidental release of chlorine.

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[4] Although the NRC has previously suggested that licensees model fumigation as a mechanism to address this situation, the NRC has conceded that the fumigation model does not appear to adequately estimate the effluent concentrations at the bases of industrial stacks.

[5] The NRC accepts the computer code PAVAN (Reference 10) for this assessment.

[6] In lieu of using Brigg's plume rise equations to estimate the amount of buoyant plume rise associated with energetic releases from steam relief valves and atmospheric dump values, the ground level χ/Q value calculated with ARCON96 may be reduced by a factor of 5 if: (1) the release point is uncapped and vertically oriented and (2) the time-dependent vertical velocity exceeds the 95-percentile wind speed at the release point height by a factor of five.

Regulatory Guide 1.78 describes assumptions and criteria for screening out hazardous chemical release events that need not be considered in the evaluation of control room habitability. The guide also provides guidance on performing detailed evaluations of control room habitability, including the distance between the release source and the control room, the frequency of shipments (to calculate release frequency from a mobile source), the quantity and duration of a release, toxicity of released chemicals, meteorological conditions (for dispersion calculations), and the rate of air infiltration into the control room.

Both Revision 0 and Revision 1 to Regulatory Guide 1.78 specify that two types of industrial accidents should be considered for each source of hazardous chemicals: maximum concentration chemical accidents and maximum concentration-duration chemical accidents.

- *Maximum Concentration Accidents:* This type of accident results in a short-term puff or instantaneous release of a large quantity of hazardous chemicals. An example of this type of accident would be the failure of a manhole cover on a chemical container or the outright failure of the container itself. This type of accident is modeled by assuming the instantaneous release of the total contents of the largest storage container that is either located at a nearby stationary facility, frequently transported near the site, or stored onsite.

- *Maximum Concentration-Duration Accidents:* This type of accident results in a long-term, low-leakage-rate release involving leakage from valves or fittings. This type of accident is modeled by assuming the continuous release from the largest safety relief valve on a stationary, mobile, or onsite source.

Revision 0 to Regulatory Guide 1.97 specified that the atmospheric diffusion model to be used in the evaluation of maximum concentration chemical accidents should be the same as or similar to the Gaussian instantaneous puff release model presented in Appendix B to the regulatory guide whereas the atmospheric diffusion model to be used in the evaluation of the maximum concentration-duration accident should be the same as or similar to the Gaussian continuous release model presented in Regulatory Guides 1.3 and 1.4 (References 13 and 14, respectively).

Revision 1 to Regulatory Guide 1.97 suggests the use of the computer code HABIT for control room habitability evaluation (Reference 15). Two of the HABIT program modules, EXTRAN and CHEM, can be executed in sequence to predict chemical concentration and exposures in the control room. The EXTRAN program computes atmospheric chemical concentrations at the control room air intake and the CHEM program uses the results of EXTRAN to determine the associated chemical buildup and consequent exposures in the control room. Note that EXTRAN is a Gaussian puff atmospheric dispersion model that uses the same diffusion coefficient adjustments for building wakes and low wind speeds as ARCON96.

Similar to DG-1111, Regulatory Guide 1.78 suggests that the 95-percentile χ/Q value be used to evaluate control room habitability. Note however that, unlike ARCON96 (which can accept multiple years of hourly meteorological data as input and determine the 95-percentile χ/Q value), EXTRAN is executed using only one set of hourly meteorological data at a time. Consequently, EXTRAN needs to be executed for a range of meteorological conditions to determine the 95-percentile χ/Q value.

4. Conclusion

As part of a revised set of guidance for evaluating control room habitability, the NRC is updating decades old methodology for performing atmospheric diffusion estimates in support of control room habitability assessments for both radiological and hazardous chemical releases. The revised atmospheric diffusion methodology is based on a NRC-sponsored building wake statistical model (Reference 16) that was derived from experimental testing in the environment and in wind tunnels. The methodology is based on a straight-line Gaussian diffusion model that utilizes a new set of composite wake diffusion coefficients to account for low wind speed and building wake corrections. The new methodology has been implemented in the ARCON96 computer code for radiological releases and the EXTRAN computer code for hazardous chemical releases.

5. References

1. Nuclear Energy Institute, "Control Room Habitability Assessment Guidance," NEI 99-03, Revision 0, June 2001.

2. USNRC, "Atmospheric Relative Concentrations For Control Room Radiological Habitability Assessments at Nuclear Power Plants," DG-1111, December 2001.

3. USNRC, "Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release," Regulatory Guide 1.78, Revision 1, December 2001.

4. K.G. Murphy and K.W. Campe, "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19," published in *Proceedings of 13th AEC Air Cleaning Conference*, San Francisco, CONF 740807, U.S. Atomic Energy Commission (now USNRC), August 1974.

5. USNRC, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Chapter 6.4, "Control Room Habitability System," NUREG-0800, USNRC, 1987.

6. J.V. Ramsdell, Jr. and C.A. Simonen, "Atmospheric Relative Concentrations in Building Wakes," NUREG/CR-6331, Revision 1, USNRC, May 1997.

7. J.J. DiNunno et al., "Calculation of Distance Factors for Power and Test Reactor Sites," USAEC TID-14844, U.S. Atomic Energy Commission (now USNRC), 1962.

8. USNRC, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," Regulatory Guide 1.183, July 2000.

9. USNRC, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," Regulatory Guide 1.145, Revision 1, November 1982.

10. T.J. Bander, "PAVAN: An Atmospheric Dispersion Program for Evaluating Design Basis Accidental Releases of Radioactive Materials from Nuclear Power Stations," NUREG/CR-2858, USNRC, November 1982.

11. S.R. Hanna et al., "Handbook on Atmospheric Diffusion," DOE/TIC-11223, 1982.

12. USNRC, "Protection of Nuclear Power Plant Control Room Operators Against an Accidental Chlorine Release," Regulatory Guide 1.95, Revision 1, January 1977.

13. USNRC, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors," Regulatory Guide 1.3, Revision 2, June 1974.

14. USNRC, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors," Regulatory Guide 1.3, Revision 2, June 1974.

15. J.V. Ramsdell, Jr. and S.A. Stage, "Computer Codes for Evaluation of Control Room Habitability (HABIT V1.1)," NUREG/CR-6210, Supplement 1, USNRC, October 1998.

16. J.V. Ramsdell, Jr. and C.J. Fosmire, "Atmospheric Dispersion Estimates in the Vicinity of Buildings," PNL-10286, Pacific Northwest Laboratory, 1995.

TABLE 1

Comparison of Murphy-Campe Versus ARCON96 Methodology For Ground Level Releases

<table>
<tr><th>Murphy-Campe</th><th>ARCON96</th></tr>
<tr><td>

• The 0-8 hour X/Q values are generated using the following algorithms:

For a single point source and a single point receptor with a difference in elevation less than 30% of the building height:

$$\frac{\chi}{Q}_{0-8hr} = \frac{1}{3\pi u \sigma_y \sigma_z}$$

For a point source and a point receptor with a difference in elevation greater than 30% of the building height, an area source with a single point receptor, and a point source with a volume receptor:

$$\frac{\chi}{Q}_{0-8hr} = \frac{1}{u\left(\pi\sigma_y\sigma_z + \frac{A}{k+2}\right)}$$

where:

u = wind speed at 10 m, m/sec
σ_y, σ_z = plume standard deviation in the horizontal and vertical cross wind directions, m
A = cross-sectional area of the upwind building creating most significant building wake impact, m^2
$k = \frac{3}{(s/d)^{1.4}}$
s = shortest distance between the building surface and receptor location, m
d = diameter or width of building, m

The parameters σ_y, σ_z, and u should be determine using site meteorological data that are statistically analyzed to derive the combination of σ_y, σ_z, and u values that are representative of the 95-percentile χ/Q value.[1]

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• For periods 8 hours or less in duration, χ/Q values are based on the following plume centerline algorithm:

$$\frac{\chi}{Q}_{pc} = \frac{1}{\pi u \Sigma_y \Sigma_z}$$

where

u = wind speed at 10 m, m/sec

$$\Sigma_y = \left(\sigma_y^2 + \Delta\sigma_{y1}^2 + \Delta\sigma_{y2}^2\right)^{0.5}$$

$$\Sigma_z = \left(\sigma_z^2 + \Delta\sigma_{z1}^2 + \Delta\sigma_{z2}^2\right)^{0.5}$$

$$\Delta\sigma_{y1}^2 = 9.13x10^5\left[1-\left(1+\frac{x}{1000u}\right)\exp\left(\frac{-x}{1000u}\right)\right]$$

$$\Delta\sigma_{z1}^2 = 6.67x10^2\left[1-\left(1+\frac{x}{100u}\right)\exp\left(\frac{-x}{100u}\right)\right]$$

$$\Delta\sigma_{y2}^2 = 5.24x10^{-2}u^2A\left[1-\left(1+\frac{x}{10\sqrt{A}}\right)\exp\left(\frac{-x}{10\sqrt{A}}\right)\right]$$

$$\Delta\sigma_{z2}^2 = 1.17x10^{-2}u^2A\left[1-\left(1+\frac{x}{10\sqrt{A}}\right)\exp\left(\frac{-x}{10\sqrt{A}}\right)\right]$$

x = distance from the release point, m

A = cross-sectional area of the upwind building creating most significant building wake impact, m^2

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</table>

[1] Note that early analysis based on the Murphy-Campe methodology may have derived values for σ_y, σ_z, and u using "default" 95-percentile meteorological conditions (i.e., F stability with wind speeds of 1.0 m/sec). However, DG-1111 states that if these early analysis are to be updated, site-specific hourly meteorological data should be used to determine the 95-percentile χ/Q values.

TABLE 1
(Continued)

<table>
<tr><th>Murphy-Campe</th><th>ARCON96</th></tr>
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• The χ/Q values for longer time averaging periods are generated using the following algorithms:

If hourly meteorological data are available:

$$\frac{\chi}{Q}_{8-24hrs} = \frac{\chi}{Q}_{0-8hrs}\left(u_{5\%}/u_{10\%}\right)(0.75 + F/4)$$

$$\frac{\chi}{Q}_{24-96hrs} = \frac{\chi}{Q}_{0-8hrs}\left(u_{5\%}/u_{20\%}\right)(0.50 + F/2)$$

$$\frac{\chi}{Q}_{96-720hrs} = \frac{\chi}{Q}_{0-8hrs}\left(u_{5\%}/u_{40\%}\right)(F)$$

where:

F = the fraction of the time throughout the year the wind is from those sectors that result in receptor contamination

$u_{5\%}$ = 5th percentile wind speed at 10m, m/sec

$u_{10\%}$ = 10th percentile wind speed at 10m, m/sec

$u_{20\%}$ = 20th percentile wind speed at 10m, m/sec

$u_{40\%}$ = 40th percentile wind speed at 10m, m/sec

If hourly meteorological data are not available:

$$\frac{\chi}{Q}_{8-24hrs} = 0.5896\left(\frac{\chi}{Q}_{0-8hrs}\right)$$

$$\frac{\chi}{Q}_{24-96hrs} = 0.375\left(\frac{\chi}{Q}_{0-8hrs}\right)$$

$$\frac{\chi}{Q}_{96-720hrs} = 0.165\left(\frac{\chi}{Q}_{0-8hrs}\right)$$

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• For periods greater than 8 hours in duration, χ/Q values are based on the following sector average algorithm:

$$\frac{\chi}{Q}_{sa} = \frac{2.032}{x\pi u}$$

• Average χ/Q values for various time intervals of length N hours are calculated as running mean values:

$$\overline{\frac{\chi}{Q}}_{0-Nhrs} = \frac{1}{N}\left[\sum_{i=1}^{8}\left(\frac{\chi}{Q}_{pc}\right)_i + \sum_{i=9}^{N}\left(\frac{\chi}{Q}_{sa}\right)_i\right]$$

These average χ/Q values are computed as running overlapping mean values. χ/Q cumulative frequency distributions are compiled and the χ/Q values that are exceeded no more than 95-percent of the time are chosen.

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TABLE 1
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<table>
<tr><th><u>Murphy-Campe</u></th><th><u>ARCON96</u></th></tr>
<tr><td>
The width of the wind direction window for those wind directions that are assumed to result in receptor contamination is a function of the ratio s/d where s is the shortest distance between the building surface having the greatest impact on building wake and the receptor, m, and d is the diameter or width of this same building, m.
<table>
<tr><th><u>Ratio s/d</u></th><th><u>Window Width</u></th></tr>
<tr><td>>2.5</td><td>68°</td></tr>
<tr><td>1.25 – 2.5</td><td>90°</td></tr>
<tr><td>0.8 – 1.25</td><td>113°</td></tr>
<tr><td>0.6 – 0.8</td><td>135°</td></tr>
<tr><td>0.5 – 0.6</td><td>158°</td></tr>
<tr><td>0.35 – 0.5</td><td>180°</td></tr>
<tr><td><0.35</td><td>225°</td></tr>
</table>
</td><td>
The width of the wind direction window for those wind directions that are assumed to result in receptor contamination is 90°, centered on the source-to-receptor direction.
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