IMPACT OF WEATHER CHANGES ON TVA NUCLEAR PLANT CHI/Q (χ/Q)

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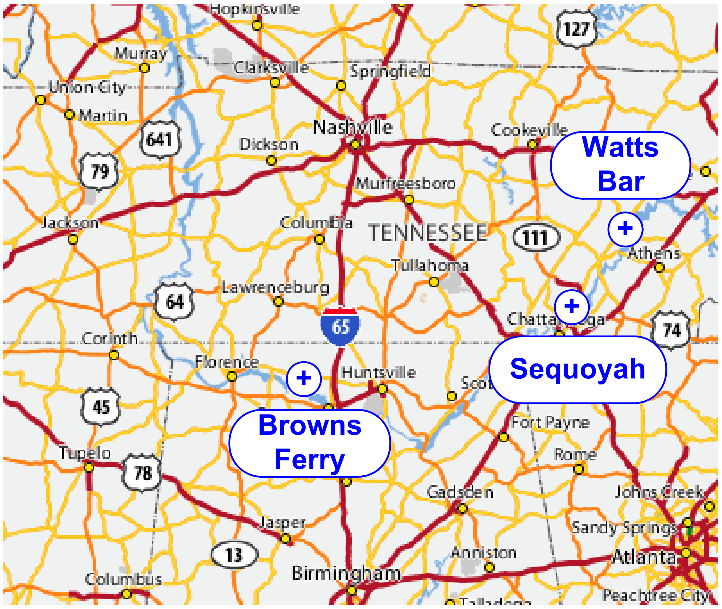
The TVA nuclear plants, like most others in the United States, were designed based on 2-3 years of meteorological data collected in the 1970s. Since then, changes in meteorological conditions and operating experience have raised concerns that the chi/Q (χ/Q) assumptions based on the original data are no longer valid. This presentation examines the original meteorological data, determines how the meteorological conditions have changed, and estimates how χ/Q assumptions are impacted.

As a consequence of the issue of RG-1.23 (revision 1), TVA changed the stability class layers used for evaluating elevated release. A case study will also examine the impact of these changes on χ/Q.

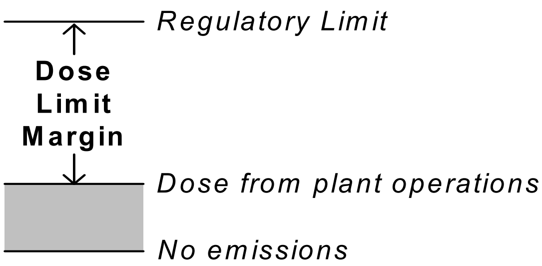
The Tennessee Valley Authority (TVA) operates three nuclear power plants along the Tennessee River in north Alabama and southeast Tennessee; Browns Ferry, Sequoyah, and Watts Bar.



At each plant, meteorological data are collected on a 91-meter tower. Wind direction/speed and air temperature are collected at the 91-, 46-, and 10-meter levels, dewpoint temperature is collected at 10 meters, and solar radiation and rainfall are collected at the surface. All data are reported hourly. Wind direction/speed, air temperature, and rainfall are also reported every 15 minutes for emergency preparedness.

Initial Plant Design Assumptions

The Nuclear Regulatory Commission (NRC) specifies dose limits that apply to emissions from nuclear power plants. Power plants are designed and operated to limit radioactive emissions to levels below the regulatory requirements. This "dose limit margin" (the difference between dose from plant emissions and the regulatory limit) ensures compliance with regulatory requirements and permits flexibility of operations for the power plant.



Meeting dose limits involves more that just controlling emissions. Weather conditions are also a major factor in determining the dose. To estimate the impact of meteorological conditions, the relative air concentration, or Chi/Q (χ/Q), values are calculated for specific points. These χ/Q values are multiplied by the emission rate (Q), to determine the concentrations (χ) at those points.

Chi/Q (χ/Q) Calculations

The basic χ/Q equation for ground-level concentrations beneath the plume centerline is:

$$\chi/Q = \left[\frac{1}{(\pi)(u)(\sigma_y)(\sigma_z)}\right]\exp\left[-\left(\frac{H^2}{(2)(\sigma_z{}^2)}\right)\right]$$

Equation 2.3 from Workbook of Atmospheric Dispersion Estimates (2nd edition)

χ = Ambient Concentration
Q = Emission Rate
H = Effective Stack Height (m)
u = wind speed (m/s)
σ_y = Horizontal diffusion coefficient (m)
σ_z = Vertical diffusion coefficient (m)
π = 3.14 . . .

Wind speed is directly measured, while the two diffusion coefficients are derived from meteorological measurements (i.e., they can be based on stability class, as determined by the temperature difference between to vertical levels). The remaining variables are constant for a release type, so the importance of having accurate meteorological measurements is clear.

- For ground-level releases, $H = 0$. Therefore the exponential term on the right = 1, and is not considered in the χ/Q calculation.
- Wind speed (u) is in the denominator. Therefore, as wind speed increases, χ/Q decreases; and as wind speed decreases, χ/Q increases.
- The diffusion coefficients (σ_y and σ_z) are in the denominator. Therefore, as diffusion coefficients increase, χ/Q decreases; and as diffusion coefficients decrease, χ/Q increases.

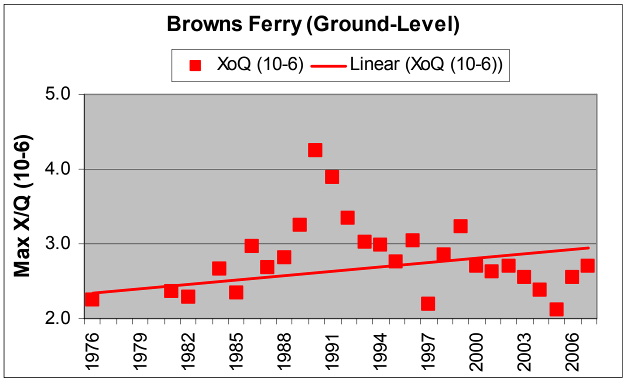
  The table below shows the diffusion coefficients are largest with the most unstable class (stability class A) and decrease as stability class becomes more stable (stability class G is the most stable). The table also shows the diffusion coefficients increase with distance from the release point.

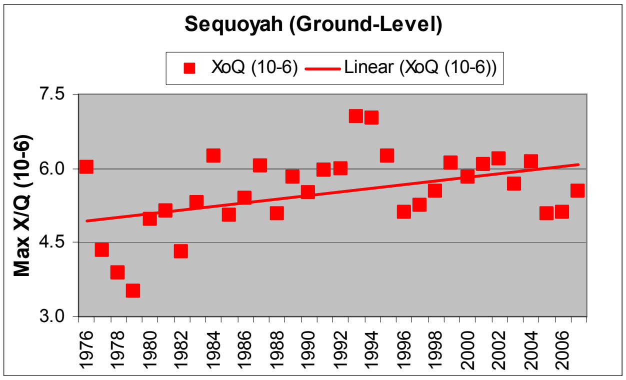
Horizontal diffusion coefficient (σ_y)					Vertical diffusion coefficient (σ_z)			
Distance from release point (meters)				Stability	Distance from release point (meters)			
500	1000	1500	2000	Class	500	1000	1500	2000
113	**209**	**298**	**384**	A	**105**	**454**	**1071**	**1968**
83	**154**	**221**	**286**	B	**51**	**109**	**171**	**234**
55	**103**	**149**	**193**	C	**32**	**61**	**89**	**115**
36	**68**	**99**	**128**	D	**18**	**32**	**42**	**50**
27	**51**	**74**	**96**	E	**13**	**22**	**28**	**33**
18	**34**	**49**	**64**	F	**8**	**14**	**18**	**22**
12	**23**	**33**	**42**	G	**6**	**9**	**12**	**14**

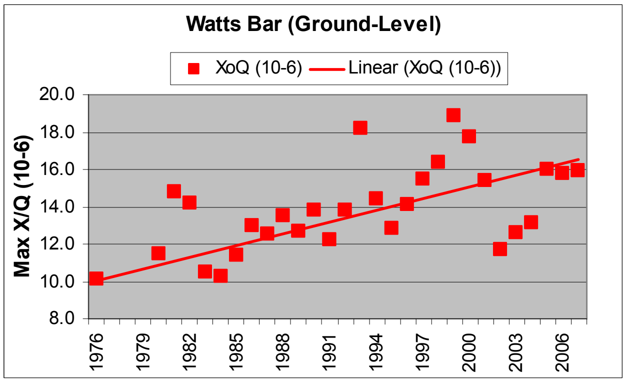
Values for classes A-F are based on Workbook of Atmospheric Dispersion Estimates (2nd edition). Values for class G based on logarithmic extrapolation of class E-F values.

Trends and Changes

There has been an overall upward trend in TVA χ/Q values since the 1970's as illustrated by the annual average values in the tables below. In more recent years (1990's and 2000's), the highest average χ/Q values are as much as 2.6 times the 1970's values. Therefore, plant operations must be altered to maintain the dose limit margin.



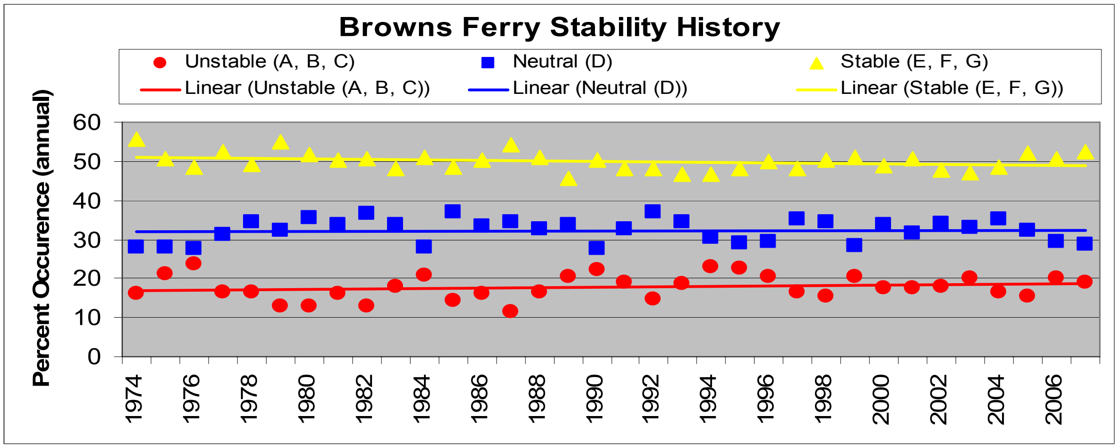


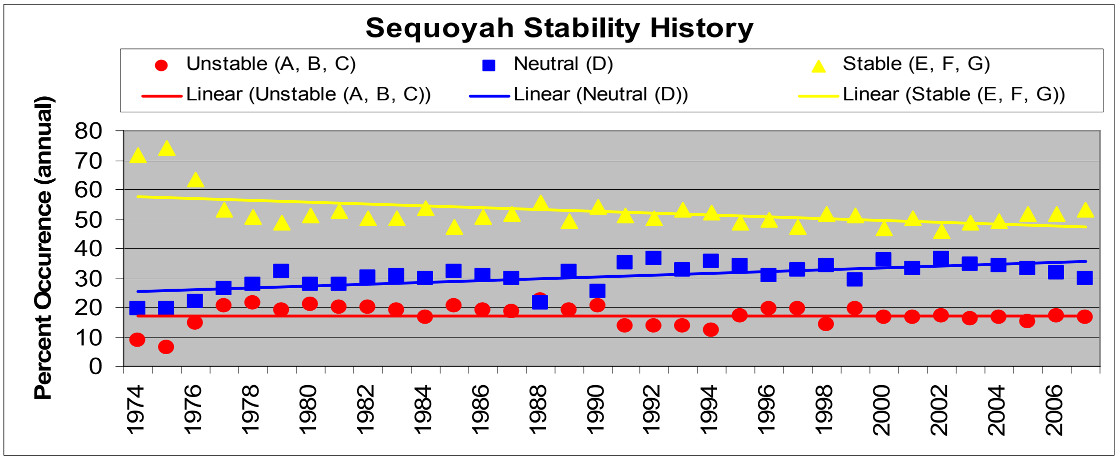


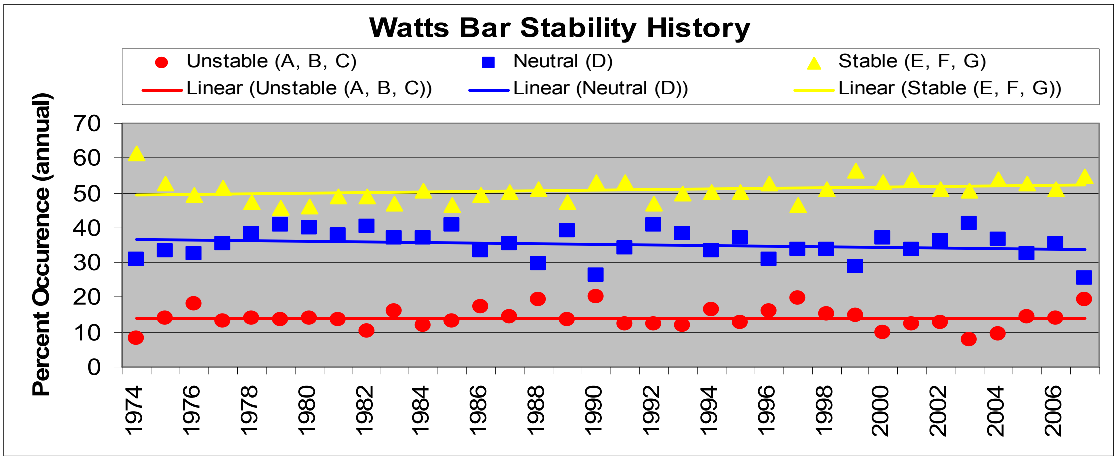
This upward trend is not unique to the TVA plants, but has been observed elsewhere.

Two meteorological conditions must be examined to determine the reasons for the increase in χ/Q values.

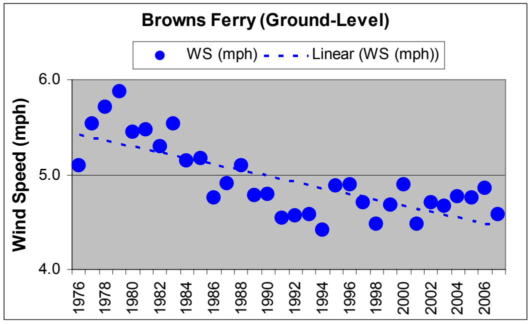
- Annual average atmospheric stability patterns have been relatively unchanged, which indicates the increases in χ/Q values are not due to changes in atmospheric stability.
    - Browns Ferry and Watts Bar display relatively flat trends for the stability occurrences.
    - Sequoyah has a slight downward trend for stable cases and an upward trend for neutral cases. However, this is primarily due to observations in the 1970's. Since 1980, the Sequoyah trends have also been relatively flat.

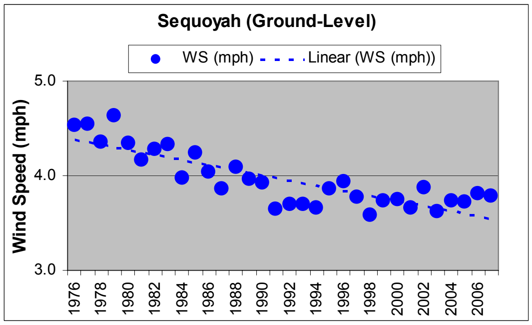

Browns Ferry Stability History
Unstable (A, B, C)
Neutral (D)
Stable (E, F, G)
Linear (Unstable (A, B, C))
Linear (Neutral (D))
Linear (Stable (E, F, G))
Percent Occurence (annual)
0
10
20
30
40
50
60
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006

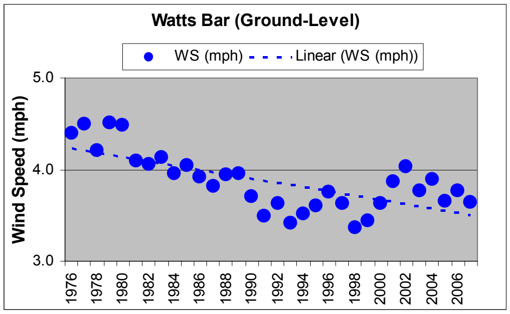

Sequoyah Stability History
Unstable (A, B, C)
Neutral (D)
Stable (E, F, G)
Linear (Unstable (A, B, C))
Linear (Neutral (D))
Linear (Stable (E, F, G))
Percent Occurence (annual)
0
10
20
30
40
50
60
70
80
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006


Watts Bar Stability History
Unstable (A, B, C)
Neutral (D)
Stable (E, F, G)
Linear (Unstable (A, B, C))
Linear (Neutral (D))
Linear (Stable (E, F, G))
Percent Occurence (annual)
0
10
20
30
40
50
60
70
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006

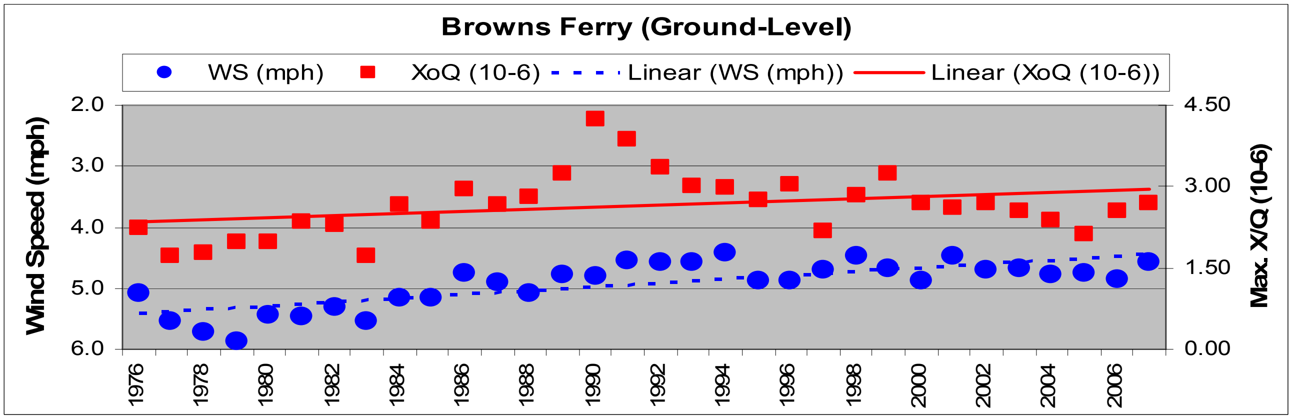
- On the other hand, average annual wind speed has shown a definite decrease with time for all plants.

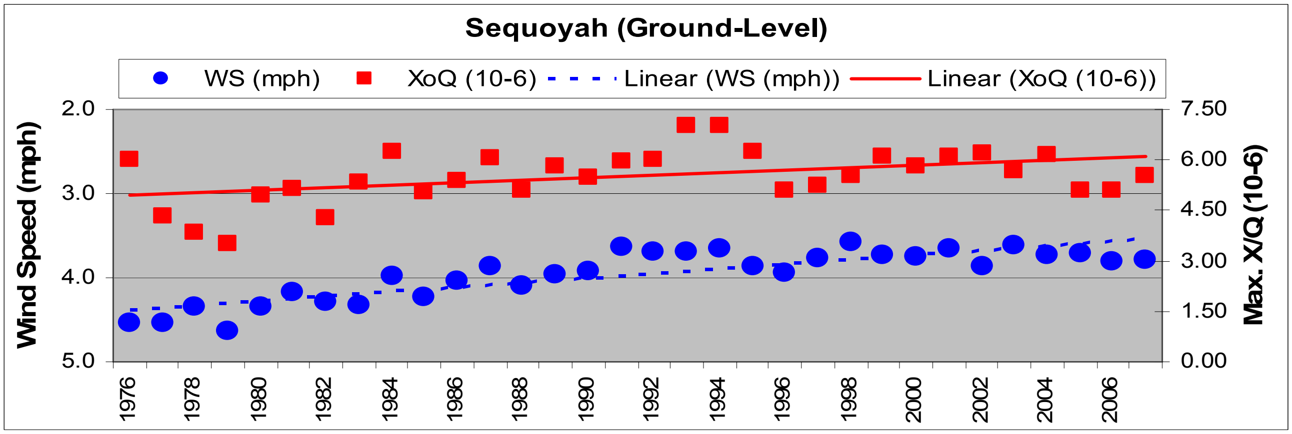


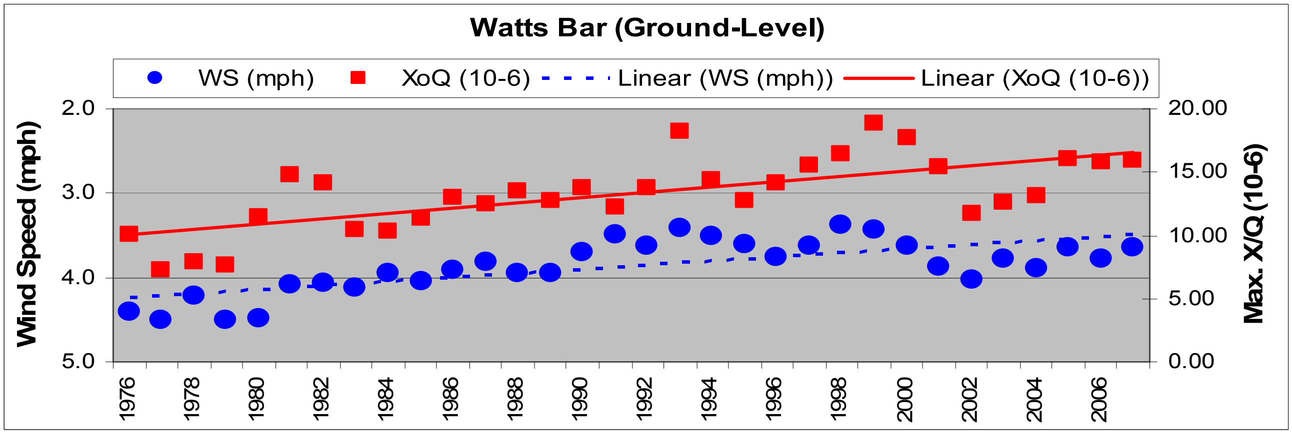




The relationship between wind speed decreasing and χ/Q increasing is confirmed when both are plotted on the same graph for each plant. *Note that wind speeds are plotted in reverse.*







Analysis

It appears that the increasing trend in χ/Q values is primarily due to decreases in wind speed, because the atmospheric stability and other terms in the χ/Q calculations are relatively unchanged during the data collection period.

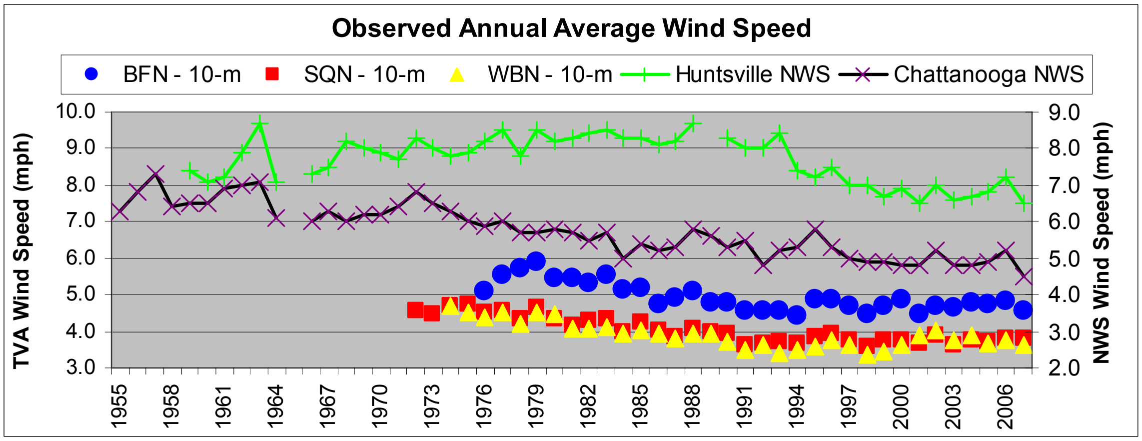
The next question is the nature of the wind speed decrease. Specifically, is it due to local influences that affect only the power plants, or is it part of a wider regional pattern?

- Local influences include construction of structures or other facilities that might obstruct wind flow, tree growth near the towers, or deterioration of wind speed instruments due to age.

  None of these explanations appears to be plausible.

  - TVA meteorologists have routinely inspected the meteorological sites since the early 1980's, and noted no significant changes that would affect wind speed.
  - As part of these inspections, tree growth was monitored. Trees were cut when they become too tall.
  - Finally, TVA changed from cup anemometers to sonic wind sensors during 2000-2001, with no apparent change in the trend.

- Reduced wind speeds appear to be a regional phenomenon. The following figure shows the observed wind speed for two NWS sites in the region also decreased at approximately the same rate as the TVA sites. *Note that a different scale is used for NWS data to avoid overlap and facilitate comparison.*



A Look to the Future

The decrease in wind speed appears to be the cause for increasing χ/Q values, but what does this mean?

While wind speed was not measured at the TVA sites prior to the 1970's, the data from the NWS stations indicates that the higher wind speeds was the normal condition from the mid-1950's until the 1970's. In the 1970's, a noticeable drop in the regional wind speeds occurred. Since 1980 (and especially the past decade), the wind speed trend has been flat. This indicates that recent years are more likely a new "normal" period and that the base data from the 1970's may no longer be applicable.

The relatively flat trend in the past decade indicates that a further significant decrease in wind speeds is unlikely. However, this is not certain.

In any case, planning based on the χ/Q values should reflect the more recent data based on low wind speeds. While higher wind speeds are possible, they should not be considered as "normal".

Lessons

- Meteorological conditions vary over time. Plant design and operation plans should assume variability in χ/Q values.
- The initial data used for plant design may not be "normal" for the entire history of plant operations.
- The dose limit margin should be adequate to handle not only the variability of meteorological conditions from year-to-year, but must also consider the possibility that the "base" data is not the "normal" data for the plant.

Case Study -- Delta-T Layers Used to Determine Stability Class for Elevated Releases

In Revision 1 of Regulatory Guide 1.23 issued in March 2007, NRC specifies that the temperature difference for determining stability class applicable to elevated releases should be ". . . between the 10-meter (33-foot) level and a higher level that is representative of diffusion conditions from release points . . ."

For TVA, this affects the χ/Q estimates for elevated releases from the stack at Browns Ferry Nuclear Plant. Previously, stability class for these releases was based on the temperature difference between 46 meters and 91 meters (old method). The new Regulatory Guide revision specifies that the temperature difference between 10 meters and 91 meters (new method) be used instead.

Since this affects the frequency of stability classes, TVA conducted an evaluation of the change. The following table shows that the frequency of neutral (D) and near neutral (E) cases decreased with the new method, while the frequency of stable (F, G) and unstable (A, B, C) cases increased. The increase in the frequency of unstable cases (+7.17) was essentially equal to the increase in frequency of stable cases (+7.18).

	15-Year Average Annual Frequency of Occurrence (percent)		
Stability Class	46-91 m layer (old method)	10-91 m layer (new method)	Difference (new minus old)
A	0.01	1.00	**+0.98**
B	0.07	2.17	**+2.10**
C	0.63	4.72	**+4.09**
D	54.89	43.40	*-11.49*
E	34.18	31.44	*-2.74*
F	8.02	13.57	**+5.55**
G	2.06	3.69	**+1.63**

The changes in stability class affect χ/Q values in three ways.

1. The diffusion coefficients change based on the stability class.
2. The height of the plume rise changes. Plume rise is not directly included in the basic χ/Q equation, but affects the value of H in the exponential portion of the basic χ/Q equation. The plume rises higher for unstable cases than for stable cases. This increases the depth of the plume mixing layer and consequently lowers the χ/Q values (because the plume diffuses in a deeper layer--i.e., the H value in the basic χ/Q equation is larger).
3. The distance of the point of maximum plume impact changes. This affects diffusion coefficients which change based on distance from the source.

Because of the multiple, and often conflicting, influences resulting from the change in stability class, it was not possible to isolate the effects in the χ/Q equation. Instead, TVA calculated annual average X/Q values for 15 years using the old method, re-calculated annual average X/Q values for the same 15 years using the new method, and compared the results.

The annual average χ/Q values for Browns Ferry dropped approximately 12 percent (individual annual averages ranged from a 7 percent increase to a 37 percent decrease).

The net result was beneficial to Browns Ferry.

References

- NRC Regulations 10 CFR 20, “Standards for Protection Against Radiation”
- NRC Regulatory Guide 1.11 (Revision 1), "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors"
- NRC Regulatory Guide 1.23 (Revision 1), “Meteorological Monitoring Programs for Nuclear Power Plants”
- Workbook of Atmospheric Dispersion Estimates
- TVA Report, “A Sensitivity Analysis of the Gaseous Effluent Licensing Code (GELC)”