Identifying Non-Linear Flow for Modeling of Routine Releases from TVA Nuclear Facilities

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The draft standard ANS-2.15, "Criteria for Modeling and Calculating Atmospheric Transport of Routine Releases from Nuclear Facilities," establishes criteria for use of meteorological data collected at nuclear facilities to evaluate the atmospheric effects on routine radioactive releases. One of the critical steps is to determine if a simple Gaussian model can be used, or if more detailed flow modeling is required. ANS-2.15 suggests using the screening method as described in "Single-Station Integral Measures of Atmospheric Stagnation, Recirculation, and Ventilation," by Allwine and Whiteman to determine if complex flow occurs more frequently than 15% of the year. This NUMUG presentation describes an application of the Allwine and Whiteman method at several Tennessee Valley Authority (TVA) nuclear sites. Examination included a detailed analysis of stagnation, recirculation, and ventilation factors.

Introduction

The Nuclear Regulatory Commission (NRC) is considering updates of dispersion modeling guidance applicable to nuclear plants to incorporate the latest models and modeling techniques. In anticipation of these revisions, the American Nuclear Society (ANS) is preparing new standards that address the state-of-the-science in dispersion modeling as it applies to nuclear facilities. The first of these, ANS-2.15 - "Criteria for Modeling and Calculating Atmospheric Transport of Routine Releases from Nuclear Facilities" - is nearing final form.

ANS-2.15 provides a roadmap for performing modeling needed to address non-linear flow affecting a nuclear facility. If the non-linear flow potential is small, the dispersion modeling process is well defined and relatively straightforward. However, if the potential is high enough, normal guidance may not apply and qualified modelers will need to conduct detailed flow and dispersion analyses (including possible field studies). Consequently, the results could significantly impact the amount of time, effort, and cost in licensing or regulatory compliance efforts at a nuclear facility.

To address the non-linear flow potential, ANS-2.15 states:

> *To determine if non-linear flow occurs more frequently than 15%, you should first identify the non-linear flow features, then you should determine a way to quantify the frequency of occurrence of those features. The recirculation and stagnation potentials defined by Allwine and Whiteman (1994) present an acceptable mechanism for determining the frequency of occurrence of non-linear flow.*

The Allwine and Whiteman Methodology

The methodology outlined by Allwine and Whiteman (1994) involves using single-station wind data to calculate local transport values at a site; specifically the wind run, transport distance, and recirculation factor. These terms are compared with predetermined Critical Transport Indices (CTIs) to determine the likelihood for stagnation, recirculation, and ventilation conditions.

The methodology requires hourly average wind direction (WD) and wind speed (WS) observations to calculate site transport values. The steps are discussed in detail below:

1) Calculate vector components for each hour.

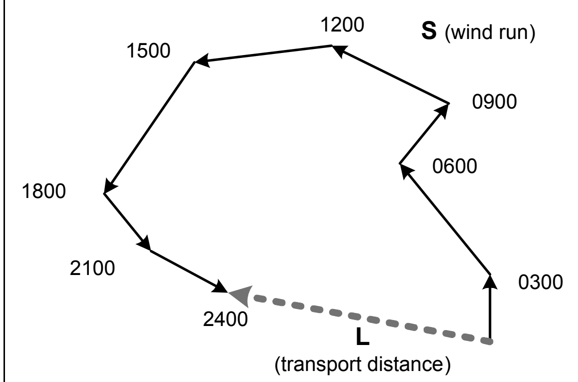
- north-south (n): $n = WS * cos(WD - 180)$
- east-west (e): $e = WS * sin(WD - 180)$

2) For each day, calculate the site transport values based on 24 hourly observations.

- wind run (S): $S = \Sigma \text{WS}$
- transport distance (L): $L = \sqrt{\Sigma n^2 + \Sigma e^2}$
- recirculation factor (R): $R = 1 - \frac{L}{S}$

3) Determine the critical transport indices (CTIs) that apply.

- S_c is the average daily CTI for stagnation.
- R_c is the average daily CTI for recirculation.
- S_{cv} and R_{cv} are the average daily CTIs for ventilation.



Based on Figure 2 in Allwine and Whiteman (1994).

Figure 1: Illustration of wind run (S) and transport distance (L).

After the daily values are calculated and the CTIs are determined, Allwine and Whiteman (1994) outline two general approaches for applying this methodology: a qualitative approach that provides an overall classification of site characteristics, and a quantitative approach that provides a percent occurrence for each type of transport condition at a site:

1. [Qualitative Approach] Determine a descriptive classification of site characteristics. Compare the average daily values of S and R (over the entire period of record) with predetermined CTIs.

   The site is classified based on the following relationships:

   - $S \leq S_c \rightarrow$ Site prone to stagnation.
   - $R \geq R_c \rightarrow$ Site prone to recirculation.
   - $R \leq R_{cv}$ and $S \geq S_{cv} \rightarrow$ Site prone to ventilation.

2. [Quantitative Approach] Calculate numerical values to classify the site. Compare individual daily values of S and R with predetermined CTIs and classify the transport conditions for each day.

   Five classifications are possible:

   - $S \leq S_c \rightarrow$ Stagnation only.
   - $R \geq R_c \rightarrow$ Recirculation only.
   - $R \leq R_{cv}$ and $S \geq S_{cv} \rightarrow$ Ventilation only.
   - $R \geq R_c$ and $S \leq S_c \rightarrow$ Stagnation plus Recirculation.
   - *No classification* (i.e., none of the transport conditions apply).

   Determine the percentage occurrence for each type of transport condition. That is, divide the number of days with a transport condition by the total number of days being examined. Express the result as a percentage.

Determining CTIs

In Allwine and Whiteman (1994), two slightly different sets of CTIs were derived and used in determining the transport characteristics of three sites in the Colorado Plateau Basin:

- The Qualitative Approach used S_c =170 km, R_c = 0.4, S_{cv} = 250 km, and R_{cv} = 0.2.
- The Quantitative Approach used S_c =130 km, R_c = 0.6, S_{cv} = 250 km, and R_{cv} = 0.2.

According to Allwine (2011), the CTIs were based on two contrasting sites – one strongly influenced by diurnal circulations and the other dominantly influenced by synoptic flows. However, Allwine and Whiteman (1994) concluded that the method of quantifying stagnation, recirculation, and ventilation "would be improved by a comprehensive investigation of these transport quantities for climatically diverse locations," and stated the need for "development of a physical or statistical basis for determining the values of the critical transport indices." Based on these conclusions, TVA identified three options for determining CTIs:

1. Use a predetermined set of values. These can be obtained from Allwine and Whiteman (1994), established by regulatory guidance, or developed by another accepted source. The CTIs could be generic for all cases or could reflect particular characteristics of the plant site (complex terrain, land/sea breeze, etc.).

   For the current ANS-2.15 application, Allwine (2011) recommends using the CTIs based on synoptic-scale flow: S_c =130 km, R_c = 0.6, S_{cv} = 250 km, and R_{cv} = 0.2. The ANS-2.15 guidance suggests that complex modeling (non-linear modeling) might be performed for sites where $R \geq 0.6$ or $S \leq 130$ km occurs more than 15% of the time.

   It is important to note that Allwine (2011) suggests that the current ANS-established non-linear flow threshold (15%) can be better determined by running both types of models - linear and non-linear - at sites of differing meteorology and deciding on an appropriate percentage based on when the modeling results are not significantly different. Regardless of which approach is used, the determination of CTIs is crucial.

2. Develop region-specific CTIs.

   Allwine and Whiteman (1994) developed CTIs for the Grand Canyon region. These CTIs may not be appropriate for other regions. For the TVA nuclear plants, data from NWS/FAA stations in the Tennessee Valley region were used to calculate the following CTIs:

   - S_c, based on the average wind run.
   - S_{cv}, based on the average 75th percentile wind run.
   - R_c, based on the average of daily R values.
   - R_{cv} is based on the average 35th percentile of daily R values.

3. Develop local CTIs.

   This uses the same approach as the region-specific CTIs, except that it uses data only from the NWS/FAA station(s) nearest the nuclear plant of interest.

Example – TVA Region

TVA examined the transport conditions at four of its nuclear plants in the Tennessee Valley Region: Browns Ferry, Bellefonte, Sequoyah, and Watts Bar. With the exception of Browns Ferry, the TVA nuclear sites are all surrounded by intermediate-to-complex terrain. Therefore, these sites would require further review to determine whether linear or nonlinear modeling is appropriate.

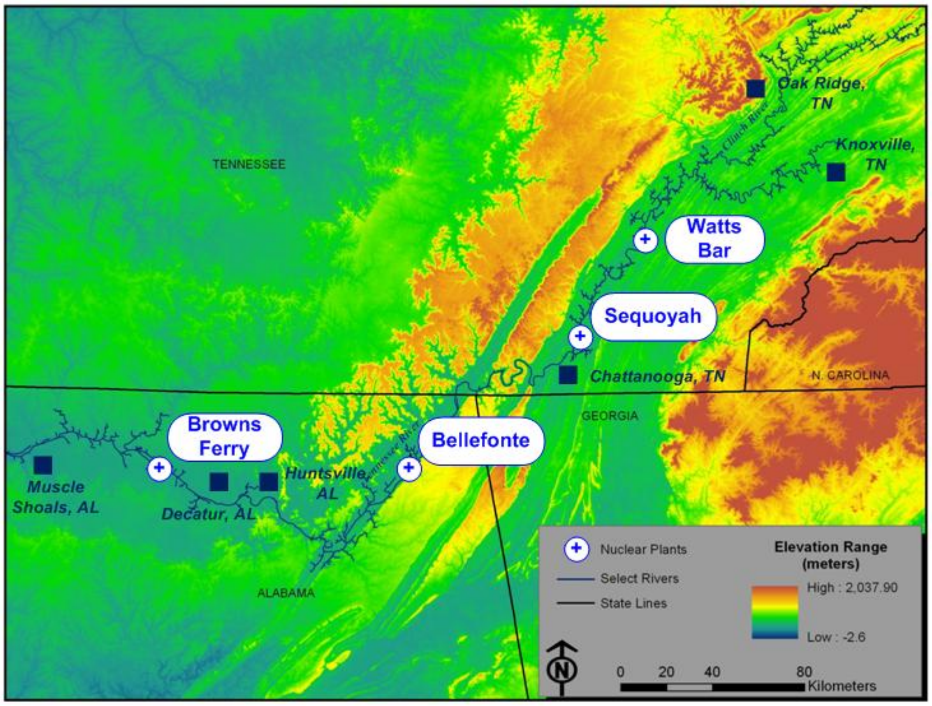


Figure 2: Location of TVA nuclear plants used in the analyses.

To demonstrate the degree of influence CTI values have on classifying site characteristics, TVA calculated CTIs for stagnation, recirculation, and ventilation using all three options discussed above (Table 1).

Table 1: CTIs determined by three different options.

Option	CTI Source	S_c (km)	R_c	S_{cv} (mi)	R_{cv}
1	Predetermined CTIs based on Allwine (2011) recommendations	130.0	0.60	249.9	0.20
2	**Regional CTIs**				
	a. 5-city Regional CTIs (Muscle Shoals, AL; Decatur, AL; Huntsville, AL; Chattanooga, TN; and Knoxville, TN).	112.4	0.29	145.5	0.15
	b. 6-city Regional CTIs (same as 2a. w/ Oak Ridge, TN)	102.8	0.32	133.1	0.19
3	**Local CTIs**				
	a. [Browns Ferry] Muscle Shoals, AL; Decatur, AL; Huntsville, AL	111.7	0.27	145.0	0.14
	b. [Bellefonte] Decatur, AL; Chattanooga, TN	112.8	0.29	145.2	0.16
	c. [Sequoyah & Watts Bar] Chattanooga, TN; Knoxville, TN	113.6	0.31	146.3	0.17

Once the CTIs were determined, TVA used the Allwine and Whiteman second quantitative approach to quantify the flow conditions at the TVA plants. Hourly observations of 10-meter average (scalar) wind speed (SWS) and vector wind speed (VWS) were used to calculate wind run, transport distance, and recirculation factor:

1. Daily wind run (S) was calculated based on the daily average SWS * 24.
2. Daily transport distance (L) was calculated based on the daily average VWS * 24.
3. Daily recirculation factor (R) was calculated using $R = 1 - \frac{L}{S}$.

The daily transport values were then compared to the CTIs derived from the three options to calculate the percentage of occurrence of each flow condition.

Results of the CTI Comparisons

The results of comparisons between daily site transport values and the derived CTIs are summarized below in Table 2. According to the comparison, none of the TVA sites showed recirculation conditions more than 15% of the time - regardless of the CTIs used - while stagnation conditions occurred more than 15% of the time in most cases. Based on these results, ANS-2.15 guidance would not require complex modeling based on the recirculation results for any of the TVA sites, but may require complex modeling based on stagnation results.

Table 2: Percent occurrence of daily transport values to CTIs at each TVA nuclear site.

Plant *	Percent Occurrence											
	Stagnation				Recirculation				Ventilation			
	1	2a	2b	3	1	2a	2b	3	1	2a	2b	3
Browns Ferry	*33.0*	19.1	13.1	19.4	*0.0*	2.0	0.9	2.7	*17.5*	52.0	61.5	51.3
Bellefonte	*39.8*	11.4	12.8	22.8	*0.0*	6.1	3.8	5.3	*10.1*	36.3	50.1	37.4
Sequoyah **	*48.5*	32.6	23.4	33.6	*0.0*	1.0	0.2	0.3	*5.3*	37.6	48.2	37.8
Watts Bar	*52.2*	39.2	31.5	40.2	*0.0*	10.4	5.5	6.6	*8.7*	36.5	44.5	37.0

1. Predetermined CTIs based on Allwine (2011) recommendations.
2a. 5-city Regional CTIs (based on Muscle Shoals, AL; Decatur, AL, Huntsville, AL, Chattanooga, TN, and Knoxville, TN).
2b. 6-city Regional CTIs (same as 2a. plus Oak Ridge, TN).
3. Local CTIs.

* Data period = 2001-2008 (Browns Ferry, Sequoyah, and Watts Bar).
= 2006-2008 (Bellefonte).
** For category 1 under recirculation, Sequoyah > 0, but does not round to 0.1%.

From the comparisons, it was apparent that the TVA sites had significantly different flow characteristics from the three sites studied in Allwine and Whiteman (1994). One of the Allwine and Whiteman sites (Bullfrog Basin, AZ) had 62% stagnation, 34% recirculation, and 8% ventilation. Another site (Desert View, AZ) had 8% stagnation, 4% recirculation, and 35% ventilation. A third site (Page, AZ) experienced 20% stagnation, 25% recirculation, and 40-70% ventilation (during a winter assessment). Using the Allwine and Whiteman CTIs, the TVA sites fall between these extremes with 33-52% stagnation, 0% recirculation, and 8-17% ventilation.

The use of different sets of CTIs significantly impacted the non-linear flow results at the plants. However, the TVA sites never reached the extremes of the Allwine and Whiteman sites, and they never demonstrated significant recirculation. These results were inconsistent with the original NRC and TVA characterizations, especially at the Watts Bar site. Therefore, CTIs may need to be adapted for each geographical area where they are used.

Conclusions

As indicated in ANS-2.15, the Allwine and Whiteman method presents an acceptable mechanism for determining the occurrence of non-linear flow conditions. However, use of this method requires establishing critical transport indices (CTIs) that are appropriate for the intended application. The results of the TVA study showed the degree of influence CTIs have in characterizing non-linear flow conditions at sites, as the percent of occurrence of non-linear flow conditions varied substantially with each set of CTIs. Furthermore, the resulting flow characteristics calculated at the TVA sites were inconsistent with original NRC and TVA characterizations, especially at the Watts Bar site.

Possible solutions to establishing appropriate CTIs might include having them set by regulatory guidance or other accepted source; outlining a specific, approved procedure to calculate them; or approving them on a case-by-case basis. Using the methodology outlined in the Allwine and Whiteman paper, a possible protocol might be to identify "benchmark" sites with known dispersion characteristics and develop CTIs based on those sites that can be universally applied. Whatever the solution, the determination of CTIs is crucial.

It is also important to mention that Allwine and Whiteman (1994) used a seasonal (winter) comparison of their Page, AZ site with their defined CTIs. This raises a crucial question as to if non-linear flow should be characterized seasonally, as synoptic-scale flow patterns vary substantially throughout the year. Additional studies are definitely needed at other sites with clearly established non-linear flow conditions to adequately determine the best solution.

Finally, the stagnation results of the TVA analyses revealed a possible concern in characterizing and modeling non-linear and linear flow. The stagnation percentages were quite substantial at the TVA sites; they dominated the other two types of flows. In some of the comparisons at Watts Bar, stagnation percentages occurred more than 50% of the time. Since the NRC Regulatory Guidance 1.111 addresses the need to characterize both recirculation and stagnation potential at sites in order to arrive at the best modeling approach, the ANS Working group may want to explore whether or not stagnation should be directly addressed in the final ANS-2.15 guidance. With stagnation flow having linear and non-linear characteristics and with linear Gaussian models unable to directly simulate stagnation conditions (i.e., very low wind speeds), current guidance is unclear as to best handle this type of flow.

References

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