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Analysis of 2010 Meteorological Data from the Knolls Atomic Power Laboratory and Kesselring Site Operations Facilities

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Section 1. Synopsis

Both the Knolls Atomic Power Laboratory (KAPL) in Schenectady, N.Y. and the Kesselring Site Operations (KSO) facility near Ballston Spa, N.Y. are required to estimate the effects of hypothetical emissions of radiological material from their respective facilities by the U.S. Environmental Protection Agency (EPA), which regulates these facilities. An atmospheric dispersion model known as CAP88, which was developed and approved by the EPA for such purposes, is used by KAPL and KSO to meet this requirement. CAP88 calculations over a given time period are based on statistical data on the meteorological conditions for that period.

Both KAPL and KSO have on-site meteorological towers which take atmospheric measurements at a frequency ideal for EPA regulatory model input. However, an independent analysis and processing of the meteorological data from each tower is required to derive a data set appropriate for use in the CAP88 model. The National Atmospheric Release Advisory Center (NARAC) was contracted by KAPL to process the on-site data for the calendar year 2010.

The purpose of this document is to:

- Summarize the procedures used in the preparation/analysis of the 2010 meteorological data
- Document adherence of these procedures to the guidance set forth in "Meteorological Monitoring Guidance for Regulatory Modeling Applications", EPA document: EPA-454/R-99-005 (EPA-454)

Section 2. Data Background

2.1 Tower Operations

The meteorological towers at KAPL and KSO are maintained by NARAC (via a subcontract with Air Resource Specialists [ARS]), in coordination with site facility personnel. The role of NARAC in tower instrument maintenance is independent from its role in this analysis.

Both of the towers are equipped with identical sets of meteorological instrumentation for measuring the following ambient parameters:

- Air temperature
- Relative humidity
- Wind speed
- Wind direction
- Precipitation as accumulation over 15-minute periods and over the entire year

The sensors on the two towers are affixed at the following heights (above ground level):

- KAPL – 13 meters
- KSO – 43 meters

The tower instruments take measurements at a frequency of a few seconds. These direct measurements are then averaged over 15 minute periods. This averaged data is accessible through an interface program called "Metview", written and maintained by ARS.

EPA-454 guidelines necessitate the availability of the 15-minute averaged data. Therefore Metview processed data were used extensively in this analysis.

Wind Measurements

The towers at both the KAPL and KSO sites are equipped with identical instrumentation for measuring wind speeds and directions including:

- A sonic wind sensor
    - Through late May, 2010 the 50.5 Solid State Wind Sensor from Met One Instruments, Inc. was used (http://www.jifbrunei.com/files/50-5Wind.pdf)
    - In late May 2010, the sensor was replaced with a heated sonic sensor from Vaisala (http://www.vaisala.com/Vaisala Documents/User Guides and Quick Ref Guides/WS425_User_Guide_in_English.pdf)
- A mechanical wind sensor using a mechanically driven propeller and wind vane from the R. M. Young Company (http://www.youngusa.com/products/7/8.html)

Both wind sensors operate simultaneously and independently, resulting in two sets of wind measurements and therefore two corresponding sets of 15-minute averaged values. Parameters derived from the wind data have redundant 15-minute averaged values as well. An example of such a parameter is the standard deviation of the measured wind direction. This is an important value (commonly referred to as "sigma theta") which may be used to directly estimate a Pasquill-Gifford (PG) stability category.

The sonic instrumentation at both KAPL and KSO was upgraded on approximately May 19, 2010. The date of the upgrade coincides with the only significant time window of missing data at both sites. The technical specifications of the new sensor are similar to that of the older sonic sensor so that distinguishing between the two is not relevant to this analysis.

2.2 Metview

While this analysis relies upon Metview to access the 15-minute averaged data, it should be emphasized that Metview was not written as a data analysis tool. Metview was developed primarily to display the tower data and to that end it selects wind measurements from just one of the two wind sensors. Under normal operating conditions, Metview uses the sonic wind sensor data as opposed to that from the mechanical sensor. Statistically, this represents over 99% of the 2010 data. In cases where the sonic wind sensors either fail to take measurements or provide data that fails to meet its own data quality tests, Metview will display wind data from the mechanical sensors so long as it is available.

2.3 Calm Wind Threshold

The calm wind threshold specifies the minimum ambient wind speed needed to properly engage a wind speed sensor (anemometer) to obtain a valid reading. The manufacturer specification for the mechanical anemometer has a reported wind speed threshold of 1.1 m/s. In contrast, the threshold for the newer sonic anemometer is much lower and is reported in its specifications to be "virtually zero".

EPA-454 provides guidance on the treatment of calm winds. A calm threshold of 0.5 m/s is recommended for site-specific meteorological monitoring, while a more conservative value of 1.0 m/s is recommended when using wind data as input to a steady state model such as CAP88. The 1.0 m/s threshold removes low wind speeds which may generate unrealistically high concentration levels in steady state dispersion models.

These EPA-454 recommended values appear to be based on mechanical instrumentation as that documents states, "sonic anemometers are not commonly used for routine monitoring and are beyond the scope of this guide." This analysis therefore takes into account the differences between the low wind speed threshold of the sonic anemometer and the higher calm wind speed thresholds recommended by the EPA-454 guidance.

2.4 Time Zone Convention

All times in this document are given in UTC (Universal Time Coordinates or Greenwich Mean Time). Eastern Standard Time, the time zone for both KAPL and KSO, is 5 hours behind UTC.

Section 3. Data Processing Procedures

The variables of interest for calculating the final data set for use in CAP88 are:

- Wind speed
- Wind direction
- Sigma theta

3.1 Data Consistency

This analysis first focused on establishing a consistent meteorological data set based on instrument specifications, taking into account missing data as well as wind data redundancy.

3.1.1 Missing Data

Missing data were almost non-existent at both sites. Both towers experienced a single time window in late May during which data were not measured, which could be directly attributed to the tower maintenance and upgrade of the sonic instrumentation discussed in the Data Background section. The periods of continuously missing data (completely devoid of any 15-minute values) are listed below:

- KAPL - 5/19 7:15 UTC through 5/20 19:00 UTC
- KSO - 5/15 17:15 UTC through 5/19 19:00 UTC

It should be noted that under normal operating conditions, missing data on the order of 4 days is atypical and such lengthy data gaps did not occur in previous years.

3.1.2 Use of Mechanically Measured Winds

A second consideration was to address the issue of redundant wind data in order to achieve a consistent data set of the highest possible quality. As discussed above, Metview primarily uses wind data from the sonic anemometer, relying on the mechanical sensor only in cases of missing or questionable sonic data. During 2010, Metview selected the mechanical sensor data only in cases where the sonic data was judged to be questionable by its own data quality indicators. The number of such cases in 2010 is given below:

- KAPL – A total of 52 15-minute periods
- KSO – A total of 19 15-minute period

In 42 of these periods, the data quality indicator used by Metview to exclude sonic data was based on the wind gusts averaged over the 15-minute period, which is reported by Metview separately from the averaged wind speed. However, in all of these cases the averaged wind speeds did not display similarly high values. Therefore, for consistency with the majority of the data, the sonic wind data was used for these periods.

The remaining 29 cases where Metview overrode the sonic values all occurred at KAPL due to the reasons shown below in Table 1. In these failover cases, this analysis used the mechanical wind sensor

values since the sonic values were clearly unreliable. KSO had no cases where the mechanical wind data could be considered more reliable.

Reason	Time Period
Stuck sensor	Jan 18 3:30 UTC through Jan 18 6:30 UTC
	Feb 24 7:15 UTC through Feb 24 10:15 UTC
Abnormally high wind speed	Feb 24 13:30 UTC through Feb 24 14:00 UTC

Table 1 - Periods for which mechanical wind sensor data were used during 2010 for KAPL

3.2 Consideration of Calm Winds

As discussed in the background section, the calm wind threshold ranges between a low of 0 m/s for the sonic anemometer and the non-instrument dependent EPA-454 guidance of 1.0 m/s, a value which also approximates the calm threshold of the mechanical wind sensor. This analysis took an intermediary approach to account for the higher precision of the sonic while addressing EPA's concern regarding overly high concentrations calculated by steady state models in low wind speed conditions. Since CAP88 uses a minimum wind speed of 1 knot (0.26 m/s), this value was a natural breakpoint for identifying calm winds.

This led to the omission of data for the following periods in 2010 due to calm wind conditions:

- KSO - A total of 3 hours out of 8662 total hours
- KAPL – A total of 5 out of 8724 total hours

The wind speeds during the three time periods in Table 1 for which mechanical anemometer data were used were all higher than the threshold wind speed of the mechanical anemometer with the exception of a single 15-minute averaged value which was slightly below that threshold. Therefore, neither the KAPL nor KSO data sets had any significant inconsistencies in the determination of calm values due to the differences in instrumentation.

3.3 Hourly Averaging

In regulatory modeling as recommended by EPA-454, hourly averaged values should be derived from sub-hourly samples with 15-minute intervals being ideal. Hourly averaged values are considered invalid when there are less than two 15-minute averaged values on which to base the hourly average. There were several isolated cases of missing 15-minute data values at both sites but none such that an hourly averaged value could not be determined based on this guideline. The computation of an hourly averaged value for each meteorological variable of interest was based on the four 15-minutes averages

ending at the top of that hour. For example, an hourly average at 3:00 UTC was calculated as the average of the four 15-minute averages from 2:15, 2:30, 2:45 and 3:00 UTC

3.2.1 Averaging Equations

The hourly averaging performed in this analysis used the following equations from EPA-454:

- Wind speed **-** Scalar wind speed equation (EPA-454 Eq.6.2.1):

$$\bar{u} = \frac{1}{N} \sum_1^N u_i$$

where $\bar{u}$ = average wind speed, and N = the number of 15-minute averages within the hour. This is an arithmetic average of the 15-minute averaged wind speeds.

- Wind Direction - Scalar mean wind direction equation (EPA-454 Eq. 6.2.4):

$$\bar{\Theta} = \frac{1}{N} \sum_1^N \mathrm{D}_i$$

$\bar{\Theta}$ = average wind direction

N = Number of hourly 15-minute averages

I = sample number per hour (1,2,3,4)

and D_i is defined as:

For I = 1:

$D_i = \Theta_i$

For I > 1:

$D_i = D_i\text{-}1 + \delta_i + 360$; for $\delta_i < -180$

$D_i = D_i\text{-}1 + \delta_i$; for $\delta_i < 180$

$D_i = D_i\text{-}1 + \delta_i - 360$; for $\delta_i > 180$

D_i is undefined for $\delta_i = 180$

where

Θ_i = 15-minute averaged wind directions

$\delta_i = \Theta_i - D_{i\text{-}1}$; for I > 1

Being a scalar average, this formula computes the average wind direction without the need for calculating the vector components of the wind directions. This averaging method is based on the assumption that the wind direction does not vary by more than 180 degrees between successive readings. There were two cases at KAPL where successive 15-minute averaged wind directions differed by exactly 180 degrees. In both cases, the value causing the 180 degree difference was removed from the hourly set. The removal of these two data points did not drop those hourly sample totals below the required minimum of two 15-minute averaging periods.

- Sigma theta - root-mean-square "average" (EPA-454, eq. 6.2.10)

$$\text{Hourly sigma theta} = \left[\frac{1}{N} \left\{ \sum_1^N \sigma_{\theta_i}{}^2 \right\} \right]^{1/2}$$

where σ_{θ_i} is the 15-minute averaged sigma theta value, and N is the number of 15-minute averages. This root-mean-square formula is recommended by EPA-454 in order to minimize the effects of wind meandering.

In the case of wind speed and direction, EPA-454 also allows for vector based averaging as opposed to the scalar based equations. However, that document recommends the scalar averaging approach that was used in this analysis.

3.4 Atmospheric Stability

There are four options in EPA-454 for calculating the atmospheric stability for use in regulatory models. Three of these options rely on specific meteorological parameters not measured by the instruments at KAPL and KSO. The final option is the commonly used "Modified Sigma Theta" (MST) method (EPA-454) based on sigma theta measurements.

3.4.1 Modified Sigma Theta (MST) Method

Sigma theta values describe the variation in the reported wind direction. The MST method uses this variation as an initial estimate of atmospheric stability with larger wind direction variability indicating unstable conditions and less variability indicating more stable conditions. Specifically, for each available hour, the MST method:

- Adjusts the measured sigma theta values based on the surface roughness of the site and the measurement height of the tower instrumentation
- Uses the height-adjusted sigma theta values to determine an initial value of the Pasquill-Gifford (PG) stability using the lookup table in EPA-454: Table 6-9a (reproduced below as Table 2)
- Uses the initial PG stability, day/night classification, and wind speed values to determine a more comprehensive value for stability using a second lookup table EPA-454: Table 6-9b (reproduced below as Table 4)

These steps are discussed in more detail in the following sub-sections.

3.4.2 Surface roughness estimates

The MST requires an estimate of the "surface roughness length" for each site. Surface roughness estimates were initially made based on discussions with KAPL staff. These estimates were then compared to EPA-454 (Table 6-10), which provides surface roughness estimates based on terrain characteristics, as well as the American Meteorological Society's surface roughness equation (e/30;

where e = averaged height of obstacles). The final estimate of surface roughness for each site is an approximate average of all of these sources.

The estimated surface roughness lengths for each site were estimated to be:

- KAPL: 0.30 meters
- KSO: 0.25 meters

3.4.3 Initial Pasquill-Gifford Stability Estimates

Initial hourly PG stabilities are determined from the measured sigma theta values according to EPA-454: Table 6-9a:

Measured Deviation of Horizontal Wind Direction Sigma theta ranges (σ_Θ = sigma theta, in units of compass degrees)	Initial estimate of P-G Stability Category
$22.5 \leq \sigma_\Theta$	A
$17.5 \leq \sigma_\Theta < 22.5$	B
$12.5 \leq \sigma_\Theta < 17.5$	C
$7.5 \leq \sigma_\Theta < 12.5$	D
$3.8 \leq \sigma_\Theta < 7.5$	E
$\sigma_\Theta < 3.8$	F

Table 2 – PG-stability correspondence to sigma theta data (reproduced from EPA-454: Table 6-9a).

The sigma theta ranges in Table 2 assume an instrument height of 10 meters. Since the instrument height at both sites differs from this standard level (13 m at KAPL, 43 m at KSO), a correction factor was applied as described in EPA-454 (section 6.4.4). The measurement height correction factor is given by:

$(Z/10)^{P_0}$

where Z = the measurement height in meters, and P_0 is a function of stability based on the following table:

PG Stability	A	B	C	D	E	F
P_0	0.06	-0.15	-0.17	-0.23	-0.38	0

Table 3 – Stability-dependent exponent values for instrumentation height correction (EPA-454).

A surface roughness correction was also required since Table 2 assumes a standard surface roughness length of 0 .15 meters. EPA-454 provides the following surface roughness correction factor:

$(Z_0/15)^{0.2}$ where Z_0 = surface roughness length as estimated in section 3.3.2.

Multiplying the correction factors for tower instrument height and surface roughness by the standard sigma theta ranges results in the following corrected table of sigma theta ranges for determining the initial estimate of PG stability for each site:

KAPL	KSO	Initial estimate of PG Stability Category
$25.4 \leq \sigma_\Theta$	$22.8 \leq \sigma_\Theta$	A
$19.3 \leq \sigma_\Theta < 25.4$	$15.6 \leq \sigma_\Theta < 22.8$	B
$13.7 \leq \sigma_\Theta < 19.3$	$10.8 \leq \sigma_\Theta < 15.6$	C
$8.1 \leq \sigma_\Theta < 13.7$	$5.9 \leq \sigma_\Theta < 10.8$	D
$4.0 \leq \sigma_\Theta < 8.1$	$2.4 \leq \sigma_\Theta < 5.9$	E
$\sigma_\Theta < 4.0$	$\sigma_\Theta < 2.4$	F

Table 4 - Modified version of EPA-454 Table 6-9a used in this analysis.

These adjusted sigma theta ranges were then used to determine the initial stability for each hour.

3.4.4 Day/Night Calculations

For the calculation of the final stability at each hour, the MST method requires that each hour be identified as occurring during the day or night. The determination of day or night periods was based on an Excel spreadsheet available from Greg Pelletier from the Department of Ecology, WA. The calculations within that spreadsheet are described at the following NOAA web sites:

- "Sunrise/Sunset Calculator" (http://www.srrb.noaa.gov/highlights/sunrise/sunrise.html)
- "Solar Position Calculator" (http://www.srrb.noaa.gov/highlights/sunrise/azel.html)

Day and night values were calculated from the NOAA program based on the solar elevation angle for each hour in the calendar year. A positive/negative solar elevation angle generated by the NOAA calculator was interpreted as a day/night value. An adjustment was made to the calculated day hours just after sunrise and before sunset for consistency with the definition of day and night in Table 6-3 of EPA-454: "Night refers to the period from one hour before sunset to one hour after sunrise".

Due to the relative proximity and approximate equality of solar parameters between the two facilities, one set of day/night values was calculated at a geographic point approximately half-way between KAPL and KSO and used for both sites.

3.3.5 Final Pasquill-Gifford Stability Estimates

The following table (EPA-454: Table 6-9b) was used to determine the final stability values, based on the initial PG classification, the day/night designation, and the wind speed.

	Initial Estimate of PG Stability	wind speed	Final Estimate of PG Stability
Daytime	A	u < 3	A
	A	3 ≤ u < 4	B
	A	4 ≤ u < 6	C
	A	6 u	D
	B	u < 4	B
	B	4 ≤ u < 6	C
	B	6 u	D
	C	u < 6	C
	C	6 u	D
	D, E, or F	any	D
Nighttime	A	u < 2.9	F
	A	2.9 ≤ u < 3.6	E
	A	3.6 u	D
	B	u < 2.4	F
	B	2.4 ≤ u < 3.0	E
	B	3.0 u	D
	C	u < 2.4	E
	C	2.4 u	D
	D	any	D
	E	u < 5	E
	E	5 u	D
	F	u < 3	F
	F	3 ≤ u < 5	E
	F	5 u	D

Table 4 – Final stability values for Modified Sigma Theta method incorporating day/night and wind speed values (EPA-454: Table 6-9b).

Section 4. CAP88 Input

The deliverable product required from this analysis was a summary of the hourly stabilities and wind values for use in running the CAP88 program. The standard CAP88 input format for meteorological data is an ASCII "Wind File" (WND). The WND file was generated via a CAP88-provided utility which uses as input a joint frequency table of stability and winds in "Stability Array file" (STAR) format. The LLNL analysis created appropriate STAR files for each site.

To create the STAR file, the hourly-averaged wind data was processed as follows:

- Each hourly wind direction was converted to its corresponding sector: e.g. NNE or North/Northeast
- Wind speed units were converted from m/s to knots and rounded to whole integers

A LLNL-developed program was then used to process the hourly wind and corresponding Pasquill-Gifford stability categories into the appropriate joint frequency category and count those values accordingly.

Section 5. Summary

This document has outlined the steps in analyzing and processing meteorological data from the Knolls Atomic Power Laboratory and Kesselring Site Operations facilities into a format that is compatible with the steady state dispersion model CAP88. This process is based on guidance from the EPA regarding the preparation of meteorological data for use in regulatory dispersion models. The analysis steps outlined in this document can be easily adapted to process data sets covering time periods other than one year. The procedures will need to be modified should the guidance in EPA-454 be updated or revised.

Appendix A

References

United States Environmental Protection Agency, Office of Air Quality Planning and Standards, Meteorological Monitoring Guidance for Regulatory Modeling Applications (EPA-454/R-99-005), February 2000.

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