Meteorological Considerations for Nuclear Power Plant Siting and Licensing

George C. Howroyd, Ph.D., P.E.
CH2M HILL, 1000 Abernathy Road, Atlanta, GA 30328

Paul B. Snead, R.E.M.,
Progress Energy, 100 E. Davie Street, Two Progress Plaza – 15, Raleigh, NC 27602

ABSTRACT

Despite the exceptional performance record of current nuclear plants, no new nuclear plant has been licensed in the United States in over 25 years. Recent initiatives, such as DOE's *Nuclear Power 2010 Program,* and projections that the U.S. will need at least 350,000 megawatts of new generating capacity by the year 2030, the equivalent of *hundreds* of new plants, have resulted in a flurry of activity to site and license new nuclear plants. More than 15 companies are in the process of preparing for or obtaining Combined License Applications (COLAs) for over 30 new reactors at 25 proposed new plant locations. One of the primary elements of a new plant license application is the characterization of site-specific meteorology and a demonstration that plant operation can meet rigid limitations for airborne radiological impacts. A cornerstone of the demonstration of compliance with these requirements is the use of multiple years of on-site meteorological data when predicting relative concentration and deposition impacts of radionuclide emissions during plant operation and hypothetical accident scenarios.

Based on Progress Energy's recent experience obtained during the siting and licensing process for two recently proposed nuclear power generating facilities in North Carolina and Florida, this paper describes some of the meteorological related considerations that should be taken into account, including the following:

- Regulatory requirements
- Lead time to obtain valid on-site data
- Designing an on-site meteorological monitoring system
- Siting the monitoring system
- Operational considerations
- Data recovery and quality
- Physical influences on wind measurements
- Effects of time and spatial averaging on meteorological parameters
- Calm/light wind influences on the data
- Other meteorological conditions that can adversely influence dispersion modeling of radionuclide emissions

The consideration of these and other factors during the nuclear power plant siting and licensing process can play an important role in the early stages of the plant development process.

INTRODUCTION

Despite the exceptional performance record of current nuclear plants, no new nuclear plant has been licensed in the United States in over 25 years. Recent initiatives, such as DOE's *Nuclear Power 2010 Program,* and projections that the U.S. will need at least 350,000 megawatts of new generating capacity by the year 2030, the equivalent of *hundreds* of new major power plants, have resulted in a recent flurry of activity to site and license new nuclear plants. This push for new and cleaner generating capacity is also being driven, and in no small part, by concerns about the effects of air pollution on the environment and the expectation that the U.S. Environmental Protection Agency will regulate carbon dioxide, the principal "greenhouse gas" that is emitted by fossil fuel-fired industrial facilities and power plants. Nuclear power generation in the U.S. currently represents more than 75 percent of the electrical generating capacity that does not emit any greenhouse gas emissions. These factors, coupled with the excellent safety and reliability of nuclear generation, makes the development of new nuclear generating plants extremely attractive. More than 15 companies are currently in the process of preparing (or have already submitted) Combined License Applications (COLAs) for over 30 new reactors at over 20 proposed locations.

One of the primary elements of a new plant license application is the characterization of site-specific meteorological conditions and the use of that information in a quantitative demonstration that plant operation can meet rigid limitations for airborne radiological impacts associated with routine radiological emissions as well as for hypothetical accidental release scenarios. A cornerstone of the demonstration of compliance with these requirements is the collection and use of multiple years of on-site meteorological data, and the use of that data to predict the relative concentration and deposition of radionuclide emissions by using established dispersion modeling techniques.

The U.S. Nuclear Regulatory Commission (NRC) has established extensive regulatory requirements and issued guidance documents related to the collection and use of on-site meteorological data in license applications for both new and existing nuclear generating facilities. These requirements address the siting of on-site monitoring systems, the parameters that must be measured, minimum accuracy requirements, data collection, quality control, and data formatting. This paper addresses some of the many considerations that should be given to on-site meteorology and climatology related issues during the siting and licensing phases of nuclear power plant development.

In contrast to the NRC's requirements for on-site meteorological monitoring at new and existing nuclear plants, state air pollution control agencies and the U.S. Environmental Protection Agency (EPA) have somewhat different meteorological monitoring requirements for the air quality permitting of industrial facilities in the United States. Except for very specialized applications where the meteorological conditions at a particular plant site might be considered unique or unduly influenced by site-specific conditions (such as complex terrain or land-sea interactions), these agencies typically allow applicants to utilize "representative" meteorological data from the National Weather Service (NWS) meteorological observing stations that are located at major airports. Data obtained from these stations typically include detailed hourly surface observations. Supplemented by twice-daily upper air observations from dedicated upper air observing stations, these data can be used to develop five-year data sets (consisting of wind speed and direction, ambient temperature, atmospheric stability, and mixing depth) that are considered suitable for use in dispersion modeling analyses. For the rare applications where it is determined that on-site meteorological observations are required to support a permit application, EPA provides comprehensive guidance that addresses issues such as tower siting, instrument threshold and accuracy, and data recovery objectives in *Meteorological Monitoring Guidance for Regulatory Modeling Applications*.[1] The primary difference between the NRC and the EPA guidance is that there are no clearly defined requirements for when the states or EPA will require on-site meteorological monitoring, whereas the NRC always requires on-site meteorological monitoring for nuclear plant licensing.

Still additional guidance, which expands on (but is generally consistent with) the guidance provided by the NRC and EPA, is provided by the American National Standards Institute/American Nuclear Society in a publication titled *Determining Meteorological Information at Nuclear Facilities*.[2]

METEOROLOGICAL REQUIREMENTS FOR PLANT SITING AND LICENSING

The role of meteorology in the nuclear power plant siting and licensing process is simple, namely to support the conclusion that a proposed new facility at a particular plant site location can be constructed and operated without undue risk to health and safety at any location, and that the meteorological characteristics of the site can be demonstrated to be within the reactor manufacturer's design site parameters. As part of this demonstration, existing licensing requirements specify that applicants provide and utilize the following information in their application and the supporting analyses:

- Regional Climatology – to characterize the climatology of the region and identify the parameters that determine safe plant design and operation. Of interest are extreme and mean values of temperature, humidity, precipitation, and wind speed; seasonal and annual frequencies of severe weather conditions such as tornadoes and hurricanes, ice and snow accumulation, hail and lightning; and a reasonable assurance that these extreme values and occurrences will not be exceeded during the life expectancy of the plant.

- Local Meteorology – to characterize local meteorological conditions and to assess the potential impact of the facility on local meteorological conditions. Areas of interest include the influence of the plant's ultimate heat sink (cooling towers and other cooling systems) on the existing environment and the potential for local climate modification, as well as the influence of the physical plant and local topography on local dispersion conditions.

- On-site Meteorological Measurements – Continuous pre- and post-operational meteorological monitoring are required for use in characterizing the atmospheric dispersion of routine radiological releases as well as for hypothetical accidental release scenarios. A qualified on-site monitoring program must demonstrate the use of appropriate instrumentation, the siting of the monitoring system, data recording methods, QA/QC programs, and the suitability of the resulting data for use in characterizing site-specific dispersion in the vicinity of the plant. The data must be deemed representative of the site and surroundings, with a minimum of one annual cycle upon submission of the license application and a minimum of two annual cycles upon license approval.

Regulatory Drivers

The NRC regulates the licensing of nuclear power plants under the basic framework of 10 CFR 52. Specific requirements related to meteorology and climatology are provided in numerous NRC publications and guidance documents, including Regulatory Guides (RG's), Technical Reports (NUREGs), and Standard Review Plans (SRPs), as well as various industry standards and guidelines that are acknowledged or used by NRC. When interest in licensing new reactors began to grow in recent years, most of these guidance documents (which have been in existence since the 1970s) were either out of date or not reflective of current technology or industry practices. As a result, many have undergone revision and updating in recent years, primarily in response to extensive requests for clarification of key issues by the nuclear industry. The primary reference document which summarizes NRC's guidance concerning criteria for on-site meteorological monitoring programs is NRC's Regulatory Guide 1.23 entitled *Meteorological Monitoring Programs for Nuclear Power Plants*.[3] Additional NRC guidance documents are available from the NRC web site[4] that pertain to the collection, use, or interpretation of meteorological data for the licensing of nuclear power plants include the following:

- RG 1.27, *Ultimate Heat Sink for Nuclear Power Plants* (Revision 2, January 1976)
- RG 1.70, *Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants* (Revision 3, November 1978) (Section 2.3, Meteorology Requirements for Safety Analysis Reports)
- RG 1.76, *Design Basis Tornado* (Revision 1, March 2007)
- RG 1.97, *Criteria for Accident Monitoring Instrumentation for Nuclear Power Plants* (Revision 4, June 2006)
- RG 1.109, *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I* (Revision 1, October 1977)
- RG 1.111, *Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases From Light Water-Cooled Reactors* (Revision 1, July 1977)
- RG 1.112, *Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Light Water-Cooled Power Reactors* (Revision 1, March 2007)
- RG 1.117, *Tornado Design Classification* (Revision 1, April 1978)
- RG 1.145, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants* (Revision 1, November 1982)
- RG 1.206, *Combined License Applications for Nuclear Power Plants* (June 2007)
- NUREG 0800, *Review of Safety Analysis Reports for Nuclear Power Plants*, (Section 2.3) (March, 2007)

- NUREG-1555, *Environmental Reviews for Nuclear Power Plants*, (Section 2.7 Meteorology and Air Quality) (March, 2000; Draft Revision 1 in Progress)

ON-SITE METEOROLOGICAL MONITORING CONSIDERATIONS

The primary objective of an on-site meteorological monitoring program is to provide meteorological data representative of the project site that will be suitable for use in dispersion modeling assessments of routine as well as hypothetical radiological releases from the facility. Because of the importance of the information collected, and the fact that it is relied upon for critical decisions in the design of the plant (including safety), adequate consideration must be given to the long lead times that are necessary to design, install, and reliably operate the facility in order to obtain a minimum of one year of hourly meteorological data from the site. The key considerations that should be accounted for in advance of the licensing phase of plant development are as follows:

Schedule and Lead Times

Because a minimum of one year of continuous on-site data is a required element of a license application at the time of submittal (two years minimum at the time of license issuance), extensive planning is necessary to ensure than an application is not delayed. Significant lead time will be required to design a complete system, order and procure all necessary equipment (including spares), assemble and bench test all equipment prior to installation in the field, deliver the tower and its components to the site, procurement of building permits (if necessary), installation of the tower, securing site power and communications, installation of instrumentation and equipment on the tower, field testing of instrumentation, and in-field calibration and validation of all instrumentation and systems. The use of an established "standard design" can significantly contribute to a speedy design process and the ordering of all components at the earliest possible date. This process can often require 3 to 6 months from the start of the system design process to the start of data collection.

System Design

Modern meteorological monitoring systems are primarily based on solid state electronics with very high reliability factors. While older systems required cumbersome environmentally controlled shelters (often small manufactured buildings) to maintain a reasonable temperature and humidity to prevent instrument failure, current systems are small enough to be housed in small tower mounted weatherproof enclosures and are relatively insensitive to wide ranges of environmental conditions. Also, the power requirements of currently available systems are very low, which allows for the use of solar powered systems, often with remote interrogation and system maintenance being made possible via cellular telephone-based modems. If the system is designed for extreme environmental conditions (primarily lightning protection and high wind speeds associated with storms), a highly reliable and accurate monitoring system is possible. Most towers are designed to withstand wind speed gusts in the range of 100 to 130 mph, but no tower is likely to be able to withstand severe storm events such as strong tornadoes or hurricanes, particularly if surface debris becomes airborne and strikes the tower or a component. Similarly, lightning protection can and should be provided on systems, but realistically no lightning protection system can prevent damage during a direct strike to the tower. Typically, the system is designed in manner that will facilitate the in-field exchange of modular bench calibrated components, alleviating the need for lengthy in-field repair and re-calibration when components fail. An additional consideration is that towers and monitoring systems should be sited and designed for long-term operation since meteorological monitoring is required not only for pre-operational licensing support, but also for the life of the operating plant.

Siting the Tower

NRC guidance requires that the monitoring tower be located in an area that is representative of the site, with terrain and meteorological exposure similar to that of the proposed facility. This requires that the following potential influences be considered when siting the monitoring tower:

- Surrounding terrain and vegetation should be similar in the vicinity of the tower to the location where the plant will be located, including surface roughness and surface heating considerations.
- No unusual natural or man-made obstructions that would unduly influence wind flow or other meteorological parameters. NRC guidance requires that the tower be located at least 10 obstruction heights from potential flow-modifying obstructions such as wooded areas, structures or terrain features.
- Proximity to natural or man-made sources of heat or cooling that would influence ambient temperature or ambient stability estimates (paved parking lots, lakes and water bodies, cooling towers, etc.).
- Construction activities that could influence local meteorological conditions during the monitoring period, such as terrain modifications, land clearing, or the addition of water features.

Basic Components of the System

NRC's standard guidance for meteorological monitoring systems dictates that the monitoring of prescribed meteorological parameters occur at least at two levels, normally at 10- and 60-meters above ground for a standard system. While these levels can vary depending on reactor design and surrounding topography and other surface features, the minimum monitoring requirements are typically as follows:

Parameter	Required Monitoring Levels	
Wind Speed	10m	60m
Wind Direction	10m	60m
Ambient Temperature	10m	60m
Vertical Temperature Difference	10m	60m
Dew Point	10m	
Precipitation	Near Ground Level	

Other parameters are often measured, including relative humidity, solar radiation, barometric pressure and various other parameters, but these are the basic parameters that are required for an assessment of radiological impacts using recent on-site meteorological data. Tower mounted instrumentation are typically mounted on retractable booms for easy access to instruments during maintenance and calibration activities. Minimum instrument accuracy requirements are specified by NRC; however, most instrument manufacturer's offer instruments that exceed these requirements and consideration should be given to the site-specific need for more accurate instrumentation.

Data from the instrumentation are typically collected by an on-site electronic data management system. These data logging devices are typically able to "sample" the tower instrumentation and store data electronically at a sampling rates on the order of 1 to 5 seconds, with the minimum required sampling rate for nuclear applications being once every 5 seconds. The system can be programmed to automatically average data over a user-specified period, typically between 15 minutes and 1 hour, providing significant flexibility when there are periods of missing data, thus increasing the annual average data recovery percentage.

For remote systems, power and communications can be a significant issue and the installation of either generators or above-ground power and communication lines to supply these basic utilities can be problematic, time consuming, and costly. Solar powered generators and cellular telephones represent significant advantages at locations where these utilities are not readily available. Their advantages are numerous in that they can be installed quickly and are self-sufficient and their relatively quick installation can alleviate these problems.

Photographs 1 through 5 illustrate a recently installed NRC-compliant 60-meter meteorological monitoring tower installation in Florida. This system utilizes solar power and a wireless cellular-based communication system and monitors basic parameters at the 10- and 60- and near-ground levels.

System Operation

Modern meteorological systems have become much more versatile due to the advances of electronics. Electronic data management systems can be programmed to sample the instrumentation at a near instantaneous rate and to store the data in independent channels for remote downloading or follow-up processing on a periodic basis.

Data can be processed and stored at the time of collection in a variety of ways including the conversion of instrument output signals to the units of desired measurement. This greatly simplifies the conversion of "raw" instrument data to the parameters of interest.

Three simple examples of how wind speed and direction can be processed electronically by a data logging device are shown in Figure 2. When wind speed is measured, it is normally measured in conjunction with a wind direction using either two separate instruments or a single instrument measuring both parameters. The measurement of these parameters implies that the wind can be represented as a *vector*, with the attributes of both speed and direction, or they can be represented as two distinct values of wind speed and wind direction. When wind speeds are averaged, they can be averaged as either a resultant "vector average" or as a "scalar average". The difference between the two averaging schemes is best illustrated in three simple examples of two consecutive observations of wind speed and direction, as illustrated in Figure 1.

Photo 1 – 200 ft. Tower and Surrounding Terrain

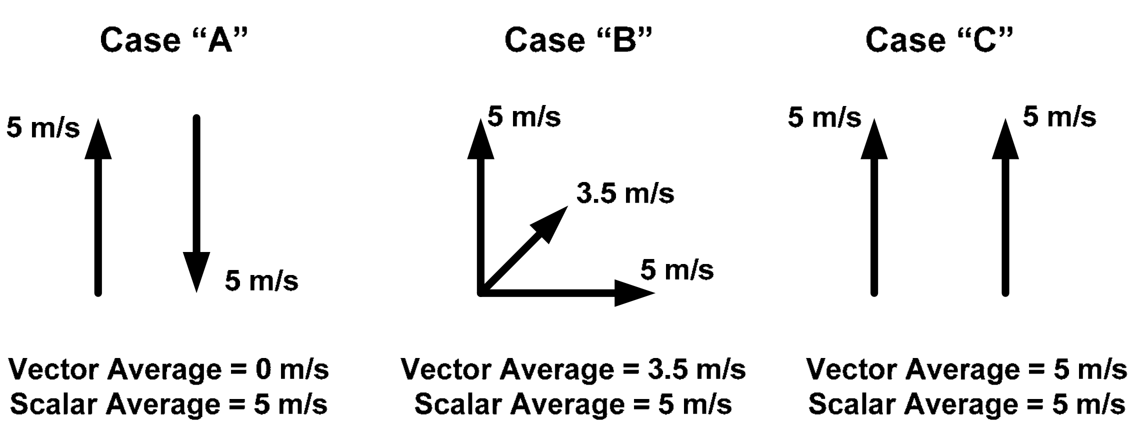
Photo 2 – Tower Base and Security Fence

Photo 3 – Solar Power System and Instrument Enclosure

Photo 4 – Lower Level Wind and Temperature Sensors

Photo 5 – Lower (10-m) and Upper (60-m) Level Sensors

Figure 1 – Examples of Vector and Scalar Averaging Schemes



While each of these methods is considered to be technically correct, it is important to understand the differences, and the implications of the differences, particularly when the data are being used for dispersion modeling purposes. As a general rule, the vector averaging of winds will typically result in an underestimate of the absolute wind speed, particularly at relatively low wind speeds when there is significant variability of wind direction (i.e., when the standard deviation of wind direction increases). In the examples shown in Figure 1, it should evident that the scalar average wind speed does not vary from the observed wind speed of 5 m/s for each of the three cases shown, however, the vector average wind speed can vary significantly. Progress Energy conducted a long-term assessment of scalar and vector average wind speed measurements using measurements obtained from two co-located instruments (see Photo 6), as well as the calculation of both vector and scalar average wind speeds derived from a single instrument.

Photo 6 – Co-located Vector and Scalar Wind Monitors

The results clearly demonstrated that there was a distinct difference between the two averaging schemes, with the vector average wind speed being notably less than the absolute, or scalar, average wind speed, particularly under light wind conditions when the variability of wind direction can be significant. The implications of using vector or scalar average values for wind speed can therefore be very important when using the data as a basis for dispersion modeling predictions of routine or accidental releases, especially under circumstances where there is a high predominance of light and/or calm winds. For dispersion modeling purposes, the use of a scalar average wind speed in conjunction with a contemporaneous wind direction measurement is generally considered to be the best choice.

Data Recovery and Quality

Meteorological monitoring systems should be serviced at a frequency that will ensure a minimum data recovery of 90 percent on an annual average basis. The 90 percent recovery objective, as stipulated in NRC's Regulatory Guide 1.23, applies to the combination of all variables (i.e., the joint frequency of distribution of wind speed, wind direction, and stability class) needed to model atmospheric diffusion for each potential release pathway. In addition, the 90-percent data recovery objective also applies to the other meteorological parameters.

The procedure that is normally followed to facilitate this is to perform parametric checks of the collected data on a daily basis in order to evaluate proper operation of the system and to ascertain if there are any data anomalies or inconsistencies. This is typically performed by comparing the upper and lower sensor measurements, redundant/backup system results, or observations from nearby meteorological stations that have real-time or near-current data availability over the internet. These types of routine checks permit one to establish trends and variations that can provide an indication of when an instrument is not performing properly or may be failing. To ensure data recovery and to prevent data loss attributable to catastrophic events (such as a direct lightning hit or severe storm damage to the tower), the data stored in the data logging device are normally downloaded and archived frequently.

Data quality can be increased by maintaining and calibrating all instrumentation on a periodic basis. For electro-mechanical instrumentation (such as wind speed and direction detection devices), a good practice is to install new or factory rebuilt and calibrated instrumentation at a minimum of six-month intervals to ensure that data are within manufacturer specifications.

Safeguards and precautions to increase data recovery include maintaining sufficient spare equipment to permit the interchange of equipment at the first sign of instrument failure or abnormal/suspect operation.

Calm/Light Wind Considerations

For regions where light and calm winds are expected to be observed at a significant or higher than average frequency, consideration should be given to using more sensitive instrumentation that are capable of providing measurements at lower starting thresholds. Most dispersion models account for calm winds by making assumptions that involve a "default" wind speed and direction. Some models specify that wind speeds associated with a reported calm wind are 50 to 100 percent of the instrument threshold or "starting" speed, and the wind directions associated with a "calm" wind may be arbitrarily set according to a protocol where the wind directions are distributed proportional to the frequency of occurrence of non-calm wind directions. The fact is that the characterization of a wind condition as a "calm wind" can result in significant biases in the modeling results. An evaluation of wind speed and direction measurements under so-called calm wind conditions should be performed to determine if there may be a more representative way of distributing wind directions other than according to the non-calm wind directions. It is important to note that Gaussian plume dispersion models are based on a theory that predicts downwind concentrations that are inversely proportional to the wind speed, meaning that as the wind speed approaches zero, the predicted concentration approaches infinity. This inherent instability in the calculation procedure indicates that special care should be taken to understand the extent of light and calm winds (especially for sites where the frequency of occurrence of calm winds is large) so as to avoid any undue bias in dispersion modeling results that are based on the use of the data.

Tower Integrity

For guyed towers, guy wires should be inspected annually, and guy wire anchors should be inspected once every three years in accordance with industry standards.

SUMMARY

The role of meteorology in the nuclear power plant siting and licensing process is simple, namely to support the conclusion that a proposed new nuclear generating facility at a given location can be constructed and operated without undue risk to health, safety, or the environment. The use of current site-specific meteorological data is considered to be a critical component of a new nuclear plant license application. Its use in demonstrating that plant operations can meet rigid limitations for airborne radiological impacts demands that the data be representative of the project site, and that it meet the quality requirements commensurate with the need to demonstrate safe operation. Given the importance of meteorology in the siting and licensing process, it is apparent that due care and consideration be given to the planning, design and operation of a meteorological monitoring system that will meet the regulatory requirements that are designed to ensure safe operation.

References

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4. United States Nuclear Regulatory Commission Web Site. See www.nrc.gov/reading-rm.html (Accessed January 2008).