CLIMATE CHANGE CONSIDERATIONS IN THE SUSTAINABLE DEVELOPMENT OF NUCLEAR POWER PLANTS IN THE UNITED STATES

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Abstract*—Nuclear power generation has become more attractive globally due to growing demand for power, increasing competition for fossil fuels, concern over greenhouse gases and climate change, and desire for energy independence. Carbon-free nuclear energy supports sustainable development of global electric power generation.*

Protecting people and the environment is a prime consideration in designing, constructing, and operating a nuclear plant. Environmental and safety concerns must be carefully evaluated and addressed. To this end, the US Nuclear Regulatory Commission (NRC) requires that applicants for early site permits (ESPs) and combined (construction/operating) licenses (COLs) identify the most severe natural phenomena historically reported for the site and surrounding area to ensure that the plant is designed with sufficient margin, considering the limited accuracy, quantity, and accumulation time of the associated data. Because these permits are valid for up to 40 years, the potential impacts of climate change on the severity of natural phenomena as they relate to design basis, nuclear safety, and environmental impact are of increasing interest.

Although no conclusive evidence or consensus of opinion is available about the long-term effect of human versus natural causes, the NRC has requested that climate change forecasts be evaluated with respect to the potential effect of such changes on the most severe natural phenomena. The specific areas of concern include extreme temperatures and precipitation (liquid and frozen)—100 years of data around the site; extreme/basic wind speeds—previous 100 years of tropical cyclone data (including hurricanes) in site vicinity; tornados—frequency and intensity trends and forecasts; drought—water availability/supply during drought conditions and drought of record; and stagnation potential—conditions resulting in restrictive dispersion of greenhouse gas emissions.

This paper examines the challenges and constraints to identifying and developing appropriate design- and operating-basis site/regional meteorological conditions while accounting for potential climate change when preparing an ESP or COL. Because no regulatory guidance or quantitative acceptance criteria are currently available, the methodology used to address climate change in a recently issued ESP is discussed as an example.

Keywords*—climate change, design basis, new nuclear power plant, operating basis, permitting, regional meteorological conditions, sustainable development*

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BACKGROUND

Part 52 to Title 10 of the Code of Federal Regulations (10 CFR 52) provides the requirements for preparing and submitting combined (construction/operating) license (COL) and early site permit (ESP) applications for nuclear power plants. Within it, 10 CFR 52.79(a)(1)(iii) requires that an ESP applicant identify the most severe of the natural phenomena historically reported for the site and surrounding area and provide sufficient design margin to take into account the limited accuracy, quantity, and accumulation time of the historical data. This regulation contains no quantitative requirements but requires that margin exist between the values for various meteorological characteristics of concern and the corresponding values relative to the characteristics for the selected site and vicinity.

As stated in both the Nuclear Energy Institute and US Department of Energy (DOE) 2008 ESP Lessons Learned reports [1, 2], the Advisory Committee on Reactor Safeguards and the US Nuclear Regulatory Commission (NRC) were specifically interested in the impacts of climate change on design-basis hurricanes and design-basis temperatures as they relate to nuclear safety and the environment.

Climatic conditions change over time; such changes are cyclical in nature on various time and spatial scales.

ABBREVIATIONS, ACRONYMS, AND TERMS

CFR	Code of Federal Regulations
COL	combined (construction/ operating) license
CP	construction permit
DC	design certification
DOE	Department of Energy
ESP	early site permit
HVAC	heating, ventilation, and air conditioning
IPCC	Intergovernmental Panel on Climate Change
NCDC	National Climatic Data Center
NRC	Nuclear Regulatory Commission
NUREG	NRC Regulation
OL	operating license
RS	(NRC) review standard
SNC	Southern Nuclear Operating Company
UHS	ultimate heat sink
VEGP	Vogtle Electric Generating Plant

In general, just analyzing past trends is not sufficient. Forecasts of climate change need to be examined.

CLIMATE CHARACTERISTICS OF CONCERN

ESP applicants should ensure that all physical attributes of the site that could affect the design basis of structures, systems, and components important to safety are reflected in the site characteristics and related design parameters acceptable to meet the requirements of 10 CFR 100.20(c)(2) and 100.21(d).

Meteorological conditions identified as (1) site characteristics for ESP applications; (2) design and operating bases for construction permit (CP), operating license (OL), and COL applications; and (3) site parameters for design certification (DC) applications are discussed in NRC Review Standard RS-002, "Processing Applications for Early Site Permits," and in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 2.3.1, Regional Climatology. [3, 4] This section identifies average and extreme climatic conditions that could affect the design and safe operation of a nuclear power plant. These climate conditions include the wind speed, temperature, humidity, and precipitation, as well as the seasonal and annual frequencies of severe weather conditions such as tornadoes and hurricanes, ice and snow accumulation, hail, and lightning.

The regional meteorological conditions that are classified as climate site characteristics for consideration in evaluating the design and operation of a nuclear power plant include:

- The weight of the 100-year return period snowpack and the weight of the 48-hour probable maximum winter precipitation for the site vicinity for use in determining the weight of snow and ice on the roof of each safety-related structure [5, 6]
- The minimum and maximum dry bulb and wet bulb temperatures for the site and vicinity used to evaluate the performance of the ultimate heat sink (UHS) with respect to (1) maximum evaporation and drift loss, (2) minimum water cooling, and, if applicable, (3) the potential for water freezing in the UHS water storage facility [7]
- Site-characteristic tornado parameters, including translational speed, rotational speed, and maximum pressure drop and rate of pressure drop [8, 9]
- The 100-year return period 3-second gust wind speed [10]
- Ambient temperature and humidity statistics (e.g., 2% and 1% annual exceedance and 100-year maximum dry bulb temperature and coincident wet bulb temperature, 2% and 1% annual exceedance and 100-year maximum wet bulb temperature [non-coincident], and 98% and 99% annual exceedance and 100-year minimum dry bulb temperature) for use in establishing heat loads for design and operation of plant heating, ventilation, and air conditioning (HVAC) systems [11, 12, 13]

CLIMATE CHANGE CONSIDERATIONS IN DEVELOPING DESIGN- AND OPERATING-BASES REGIONAL METEOROLOGICAL CONDITIONS

It is understood that climatic conditions change over time and that such changes are cyclical in nature on various time and spatial scales. The timing, magnitude, relative contributions to,

and implications of these changes are generally difficult to predict accurately. Thus, the NRC staff implemented in 2007 an approach to the study of climate change impacts that considers current scientific thoughts, including those of the 2007 Intergovernmental Panel on Climate Change (IPCC) report [14].

The NRC asks applicants to review 100 years of relevant climate data around the site versus the historical 30-year period. Also, future applicants should be prepared to provide data and/or analyses that adequately address apparent trends toward increased frequency and intensity of relevant climate parameters as they relate to the ESP/COL site.

The specific subject areas of concern related to potential impacts of climate change are:

- Extreme temperature statistics—review 100 years of data around the site versus the historical 30 years of data
- Extreme precipitation (liquid and frozen)—review 100 years of data around the site versus the historical 30 years of data
- Extreme wind/basic wind speed—review 100 years of tropical cyclone data around the site (including hurricanes) versus the historical 30 years of data
- Hurricane—review frequency and intensity trends and forecasts
- Drought—review water availability/water supply during drought conditions and frequency/severity of droughts
- Stagnation potential—review conditions that would result in restrictive dispersion of greenhouse gas emissions

POTENTIAL CLIMATE CHANGES CASE STUDY

Although no conclusive evidence or consensus of opinion is available on the long-term climatic changes resulting from human or natural causes, the NRC has requested that climate change forecasts be analyzed for the potential of climatic changes to affect the most severe natural phenomena. During its review of Southern Nuclear Operating Company's (SNC's) ESP application for the Vogtle Electric Generating Plant (VEGP) (Units 3 and 4) [15], the NRC validated the representativeness of the data used to describe severe weather phenomena that may affect the proposed plant during the expected period of operation. As a part of that validation, the NRC considered the long-term environmental changes to the region that might affect the ability of historical data to accurately represent the future site climate characteristics. Although the NRC did acknowledge that there is no consensus regarding the issue of climate change, it also stated that climate trends identified (specifically those related to temperature and precipitation) should be evaluated for their impact on the description of severe weather phenomena. [16]

Quantified Climate Change Trends

To analyze trends in temperature and rainfall, SNC reviewed normals and standard deviations over a 70-year period for successive 30-year intervals, updated every 10 years, beginning in 1931 (e.g., 1931–1960, 1941–1970) through the most recent normal period (i.e., 1971–2000), based on the National Climatic Data Center (NCDC) publication "Climatography of the United States," No. 85. [12] The report summarizes these observations for the 344 climate divisions in the 48 contiguous states.

Future applicants should be prepared to adequately address apparent trends toward increased frequency and intensity of relevant climate parameters as they relate to the ESP/COL site.

A climate division represents a region within a state that is as climatically homogeneous as possible. Division boundaries generally coincide with county boundaries except in the western United States. In Georgia, the VEGP site is located within Climate Division GA-06 (East Central). In South Carolina, Climate Division SC-05 (West Central), whose southern extent includes Aiken County, is nearly adjacent to the VEGP site.

Summaries of successive annual temperature and rainfall normals, as well as the composite 70-year average, are provided for these climate divisions in **Table 1**. [12]

Table 1. Annual Temperature and Rainfall Summaries for Climate Divisions GA-06 and SC-05

Period	Temperature, °F		Rainfall, in.	
	GA-06	SC-05	GA-06	SC-05
1931–2000	64.3	62.2	45.60	46.99
1931–1960	65.0	62.9	43.42	44.88
1941–1970	64.3	62.3	45.35	46.46
1951–1980	63.8	61.8	45.95	47.53
1961–1990	63.6	61.6	46.61	48.46
1971–2000	63.9	61.8	47.06	48.36

This data identifies that the average temperature increased only slightly (i.e., 0.2 °F to 0.3 °F) over the latest 30-year period, and rainfall, on average, increased 1.5 inches over that same period. The NRC staff confirmed SNC's findings

by reviewing 1-year, 10-year, and 20-year trends in the annual average daily maximum temperatures and annual extreme daily precipitation using data from Waynesboro and Augusta for the period from 1951 to 2004. As a result of this review, the staff concluded that "the trends over 20 years show that annual extreme minimum temperatures have increased 2 °F and average annual precipitation has increased about 1.5 to 2.5 inches over the period of record. All other meteorological parameters showed no discernible signs of climate change." [16]

"Whether hurricanes are becoming more destructive because of global warming is a contested issue in the scientific debate over climate change." [16]

The following paragraphs, extracted from [16] immediately after this quote, continue the NRC staff's discussion regarding the potential effect of climate change on the viability of the data and the conclusions provided by SNC in its VEGP ESP application:

> "The Intergovernmental Panel on Climate Change (IPCC) issued its Fourth Assessment Report on Climate Change in February 2007. The staff considered Chapter 11 in 'Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change,' regarding the southeastern portion of the United States. The IPCC models projecting potential future climate change depend on human activity and land use. To account for this, the IPCC uses different global scenarios as input to the models. Chapter 11 of the IPCC report discusses the following three scenarios:
>
> - (A2) 'A more divided world with self-reliant, independently operating nations'
> - (A1B) 'A more integrated world with an emphasis on all energy sources'
> - (B1) 'A world more integrated and ecologically friendly' (i.e., less energy consumption and more cooperating nations)
>
> "During the 100-year period under the A1B scenario (i.e., 1980–1999 as compared to 2080–2099), the IPCC projection estimates that the proposed VEGP site may see an increase in average annual temperature of 3 °C and an increase in precipitation of 0 to 5 percent. Under the more and less extreme scenarios, increases in annual average temperature may range from 2 °C to 7.5 °C. The projection also shows a general decrease in snow depth as a result of delayed autumn snowfall and earlier spring snow melt.
>
> "The staff also analyzed climate-change-induced hurricane trends within 100 nautical miles of the site and found no discernible trends in hurricane frequency or intensity. The 'Summary for Policymakers' based on the February 2007 IPCC report makes the following statement concerning tropical cyclones: 'Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures.' (IPCC Sections 3.8, 9.5, and 10.3)
>
> "However, the question of whether hurricanes are becoming more destructive because of global warming is a contested issue in the scientific debate over climate change. A number of academic papers have been published either supporting or debunking the idea that warmer temperatures linked to human activity have created more intense storms, and the issue is currently unresolved (Dean; Eilperin; Kerr; Witze)[*]. Based on the current amount of scientific uncertainty regarding this subject, the staff believes the applicant has adequately addressed the issue of hurricanes and provided conservative site characteristics.
>
> "The applicant stated that the number of recorded tornado events has increased, in general, since detailed records were routinely kept beginning around 1950. However, some of this increase is attributable to a growing population, greater public awareness and interest, and technological advances in detection. These changes are superimposed on normal year-to-year variations. Consequently, the number of observations recorded within a 2-degree latitude and longitude square centered on the VEGP site reflects these effects. The staff has confirmed and accepts the applicant's statements regarding tornadoes. The 'Summary for Policymakers' based on the February 2007 IPCC report states, 'there is insufficient evidence to determine whether trends exist in small scale phenomena such as tornadoes, hail, lightning, and dust storms.' (IPCC Sections 3.8 and 5.3)" [16]

The NRC staff ultimately drew the following conclusion: "The NRC staff has evaluated the relevant sections of the application, as supplemented by letters dated January 30, 2007, March 26, 2007, and March 30, 2007, pursuant to the acceptance criteria described [in] RS-002, Section 2.3.1 and applicable regulatory requirements of 10 CFR Part 52 and 10 CFR Part 100. The applicant has presented and substantiated information relative to the regional meteorological conditions. The staff has reviewed the information presented by the applicant and concludes that the identification and consideration of the regional and site meteorological characteristics meet the requirements of 10 CFR 52.17(a)(1), 10 CFR 100.20(c), and 10 CFR 100.21(d)." [16]

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CONCLUSIONS

10 CFR 52.79(a)(iii) requires that a COL applicant identify the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin to account for the limited accuracy, quantity, and accumulation time of the historical data.

A new approach to the study of climate change impacts that considers current scientific thoughts was implemented in 2007 by the NRC staff. The areas potentially most affected by this review are the design-basis hurricane and design-basis temperature. Both ESP and COL applicants are now required to review 100 years of data around the site versus the historical 30-year look back to ensure that sufficient margin has been incorporated in the design-basis consideration.

For its evaluation of the VEGP site, the NRC "staff acknowledges that long-term climatic change resulting from human or natural causes may introduce changes into the most severe natural phenomena reported for the site. However, no conclusive evidence or consensus of opinion is available on the rapidity or nature of such changes. If in the future, the ESP site is no longer in compliance with the terms and conditions of the ESP (e.g., if new information shows that the climate has changed and that the climatic site characteristics no longer represent extreme weather conditions), the staff may seek to modify the ESP or impose requirements on the site in accordance with the provisions of 10 CFR 52.39, 'Finality of Early Site Permit Determinations.'" [16] ■

The NRC "staff acknowledges that long-term climatic change resulting from human or natural causes may introduce changes into the most severe natural phenomena reported for the site." [16]

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BIOGRAPHIES

Ping Wan has over 35 years of environmental engineering experience, specializing in environmental studies for permitting, constructing, and operating power generation plants, industrial facilities, and highway projects worldwide. She is a recognized industry expert in environmental engineering and air pollution meteorology and has performed numerous first-of-a-kind (FOAK) permit applications for site selection, facility construction, and facility operation.

In her early years with Bechtel, Ping secured a large number of prevention of significant deterioration (PSD) air permits for fossil-fired power plants, including those that were among the first few PSD permits issued by the states of Delaware, Maryland, New Jersey, and Pennsylvania under the New Source Review, the Clean Air Act Amendments of 1977. Her work went on to include permitting the first Clean Air Act Title V, Operating Air Permit, for the national laboratories at both the Nevada test site and Idaho Falls site. Ping then led an environment team that obtained the FOAK construction and operating certifications for the Boston Central Artery/Third Harbor Tunnel project (the largest highway project in the United States). She also developed an innovative and cost-effective engineering solution to comply with the most stringent regulatory requirements worldwide regarding continuous emission monitoring of the project's vehicular tunnel emissions through the ventilation systems. Her latest efforts include acquisition of an ESP (North Anna), preparation of a COL application for various new reactors at existing nuclear and greenfield sites in the US, and intensive involvement in preparing the safety analysis report and nuclear environmental impact assessment for the Baraka nuclear power plant in the United Arab Emirates.

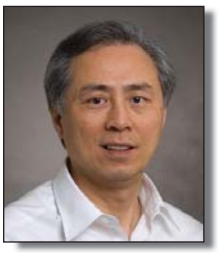
Ping is an active standard committee member for the American National Standard, ANSI/ANS 2.15 (standard development), 2.21 (standard reviewer), and 3.11 (standard affirmation), regarding atmospheric dispersion modeling, meteorological criteria for cooling system design, and meteorological monitoring. She has been a Bechtel Fellow since 1996.

Ping holds two MSc degrees, one in Physics from Montana State University in Bozeman and one in Natural Science from Pacific Lutheran University in Tacoma, Washington. She received a BSc in Physics from the Chinese University of Hong Kong (Chung Chi College). Ping has also done doctorate-level work in Physics at Montana State University and in Meteorology at the University of Maryland, College Park.

Alice C. Carson has worked in nuclear licensing for 20 years on a wide range of projects. She has supported the licensing of steam generator replacement and other major modification projects associated with operating reactors, supported the licensing of independent spent storage facilities, authored portions of applications for plant license renewals, led the development of the license termination plans for two decommissioning nuclear power plants, and authored portions of and supported the licensing of multiple new reactor license applications.

Alice is currently employed in Bechtel Corporation's NuGen group working on multiple COL and ESP applications as well as providing support to a reactor pressure vessel head/steam generator replacement project.

Alice holds a BNE from The Georgia Institute of Technology in Atlanta and a BA from Wesleyan College in Macon, Georgia.



Desmond Chan, PhD, joined Bechtel Power Corporation in 2009 as senior licensing engineer and 6 months later was promoted to manager of licensing. Now a chief engineer, he focuses his expertise on nuclear power generation and environmental projects, where his responsibilities encompass nuclear licensing, regulatory affairs, environmental engineering, project oversight, and staff development. Desmond supports and contributes to both new and operating nuclear plant work ranging from ESP applications, design certification, and COL applications to current licensing basis assessments, safety evaluations and safety analysis report updates, steam generator replacements, and extended power uprates.

Over the course of his 31-year career, Desmond has managed numerous engineering groups (nuclear, environmental, radiological, health physics, chemistry, emergency preparedness, and training), regional offices, field project offices (nuclear power plants, DOE sites, and Department of Defense bases), and laboratories (environmental and chemical demilitarization). In addition, he has been project director/manager of many major multidisciplinary, multiyear technical projects involving reactor safety, radiological engineering, decommissioning and decontamination, environmental engineering, installation restoration, low-level radioactive waste management, remedial investigation, regulatory compliance, environmental impact analysis, health and cost benefit analysis, industrial hygiene assessment, feasibility studies, risk analysis, computer modeling, environmental permitting, nuclear licensing, quality control programs, technical training, and facility audits. Companies benefiting from his expertise over the years have included more than 40 nuclear power plants, DOE facilities, DOD installations, NRC, EPA, and FEMA, as well as his own company, of which he was managing partner and executive vice president.

Desmond was chief editor of the eight-volume Advanced Health Physics for Nuclear Utilities and has authored/coauthored more than 100 papers, technical reports, and training programs. He is currently a member of the Nuclear Energy Institute Working Group and was a governor-appointed member of the State of Maryland Radiation Control Advisory Board, chair of the Nuclear Utilities Committee on Below-Regulatory-Concern Radioactive Waste, a member of the Electric Power Research Institute's Steering Committee on Below-Regulatory-Concern Radioactive Waste, and alternate chair of Consolidated Edison Company's Oversight Committee on Radiation Protection.

Desmond holds a PhD in Computational Nuclear Physics, an MS in Nuclear Physics, and a BS in Physics (magna cum laude), all from the University of Massachusetts in Lowell.