UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	Docket No. 52-043-ESP
PSEG POWER, LLC AND PSEG	)	
NUCLEAR, LLC	)	ASLBP No. 15-943-01-ESP-BC01
	)	
(Early Site Permit Application)	)	February 25, 2016

NRC STAFF TESTIMONY RELATED TO JANUARY 27, 2016 ORDER
<u>TOPIC 4: CLIMATE CHANGE INDUCED INCREASES IN THE POWER AND FREQUENCY OF HURRICANES</u>

Q1: Please state your name, occupation, employer, and professional qualifications.

A1: (KRQ) My name is Kevin R. Quinlan. I am a Physical Scientist (Meteorologist) in the Hydrology and Meteorology Branch, Division of Site and Environmental Analysis (DSEA), Office of New Reactors (NRO), U.S. Nuclear Regulatory Commission (NRC). A statement of my professional qualifications is attached (Exhibit (Ex.) NRC002).

(HJ) My name is Henry Jones. I am a Hydrologist in the Hydrology and Meteorology Branch, DSEA, NRO, NRC. A statement of my professional qualifications is attached (Ex. NRC002).

Q2: Please describe your responsibilities with regard to the Staff's review of the PSEG Site Early Site Permit (ESP) application.

A2: (KRQ) As the lead meteorological reviewer for the Staff's Final Safety Evaluation Report (FSER) Section 2.3 "Meteorology," I was responsible for coordinating the review of the Site Safety Analysis Report (SSAR) Section 2.3, "Meteorology," developing the Staff's FSER for this section, and presenting to the Advisory Committee on Reactor Safeguards (ACRS) (Ex. NRC003 and PSEG004B).

(HJ) As the hydrology team lead oceanographer, I was responsible for reviewing the SSAR, subsections 2.4.5, "Probable Maximum Surge and Seiche Flooding," and 2.4.6 "Probable Maximum Tsunami Hazards," developing the Staff's FSER for those subsections, and presenting those two sections to the ACRS (Ex. NRC003 and PSEG004B).

Q3: What is the purpose of your testimony?

A3: (KRQ) The purpose of my testimony is to explain the development and review of the site characteristic hurricane wind speed and how climate change induced increases in hurricane power and frequency may affect the wind speed value.

(HJ) The purpose of my testimony is to explain the factors that demonstrate that the Probable Maximum Hurricane (PMH) models used to establish the PMH for the PSEG Site are conservative in view of climate change predictions.

Q4: How did the Applicant identify, and how did the Staff review, the hurricane site characteristic wind speed at the PSEG site?

A4: (KRQ) In October 2011, the NRC issued Regulatory Guide (RG) 1.221, "Design-Basis Hurricane Missiles for Nuclear Power Plants," which provides the design-basis hurricane wind speeds with an exceedance frequency of 10^{-7} per year. This very conservative exceedance frequency represents the hurricane wind speed that has a 10^{-7} per year chance of occurring, or, put differently, a hurricane wind speed that is expected to occur once every 10 million years. The Applicant identified the hurricane site characteristic wind speed, which it derived from applying the RG 1.221 criteria and selecting the 10^{-7} per year wind speed value from RG 1.221, Figure 3, "Design-Basis Hurricane Windspeeds for the Mid- and Northern Atlantic U.S. Coastline Representing Exceedance Probabilities of 10^{-7} per year." RG 1.221 provides figures of design-basis windspeed contours for both the Atlantic and Gulf of Mexico coastlines. To meet the criteria in RG 1.221, the Applicant must interpolate between contours to determine the windspeed value for the site. The Applicant correctly identified the design-basis windspeed, in SSAR Subsection 2.3.1.5.3, "Tropical Cyclones." The Staff, through the use of the same RG, confirmed the Applicant's site characteristic hurricane wind speed value (Ex. NRC003 and PSEG004B).

Q5: How was consideration of climate change induced increases in the power and frequency of hurricanes factored into the Staff's conclusions?

A5: (KRQ) RG 1.221 derived the Design-Basis Hurricane Wind Speed values from NUREG/CR-7005, "Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speed for Nuclear Power Plants." This NUREG considers peak-gust wind speeds and estimates maximum hurricane wind speeds for hurricanes that originate in the Atlantic and make landfall along the Atlantic and Gulf coasts of the contiguous United States.

The Staff has determined that design-basis hurricane wind speeds should correspond to the exceedance frequency of 10^{-7} per year (calculated as a best estimate). This is the same exceedance frequency used to establish the design-basis tornado parameters in Revision 1 to RG 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants." This very conservative exceedance frequency is also consistent with the criterion in Revision 3 of the Standard Review Plan (NUREG-0800), Section 2.2.3, "Evaluation of Potential Accidents," issued March 2007, for identifying design basis events involving hazardous materials or activities onsite and in the vicinity of a proposed site.

The analysis in NUREG/CR-7005 is based on a peer-reviewed hurricane simulation model that was used for the development of wind speed maps for the American Society of Civil Engineers (ASCE) and the Structural Engineering Institute (SEI) Standard, ASCE/SEI 7-05, "Minimum Design Loads for Buildings and Other Structures." The resulting wind speeds are 3-second peak-gust values at a height of 10 meters (m) (33 feet (ft)) in flat open terrain, which is consistent with the definition of design wind speeds in the ASCE/SEI design standard. Figures 1 through 3 in RG 1.221 provide hurricane wind speed contour maps from NUREG/CR-7005 that correspond to an exceedance frequency of 10^{-7} per year.

The study performed in NUREG/CR-7005 used a sensitivity analysis to assess the possible effects of increased hurricane frequency in the future (Section 2.6, "Sensitivity to Increased Hurricane Frequency"). The analysis considered the effect of a potential doubling in hurricane frequency on the 1.0×10^{-7} per year exceedance probability winds. Through this sensitivity analysis, an estimate of the increase in the wind speed with an annual exceedance probability of 1.0×10^{-7} can be obtained. The results of this analysis suggest that a factor of 2 increase in hurricane frequency would result in less than a 2 percent increase in the wind speed with an annual exceedance probability of 1.0×10^{-7}. The Staff considers the hurricane wind speeds defined in RG 1.221 to be conservative values, and the Staff further notes that a 2 percent increase in the wind speed of 159 mph (3-second gust) that RG 1.221

indicates is applicable to the PSEG Site would result in only a 3 mph increase to the site characteristic. Therefore, the Staff concludes that the site characteristic hurricane wind speeds are appropriately conservative to account for potential climate change related increase in hurricane power and frequency.

The latest U.S. Global Change Research Program (USGCRP) assessment (2015) stated that "the intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (Category 4 and 5) hurricanes, have all increased since the early 1980s. The relative contributions of human and natural causes to these increases are still uncertain. Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm." However, the report did not provide projections as to how much the hurricane frequency may change over the coming decades. The staff considers the doubling of hurricane frequency, as discussed above, to be a conservative assumption.

The 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 PSEG Site. However, no conclusive evidence or consensus of opinion is available on the rapidity or nature of such changes. There is a level of uncertainty in projecting future conditions because the assumptions regarding the future level of emissions of heat trapping gases depend on projections of population, economic activity, and choice of energy technologies. If it becomes evident that long-term climatic change is influencing the most severe natural phenomena reported at the PSEG Site, the combined license (COL) holders have a continuing obligation to ensure that their plants stay within the licensing basis.

Q6: What consideration is taken to account for climate change induced increases in the power and frequency of hurricanes as it relates to hurricane wind generated missiles?

A6: (KRQ) RG 1.221 includes Table 1, "Design Basis Missile Spectrum," which includes three missile types to be considered in the design of the plant. The three missile types included are an automobile, a schedule 40 pipe, and a solid steel sphere. These missile types provide protection from a spectrum of missiles (ranging from a massive missile that deforms on impact to a rigid penetrating missile) and provide assurance that the necessary structures, systems, and components (SSCs) will be available to mitigate the potential effects of a hurricane on plant safety. RG 1.221, Table 2, "Design-Basis Missile Velocities as a Function of Hurricane Windspeed," provides the horizontal missile velocity for each of the missiles in the spectrum as a function of the hurricane wind speed. These values are intended to be used in conjunction with the hurricane wind speed maps in RG 1.221, Figures 1 through 3.

As discussed in A5 above, the Staff concludes that the site characteristic hurricane wind speeds are appropriately conservative to account for any climate change related increase in hurricane power and frequency. SSAR Table 2.3-38, "Hurricane Missile Site Characteristics for PSEG Site," provides the hurricane missile site characteristics for the PSEG Site (Ex. PSEG004B). Although the hurricane site characteristic missiles are not used for design of SSCs at the ESP stage, these site characteristics will be compared against design parameters should this permit be referenced in a COL application.

Q7: What factors determine a PMH and what is the PMH used for in the Staff's analysis?

A7: (HJ) The PMH comprises the meteorological factors such as radius of maximum winds, central pressure, latitude, forward speed, track direction, peripheral pressure, inflow angle, location of landfall, etc. The intensity of a hurricane is influenced by all of the aforementioned parameters but is mostly determined by the oceanographic parameter of sea surface temperature (SST). SST is directly related to the PMH via the central pressure and the pressure gradient (difference between the central and peripheral pressure). It is the pressure gradient that determines the wind velocity. The PMH is used in computing the probable maximum storm surge (PMSS), which is comprised of several meteorological and oceanographic parameters that are site specific.

Q8: What is the scope of the USGCRP report as it relates to the power and frequency of hurricanes?

A8: (HJ) Hurricane intensity and development is mostly determined by SST. Therefore, the analysis of long-term temperature trends is critical in determining the impact of climate change on future hurricane patterns. In all long-term temperature records, factors such as instrument changes, changes in observation times, and changes in methodology can introduce artificial jumps or trends into the data records. Most global or even regional temperature analyses such as the USGCRP cannot account for these site-specific factors. For example, projections that hurricane frequency has increased may reflect better detection of storms in the post-satellite era. Another factor is that numerical models that simulate future climate are unable to resolve individual storms.

Current climate change science is conflicted with regard to the possible change in hurricane frequency and intensity with some studies showing an increase in Atlantic hurricane frequency and others showing that storm frequency follows a 30- to 50-year cycle associated with changes in ocean currents. In regard to hurricane intensity, basic climate theory is that a warming atmosphere will lead to warmer SSTs, which fuel hurricanes, thereby causing more and stronger storms. However, there are studies that show that warming can lead to more El Nino events which hinder hurricane development along the northern Atlantic Seaboard. For the PSEG ESP site In particular, the divergence of the Gulfstream offshore north of Cape Hatteras allows cooler seawater from New England to move south along the mid-Atlantic coast, resulting in hurricanes losing energy as they approach the mid-Atlantic Coast. This feature of the Gulfstream is likely to be present irrespective of near term climate change and, as noted, USGCRP does not address the impacts in specific areas and localities.

In regard to hurricane frequency, several periods of activity can be seen in the late 1800's, the 1930's, the 1950's, and from 1995 to 2005. Relatively inactive periods have occurred around 1920, 1970, and 1985. There is a general trend of increasing activity over the whole period, but there is uncertainty in whether this is real or an artifact of poor detection of storms before aircraft reconnaissance or satellites.

There are five categories of tropical cyclones based on wind intensity. Historically (measured from 1869 to present), the northern Atlantic seaboard has experienced the landfall of 41 tropical cyclones with only three reaching Category 3 (110-130 mph) intensity. No storms have been recorded with greater intensity in the mid-Atlantic region of the United States. Since 1900, the largest number of landfall strikes have occurred in northeast Texas, southern Louisiana and Mississippi, southeastern Florida and eastern North Carolina. Thus, at the PSEG Site, additional margin for climate change is included by using a Category 4 (133 mph) PMH for the PMSS calculation.

Q9: What factors demonstrate that the models used to establish the PMH for the PSEG Site are conservative in view of climate change predictions?

A9: (HJ) Multiple storm surge model simulations were performed by the Applicant and the Staff using wind fields derived from multiple PMH profiles. The final PMH was the tropical cyclone that produced the highest storm surge (i.e., PMSS) at the PSEG Site. The controlling PMH at the PSEG Site is a Category 4 (133 mph) tropical cyclone with a central pressure of 26.64 in. Hg (902 mb) at landfall and a resultant storm surge of 32.1 feet. Furthermore, this analysis includes several factors that build in additional conservatism, including the assumption of steady-state winds, no decay in intensity prior to landfall, and no deviation in track speed or direction. The record for storm surge in United States is 29 feet in the Gulf of Mexico from the 2005 Category 3 Hurricane Katrina (at landfall with a storm intensity of 130 mph, a radius of maximum winds of 30 miles and a central pressure of 27.17 in of Hg (920 mb).

As mentioned in the Staff's answer to question Q8 above, only three Category 3 hurricanes made landfall on the Atlantic seaboard since 1869. When factored with the influence of land and associated frontal systems, the environment near the PSEG Site is not optimal for intense hurricanes. As previously mentioned, the divergence of the Gulfstream offshore north of Cape Hatteras allows cooler seawater from New England to move south along the mid-Atlantic coast, resulting in hurricanes losing energy as they approach the mid-Atlantic coast. This feature of the Gulfstream is likely to be present irrespective of near term climate change and, as noted, USGCRP does not address the impacts in specific areas and localities.

In sum, given these geographic considerations; the various conservative assumptions the applicant incorporated into its evaluation (calculating a storm surge that would exceed the U.S. record, which occurred in a more hurricane-susceptible region); and the sensitivity analysis described above that assessed the implications of climate change for the inputs defined in RG 1.221, the Staff concludes that the models used to establish the PMH for the PSEG Site remain appropriately conservative.

Q10: Does this conclude your testimony?

A10: (KRQ; HJ) Yes.

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AFFIDAVIT OF KEVIN R. QUINLAN

I, Kevin R. Quinlan, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications (Ex. NRC002) are true and correct to the best of my knowledge and belief. I attest to the accuracy of my testimony and endorse its inclusion into the record of this proceeding.

Executed in Accord with 10 CFR § 2.304(d)

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Executed at Rockville, Maryland
This 25th day of February, 2016

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AFFIDAVIT OF HENRY JONES

I, Henry Jones, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications (Ex. NRC002) are true and correct to the best of my knowledge and belief. I attest to the accuracy of my testimony and endorse its inclusion into the record of this proceeding.

Executed in Accord with 10 CFR § 2.304(d)
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This 25th day of February, 2016