UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 8, 2016

Mr. Robert Braun
President and CNO
PSEG Nuclear LLC-N09
P. O. Box 236
Hancocks Bridge, NJ 08038

SUBJECT: NUCLEAR REGULATORY COMMISSION REPORT FOR THE AUDIT OF PSEG NUCLEAR LLC'S FLOOD HAZARD REEVALUATION REPORT SUBMITTALS RELATING TO THE NEAR-TERM TASK FORCE RECOMMENDATION 2.1-FLOODING FOR SALEM NUCLEAR GENERATING STATION, UNITS 1 AND 2 (CAC NOS. MF3790 AND MF3791)

Dear Mr. Braun:

By letter dated June 1, 2015 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15146A220), the U.S. Nuclear Regulatory Commission (NRC) informed you of the staff's plan to conduct a regulatory audit of PSEG Nuclear LLC's (PSEG, the licensee) Flood Hazard Reevaluation Report (FHRR) submittal related to the Near-Term Task Force Recommendation 2.1-Flooding for Salem Nuclear Generating Station, Units 1 and 2 (Salem). The audit was intended to support the NRC staff review of the licensee's FHRR and the subsequent issuance of a staff assessment.

The audits conducted on June 22, 2015, and July 16, 2015 were performed consistent with NRC Office of Nuclear Reactor Regulation, Office Instruction LIC-111, "Regulatory Audits," dated December 29, 2008, (ADAMS Accession No. ML082900195). Therefore, the purpose of this letter is to provide you with the final audit report which summarizes and documents the NRC's regulatory audit of the licensee's FHRR submittal. Based on shared site characteristics, this audit was combined with the audit of PSEG's Hope Creek Generating Station, Unit 1 (Hope Creek). The results of this audit report are applicable to both Salem and Hope Creek. The NRC staff has prepared a separate audit report for Hope Creek with the same audit results.

If you have any questions, please contact me at (301) 415-6197 or by e-mail at Tekia.Govan@nrc.gov.

Sincerely,

Tekia V. Govan, Project Manager
Office of Nuclear Reactor Regulation
Japan Lessons-Learned Division
Hazards Management Branch

Docket Nos. 50-272 and 50-311

Enclosure:
Audit Report

cc w/encl: Distribution via Listserv

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NUCLEAR REGULATORY COMMISSION AUDIT REPORT FOR THE AUDIT OF PSEG NUCLEAR LLC'S FLOOD HAZARD REEVALUATION REPORT SUBMITTALS RELATING TO THE NEAR-TERM TASK FORCE RECOMMENDATION 2.1-FLOODING FOR SALEM NUCLEAR GENERATING STATION, UNITS 1 AND 2

BACKGROUND AND AUDIT BASIS

By letter dated March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information to all power reactor licensees and holders of construction permits in active or deferred status, pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.54(f) "Conditions of license" (hereafter referred to as the "50.54(f) letter"). The request was issued in connection with implementing lessons-learned from the 2011 accident at the Fukushima Dai-ichi nuclear power plant, as documented in The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident. Recommendation 2.1 in that document recommended that the NRC staff issue orders to all licensees to reevaluate seismic and flooding for their sites against current NRC requirements and guidance. Subsequent Staff Requirements Memoranda associated with Commission Papers SECY 11-0124 and SECY-11-0137, instructed the NRC staff to issue requests for information to licensees pursuant to 10 CFR 50.54(f).

By letter dated March 11, 2014, PSEG Nuclear LLC (PSEG, the licensee) submitted its Flood Hazard Reevaluation Reports (FHRRs) for Salem Nuclear Generating Station, Units 1 and 2 (Salem) (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14071A401). The NRC is in the process of reviewing the aforementioned submittal and has completed a regulatory audit of the licensee to better understand the development of the submittal, identify any similarities/differences with past work completed and ultimately aid in its review of the licensees' FHRR. This audit summary is being completed in accordance with the guidance set forth in NRC Office of Nuclear Reactor Regulation, Office Instruction LIC-111, "Regulatory Audits," dated December 29, 2008, (ADAMS Accession No. ML082900195).

AUDIT LOCATION AND DATES

The audit was completed by document review via a webinar session in conjunction with the use of the licensee's established electronic reading room (ERR) and teleconference on June 22, 2015, from 9am to 3pm and July 16, 2015, from 1:00pm to 4:00pm.

Enclosure

AUDIT TEAM

Title	Team Member	Organization
Team Leader, NRR/JLD	Tekia Govan	NRC
Technical Monitor	Michael Willingham	NRC
Technical Staff	Mike Lee	NRC
Technical Staff	Michelle Bensi	NRC
Technical Team Lead	Kenneth Erwin	NRC
Technical Branch Chief	Christopher Cook	NRC
NRC Contractor	Philip Meyer	Pacific Northwest National Lab
NRC Contractor	Christopher Bender	Taylor Engineering

A list of the Licensee's participants can be found in Attachment 2.

DOCUMENTS AUDITED

Attachment 1 of this report contains a list which details the documents that were reviewed by the NRC staff, in part or in whole, as part of this audit. The documents were located in an electronic reading room during the NRC staff's review. The documents, or portions thereof, that were used by the NRC staff as part of the technical analysis and/or as reference in the completion of the staff assessment, were submitted by the licensee and docketed for completeness of information, as necessary. These documents are identified in Table 1.

AUDIT ACTIVITIES

In general, the audit activities consisted mainly of the following actions:

- Review background information on site topography and geographical characteristics of the watershed.
- Review site physical features and plant layout.
- Understand the selection of important assumptions and parameters that would be the basis for evaluating the individual flood causing mechanisms described in the 50.54(f) letter.
- Review model input/output files to computer analyses such as Delft-3D and FLO-2D to have an understanding of how modeling assumptions were programmed and executed.
- Review of data filtering and statistical approaches utilized to develop storm recurrence rate and distribution of storm parameters used in the Joint Probability Method (JPM).
- Review of key assumptions, approximations, and heuristics utilized in conjunction with the JPM.

Table 1 summarizes specific technical topics (and resolution) of important items that were discussed and clarified during the audit. The items discussed in Table 1 may be referenced/mentioned in the staff assessment in more detail.

EXIT MEETING/BRIEFING

On August 14, 2015, the NRC staff closed out the discussion of the technical topics described above. There are no outstanding information needs remaining as a result of this audit.

Table 1: Salem/Hope Creek Information Needs – Audit/Post-Audit Summary

INFO NEED	INFORMATION NEED DESCRIPTION	ACTION (POST-AUDIT)
1	**Storm Surge - Data used for Development of Distributions** Evaluation of the effects of flooding from storm surge on water surface elevations at the Salem/Hope Creek site (hereafter the "PSEG site") is requested in the 50.54 (f) letter. The flood hazard reevaluation reports (FHRRs) for Salem and Hope Creek (References [1] and [2]) provide Table 2.4-10 containing storms crossing a line of demarcation running from a point at 36.5°N,76°N to a point at 41.5°N,71°W (shown in Figure 2.4-11). The table lists values for central pressure, forward velocity, and track angle for each of the storms. The September 2014 request for additional information (RAI) response (Reference. [3]) contains similar information in Table RAI-5-2 for storms crossing a line a line extending from a point at 37°N,76°N to a point at 41°N,72°W. However, differences are noted between the two tables with respect to the storms included in the tables as well as values of parameters assigned to storms appearing in both tables. It is understood that the information in FHRR Table 2.4-10 is used to develop distributions for central pressure differential. The data is Table RAI-5-2 is used to develop distributions for central pressure differential, forward velocity, and storm heading. In connection with the 50.54 (f) request, the licensee was requested to provide the following information: a. Description of the approach used for screening or filtering data. b. Clarification of the reason(s) for the differences between the dataset used in the FHRRs (Table 2.4-10) and that used in the September 2014 RAI response (Table RAI-5-2). Specifically, clarification is requested regarding differences in storms considered within the two datasets, as well as differences in parameter values assigned to storms that appear in both datasets.	In response to the NRC staff information requests: a. The licensee described the approach used to geographically filter data using a capture zone approach. The licensee provided a Fortran computer code (file name "hdatpsegf.for") that was used by the licensee for investigations of tropical cyclone statistics. It was noted by the licensee that the input file for the Fortran computer code was the "latest HURDAT file that was available at the time of the work conducted for PSEG in late summer and fall of 2014" (the file name assigned by the licensee is "newhurdat2013.txt"). The licensee stated that a line of demarcation was drawn from 75.5 W, 37.0 N to 71.0 W, 41.0 N. Storms that crossed this line were identified by the licensee as being close enough to the PSEG site to include in the analysis. The licensee noted that the coordinates used were slightly different than what was provided in the RAI response (Reference [3]); however, the licensee clarified that these coordinates reflected those used in the calculation (i.e., the discrepancy was identified as a reporting error rather than a calculation error). The licensee stated that a central pressure threshold of 980mb was established in the computer code to filter any storms that were "too weak to produce a significant surge response." Using this information, the licensee's execution of the hdatpsegf.for code produces an output file (file name 'table.txt') that contains the filtered storm dataset. The licensee noted that the track angle assigned to storm event Sandy was manually adjusted. The licensee further noted that there are several discrepancies between the Table RAI-5-2 (Reference [3]) and the values used in the FHRR analysis. The licensee stated that the values in Table RAI-5-2 were incorrect due to an apparent transcription error in generating the

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	c. Description of the method for assigning central pressure values to storms for which central pressure data is not included in the HURDAT2 dataset. d. Discussion of the treatment of storm events in the analysis passing close to but not across the line of demarcation, as well as storm events that are not included the HURDAT2 database (Reference [4]).	tables. The licensee stated that values used in subsequent calculations are as shown in Table 2 of this audit summary. b. The licensee stated that there are two "main reasons for the different datasets" observed between FHRR Table 2.4-10 and RAI Table 5-2: i. The "line of demarcation" was modified causing the number of filtered storms to be potentially altered. The licensee noted that the Fortran code was setup to identify the point at which the storm passes the line of demarcation. Once a storm has crossed into the area of interest, the Fortran code will identify the minimum central pressure and associated forward speed and heading (based on the specific point that is chosen as the minimum central pressure). As a result, changes to the line of demarcation would potentially change the number of filtered storms and the specific data values used in the analysis ii. The HURDAT database was significantly modified around the 2011-2012 time period. The licensee stated that a review of the summary of changes (available at: http://www.aoml.noaa.gov/hrd/hurdat/metadata_master.html) indicated that significant changes were performed on the database, including changes to track and intensity information. Modifications to track and intensity information could potentially affect the storms that are selected and the specific data that is extracted from the database. c. The licensee stated that only events for which historical information is available for central pressure were used. Wind-pressure relationships were not used. d. The licensee stated that events not passing the line of demarcation were not included. The NRC staff concluded that the information provided by the licensee was responsive to the information need request.

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2	**<u>Storm Surge – Storm Rate</u>** Evaluation of the effects of flooding from storm surge on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. Section 2.4.3.4.2 of the FHRRs for Salem and Hope Creek (References [1] and [2]) state the following: *"Although the FEMA storm surge study focused on surges for a much lower range of return periods than those of interest in this analysis, the objective measure of storm rate within the angle range of interest is used for the PSEG site, as the catalog of historical storm data is the same. In the FEMA storm surge study the omnidirectional storm rate in the vicinity of the mouth of Delaware Bay is approximately 0.045 storms per year per degree [of latitude]."* It is noted that the above reference to the FEMA study is a draft report that provides the rate in units of storms/year/degree of latitude. The published version of the FEMA study provides the rate in units of storms/year/km, which (by unit conversion) yields an approximately equivalent rate of 0.0004 storms/km/year. The omni-directional storm rate provided in the FHRR is subsequently multiplied by 0.1695% (0.001695), which the licensee states is the percentage of the total omni-directional population considered to be "heading in the critical storm track needed to generate the 10^{-6} AEP storm surges." This yields 7.628×10^{-5}. In the licensee's September 2014 RAI response (Reference [3]), the licensee states the following: *"[I]n this area (the coastal region defined in Figure RAI-5-2) there have only been 6 landfalling storms (Unnamed 1938, Donna, Belle, Gloria, Irene, and Sandy) over the last 163 years. Thus, the frequency of storms in our range of angles is given by number of landfalling storms divided by the number of years (6/163) divided by the number of degrees along the line defined*	In response to the NRC staff information requests: a. The licensee stated that the rate originally used in the FHRR evaluation (based on a FEMA study) was subsequently considered not appropriate for the PSEG site. b. The licensee stated that only storm events that make landfall were considered in the event rate calculation. The licensee initially stated that no further filters were utilized but later revised their response to indicate that a filter based on event categorization appears to have been used. The licensee stated that Fortran computer code used to filter historical data identified "the storm events that crossed the area of interest in order to define the storm characteristics, but not necessarily only the storms that make landfall." The licensee identified eight storms that make landfall within the area of interest: an unnamed 1938 event, Agnes, Donna, Belle, Floyd, Gloria, Irene, and Sandy. However, the licensee stated that Agnes and Floyd storm events have central pressures less than the 980mb threshold at landfall and were thus deemed by the licensee to be too weak at landfall to produce a significant storm surge at the site and were excluded from the storm rate analysis. c. Based on information provided in response to Information Need 1 (above), the NRC staff noted that the 1893, 1903, and 1934 storm events appeared to have been screened based on central pressure criteria. The licensee confirmed that these events were "were too weak within the area of interest and were excluded via the filtering process." The licensee further noted the following: • The 1893 storm event had an observed central pressure of 986 mb and an estimated wind speed of 75 mph at landfall (storm AL041893 on August 24 at 1200 hours GMT). • The 1903 storm event had an observed central pressure of 990 mb and its estimated wind speed was 70 mph (storm AL041903 on September 16 at 1100 hours GMT).

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	as the crossing boundary here (5.93) times the fraction that travel in this direction (0.0117), which results in a storm frequency value at the PSEG site of 7.26 × 10^{-5} storms per year per degree.” Thus, via the RAI response, the omni-directional rate appears to be reduced from 0.045 storms/year/degree to a value of 0.0062 storms/year/degree. In connection with the 50.54 (f) request, the licensee is requested to: a. Describe the technical basis for modifying from the omni-directional rate provided in the FHRR such that the rate is apparently reduced. b. Describe the criteria used to screen events so that only six events that were included in the omni-directional rate calculation. c. Describe the reason for exclusion of storm events that appear to have similar characteristics to the six events included in the event list used to calculate that the omni-directional rate (e.g., exclusion of events such as Unnamed 1903, NotNamed 1893, and Unnamed 1934). d. Discuss whether the distributions for storm parameters are defined consistent with the criteria used to define the omni-directional event rate (e.g., whether input data used to develop distributions are consistent with the characteristics of events list used to define the omni-directional rate). e. Discuss whether the omni-directional rate is defined in a manner such that it is appropriate to subsequently multiply the calculated rate by a factor intended to include only events approaching in the “critical direction” (i.e., discuss whether it is consistent to (i) include only landfilling events with limited range of headings in the event rate calculation but (ii) include a wider range of events in	• The 1934 storm event had an estimated central pressure of 989 mb and 65 mph wind speed at landfall (storm AL061934 on September 9 at 0200 hours). The licensee additionally stated that storm events occurring in calendar years 1867, 1869, and 1879 had recorded central pressures less than 980 mb but had estimated wind speeds at landfall of 80 mph, 100 mph, and 90 mph, respectively. The licensee concluded that, because these wind speeds are all above the wind speeds for the 1893, 1903 and 1934 storm events at landfall, the omission of these storms in the analysis was justified. The NRC staff further identified another subset of storms (i.e., Unnamed events in 1869 and 1944 as well as the 1954 event Carol). The licensee provided the following explanations for the exclusion of the following storm events: • The September 7-9, 1869, storm (AL061869) data does not have any observation points that fall within the sample area. • The September 9-16, 1944, storm (AL071944) data has a single point that falls inside the sample area, but its wind speed is 75 mph (minimal hurricane). The event data has no pressure observations inside the sample area. • The event Carol data has two points which “clip” the sample area, but has no pressure readings inside the sample area. The licensee noted that this storm data has a slightly-higher wind speed (85 mph) than the lowest storm in the sample considered for computation of the recurrence rate (80 mph). However, the licensee further stated the other storm events included in the sample had pressure data recorded (unlike the event Carol). The licensee stated that there is a large error band in estimating central pressure from HURDAT wind speeds. The licensee concluded that, because the storm set is only used to specify the parameter distributions and not to estimate storm frequency, it was better to omit the event from

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	calculating the distribution of heading, including events that do not make landfall).	the storm catalog rather than to attempt to assign this weak storm a pressure value and include it in the analyses. d. The licensee stated that "[t]his assumption is consistent with the state of the art in the field of surge prediction within JPM models." The licensee noted that the Sandy storm was viewed as an outlier with regard to storm heading. The licensee also noted (i) that examination of the correlation between storm heading and central pressures (excluding Hurricane Sandy) yielded a product-moment correlation coefficient of -0.4 and (ii) the t-Statistic is not significant for a two-tailed test at the 0.10 level. The licensee concluded that it would not be considered statistically-correlated in a typical test of significance. e. The licensee noted that a storm must make landfall to generate a large surge. However, in order to have a larger distribution for fitting the distributions of associated storm parameters, the licensee extended the sample area. With regard to the frequency with which these storms make landfall in the study area, the licensee concluded that the representation had to be quantified in terms of the frequency of landfalling storms. The licensee further stated that the frequency of landfalling storms with central pressures less than 980 mb can be combined with additional parameters (e.g. central pressure distribution, heading distribution, size and speed distributions) for storms with central pressures less than 980 mb, to form an appropriate estimate of the statistical annual rate of the occurrence of a combination of events (given that the storm makes landfall). The licensee stated that, had the analysis included non-landfalling storms, this would not have been the correct rate for landfalling storms. The NRC staff concluded that the information provided by the licensee was responsive to the information need request.

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3	**<u>Storm Surge – Distribution of R_{max}</u>** Evaluation of the effects of flooding from storm surge on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. The FHRRs for Hope Creek (Reference [1]) and Salem (Reference [2]) state that the following distribution is used for radius to maximum winds (R_{max}) conditional on central pressure differential (Δp): $$p(R_{max} \mid C_p) = \text{Lognormal } (\hat{R}_{max}), \sigma_{\ln(R_{max})}) = \Phi(\ln(\hat{R}_{max}), \sigma_{\ln(R_{max})})$$ where: $$\hat{R}_{max} = \exp(3.015 - 6.291 \times 10^{-5} (\Delta p)^2 + 0.0337\Psi)/1.852$$ $$\sigma_{\ln(R_{max})} = 0.44\text{km} = 0.24\text{nm}$$ In the above expressions, Ψ corresponds to the site latitude in degrees. The RAI response (Reference [3]) indicates that: $\sigma_{\ln(R_{max})} = 0.176\text{nm}$. In a Fortran input file (designated "prmax3.for") associated with the RAI response, the modified standard deviation appears to have been calculated as: $$\sigma_{\ln(R_{max})} = \lvert \ln(\exp(0.44)/1.852) \rvert$$ In connection with the §50.54 request, the licensee is requested to: a. Clarify the reason for the change in distribution assumptions. b. Confirm that the computed probabilities are not affected by a change in units (e.g., computed probabilities for a fixed R_{max} are invariant to the units selected for measurement).	In response to the NRC staff information requests: a. The licensee stated that the distribution assumptions were changed in response to an error identified by peer reviewers. b. During the audit, the NRC staff showed an illustration of a potential issue in which the computed probabilities for a fixed R_{max} are not invariant to the units selected for measurement. In response and after performing some checks (as part of the current audit process) on the cumulative probability distribution, the licensee found that the latest version of the transformation did not conserve probability. As a result, the licensee changed to a kilometer-based Cumulative Distribution Function in the Fortran script prmaxnewf.for to address this problem. The calculation for the new distribution was then carried out in units of kilometers with the category boundaries given by the boundaries in nautical miles converted to kilometers. The licensee stated that the output from this new code is used in the Joint Probability Method (JPM) code and is consistent with the reference (Reference [5]) cited in Revision 2 of the calculation (Reference [7]). The NRC staff concluded that the information provided by the licensee was sufficient to address the information need request.
4	**<u>Storm Surge – Forward Scaling Velocity</u>** Evaluation of the effects of flooding from storm surge on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. The FHRRs (References [1] and [2]) state that a velocity scaling	In response to the NRC staff information requests: a. The licensee stated that the expression in FHRR equation 2.4-6 was not correct but the calculations inside the JPM code are consistent

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	relationship is used in the generation of the response surface, which is based on an approximation in which forward velocity is scaled linearly with *wind speed*. The relationship provided in the FHRRs (equation 2.4-6) is: $\eta = \eta_0 + \lambda\, \delta v_f$ where: • η = surge with forward velocity v_f • η_0 = surge with reference forward velocity of 30 knots • λ =1.09 (a constant value) • δv_f = difference between the storm forward velocity and a reference storm forward velocity of 30knots The input file (jpmzp2.for) associated with the September 2014 RAI response appears to define scaling factors (vfscla(i)) equal to 0.84, 0.92, 1.0, and 1.09. In addition, the input file appears to apply the scaling factor after the addition of the error term (e.g., see line of input file containing expression isrg=vfscl*(srg(idx,irp,idp,iang)+tideadj+xdif)*10+1.0)). In connection with the 50.54 (f) request, the licensee is requested to: a. Clarify whether the computed scaling factors in the input file (jpmzp2.for) are consistent with the expression provided in FHRR equation 2.4-6. b. Provide clarifying information if the above characterization is not accurate or describe the reason for the apparent application of the scaling factor after the addition to the error term. c. Discuss whether the use of the velocity scaling relationship introduces a source of error that should be included in the JPM integration.	with the intended scaling. The licensee stated that equation 2.4-6 should be corrected to read as follows: $\eta_m = \eta_0 * (1.09)^{m-m_0}$ where: • η = surge in the m[th] forward speed • η_0 = surge in the reference forward speed (30 knots) • m = the forward speed category counter (m=1 for 10 knots, m=2 for 20 knots, m=3 for 30 knots, m=4 for 40 knots). The above expression yields multipliers for categories, 1, 2, 3, and 4 of 1.09^{-2}, 1.09^{-1}, 1.09^{0}, and 1.09^{+1}, respectively. The licensee stated that this is consistent with the multipliers 0.84, 0.92, 1.0, and 1.09 found in the JPM code. b. The licensee performed a sensitivity study to identify whether the application of the scaling factor after addition of the error term is inappropriately affecting the results. The licensee stated that the difference in the estimated value 1E-6 surge level was less than 0.01 meter. c. The licensee indicated that assumptions associated with the error term (i.e., standard deviation) in the JPM integration may implicitly cover error associated with this approximation. However, the treatment is not explicit or quantified. The licensee and NRC staff discussed this topic as potentially appropriate for a sensitivity study (e.g., by increasing the standard deviation associated with the error term). No further action was requested by the licensee as part of the audit. The NRC staff concluded that the information provided by the licensee was responsive to the information need request.

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5	**Storm Surge – Central Pressure Distribution** Evaluation of the effects of flooding from storm surge on water surface elevations at the PSEG site is requested in the 50.54 letter. The FHRRs (References [1] and [2]) state that the distribution of central pressure differential is a Gumbel distribution given by the expression: $F(z)=\exp(\exp(-z))$ where $z = \vert(\Delta p - a_0)/a_1\vert$, $a_0 = 36.68$, and $a_1 = 14.67$. The FHRR states that the distribution was developed using input data that was screened from the HURDAT dataset using a line-crossing approach. The post-screening dataset is provided in Table 2.4-10 of the FHRRs. In the September 2014 RAI response (Reference [3]), the licensee utilized a modified set of storms (Table RAI-5-2) and stated that the data exhibited significant departure from the Gumbel distribution. As a result, a Generalized Extreme Value distribution for central pressure was developed: $F(z) = \exp(-(1-z/\zeta)^{\zeta})$ where $z = \vert(\Delta p - a_0)/a_1\vert$, $a_0 = 42.96$, $a_1 = 16.77$, and $\zeta = 6.494$. In connection with the 50.54 (f) request, the licensee is requested to: a. Describe the statistical approach used to select distributional form and estimate distribution parameters based on historical data. b. Identify whether the distribution selected and associated parameters are sensitive to the statistical approach utilized. c. Describe the reason for the difference between the distribution form and parameters identified in the FHRR and the RAI response.	In response to the NRC staff information requests: a. The licensee indicated that the method of moments (iterative solution) was used to estimate distribution parameters. Three tests with the JPM code were performed by the licensee with various solutions to the parameters of the distribution generated in three different manners (two self-developed codes and one commercial code) yielding the following: i. Iterative Method of Moments (based on licensee-developed code) where c = 0.159, $a_1 = 46.17$, and $a_2 = 14.49$ ii. EasyFit (commercial software package) with Maximum Likelihood Method (with default settings) where c = 0.05095, $a_1 = 49.474$, and $a_2 = 11.931$ iii. Maximum Likelihood Method where c = 0.088, $a_1 = 49.64$, and $a_2 = 13.46$. The licensee stated that the resulting stillwater values for the 1E-6 annual exceedance probability are 6.3m, 6.5m, and 6.5m, respectively. b. The licensee indicated that goodness of fit was checked via a graphic assessment of the data (e.g., Q-Q plot). The licensee observed that the fitted distribution overestimates the highest value in the set, but overall fits "the data quite well and cannot be rejected even at the 0.2 level of significance in the Kolmogorov-Smirnov test, the Anderson-Darling test and the Chi-Squared test." c. The licensee indicated the distribution form was changed because the previously selected distribution (Gumbel) was subsequently determined not to adequately fit the data. The NRC staff concluded that the information provided by the licensee was responsive to the information need request.
6	**Storm Surge - Distribution for Forward Velocity and Storm Heading** Evaluation of the effects of flooding from storm surge on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. The	In response to the NRC staff information requests: a. For parameters other than central pressure (see Information Need 5 above), the licensee stated that the small data set was not

INFO NEED	INFORMATION NEED DESCRIPTION	ACTION (POST-AUDIT)
	FHRR indicates that the distribution for forward velocity (v_f) is based on previous FEMA studies and is a normal distribution (defined conditional on Δp) with parameters $\mu = 6 + 0.4\Delta p$ (knots) and $\sigma = 7$ knots. The RAI response specifies that the distribution of forward velocity is developed based on an analysis of data contained in Table RAI-5-2 and results in use of a normal distribution with $\mu = 23.6$ knots and $\sigma = 9.6$ knots. The FHRR further indicates that the distribution of heading is based on a modification of a FEMA distribution and results in the use of a Normal distribution with $\mu = 4$ degrees east of north and $\sigma = 10$ degrees. The RAI response specifies that the distribution of forward velocity is developed based on an analysis of data contained in Table RAI-5-2 and results in use of a normal distribution with $\mu = 70.9$ degrees in a mathematical coordinate system (19.1 degrees east-of-north) and $\sigma = 21.1$ degrees. In connection with the 50.54 (f) request, the licensee is requested to: a. Describe the statistical approach and statistical tests used to select distributional form and estimate distribution parameters based on historical data. b. Identify whether the distribution selected and associated parameters are sensitive to the statistical approach utilized.	considered adequate to justify deviation from previous works with larger data sets, which found heading to be reasonably represented by a Gaussian distribution. The licensee stated that introduction of skewness into this distribution would cause sensitivity to outliers such as the heading of Hurricane Sandy. As a result, the licensee opted to use the generalized form that is used in JPM studies with distributions based on observational data to date. The licensee emphasized the importance consistency between the analysis of the storm heading directions and their application in the simulations performed. For storms that did not make landfall, the licensee selected the heading at the time of minimum pressure. However, the licensee noted that, in the landfalling storms, it is important to form smooth tracks that are similar in overall manner in which they are used in the simulations, which usually meant that the direction at landfall was used. For Hurricane Sandy, the licensee noted that the storm heading veered to the left about 120 miles off the coast (heading 148 degrees in a mathematical coordinate system) and, about 35 miles off the coast, it veered back to the north (heading 127.5 degrees in a mathematical coordinate system). In the RAI response (Reference [3]), the licensee used the landfall heading for this storm; however, the licensee stated that it is likely that the track location only reflects a "wobble" in the eye position within this large storm rather than an actual shift in the position of the entire large storm. For the purpose of maintaining an analogue to the simulations, the licensee opted to use a smoothed track with a heading of 137.75. Use of this data point resulted in a re-estimation of the sample distribution parameters, yielding a mean heading of 71.59 degrees and a standard deviation of 22.43 degrees. The licensee observed that 1.78 percent of the storms making landfall enter the simulation direction banks included in the simulations.

<table>
<tr><th>INFO NEED</th><th>INFORMATION NEED DESCRIPTION</th><th>ACTION (POST-AUDIT)</th></tr>
<tr><td></td><td></td><td>b. The licensee stated that they tried to "limit the storm set to move away from the conundrum created in the data analysis performed by FEMA in which storms with heading along tracks considered within our region would have been far less frequent." The licensee noted that an existing FEMA study uses a mean direction of 22 degrees and a standard deviation of 10 degrees.

The NRC staff concluded that the information provided by the licensee was responsive to the information need request.</td></tr>
<tr><td>7</td><td><u>Storm Surge - Pressure Differential Scaling</u>

Evaluation of the effects of flooding from storm surge on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. The FHRR (Reference. [1], Reference [2]) states that a scaling function was used (in addition to interpolation and extrapolation) in establishing the response surface. The scaling relationship relates surge heights for events with differing central pressure differential but the same values of other storm parameters (e.g., R_{max}, v_f, heading, landfall location, Holland B). The scaling relationship is specified as:

$\eta_2 = (\Delta p_2 / \Delta p_1) \cdot \eta_1$

where:
• η_1 = surge associated with storm 1 (e.g., as estimated by a numerical model)
• η_2 = surge associated with storm 2
• Δp_1 = pressure differential of storm 1
• Δp_2 = pressure differential of storm 2
The NRC staff observed that comparison between values computed using the pressure differential relationship and those computed using numerical models suggest some variability and that the use of the relationship appears, in some cases, to be biased unconservative. As a result, the licensee was requested to discuss:</td><td>In response to the NRC staff information requests, the licensee provided the following information:
a. The licensee provided a literature reference (Reference [6]).

b. The licensee stated that NRC previously observed that the pressure differential scaling relationship appeared to underestimate the surges for the 928-mb storms. In response, the licensee compensated for the under predication by replacing the original scaling relationship:

$\eta_2 = (\Delta p_2 / \Delta p_1) \cdot \eta_1$
with the following (alternative) relationship:
$\eta_2 = (\Delta p_2 / \Delta p_1) \cdot \eta_1 \cdot [1 - (k - k_0)(0.046)]$

where:

η_1 = is the surge height for a storm with a pressure differential of Δp_1
η_2 = is the surge height for a storm with a pressure differential of Δp_2
k_0 = the counter for the reference pressure (918mb)
k = the counter for the alternate central pressure being estimated.

The licensee noted that, to retain some conservatism in the estimates, the scaling in the larger pressure differential direction to its initial value is used. The licensee provided the following multipliers as a function of central pressure:</td></tr>
</table>

<table>
<tr><th>INFO NEED</th><th>INFORMATION NEED DESCRIPTION</th><th>ACTION (POST-AUDIT)</th></tr>
<tr><td></td><td>a. The applicability of the pressure-differential scaling for estuary environments.
b. The potential for error (including bias) arising from the use of the scaling function.
c. Whether the use of the pressure differential scaling relationship introduces a source of error that should be included in the JPM integration.</td><td><table><tr><td>Central pressure</td><td>948</td><td>938</td><td>928</td><td>918</td><td>908</td></tr><tr><td>Multiplier</td><td>0.7966</td><td>0.8736</td><td>0.9414</td><td>1.00</td><td>1.10</td></tr></table>
c. The licensee and staff discussed this topic as potentially appropriate for application of a sensitivity study (e.g., by increasing the standard deviation associated with the error term).

The NRC staff concluded that the information provided by the licensee was responsive to the information need request.</td></tr>
<tr><td>8</td><td><u>Storm Surge - Approximations and Heuristics in Computation Codes</u>
Evaluation of the effects of flooding from storm surge on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. The Fortran input file (jpmzp2.for) associated with the September 2014 RAI response (Reference [3]) appears to utilize some approximations or heuristics (e.g., indexing structure used to compute bins probabilities for development of the hazard curve) that may have implications for the final computed results (e.g., due to rounding).

In connection with the 50.54 (f) request, the licensee is requested to discuss the coding structure utilized in the Fortran input file jpmzp2.for associated with the September 2014 RAI response and the potential implications associated with any approximations or heuristics utilized. In addition, the licensee is requested to be prepared (if needed/requested) to provide output for intermediate results generated by the code.</td><td>In response to the NRC staff information requests, the licensee noted that an observed rounding issue is expected to have a maximum impact of 0.05 meters. The licensee further stated that the definition of the exceedance value at each increment is estimated with an accuracy equal to the accuracy of the computer, since (i) for any value of surge greater than a given integer value in tenths of a meter it will get added to the next category without any rounding and (ii) for any value smaller than the integer, it will get placed in the category below the integer value in tenths of a meter, where it belongs, with no rounding.

The licensee also stated that a heuristic approximation was used when computing an uncertainty component of the storm surge analysis that assumed that the uncertainty could be written as a constant of 0.2 times the still water level. The licensee stated that subsequent studies have shown that this is a poor approximation for the Salem-Hope Creek site because the ratio of the uncertainty to the pressure differential only reaches a value of 0.2 when the pressure differential exceeds 105 mb (i.e. the central pressure is less than 913 mb). The licensee stated that this was a very conservative approximation. Consequently, the value was replaced with an alternate approximation.

The NRC staff concluded that the information provided by the licensee was responsive to the information need request.</td></tr>
</table>

INFO NEED	INFORMATION NEED DESCRIPTION	ACTION (POST-AUDIT)
9	**Local Intense Precipitation (LIP) - LIP 1-hr Front-Loaded Rainfall Distributions** Evaluation of the effects of flooding from LIP on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. The licensee quoted NUREG/CR-7046's conclusion that, "... local intense precipitation is, therefore, deemed equivalent to the 1-hr, 2.56-km^2 (1-mi^2) PMP at the location of the site...." The licensee also stated that the PSEG site is bounded by the 1-mi^2 area, and that the National Weather Service *Hydrologic Monitoring Report (HMR)-52* and NUREG/CR-7046 procedures were used to develop the rainfall event. The licensee stated that a front-loaded distribution was used because it results in maximum flood depths early in the event and minimizes the response time, which, the licensee stated, is conservative because once the water-tight doors are closed, the flooding from the LIP event is nonconsequential. The licensee also stated that, "procedural changes have been made to close the doors well in advance of a LIP event." The NRC staff concurs that the front-loaded, 1-hr probable maximum precipitation (PMP) event used by the licensee minimizes the response time needed to prevent incursion of water at critical door locations, and thus provides a bounding case for warning time. However, the licensee's RAI response does not address the NRC staff's request for justification that the LIP analysis presented in the FHRR is bounding in terms of the flood depth and flood duration. The RAI stated that justification can include sensitivity analysis to localized PMP events up to 72 hours in duration. The licensee's response included a statement from NUREG/CR-7046, Section 3.2, that, "... the amount of extreme precipitation decreases with increasing duration ...." This statement must have been intended to refer to the intensity of extreme precipitation, and not the depth of precipitation. The PMP depths provided in HMR 51 increase with duration (compare HMR 51, Figures 18 to 22). Longer duration LIP events can be constructed from the information in HMR 51 and HMR 52; NUREG/CR-7046, Appendix B, provides an example of a 6-hr LIP event. The NRC staff therefore requests that the licensee provide a revised response to the RAI.	Upon further review, the NRC staff determined that current staff guidance on the estimation of LIP duration is ambiguous and subject to multiple, equally valid interpretations. As a consequence, the NRC staff decided to withdraw this Information Need Request. The NRC staff concluded that the information provided by the licensee was responsive to the information need request.

INFO NEED	INFORMATION NEED DESCRIPTION	ACTION (POST-AUDIT)
10	**PMF Snowpack and Snowmelt Evaluation** Evaluation of the effects of flooding from LIP on water surface elevations at the PSEG site is requested in the 50.54 (f) letter. The licensee stated that the potential for flooding of the site arises from a combined event with storm surge and tides being the main contributors, and stated that snowmelt is not a consideration in the combined event alternatives described in ANSI/ANS-2.8. The licensee also stated that major snowmelt events would occur in the winter or early spring, while storm surge events would occur in the summer and fall. Finally, the licensee stated that PMP-based flooding of the Delaware River does not have a major effect on water levels at the site, and that current procedures require that the water-tight doors providing flood protection be closed when river elevation is well below the nominal site grade. The RAI addressed the consideration of snowmelt in evaluating the probable maximum flood (PMF), not as a component of the combined events analysis. In ANS 2.8, Section 5.3, directs the consideration of (a) probable maximum precipitation on snow, and (b) probable maximum snowpack with rain. The FHRR does not discuss either of these conditions in evaluating the PMF on the Delaware River. The NRC staff therefore request that the licensee provide a revised response to the RAI. Info Need No. 10 noted that ANS 2.8, Section 5.3, directs the consideration of (i) probable maximum precipitation on snow, and (ii) probable maximum snowpack with rain. The FHRR does not discuss either of these conditions in evaluating the PMF on the Delaware River. The NRC staff requested that the licensee provide a revised response to the RAI addressing this issue.	In response to the NRC staff information requests, the licensee stated that ANS 2.8 requires consideration of snowmelt only when it contributes to the controlling flood. At this particular site, the licensee stated that storm surge is the controlling flood event and is thus a more significant flooding event than the PMF event. At the PSEG site, the licensee observed that snow melt would occur only in the Spring and that storm surge-related flooding would occur later in the year – typically in the summer/fall timeframe so that there is little physical potential for a combined event involving these two processes. The NRC staff decided that no additional information would be requested of the licensee and that the NRC staff would address the issue in the staff assessment.

Table 2: Selected storms from the HURDAT database

YEAR	STORM NUMBER	STORM NAME	CENTRAL PRESSURE (mb)	HEADING (deg)	FORWARD SPEED (knots)
1867	AL021867	Unnamed	969	61.9	16.3
1869	AL061869	Unnamed	950	79.6	38.4
1879	AL021879	Unnamed	979	63.4	26.9
1936	AL131936	Unnamed	968	90.0	13.0
1938	AL061938	Unnamed	940	87.2	14.0
1958	AL041958	Daisy	970	58.6	20.0
1960	AL051960	Donna	965	47.6	30.0
1972	AL021972	Agnes	977	47.3	20.1
1976	AL071976	Belle	977	79.7	22.2
1985	AL091985	Gloria	951	71.0	30.0
1991	AL031991	Bob	953	58.0	26.7
1999	AL081999	Floyd	974	56.9	29.4
2011	AL092011	Irene	958	63.4	3.1
2012	AL182012	Sandy	940	137.75	1.3

ATTACHMENT 1
Salem/Hope Creek Audit Document List

1. PSEG Nuclear LLC, PSEG Nuclear LLC's Response to Request for Information Regarding Flooding Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident- Hope Creek Generating Station Flood Hazard Reevaluation, dated March 12, 2014, ADAMS Accession No. ML14071A511.

2. PSEG Nuclear LLC, PSEG Nuclear LLC's Response to Request for Information Regarding Flooding Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident- Salem Generating Station Flood Hazard Reevaluation, dated March 11, 2014, ADAMS Accession No. ML14071A401.

3. PSEG Nuclear LLC, PSEG Nuclear LLC's 90-day Response to Request for Additional Information Regarding Flooding Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident, dated September 23, 2014, ADAMS Accession No. ML14268A469.

4. National Oceanic and Atmospheric Administration (NOAA), "Hurricane Research Division Re-Analysis Project (HURDAT2)," [Online]. Available: http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html

5. D. W. Peter J. Vickery, "Statistical Models of Holland Pressure Profile Parameter and Radius to Maximum Winds of Hurricanes from Flight-Level Pressure and H*Wind Data," Journal of Applied Meteorology and Climatology, vol. 47, pp. 2497-2517, 2008.

6. N. Taylor, J. Irish, I. Udoh, M. Bilskie, & S. Hagen, "Development and Uncertainty Quantification Of Hurricane Surge Response Functions for Hazard Assessment in Coastal Bays". Natural Hazards, pp. 1-21, 2015.

7. PSEG Nuclear LLC & PSEG Power LLC, Calculation Number 2013-10436: Probable Maximum Storm Surge Using Joint Probability Method for ESPA Site, Revision 2, 2014.

8. PSEG Nuclear LLC & PSEG Power LLC, Calculation Number 2013-10436: Probable Maximum Storm Surge Using Joint Probability Method for ESPA Site, Revision 1, 2014.

9. PSEG Nuclear LLC & PSEG Power LLC, Calculation Number 2013-10436: Probable Maximum Storm Surge Using Joint Probability Method for ESPA Site, Revision 0, 2013.

ATTACHMENT 2
List of Salem Audit Participants

Name	Organization
1. Greg Sosson	PSEG Nuclear LLC (PSEG)
2. Bob Henriksen	PSEG
3. Tim Devik	PSEG
4. Charlotte Geiger	PSEG
5. William McTigue	PSEG
6. Don Resio	University of North Florida/PSEG Contractor
7. Mike Salisbury	Atkins Global/PSEG Contractor
8. Dan Blount	Sargent Lundy
9. Mehrdad Salehi	Sargent Lundy

If you have any questions, please contact me at (301) 415-6197 or by e-mail at Tekia.Govan@nrc.gov.

Sincerely,

/RA/

Tekia V. Govan, Project Manager
Office of Nuclear Reactor Regulation
Japan Lessons-Learned Division
Hazards Management Branch

Docket Nos. 50-272 and 50-311

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Audit Report

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OFFICE	NRR/JLD/JHMB/PM	NRR/JLD/JHMB/LA	NRO/DSEA/RHM1/TR	NRO/DSEA/RHM1/TR
NAME	TGovan	SLent	MLee*	MBensi*
DATE	01/05/2016	12/31/2015	12/22/2015	12/22/2015
OFFICE	NRO/DSEA/RHM1/BC	NRR/JLD/JHMB/BC	NRR/JLD/JHMB/PM	
NAME	CCook*	MShams (MMarshall for)	TGovan	
DATE	01/04/2016	01/04/2016	01/08/2016	

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