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

October 7, 2019

Mr. Daniel G. Stoddard
Senior Vice President and
Chief Nuclear Officer
Dominion Nuclear Connecticut, Inc.
Millstone Power Station
Innsbrook Technical Center
5000 Dominion Boulevard
Glen Allen, VA 29060

SUBJECT: MILLSTONE POWER STATION, UNITS 2 AND 3 - SUMMARY REPORT FOR THE AUDIT OF THE RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (EPID NOS. L-2015-JLD-0011 AND L-2015-JLD-0012)

Dear Mr. Stoddard:

The purpose of this letter is to provide the U.S. Nuclear Regulatory Commission's (NRC) audit summary report associated with the Millstone Power Station, Units 2 and 3 (Millstone) post-Fukushima reevaluated flood hazard. The regulatory audit provided insights to the staff's development of the Millstone flood hazard reevaluation report (FHRR) staff assessments that were issued on October 3, 2018, and October 7, 2019 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML18256A200 and ML19246A116, respectively). These staff assessments document the resolution of the issues associated with the staff's review of the FHRR including issues that were identified during the audit process.

By letter dated March 12, 2012 (ADAMS Accession No. ML12053A340), the NRC issued a request for information pursuant to Title 10 of the *Code of Federal Regulations*, Section 50.54(f) (hereafter referred to as the 50.54(f) letter). The request was issued as part of implementing lessons learned from the accident at the Fukushima Dai-ichi nuclear power plant. Enclosure 2 to the 50.54(f) letter requested that licensees reevaluate flood-causing mechanisms using present-day methodologies and guidance. By letter dated March 12, 2015 (ADAMS Accession No. ML15078A204), as supplemented by letter dated January 4, 2019 (ADAMS Accession No. ML19011A110), Dominion Nuclear Connecticut, Inc. (Dominion, the licensee) responded to this request for Millstone by providing the FHRR.

By letter dated June 15, 2015 (ADAMS Accession No. ML15153A077), the NRC notified Dominion of the staff's plan to perform a regulatory audit of Millstone's supporting calculations of the FHRR. The technical audit was performed consistent with NRC Office of Nuclear Reactor Regulation, Office Instruction LIC-111, "Regulatory Audits," dated December 29, 2008 (ADAMS Accession No. ML082900195). This audit summary report closes out the audit process associated with the Millstone FHRR review. Based on the issuance of the October 3, 2018, and October 7, 2019, FHRR staff assessments and the issuance of this audit summary report the NRC will close EPID Nos. L-2015-JLD -0011 and L-2015-JLD-0012.

If you have any questions, please contact me at (301) 415-1132 or by e-mail at Joseph.Sebrosky@nrc.gov.

Sincerely,

Joseph M. Sebrosky, Senior Project Manager
Beyond-Design-Basis Management Branch
Division of Licensing Projects
Office of Nuclear Reactor Regulation

Docket Nos. 50-336 and 50-423

Enclosure:
Audit Summary Report

cc w/encl: Distribution via Listserv

NUCLEAR REGULATORY COMMISSION AUDIT REPORT FOR THE AUDIT OF DOMINION NUCLEAR CONNECTICUT INC.'S FLOOD HAZARD REEVALUATION REPORT SUBMITTALS RELATING TO THE NEAR-TERM TASK FORCE RECOMMENDATION 2.1-FLOODING FOR MILLSTONE POWER STATION, UNITS 2 AND 3 (EPID NOS. L 2015 JLD-0011 AND L-2015-JLD-0012)

BACKGROUND AND AUDIT BASIS

By letter dated March 12, 2012 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12053A340), 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 hazards 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 12, 2015 (ADAMS Accession No. ML15078A204), as supplemented by letter dated January 4, 2019 (ADAMS Accession No. ML19011A110), Dominion Nuclear Connecticut, Inc. (Dominion, the licensee) responded to this request for Millstone Power Station, Units 2 and 3 (Millstone) by providing the flood hazard reevaluation report (FHRR). By letter dated June 15, 2015 (ADAMS Accession No. ML15153A077), the NRC notified Dominion of the staff's plan to perform a regulatory audit of Millstone's supporting calculations of the FHRR. The regulatory audit provided insights to the staff's development of the Millstone FHRR staff assessments that were issued on October 3, 2018, and October 7, 2019 (ADAMS Accession Nos. ML18256A200 and ML19246A116, respectively).

This audit summary was 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 staff notes that on December 21, 2016 (ADAMS Accession No. ML16308A226), the NRC staff sent the licensee a summary of the staff's review of Millstone reevaluated flood-causing mechanisms. This letter did not include the staff's conclusions associated with the storm surge flood-causing mechanism and stated that the staff's evaluation of the storm surge analysis was ongoing. The October 3, 2018, letter provided the staff's assessment of flood mechanisms, other than storm surge, that supported the staff's conclusions summarized in the December 21, 2016, letter.

As noted in the October 3, 2018, FHRR staff assessment for flood mechanisms other than storm surge, the staff used the audit process for other flood hazard mechanisms including the staff's review of the licensee's site-specific probable maximum precipitation flood hazard analysis. The audit process for hazards other than storm surge included the licensee making calculation packages available to the NRC staff via an electronic reading room. The calculation packages were used to expand upon and clarity the information provided on the docket.

Because the October 3, 2018, FHRR staff assessment documents the staff's review of flood mechanisms other than storm surge and describes the audit process used for these mechanisms an audit report for these mechanisms is not necessary. The audit dates and issues discussed in the audit summary are associated with the staff's review of the storm surge flood mechanism. The audit was completed by document review in conjunction with the use of the licensee's established electronic reading room and interactions with the licensee on March 2 and 3, 2017, July 20, 2017, October 26, 2017, January 25, 2018, April 4, 2018, and June 26, 2018. Table 1 provides a list of the participants for the various audit interactions.

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

Table 2 summarizes specific technical topics (and resolution) of important items that were discussed and clarified during the audit.

EXIT MEETING/BRIEFING

The Millstone FHRR staff assessments were issued on October 3, 2018, and October 7, 2019 (ADAMS Accession Nos. ML18256A200 and ML19246A116, respectively). These staff assessments document the resolution of the issues associated with the staff's review of the FHRR including issues that were identified during the audit process.

There are no outstanding information needs remaining as a result of this audit.

Table 1 – Audit Attendees

Audit Date	Name	Organization
March 2 and 3, 2017	Michelle Bensi	NRC/NRO/DLSE
	Chris Cook	NRC/NRO/DLSE
	Steve Breithaupt	NRC/NRO/DLSE
	Brad Harvey	NRC/NRO/DLSE
	Laura Quinn-Willingham	NRC/NRO/DLSE
	Mike Lee	NRC/NRO/DLSE
	Lyle Hibler	NRC/NRO/DLSE
	Kevin Quinlan	NRC/NRO/DLSE
	Thomas Weaver	NRC/RES
	Patrick Fitzpatrick	WorldWinds, Inc. (NRC Contractor)
	Chris Bender	Taylor Engineering (NRC Contractor)
	Lauren Gibson	NRC/NRR/JLD
	James Kasper	Dominion Energy
	Paul Young	Dominion Energy
	Daniel Cabonor	Dominion Energy
	Paul Phelps	Dominion Energy
	Wanda Craft	Dominion Energy
	Daniel Stapelton	GZA
	Michael Mobile	GZA
	Bin Wang	GZA
	Lee Branscome	CCC
	Douglas Stewart	CCC
	Michael Kerst	Zachry
	Stephen Superson	Zachry
July 20, 2017	Michelle Bensi	NRC/NRO/DSEA/RHM1
	Christopher Cook	NRC/NRO/DSEA/RHM1
	Frankie Vega	NRC/NRR/JLD
	Nathan Sanfilippo	NRC/NRR/JLD
	Thomas Weaver	NRC/RES/DE/SGSEB
	Wanda Craft	Dominion Energy
	Paul Young	Dominion Energy

Audit Date	Name	Organization
	Michael Moore	GZA
	Bin Wang	GZA
	David Leone	GZA
	Mike Kerst	Zachry
	Stephen Superson	Zachry
October 26, 2017	Stephanie Devlin-Gill	NRC/NRO/DSEA/RHM
	Nilesh Chokshi	NRC/NRO/DSEA
	Christopher Cook	NRC/NRO/DSEA
	Cliff Munson	NRC/NRO/DSEA
	Hosung Ahn	NRC/NRO/DSEA
	Dan Barnhurst	NRC/NRO/DSEA
	Joseph Kanney	NRC/RES/DRA
	Thomas Weaver	NRC/RES/DRA
	Meredith Carr	NRC/RES/DRA
	Wanda Craft, et. al,	Dominion Energy
January 25, 2018	Dan Barnhurst	NRC/NRO/DSEA/RHM
	Stephanie Devlin-Gill	NRC/NRO/DSEA
	Hosung Ahn	NRC/NRO/DSEA
	Cliff Munson	NRC/NRO/DSEA
	Joseph Kanney	NRC/RES
	Frankie Vega	NRR/DLP/PBMB
	Mo Shams	NRR/DLP/PBMB
	Brandford Stanley	Dominion Energy
	Cathie Tiernan	Dominion Energy
	Mayo Oppenhimer	Dominion Energy
	Wanda Craft	Dominion Energy
	James Kasper	Dominion Energy
	William Webster	Dominion Energy
	Michael Moble	GZA
	Dan Stapleton	GZA
	Mike Kerst	Zachry
	Stephen Superson	Zachry

Audit Date	Name	Organization
April 4, 2018	Stephanie Devlin-Gill	NRC/NRO/DSEA/RHM
	Dan Barnhurst	NRC/NRO/DSEA/RHM
	Cliff Munson	NRC/NRO/DSEA
	Hosung Ahn	NRC/NRO/DSEA/RHM
	Thomas Weaver	NRC/RES/SGSEB
	Joseph Kanney	NRC/RES/DRA/FXHAB
	Frankie Vega	NRC/NRR/DLP/PBMB
	Wanda Craft	Dominion Energy
	Craig Sly	Dominion Energy
	Cathie Tiernan	Dominion Energy
	Mike Kerst	Zachary
	Stephen Superson	Zachary
	David Leone	GZA
	Bin Wang	GZA
	Dan Stapleton	GZA
June 26, 2018	Dan Barnhurst	NRC/NRO/DSEA/RHM
	Stephanie Devlin-Gill	NRC/NRO/DLSE
	Hosung Ahn	NRC/NRO/DLSE
	Christopher Cook	NRC/NRO/DLSE
	Joseph Kanney	NRC/RES/DRA/FXHAB
	Meredith Carr	NRC/RES/DRA/FXHAB
	Thomas Weaver	NRC/RES/DE/SGSEB
	Brett Titus	NRC/NRR/DLP/PBMB
	Wanda Craft	Dominion Energy
	Craig Sly	Dominion Energy
	Cathie Tiernan	Dominion Energy
	Bin Wang	Dominion Energy
	Stephen Superson	Zachry
	Mark Pollin	Zachry
	Dan Stapleton	GZA
	David Leone	GZA

Table 2: Millstone Power Station, Units 1 and 2 Information Needs and Responses

Information Need No.	Information Need Description	Licensee Response	NRC Response
1	**Overview of Evaluation** The licensee is requested to prepare an overview presentation describing the probabilistic evaluation of storm surge, including components that were leveraged from the statistical analysis initially used to support the deterministic assessment. As part of the presentation, the licensee is requested to: 1. Provide mathematical expressions associated with key components of the evaluation, including the JPM integral showing the explicit components utilized in the site-specific assessment (e.g., provide an expanded expression showing product of conditional probabilities used to represent the joint distribution of storm parameters and the mathematical expression showing the inclusion of the error term). 2. Clarify terminology utilized in Zachry Calculation No. 14-161 (e.g., Section 6.2.3 appears to use AEP ("annual exceedance probabilities" for quantities that appear to be probability masses or frequencies of occurrence of specific parameter combinations). The information needs that follow (i.e., information needs 2 through 10) are intended to support the licensee in developing the requested overview presentation by focusing on areas initially identified by staff as requiring clarification or for which additional details or discussions are judged to be beneficial to staff's understanding of the licensee's evaluation.	During the 02 March 2017 audit, the licensee provided a description of the JPM integral used for their PSSA analysis. Staff also notes that the licensee's formulation of the JPM is similar to Equation (2) in Toro, et al, (2010). Staff noted that the equation provided in the licensee's presentation during the first day (02 March 2017) was missing terms related to conditional probabilities and the distribution of errors, though staff also notes the error term is included in the second day's presentation (02 March 2017). The presentation also notes the probabilities are conditional, though formation does not explicitly include them. The licenses continuous and discrete forms of the JPM are as follows: $$P[\eta_{\max(1\,yr)} > \eta] = \lambda \int \dots \int_x f_x(\underline{x}) P[\eta_m(\underline{x}) + \varepsilon > \eta]\, d\underline{x} \approx \approx \sum_{i=1}^{n} \lambda_i P[\eta_m(\underline{x}_i) + \varepsilon > \eta]$$ with $$\underline{x}_i = (V_{max,i}, R_{max,i}, V_{f,i}, \theta_i, Landfall_i)$$ λ = annual omni-directional storm frequency of the area of interest; η = surge elevation of interest; η_m = modeled surge elevation; $P[\eta_m(\underline{x}_i)]$ = cumulative flood probability presented by flood –frequency curve; ε = error and uncertainty related to additional flood elevation; i = JPM storm index; n = total number of JPM storms; $V_{max,i}$ = maximum wind speed of i-th JPM storm; $R_{max,i}$ = maximum radius of the the i-th JPM storm; $V_{f,i}$ = forward speed of the i-th JPM storm; θ_i = compass heading of the i-th JPM storm; $Landfall_i$ = landfall location of the i-th JPM storm. The licensee indicated in the audit information that there were two versions of the function of $\eta_{max}(x)$: one that used central pressure deficit as the storm intensity parameter and another that used maximum wind speed as the storm intensity parameter. The licensee's method for estimating the surge response was an optimal sampling scheme (JPM-OS), which is used to increase the computational efficiency of the estimation of surge height for the numerous storm parameter combinations. The licensee's JPM-OS is based Equations (3), (4), and (5) in Toro, et al (2010), which calls the method the response surface JPM-OS scheme (JPM-OS-RS). The RS scheme estimates a change in surge response as the linear combination of incremental variations of surge response to each storm parameter (i.e., the slope of the surge elevation to parameter line) times the change/difference in the parameter with respect to a parameter reference value. The surge-response changes for each parameter are added to the surge of the reference set to provide an	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110), 2) information provided to staff via an Electronic Reading Room (ERR), 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
		estimate of the surge for the set of storm parameters. The licensee provides the following equation of the change in response to change in forward speed: The licensee provides an example equation of the variation in surge with respect to forward speed at a particular location $$\phi_{kmn}(V_{max}, R_{max}, \theta, V_f, LF) = \phi_{km_0n}(V_{max}, R_{max}, \theta, V_{f0}, LF) + \psi_{kmn}$$ with $$\psi_{kmn} = \frac{\partial \phi_{kmn}(V_{max}, R_{max}, \theta, V_f, LF)}{\partial V_f}(V_f - V_{f0})$$ ϕ_{kmn} = surge response function with k, m, m indicating the specific landfall location, the forward speed, and track angle and V_{f0} = reference value for forward speed.	

2	**<u>Storm Rate</u>**
	
	<u>Background:</u> Calculation No. 14-161 identifies the annual storm frequency for the study area as 0.20371 storms per year, which is then used to compute an omni-directional rate by dividing by the approximate length of coastline over which the annual frequency was evaluated (216nm).
	
	Calculation No. 14-034, Attachment F provides the following computed values:
	
	- Annual frequency for the inner region (IR)=0.257775
	- Annual frequency for the offshore IR (OIR) =0.20371
	
	Calculation No. 14-034, Section 6.3.1.1 identifies that an "annual frequency factor" of 0.549 was "calculated by dividing the number of HURDAT2 storm tracks intersecting the IR (i.e., 89 storms) by the period of record (i.e., 162 years) associated with the dataset."
		According to the information provided by the licensee, the storm rate of the Offshore Inner Region (OIR) was 0.20371 storms per year over the 400-km diameter capture zone. This value was developed for the P-PMSS calculation. The calculation consists of computing the arithmetic mean of an adjusted annual frequency computed in a program named "filter-WRT.f." The adjustment to the number of storms is made by use of a OIR spatial filter that scales the annual frequency value by the count of OIR to IR storms.
		
		The capture zone (OIR) is centered on the Atlantic Coast of eastern Long Island. Only storms with wind speeds exceeding 40 knots are included in the estimation of storm rate. Within the capture zone, 7,957 storms from the WRT data are included, while for HURDAT2 data there are 50 storms within the capture zone.
		
		Comparison of the storm rates between WRT and HURDAT2 data are made for maximum velocities greater than 40 knots (with one exception):
		
		• For WRT data
		  ○ Within the IR = 0.2578 storms/year (= 0.00064 storms/yr/km in 400-km wide capture zone)
		  ○ Within the OIR = 0.2037 storms/year (= 0.00051 storms/yr/km) (used of P-PMSS analyses)
		• For HURDAT2 data
		  ○ Within the IR = 0.5494 storms/year (= 89 storms in 162 years) with maximum velocities greater than 0 knots (= 0.00137 storms/yr/km)
			This information need was closed based on the following:
			
			1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110),
			
			2) information provided to staff via an ERR,
			
			3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
	Request: The licensee is requested to: 1. Describe the process used to compute the annual storm frequency for the IR and the OIR using the WRT (synthetic) data set. 2. Describe the consistency between the annual storm frequency computed using the WRT (synthetic) data set and the HURDAT2 dataset. 3. Discuss the variation in the computed annual frequency computed using the WRT with time and length of synthetic record (see Calculation No. 14-034, Figure 38). 4. Discuss the effect of the underlying data generating process for the WRT data set on the computed annual storm frequency.	○ Within the OIR = 0.308 storms/year (=50 storms in 162 years) (= 0.00077 storms/yr/km) The licensee conveyed information from Dr. Kerry Emanuel who supplied the WRT data. • Seeding rates empirically determined to produce a specific number storms per year within a given basin • Seeding fixed for all time in a given reanalysis • Simulation forward in downscaled environment • Ratio of storm intersecting the IR to total generated storms results in variable annual frequency	
3	**Storm Parameter Discretization** Background: Flood hazard reevaluation report (FHRR) Section 2.4.1.3 and Calculation No. 14-161, Section 6.2.1 describe the following hurricane parameter discretization: • fdir: 11 bearing values spanning -50° to 50° in 10° intervals • fspd: 8 values spanning 15 to 50 kt discretized in 5 kt intervals • RMW: 9 values spanning 15 to 55 nm discretized in 5 nm intervals • Vm: 8 values spanning range of 70 to 140 kt discretized in 10 kt intervals • Landfall locations: 5 locations spanning the distance between NWS 23 Mile Posts 2550 and 2650 in 25nm intervals Request: The licensee is requested to: 1. Describe the basis for the chosen parameter (i.e., fdir, fspd, RMW, Vm) discretization and discuss any associated sensitivity studies. 2. Describe (a) the basis for the selection of the discrete landfall locations, (b) the variation of surge	The licensee setup an ERR which provided the staff with additional information.	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110). 2) information provided to staff via an ERR, 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
	with landfall location, and (c) any sensitivity studies performed to show whether further refinement of track spacing will substantially affect results. 3. Describe the basis for parameter ranges selected. 4. Clarify whether the definition of synthetic RMW observations in the synthetic (WRT) database is consistent with the definition of Rmax conventionally used in the JPM integration and in numerical models and discuss whether observed historical Rmax values are consistent with the RMW parameter range considered. 5. Clarify how the values of forward speed less than 15kt were utilized in the analysis and how they were used to support the interpolation and extrapolation to lower forward speeds.		
4	**Statistical Analysis of HURDAT and WRT Datasets** Background: Calculation No. 14-034 describes the statistical analysis of historical data (Section 6.3.1) and statistical analysis and verification of synthetic data (Section 6.3.2). The descriptions include analysis of geographic filter regions, development of univariate distributions using a non-parametric kernel-based method, extreme value analysis, analysis of hurricane parameter co-variability, analysis of autocorrelation, and comparison of distributions developed based on the historical and synthetic dataset. Calculation No. 14-034, Section 6.3.3.4 also describes used of a tree-structured approach and development of the "3M dataset." Request: The licensee is requested to clarify: 1. The relationship between (a) the analyses described in Calculation No. 14-034, Sections 6.3.1 and 6.3.2 (including development of univariate distributions using a non-parametric kernel based method, extreme value analysis, analysis of hurricane parameter co-variability, and analysis of autocorrelation) and (b) the "tree-structured" calculation procedure and development of the 3M dataset.	The licensee setup an ERR which provided the staff with additional information.	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110), 2) information provided to staff via an ERR, 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
	2. How the items discussed in item (1) relate to the joint probabilities developed to support the probabilistic assessment of the storm surge hazard. 3. Discuss the consistency between the historical data and the synthetic data, particularly with respect to parameter Vm (see Calculation No. 14-034, Figure 36). Note: Information requests related specifically to the "tree-structured approach" are provided in **Error! Reference source not found.** and information requests related to the "3M dataset" are provided in **Error! Reference source not found.**.		
5	<u>**Synthetic Hurricane Parameter Co-variability**</u> <u>Background:</u> Calculation No. 14-034, Sections 6.3.1.3 and 6.3.3.4 describe a co-variability analysis for the HURDAT2 and WRT datasets, respectively. In addition, Section 6.3.3.4 describes a "tree-structured conditional probability calculation procedure" that was used to develop conditional distributions of hurricane parameters. <u>Request:</u> The licensee is requested to: 1. Provide an overview of the tree-structured approach with emphasis on mathematical representations (e.g., mathematical expressions for derived conditional distributions). 2. Discuss the data filtering or sub-dividing procedure at each "layer" of the tree-structured approach and provide samples sizes associated with each sub-divided data set. 3. Discuss the basis for the discretization of the parameter space (e.g., bin sizes, bin numbers) and any sensitivity studies performed. 4. Discuss the approach used to estimate and validate distributions developed using the tree-structured approach.	The licensee developed a tree of the storm parameter combinations from the WRT data. The tree provides a means of estimating the parameter co-variability. For the four parameters considered (maximum wind speed = 1, forward speed = 2, forward direction = 3, and radius of maximum winds= 4), 24 different permutations of the parameter ordering are possible (1234, 1243, 1324, ..., 4312, 4321). The method first reads the WRT data for the four parameters into separate arrays. Then the method loops through the 24 different permutations. For the parameter in the first position/generation, a PDF and CDF are generated from the all the WRT data for the first generation parameter and five partitions are made (the tercile bounds) with all the WRT data for the first-generation parameter. For the parameter in the second position/generation and using only the WRT data from one of the partitions of the first-generation parameter, a PDF and CDF are generated for the second-generation parameter, and five further partitions are made. This process continues recursively for the third- and fourth-generation parameters. The output of this recursive method are PDFs and CDFs conditioned on the previous generation's parameters. This produces 3,744 distributions ((1+5+25+125)*24 = 3,744). The sizes (number of WRT parameter combinations) of the distributions decreases with the level of conditioning: • p1 (first generation, unconditional), n = 23,993 • p2 (second generation, conditioned on p1 quintile), n = 4,798 • p3 (third generation, conditioned on p1 and p2 quintiles), n = 959 • p4 (fourth generation, conditioned on p1, p2, and p3 quintiles), n = 191 To generate the 3M data set, the outer loop of the method is run 3,000,000 times. One of the 24 permutations of parameters is sampled, and the distributions for each parameter are sampled. The first-generation, unconditioned CDF is sampled and the quintile identified. For that quintile,	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110), 2) information provided to staff via an ERR, 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
	5. Describe how the procedure was used to develop the "3M dataset." Note: Information requests specifically related to the 3M dataset are provided in **Error! Reference source not found.**.	the second-generation, conditional CDF is sampled, and the quintile identified. This is repeated for the third- and fourth-generation parameters of the permutation. The output for each run through the loop is the sampled parameter values for that permutation set.	
6	**<u>Development of "3M Data Set"</u>** **Background:** Calculation No. 14-034 identifies an "extension to the WRT storm set" that is called the "3,000,000 (3M) data set" and that was used to "characterize non-linear co-variability." Calculation No. 14-034, Section 3.3.3.3 identifies a "tree-structured" method of developing conditional probability density functions (PDFs) for the following four parameters from the WRT storm set: • storm bearing (i.e., translational direction, fdir) • forward speed (fspd) • radius of maximum winds (RMW) • maximum (i.e., 1-minute average at an altitude of 10 meters) wind speed (Vm) Calculation No. 14-034, Section 3.3.3.3 further states that a "randomized sampling process was applied to generate synthetic vectors based on the conditional distributions." Calculation No. 14-161 states the following with respect to development of joint probabilities used in the probabilistic storm surge assessment: *"Joint probabilities were calculated for each synthetic storm in a manner that recovered parameter co-variability, as reflected within the 3M data set, which was used as input to this calculation… The joint probability for STORMID = i, or CPr(STORMID=i), was calculated by querying the 3M data set. The number of parameter combinations within the 3M data set matching (i.e., as defined by upper and lower bounds defined by the tabulated PDF results) the parameter specifications (i.e.,*	See IN 5.	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110), 2) information provided to staff via an ERR, 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
	Fdir, Fspd, RMW and Vm) associated with a given JPM Storm Set combination was counted. The resulting count was then divided by the total number of parameter combinations within the 3M data set (i.e., 3,000,000) to calculate the joint probability. Based on this calculation process, parameter combinations for which no matches existed within the 3M dataset were assigned CPr values of 0 (i.e., less than 1 in 3,000,000 or approximately 3.33e-7)" Request: The licensee is requested to clarify: 1. The process used to develop the 3M dataset. 2. How the 3M dataset was used to compute the joint probability of storm parameter combinations. The licensee is further requested to identify relevant supporting calculation tools (e.g., Excel Spreadsheets or FORTRAN scripts) and provide a "walk-through" of those tools.		
7	**Use of JPM-OS** Background: Calculation No. 14-161, Section 6.2.6 describes the identification of the JPM-OS storm set. Request: The licensee is requested to discuss: 1. The process used to identify the JPM-OS set (Step 6), including the basis for parameter combinations selected for the reference set and sensitivity tests. 2. The development and application of the parameter-specific slope terms. 3. The validation of the OS-set, including validation of extrapolated values. The licensee is also requested to provide the above information in conjunction with a "walkthrough" of Attachment G of Calculation No. 14-161 (spreadsheet JPM_JPM-OS_Calculation_10-8-14.xlsx).	Since the time when the information presented in the 02 March 2017 audit meeting, the licensee has modified the approach used in the stillwater storm surge analysis. Formerly, the approach relied on the synthetic data provided by WRT from which a 3M data set was developed for use to compute the probabilities of storm parameter combinations. Currently, the licensee has relegated that analysis to a branch (or a few branches) of the logic tree. Most other branches rely on data from NACCS (USACE, 2015) from which the licensee draws the JPM-OS set. Consequently, it is only for the few WRT-based branches that the licensee identified the JPM-OS set. For Item 1, the licensee used the SLOSH model to simulate a many storms with a range of parameters since it is computationally efficient, but the results are not as accurate as those from ADCIRC, which is not computationally efficient. From the SLOSH simulation, evaluated the surge sensitivity to heading (-50 deg to +50 deg) and five land fall locations. Selected the parameter combination of Vmax = 100 kt; Vf = 25 kt; and Rmax = 35 nm to provide low-probability surge elevations. Using 11 headings and five landfall locations and the low-probability storm parameter combination, 55 simulations are available for the JPM-OS. An additional 16 test storms were selected from which to compute slopes (Item 2). In addition to the SLOSH model runs, ADCIRC was run for these 71 simulations. For Item 2, the equations for the JPM-OS-RS are discussed in Information Need No. 3 of this audit report including development of the slope terms.	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110). 2) information provided to staff via an Electronic Reading Room (ERR). 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
		For Item 3, the licensee compared the complete JPM surge-frequency curve generated from 26,970 SLOSH simulations and compared with surge estimates (OS) using the slope terms calculated from the SLOSH results. The results were found to be comparable: e.g., at 1E-04 event probability the complete-set elevation is approximately 13 ft NAVD88, while the OS-set elevation is only slightly higher (<1 ft difference).	
8	**Extrapolation in OS set** Background: Calculation package 14-161, Attachment G, sheet 'OS_Model_Results' provides surge elevations computed using ADCIRC for a selected number of parameter combinations referred to as the reference set and the sensitivity set. The computed surge elevations (as computed by ADCIRC) in the reference set range from a minimum of 3.7 ft to a maximum of 12.3ft NAVD8. The sensitivity set spans a range of 3.8ft to 15.9ft. Calculation No. 14-161, Attachment G, sheet 'ADCIRC_OS_Complete_Set' shows interpolated and extrapolated values of surge elevations based on the reference set. The reported stillwater elevation associated with an annual exceedance probability of 1E-6 is 19.7 ft NAVD88 (this value includes the contribution of an uncertainty term and sea-level rise). Request: The licensee is requested to: 1. Discuss the validation of the OS approach for estimation of surge elevations for parameter combinations associated with surge elevations in excess of 12.3ft NAVD88 (i.e., the maximum surge elevation included in the reference set). 2. Given the magnitude of surge elevations of relevance to estimation of the stillwater elevation associated with an annual exceedance probability of 1E-6, discuss the effects of extrapolations on the final estimate of the 1E-6 surge elevation. 3. Provide a comparison of the surge heights computed using ADCIRC in conjunction with the deterministic evaluation (see Calculation No. 14-162, Section 7.1) with the surge heights computed for similar parameter combinations using the	The licensee setup an ERR which provided the staff with additional information.	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110), 2) information provided to staff via an Electronic Reading Room (ERR), 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
	extrapolation procedure associated with development of the ADCIRC OS (see Attachment G of Calculation No. 14-161, sheet 'ADCIRC_OS_Complete_Set').		
9	**Treatment of Uncertainty** Background: Calculation No. 14-161, Section 6.4.1 describes the adjustments made for uncertainty, error, and sea level rise. The standard deviation of the error term includes contributions from tidal variability, numerical surge and wind field models, sampling uncertainty, and error within the "3M dataset." Request: The licensee is requested to: 1. Discuss the basis for the values assigned to each error component. 2. Describe whether the magnitude of the numerical model error term is similar to previously performed studies regarding the accuracy of ADCIRC (e.g., existing FEMA studies and available literature). 3. Provide mathematical details regarding the approach used to incorporate error into the JPM integration.	The licensee estimates uncertainty as the standard deviation computed from the uncertainty of four different components of the storm surge analysis. This takes the form $\sigma = \sqrt{a^2 + (b\eta)^2}$ in which $a = \sqrt{\varepsilon_1^2 + \varepsilon_2^2}$ $b = F(\varepsilon_3, \varepsilon_4)$ ε_1= uncertainty due to coincidence of tide with maximum storm surge ε_2 = uncertainty due to the numerical surge model (i.e., ADCIRC model results) ε_3 = uncertainty due to sample (aleatory variability associated with maximum wind speed) ε_4 = error within the 3M data set with respect to the WRT data associated with maximum wind speed > 96 knots. The 'a' term represents a constant value while the 'b' term represents the surge-varying component of uncertainty. The licensee estimates the uncertainty due to tides (ε_1) to be 1.16 ft, derived from the tidal difference of 1.57 ft between MHW and MSL at the Newport, RI tide gage (NOAA Station 8452660) multiplied by a factor of 0.74 to account for attenuation from the Newport gage to the Watch Hill Point, RI tide station (NOAA Station 8458694) near the Millstone site. The licensee estimates the uncertainty due to model error (ε_2) to be 2 times the ADCIRC model error of 0.39 ft for Storm Sandy (2012), i.e., 0.78 ft. The licensee's estimates for ε_3 and ε_4 are based on resampling of the 3M data. For ε_3, the licensee developed a relation of the difference of the maximum wind speed at 95% CL as a function of mean maximum wind speed. For ε_4, the licensee examined difference in intensity (maximum wind speed) between the WRT and 3M data. Together, ε_3 and ε_4 were considered the aleatory variability and error (maximum wind speed) of the surge response as a function of surge elevation. The relation was fitted to a linear function with a mean of zero that had a slope of 0.28.	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No. ML19011A110), 2) information provided to staff via an Electronic Reading Room (ERR), 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No. ML19246A116).

Information Need No.	Information Need Description	Licensee Response	NRC Response
		From these analyses, the licensee estimated the 'a' term to be 1.40 ft and the 'b' term to be 0.28 ft/ft.	
10	**Treatment of Baroclinic Energy Sources in Development of WRT Data Set** Background: Calculation No. 14-034, Section 6.3.2.1 provides a summary description of the synthetic hurricane data. Information requested: The licensee is requested to summarize (a) key assumptions associated with the data generating process used to develop the WRT data and (b) any limitations of the data generating process (e.g., how the process treats coastal effects on storms and the contribution of baroclinic energy sources).	The licensee setup an ERR which provided the staff with additional information.	This information need was closed based on the following: 1) information provided in the licensee's supplemental FHRR dated January 4, 2019 (ADAMS Accession No ML19011A110), 2) information provided to staff via an Electronic Reading Room (ERR), 3) the NRC staff's independent analysis as documented in the Attachment to the NRC Supplemental Staff Assessment dated October 7, 2019 (ADAMS Accession No ML19246A116).

Table 2 References

Toro, GR, Resio, DT, Divoky, D, Niedoroda, AW, and Reed, C., 2010. "Efficient joint probability methods for hurricane surge frequency analysis," Ocean Engineering: 37 (125-134).

USACE, 2015, "North Atlantic Coast Comprehensive Study (NACCSO Coastal Storm Model Simulations: Waves and Water Levels," Cialone, M. A., Massey, T. C., Anderson, M. E., Grzegorzewski, A. S., Jensen, R. E., Cialone, A., Mark, D. J., Pevey, K. C., Gunkel, B. L., McAlpin, T. O., 2015, Vicksburg, Mississippi: U.S. Army Engineer Research and Development Center, Technical Report ERDC/CHL TR-15-14

Zachry Calculation No. 14-034, Revision 0, Probable Maximum Hurricane for Millstone Power Station, GZA GeoEnvironmental, Inc., 2014.

Zachry Calculation No. 14-161, Revision 0, Probabilistic Storm Surge for Millstone Power Station, GZA GeoEnvironmental, Inc., 2015.

SUBJECT: MILLSTONE POWER STATION, UNITS 2 AND 3 - SUMMARY REPORT FOR THE AUDIT OF THE RESPONSE TO 10 CFR 50.54(f) INFORMATION REQUEST – FLOOD-CAUSING MECHANISM REEVALUATION (EPID NOS. L-2015-JLD-0011 AND L-2015-JLD-0012) DATED October 7, 2019

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