



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

February 17, 2016

Mr. Bryan C. Hanson  
Senior Vice President  
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President and Chief Nuclear Officer  
Exelon Nuclear  
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Warrenville, IL 605

**SUBJECT: BYRON STATION, UNITS 1 AND 2 - STAFF ASSESSMENT OF INFORMATION PROVIDED PURSUANT TO TITLE 10 OF THE *CODE OF FEDERAL REGULATIONS* PART 50, SECTION 50.54(f), SEISMIC HAZARD REEVALUATIONS FOR RECOMMENDATION 2.1 OF THE NEAR-TERM TASK FORCE REVIEW OF INSIGHTS FROM THE FUKUSHIMA DAI-ICHI ACCIDENT (CAC NOS. MF3884 AND MF3885)**

Dear Mr. Hanson:

On March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information pursuant to Title 10 of the *Code of Federal Regulations*, Part 50, Section 50.54(f) (hereafter referred to as the 50.54(f) letter). The purpose of that request was to gather information concerning, in part, seismic hazards at each operating reactor site and to enable the NRC staff, using present-day NRC requirements and guidance, to determine whether licenses should be modified, suspended, or revoked.

By letter dated March 31, 2014, Exelon Generation Company, LLC (Exelon, the licensee), responded to this request for Byron Station, Units 1 and 2 (Byron).

The NRC staff has reviewed the information provided related to the reevaluated seismic hazard for Byron and, as documented in the enclosed staff assessment, determined that you provided sufficient information in response to Enclosure 1, Items (1) – (3), (5) - (8) and the comparison portion of Item (4) of the 50.54(f) letter. Further, the NRC staff concludes that the licensee's reevaluated seismic hazard is suitable for other actions associated with Near-Term Task Force Recommendation 2.1, "Seismic".

As indicated in the NRC letter dated October 27, 2015 (ADAMS Accession No. ML15194A015), Exelon is requested to submit a spent fuel pool evaluation and either a full-scope Individual Plant Examination of External Events (IPEEE) relay chatter review or a High Frequency (HF) confirmation. In choosing one of the two options, Exelon should consider that a relay chatter study will continue to be needed for the IPEEE submittal to meet the Screening, Prioritization, and Implementation Details (SPID) acceptance criteria. Meeting the SPID criteria will be necessary if Exelon plans to rely on the IPEEE results in its mitigation strategies assessment with respect to the reevaluated hazard.

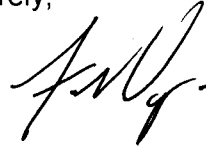
B. Hanson

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Contingent upon the NRC staff's review and acceptance of Exelon's HF confirmation (Item 4) or the full-scope IPEEE relay chatter review and spent fuel pool evaluation (Item 9)) for Byron, the Seismic Hazard Evaluation identified in Enclosure 1 of the 50.54(f) letter will be completed.

If you have any questions, please contact me at (301) 415-1617 or at [Frankie.Vega@nrc.gov](mailto:Frankie.Vega@nrc.gov).

Sincerely,



Frankie G. Vega, Project Manager  
Hazards Management Branch  
Japan Lessons-Learned Division  
Office of Nuclear Reactor Regulation

Docket Nos. 50-454 and 50-455

Enclosure:  
Staff Assessment of Seismic  
Hazard Evaluation and Screening Report

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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO SEISMIC HAZARD AND SCREENING REPORT

BYRON STATION, UNITS 1 AND 2

DOCKET NOS. 50-454 AND 50-455

1.0 INTRODUCTION

By letter dated March 12, 2012 (NRC, 2012a), the U.S. Nuclear Regulatory Commission (NRC or Commission) 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 and other regulatory actions were 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" (NRC, 2011b).<sup>1</sup> In particular, the NRC Near-Term Task Force (NTTF) Recommendation 2.1, and subsequent Staff Requirements Memoranda (SRM) associated with Commission Papers SECY-11-0124 (NRC, 2011c) and SECY-11-0137 (NRC, 2011d), instructed the NRC staff to issue requests for information to licensees pursuant to 10 CFR 50.54(f).

Enclosure 1 to the 50.54(f) letter requests that addressees perform a reevaluation of the seismic hazards at their sites using present-day NRC requirements and guidance to develop a ground motion response spectrum (GMRS).

The required response section of Enclosure 1 requests that each addressee provide the following information:

- (1) Site-specific hazard curves (common fractiles and mean) over a range of spectral frequencies and annual exceedance frequencies,
- (2) Site-specific, performance-based GMRS developed from the new site-specific seismic hazard curves at the control point elevation,
- (3) Safe Shutdown Earthquake (SSE) ground motion values including specification of the control point elevation,
- (4) Comparison of the GMRS and SSE. A high-frequency (HF) evaluation (if necessary),

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<sup>1</sup> Issued as an enclosure to Commission Paper SECY-11-0093 (NRC, 2011a).

- (5) Additional information such as insights from NTF Recommendation 2.3 walkdown and estimates of plant seismic capacity developed from previous risk assessments to inform NRC screening and prioritization,
- (6) Interim evaluation and actions taken or planned to address the higher seismic hazard relative to the design basis, as appropriate, prior to completion of the risk evaluation (if necessary),
- (7) Statement if a seismic risk evaluation is necessary,
- (8) Seismic risk evaluation (if necessary), and
- (9) Spent fuel pool (SFP) evaluation (if necessary).

Present-day NRC requirements and guidance with respect to characterizing seismic hazards use a probabilistic approach in order to develop a risk-informed performance-based GMRS for the site. Regulatory Guide (RG) 1.208, A Performance-based Approach to Define the Site-Specific Earthquake Ground Motion (NRC, 2007), describes this approach. As described in the 50.54(f) letter, if the reevaluated seismic hazard, as characterized by the GMRS, is not bounded by the current plant design-basis SSE, further seismic risk evaluation of the plant is merited.

By letter dated November 27, 2012 (Keithline, 2012), the Nuclear Energy Institute (NEI) submitted Electric Power Research Institute (EPRI) report "Seismic Evaluation Guidance: Screening, Prioritization, and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1 Seismic" (EPRI, 2012), hereafter called the SPID. The SPID supplements the 50.54(f) letter with guidance necessary to perform seismic reevaluations and report the results to NRC in a manner that will address the Requested Information Items in Enclosure 1 of the 50.54(f) letter. By letter dated February 15, 2013 (NRC, 2013b), the staff endorsed the SPID.

The required response section of Enclosure 1 to the 50.54(f) letter specifies that Central and Eastern United States (CEUS) licensees provide their Seismic Hazard and Screening Report (SHSR) by 1.5 years after issuance of the 50.54(f) letter. However, in order to complete its update of the EPRI seismic ground motion models (GMM) for the CEUS (EPRI, 2013), industry proposed a six-month extension to March 31, 2014, for submitting the SHSR. Industry also proposed that licensees perform an expedited assessment, referred to as the Augmented Approach, for addressing the requested interim evaluation (Item 6 above), which would use a simplified assessment to demonstrate that certain key pieces of plant equipment for core cooling and containment functions, given a loss of all alternating current power, would be able to withstand a seismic hazard up to two times the design basis. Attachment 2 to the April 9, 2013, letter (Pietrangelo, 2013) provides a revised schedule for plants needing to perform (1) the Augmented Approach by implementing the Expedited Seismic Evaluation Process and (2) a seismic risk evaluation. By letter dated May 7, 2013 (NRC, 2013a), the NRC determined that the modified schedule was acceptable and by letter dated August 28, 2013 (NRC, 2013c), the NRC determined that the updated GMM (EPRI, 2013) is an acceptable GMM for use by CEUS plants in developing a plant-specific GMRS.

By letter dated April 9, 2013 (Pietrangelo, 2013), industry agreed to follow the SPID to develop the SHSR for existing nuclear power plants. By letter dated September 12, 2013 (Kaegi, 2013), Exelon Generation Company, LLC (Exelon, the licensee) submitted at least partial site response information for Byron Station, Units 1 and 2 (Byron). By letter dated March 31, 2014 (Kaegi, 2014), the licensee submitted its SHSR.

## 2.0 REGULATORY BACKGROUND

The structures, systems, and components (SSCs) important to safety in operating nuclear power plants are designed either in accordance with, or meet the intent of Appendix A to 10 CFR Part 50, General Design Criteria (GDC) 2: "Design Bases for Protection Against Natural Phenomena;" and Appendix A to 10 CFR Part 100, "Reactor Site Criteria." The GDC 2 states that SSCs important to safety at nuclear power plants shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

For initial licensing, each licensee was required to develop and maintain design bases that, as defined by 10 CFR 50.2, identify the specific functions that an SSC of a facility must perform, and the specific values or ranges of values chosen for controlling parameters as reference bounds for the design. The design bases for the SSCs reflect appropriate consideration of the most severe natural phenomena that had been historically reported for the site and surrounding area. The design bases also considered limited accuracy, quantity, and period of time in which the historical data have been accumulated.

The seismic design bases for currently operating nuclear power plants were either developed in accordance with, or meet the intent of GDC 2 and 10 CFR Part 100, Appendix A. Although the regulatory requirements in Appendix A to 10 CFR Part 100 are fundamentally deterministic, the NRC process for determining the seismic design-basis ground motions for new reactor applications after January 10, 1997, as described in 10 CFR 100.23, requires that uncertainties be addressed through an appropriate analysis such as a probabilistic seismic hazard analysis (PSHA).

Section 50.54(f) of 10 CFR states that a licensee shall at any time before expiration of its license, upon request of the Commission, submit written statements, signed under oath or affirmation, to enable the Commission to determine whether or not the license should be modified, suspended, or revoked. On March 12, 2012, the NRC staff issued requests for licensees to reevaluate the seismic hazards at their sites using present-day NRC requirements and guidance, and identify actions planned to address plant-specific vulnerabilities associated with the updated seismic hazards.

Attachment 1 to Enclosure 1 of the 50.54(f) letter described an acceptable approach for performing the seismic hazard reevaluation for plants located in the CEUS. Licensees are expected to use the CEUS Seismic Source Characterization (CEUS-SSC) model in NUREG-2115 (NRC, 2012b) along with the appropriate EPRI (2004, 2006) GMMs. The SPID provided further guidance regarding the appropriate use of GMMs for the CEUS. Specifically, Section 2.3 of the SPID recommended the use of the updated GMM (EPRI, 2013) and, as such, licensees used the NRC-endorsed updated EPRI GMM instead of the older EPRI (2004, 2006) GMM to

develop PSHA base rock hazard curves. Finally, Attachment 1 requested that licensees conduct an evaluation of the local site response in order to develop site-specific hazard curves and GMRS for comparison with the plant SSE.

## 2.1 Screening Evaluation Results

By letter dated March 31, 2014 (Kaegi, 2014), the licensee provided the Byron SHSR. The licensee's SHSR indicates that the site GMRS exceeds the site SSE for a portion of the frequency range between 1 to 10 Hertz (Hz). However, the licensee indicated that over the frequency range of 1 to 10 Hz, the GMRS is bounded by either the site SSE or the site Individual Plant Examination of External Events (IPEEE) plant-level high confidence of low probability of failure (HCLPF) spectrum (IHS). In order to use the IHS as the plant capacity spectrum for screening, the licensee demonstrated the adequacy of its IPEEE program, as specified in Section 3.3 of the SPID. Above the frequency of 10 Hz, the IHS also bounds the licensee's site GMRS. However, because the full scope IPEEE detailed review of relay chatter required in SPID Section 3.3.1 has not been completed, the licensee stated that it will complete the relay chatter review consistent with the NEI letter to the NRC dated October 3, 2013 (Keithline, 2013). The licensee stated that it will complete the relay chatter review on the same schedule as the HF confirmation as proposed in the NEI letter dated April 9, 2013 (Pietrangelo, 2013), and accepted in NRC's letter dated May 7, 2013 (NRC, 2013a).

On May 9, 2014 (NRC, 2014a), the NRC staff issued a letter providing the outcome of its 30-day, preliminary, screening and prioritization evaluation. In the letter, the NRC staff characterized the Byron site as screened-out, because, consistent with the SPID, the licensee demonstrated the IPEEE plant capacity bounds the re-evaluated hazard. The licensee's GMRS, as well as the NRC staff's confirmatory GMRS, exceeds the SSE for Byron over a portion of the frequency range of 1 to 10 Hz. However, Byron demonstrated that the plant met the IPEEE screening program in the SPID, provided that a IPEEE relay chatter review is successfully completed, and either the SSE or IHS bounds the GMRS over the 1 to 10 Hz range. Therefore, Byron was screened out for conducting a seismic risk evaluation. This initial screening decision was contingent on the licensee's successful completion of the IPEEE relay chatter review, in accordance with the IPEEE program screening criteria in the SPID. As stated in the October 27, 2015 (NRC, 2015), letter, the NRC revised this initial screening determination. Based on the NRC staff's comparison of the GMRS to the SSE and the review of additional hazard and risk information, the NRC concluded that a seismic risk evaluation was not merited for Byron regardless of satisfying the IPEEE acceptance criteria in the SPID. Because the IPEEE program did not include an evaluation of the SFP and the GMRS exceeds the SSE above 7 Hz, the SFP evaluation is merited. Additionally, in the frequency range above 10 Hz, the GMRS exceeds the IHS. As such, and in accordance with the October 27, 2015, letter either a HF confirmation or a IPEEE relay chatter review are merited.

## 3.0 TECHNICAL EVALUATION

The NRC staff evaluated the licensee's submittal to determine if the provided information responded appropriately to Enclosure 1 of the 50.54(f) letter with respect to characterizing the reevaluated seismic hazard.

### 3.1 Plant Seismic Design-Basis

Enclosure 1 of the 50.54(f) letter requests the licensee provide the SSE ground motion values, as well as the specification of the control point elevation(s) for comparison to the GMRS. For operating reactors licensed before 1997, the SSE is the plant licensing basis earthquake and is characterized by (1) a peak ground acceleration (PGA) value which anchors the response spectra at high frequencies (typically between 20 to 30 Hz for the existing fleet of nuclear power plants); (2) a response spectrum shape which depicts the amplified response at all frequencies below the PGA; and (3) a control point where the SSE is defined.

In Section 3.1 of its SHSR, the licensee described its seismic design bases for the Byron site and stated that the SSE is defined in terms of a PGA and a design response spectrum. The licensee stated that the SSE for Byron is based on a postulated Intensity VIII earthquake occurring in the Eastern Central Stable Region. Based on this earthquake, the licensee defined the SSE with a RG1.60 response spectral shape anchored at a PGA of 0.20 g (20 percent of the acceleration due to earth's gravity). In Section 3.2 of its SHSR, the licensee specified that the SSE control point is defined at the bedrock-soil interface at elevation 869 ft. (265 m) mean sea level (msl).

The NRC staff reviewed the licensee's description of its SSE in the SHSR for the Byron site. With regard to the Byron site SSE, based on its review of the SHSR and Updated Final Safety Analysis Report (UFSAR) (Byron, 2012), the NRC staff confirmed that the licensee's SSE is a RG1.60 spectrum anchored at 0.2 g, as described by the licensee. Finally, based on its review of the SHSR and the UFSAR (Byron, 2012), the NRC staff confirmed that the licensee's control point elevation for the Byron site SSE is defined at elevation 869 ft. (265 m) MSL and is consistent with the guidance provided in the SPID.

### 3.2 Probabilistic Seismic Hazard Analysis

In Section 2.2 of its SHSR, the licensee stated that, in accordance with the 50.54(f) letter and the SPID, it performed a PSHA using the CEUS-SSC model and the updated EPRI GMM for the CEUS (EPRI, 2013). The licensee used a minimum magnitude (**M**) of 5.0, as specified in the 50.54(f) letter. The licensee further stated that it included the CEUS-SSC background sources out to a distance of 400 miles (640 km) around the site and included the Commerce, Eastern Rift Margin – North, Eastern Rift Margin – South, Marianna, New Madrid Fault System, and Wabash Valley repeated large magnitude earthquake (RLME) sources, which lie within 621 mi (1,000 km) of the site. The RLME sources are those source areas or faults for which more than one large magnitude (**M** ≥ 6.5) earthquake has occurred in the historical or paleo-earthquake (geologic evidence for prehistoric seismicity) record. The licensee used the mid-continent version of the updated EPRI GMM (EPRI, 2013) for each of the CEUS-SSC sources. Consistent with the SPID, the licensee did not provide its base rock seismic hazard curves in SHSR Section 2.2.2 since a site response analysis is necessary to determine the control point seismic hazard curves. The licensee provides its control point seismic hazard curves in Section 2.3.7 of its SHSR. The staff's review of the licensee's control point seismic hazard curves is provided in Section 3.3 of this staff assessment.

As part of its confirmatory analysis of the licensee's GMRS, the NRC staff performed its own PSHA calculations for base rock conditions at the Byron site. As input, the NRC staff used the CEUS-SSC model as documented in NUREG-2115 (NRC, 2012b) along with the updated EPRI GMM (EPRI, 2013). Consistent with the guidance provided in the SPID, the NRC staff included all CEUS-SSC background seismic sources within a 310 mi (500 km) radius of the Byron site. In addition, the NRC staff included RLME sources which lie within 621 mi (1,000 km) of the site. For each of the CEUS-SSC sources used in the PSHA, the NRC staff used the mid-continent version of the updated EPRI GMM (EPRI, 2013). The NRC staff used the resulting base rock seismic hazard curves together with a confirmatory site response analysis, described in the next section, to develop control point seismic hazard curves and a GMRS for comparison with the licensee's results.

Based on its review of the SHSR, the NRC staff concludes that the licensee appropriately followed guidance provided in the SPID for selecting PSHA input models and parameters for the site. This includes the licensee's use and implementation of the CEUS-SSC model and the updated EPRI GMM.

### 3.3 Site Response Evaluation

After completing PSHA calculations for reference rock site conditions, Attachment 1 to Enclosure 1 of the 50.54(f) letter requests that the licensee provide a GMRS developed from the site-specific seismic hazard curves at the control point elevation. In addition, the 50.54(f) letter specifies that the subsurface site response model, for both soil and rock sites, should extend to sufficient depth to reach the generic or reference rock conditions as defined in the GMMs used in the PSHA. To develop site-specific hazard curves at the control point elevation, Attachment 1 requests that the licensee perform a site response analysis.

Detailed site response analyses were not typically performed for many of the older operating plants; therefore, Appendix B of the SPID provides detailed guidance on the development of site-specific amplification factors (including the treatment of uncertainty) for sites that do not have detailed, measured soil and rock parameters to extensive depths.

The purpose of the site response analysis is to determine the site amplification that will occur as a result of base rock or bedrock ground motions propagating upwards through the soil/rock column to the surface. The critical parameters that determine what frequencies of ground motion are affected by the upward propagation of bedrock motions are the layering of soil and/or soft rock, the thicknesses of these layers, the shear-wave velocities and low-strain damping of the layers, and the degree to which the shear modulus and damping change with increasing input bedrock amplitude.

#### 3.3.1 Site Base Case Profiles

The licensee provides detailed site profile descriptions in Sections 2.3.1 and 2.3.2 of its SHSR based on information provided in the Byron Station UFSAR (Byron, 2012) and the guidance in Appendix B of the SPID. According to the licensee, the Byron site is located in north central Illinois within the Till Plains Section of the Central Lowlands Physiographic Province. The Central Lowlands is characterized by glacial deposits overlying Ordovician and Cambrian age



dolomites, sandstones, and shales. The licensee stated that the main plant power block structures are founded on bedrock of the Ordovician Dunleith Formation.

In Table 2.3.1-1 of its SHSR, the licensee provides a brief description of the subsurface materials in terms of the geologic units, layer thicknesses, and shear wave velocities. The Byron site investigations included refraction surveys and uphole and downhole seismic tests. The licensee also considered the shear-wave velocities determined for the nearby independent spent fuel storage installation.

The licensee developed three base case shear-wave velocity profiles for the Byron site. The best estimate profile was developed using the measured shear wave velocities and consists of 114 ft. (44 m) of firm rock overlying hard bedrock. To develop the upper and lower cases, the licensee used a scale factor of 1.25 in the upper 114 ft. (44 m) and a factor of 1.57 below that depth. Table 2.3.2-1 and Figure 2.3.2-1 of the SHSR provide the licensee's shear-wave velocity profile for each of the three base cases. Figure 3.3-1 of this assessment shows the licensee's three shear-wave velocity base case profiles.

In Section 2.3.2.1 of its SHSR, the licensee states that no site-specific dynamic material properties were available for the firm rock materials at the Byron site. Therefore, the licensee followed the SPID guidance by modeling both nonlinear and linear responses of the rock to a range of input loading levels. The licensee used the EPRI rock curves (model M1) to model the nonlinear behavior at the site and assumed a linear analyses (model M2) with a constant damping level of about three percent as an alternative model.

The licensee also considered the impact of kappa, or small strain damping, on site response. Kappa is measured in units of seconds (sec), and is the damping contributed by both intrinsic hysteretic damping as well as scattering due to wave propagation in heterogeneous material. For the Byron site, the licensee provided estimates of kappa in Table 2.3.2-2 of its SHSR. The licensee's total profile kappa values for the best estimate, upper, and lower base case velocity profiles are 0.008s, 0.008s, and 0.0023s, respectively.

To account for randomness in material properties across the plant site, the licensee stated in Section 2.3.3 of its SHSR that it randomized its base case shear-wave velocity profiles in accordance with Appendix B of the SPID. In addition, as stated in Section 2.3.2 of its SHSR, the licensee randomized the depth to bedrock by  $\pm 900$  ft. ( $\pm 274$  m), which corresponds to 30 percent of the total profile thickness. The licensee stated that this randomization did not represent the actual uncertainty in the depth to bedrock, but was used to provide a realistic broadening of the fundamental resonance at deep sites.

### 3.3.2 Site Response Method and Results

In Section 2.3.4 of its SHSR, the licensee stated that it followed the guidance in Appendix B of the SPID to develop input ground motions for the site response analysis and in Section 2.3.5 of the SHSR; the licensee described its implementation of the random vibration theory (RVT) approach to perform its site response calculations. Finally, Section 2.3.6 of the SHSR showed

the resulting amplification functions and associated uncertainties for the 11 input loading levels for the base case profile and EPRI rock shear modulus and damping curves.

In order to develop probabilistic site-specific control point hazard curves, as requested in Requested Information Item 1 of the 50.54(f) letter, the licensee used Method 3, described in Appendix B-6.0 of the SPID. The licensee's use of Method 3 involved computing the site-specific control point elevation hazard curves for a broad range of spectral accelerations by combining the site-specific bedrock hazard curves, determined from the initial PSHA (Section 3.2 of this assessment), and the amplification functions and their associated uncertainties, determined from the site response analysis.

### 3.3.3 Staff Confirmatory Analysis

The NRC staff performed independent calculations to confirm that the licensee's amplification factors and control point hazard curves adequately characterize the site response, including the uncertainty associated with the subsurface material properties, for the Byron site.

To perform its confirmatory analysis, the NRC staff utilized information from the Byron UFSAR to estimate the near surface shear wave velocity of the dolomite. As such, the NRC staff's best estimate base case profile is the same as the licensee's over the upper 90 ft. (27.4 m). Below this depth, the NRC staff's best case profile increases to an intermediate shear wave velocity of 5250 ft./sec (1600 m/s) until reaching base rock at a depth of 105 ft. (32 m). As a result of multiple near surface measurements, the NRC staff used a natural log standard deviation of 0.20 to estimate upper and lower base case velocity profiles. The NRC staff used assumed a linear increase in velocity with depth in the deeper layers for the lower base case velocity. Figure 3.3-1 of this assessment shows a comparison of the licensee's and NRC staff's three base case velocity profiles. As shown in Figure 3.3-1, the licensee's base case and upper profiles reach base rock at a depth of 114 ft. (35 m). The licensee's lower base case profile has a constant shear wave velocity of 5942 ft./sec from a depth of 114 ft. (35 m) to base rock at 3000 ft. (914 m).

The NRC staff assumed the upper rock material could demonstrate either linear or non-linear dynamic properties. To model the non-linear behavior of the rock, the NRC staff used EPRI Rock shear modulus degradation and damping curves while for the linear behavior, the NRC staff used a constant damping of 1.25 percent. The depth of non-linear behavior extended 105 ft. for the base case and upper case profiles and to approximately 500 ft. for the lower case profile.

Based on the guidance in the SPID, the NRC staff determined kappa values of 0.0068, 0.0145 and 0.0066 seconds for the base, lower case and upper case velocity profiles, respectively. The licensee's kappa values are slightly larger, 0.008 for the base case and upper case profiles and 0.023 for the lower base case profile.

Figure 3.3-2 of this assessment shows a comparison of the staff's and licensee's median site amplification functions and uncertainties for the base case profile with EPRI rock curves at input loading levels of 0.1 g and 0.5 g. The licensee's and NRC staff's amplification functions are similar with minor to moderate differences in amplification above 20 Hz. This difference is due

primarily to differences in kappa used by the licensee and NRC staff. As shown in Figure 3.3-3, these differences do not substantially impact the control point hazard curves, which are very similar.

Overall, the licensee's approach to modeling the subsurface rock properties and uncertainty results in similar site amplification factors and standard deviation, as well as the control point seismic hazard curves. Because the licensee followed the guidance in the SPID for characterizing the site response inputs, these minor differences are acceptable to the NRC staff. Appendix B of the SPID provides guidance for performing site response analyses, including capturing the uncertainty for sites with less subsurface data; however, the guidance is neither entirely prescriptive nor comprehensive. As such, various approaches in performing site response analyses, including the modeling of uncertainty, are acceptable.

In summary, the NRC staff concludes that the licensee's site response was conducted using present-day guidance and methodology, including the NRC-endorsed SPID. The NRC staff performed independent calculations to confirm that the licensee's amplification factors and control point hazard curves adequately characterize the site response, including the uncertainty associated with the subsurface material properties, for the site.

#### 3.4 Ground Motion Response Spectra

In Section 2.4 of its SHSR, the licensee states that it used the control point hazard curves, described in SHSR Section 2.3.7, to develop the  $10^{-4}$  and  $10^{-5}$  (mean annual frequency of exceedance) uniform hazard response spectra (UHRS) and then computed the GMRS using the criteria in RG 1.208.

The NRC staff independently calculated the  $10^{-4}$  and  $10^{-5}$  UHRS using the results of its confirmatory PSHA and site response analyses, as described in Sections 3.2 and 3.3 of this staff assessment, respectively. Figure 3.4-1 of this assessment shows a comparison of the GMRS determined by the licensee to that determined by the NRC staff.

As shown in Figure 3.4-1, the licensee's GMRS shape is generally similar to that calculated by the NRC staff. However, NRC staff's confirmatory GMRS is somewhat higher than the licensee's at frequencies near 10 Hz and greater frequencies. As described above in Section 3.3, the NRC staff concludes that these minor differences over the higher frequency range are primarily due to the differences in the site response analyses performed by the licensee and NRC staff. The NRC staff concludes that these differences are acceptable because the licensee followed the guidance provided in the SPID with respect to both the PSHA and site response analysis for the Byron site.

The NRC staff confirms that the licensee used the present-day guidance and methodology outlined in RG 1.208 and the SPID to calculate the horizontal GMRS, as requested in the 50.54(f) letter. The NRC staff performed both a PSHA and site response confirmatory analysis and achieved results consistent with the licensee's horizontal GMRS. As such, the NRC staff concludes that the GMRS determined by the licensee adequately characterizing the reevaluated hazard for the Byron site. Therefore, this GMRS is suitable for use in subsequent evaluations and confirmations, as needed, for the response to the 50.54(f) letter.

#### 4.0 CONCLUSION

The NRC staff reviewed the information provided by the licensee for the reevaluated seismic hazard for the Byron site. Based on its review, the NRC staff concludes that the licensee conducted the hazard reevaluation using present-day methodologies and regulatory guidance, it appropriately characterized the site given the information available, and met the intent of the guidance for determining the reevaluated seismic hazard. The NRC staff concluded that the licensee demonstrated that the IHS could be used for comparison with the GMRS for the screening decision. Based upon the preceding analysis the NRC staff concludes that the licensee provided an acceptable response to Requested Information Items (1) – (3), (5) – (7), and the comparison portion to Item (4) identified in Enclosure 1 of the 50.54(f) letter. Further, the licensee's reevaluated seismic hazard is acceptable to address other actions associated with NTTF Recommendation 2.1: "Seismic".

As stated in the October 27, 2015, letter, a seismic risk evaluation (i.e., Item 8) is not merited. Because the IPEEE program did not include an evaluation of the SFP and the GMRS exceeds the SSE above 7 Hz, the SFP evaluation (Item 9) is merited. Additionally, in the frequency range above 10 Hz, the GMRS exceeds the IHS therefore, either a HF confirmation (Item 4) or relay chatter review is merited.

The NRC review and acceptance of Exelon's SFP evaluation, and either a HF confirmation or the IPEEE relay chatter review for Byron will complete the Seismic Hazard Evaluation identified in Enclosure 1 of the 50.54(f) letter.

## REFERENCES

Note: ADAMS Accession Nos. refers to documents available through NRC's Agencywide Documents Access and Management System (ADAMS). Publicly-available ADAMS documents may be accessed through <http://www.nrc.gov/reading-rm/adams.html>.

### U.S. Nuclear Regulatory Commission Documents and Publications

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Figure 3.3-1 Plot of the Staff's and Licensee's Base Case Shear-Wave Velocity Profiles for the Byron site: a) entire profile, b) profile in upper 200 ft.

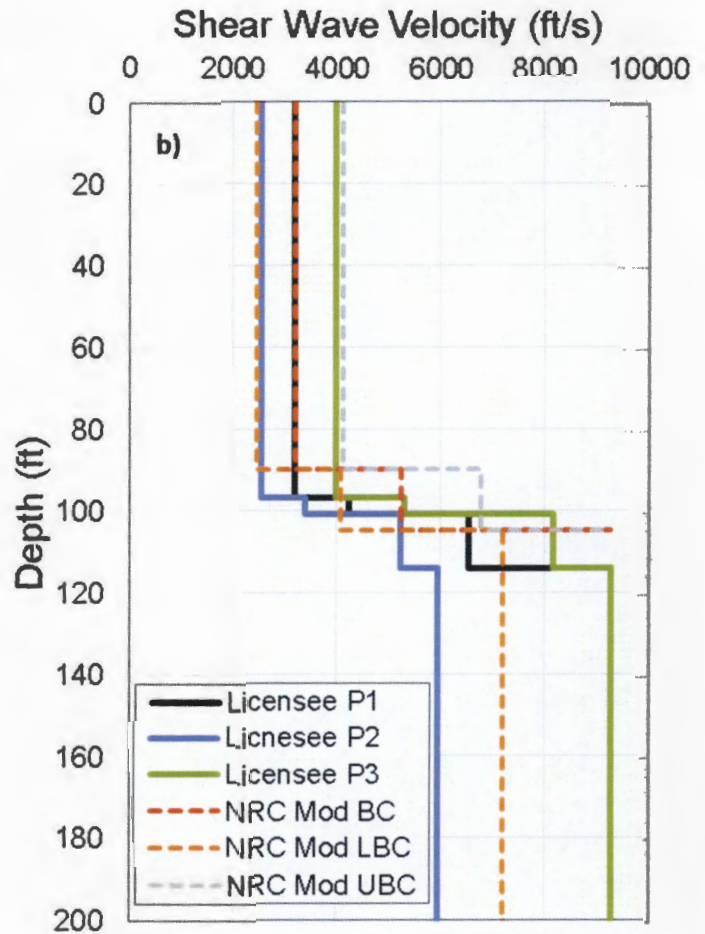
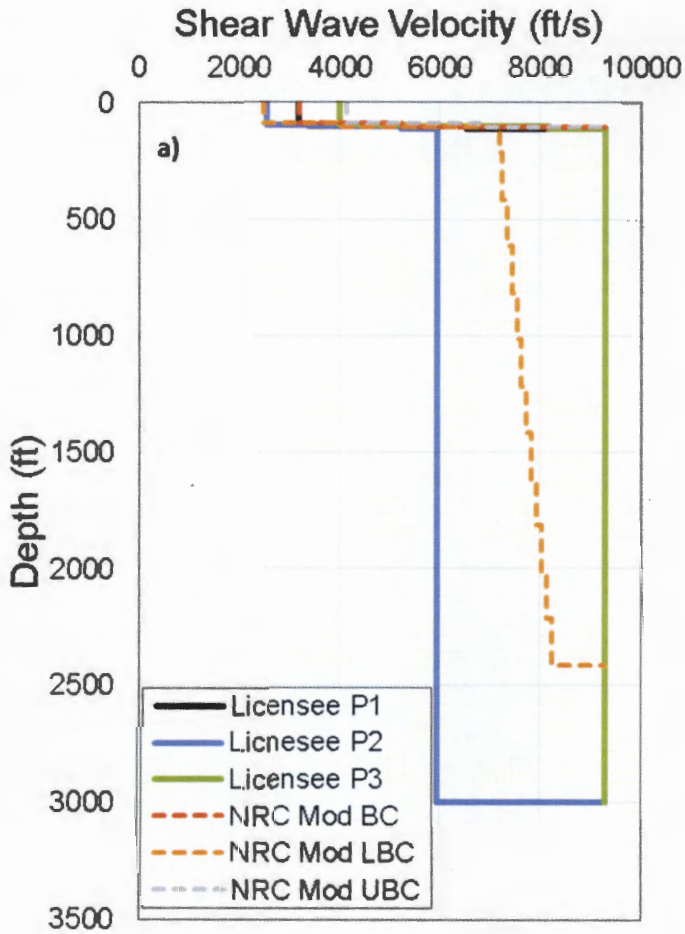




Figure 3.3- 2 Plot Comparing the Staff's and the License's Median Amplification Functions and Uncertainties for Model 1, Profile 1 at two input loading levels for the Byron site: a) loading level of 0.1 g, b) loading level of 0.5 g.

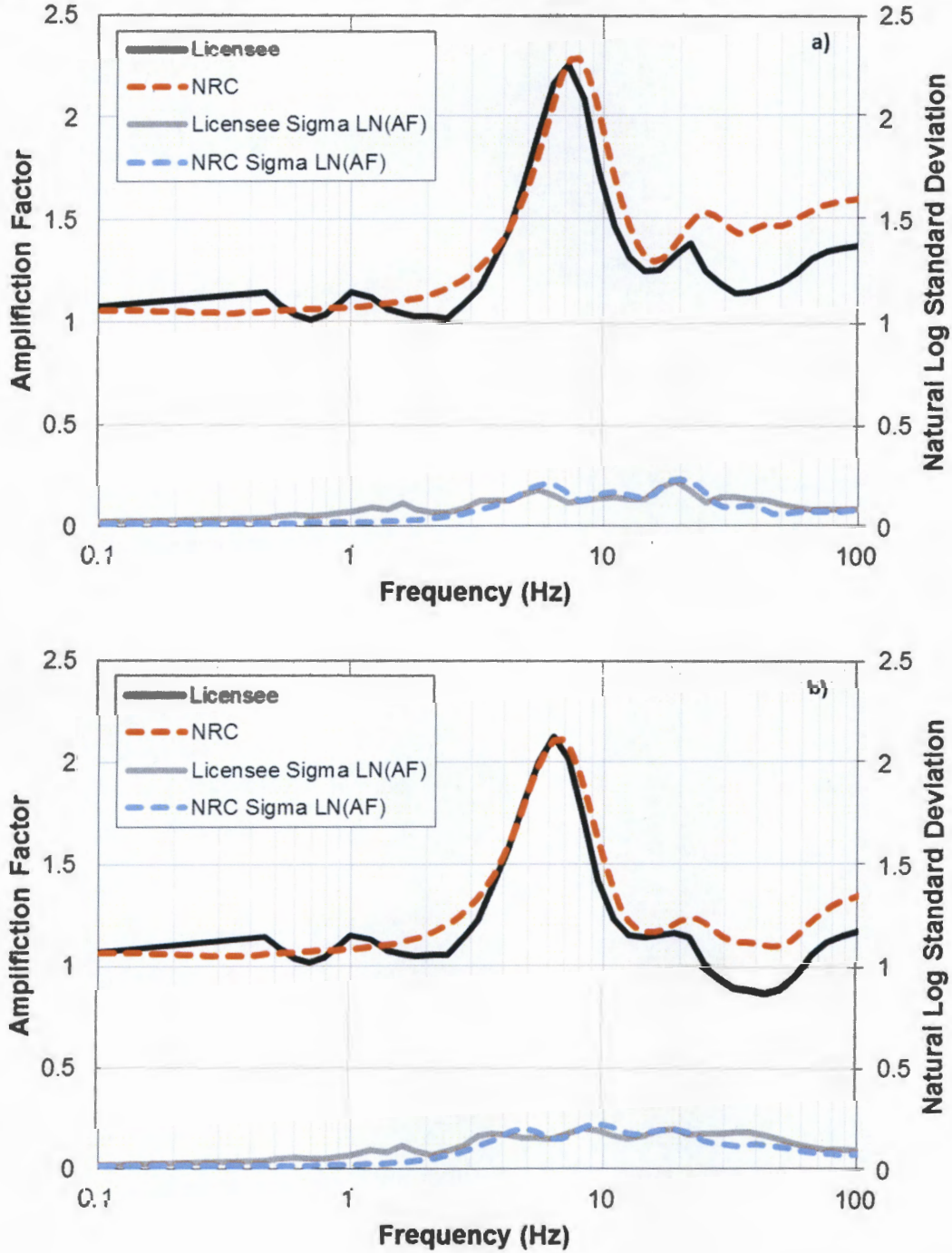


Figure 3.3-3 Plot Comparing the Staff's and the Licensee's Mean Control Point Hazard Curves at a Variety of Frequencies for the Byron site

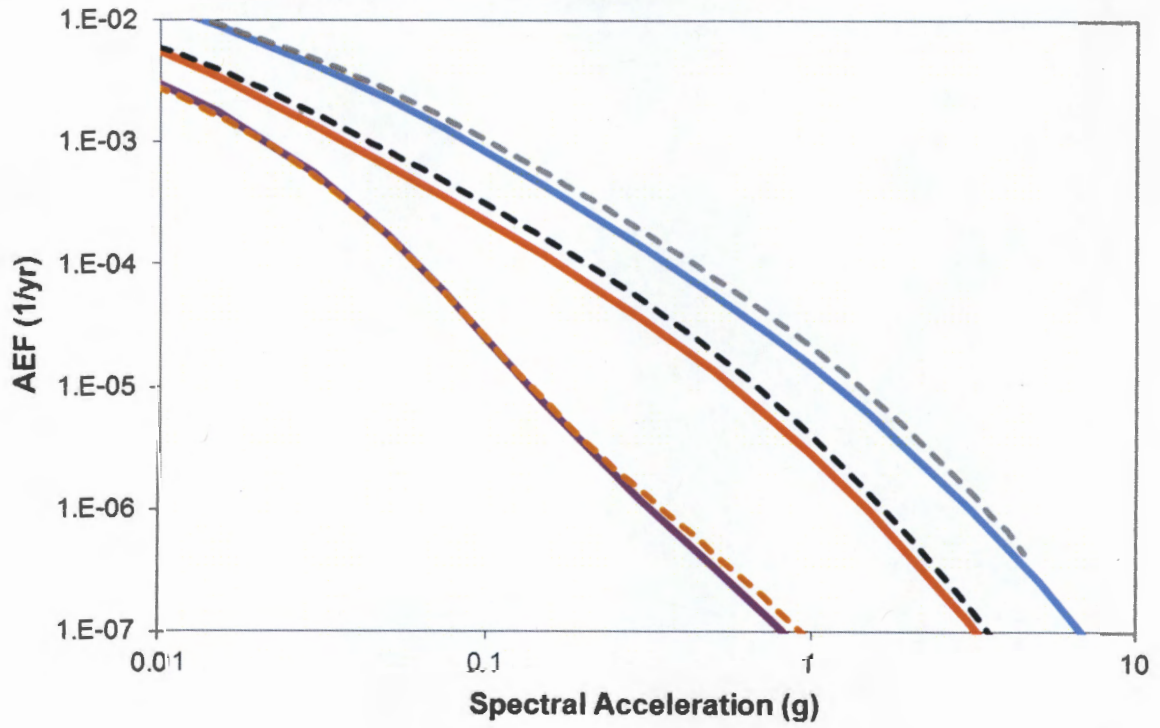
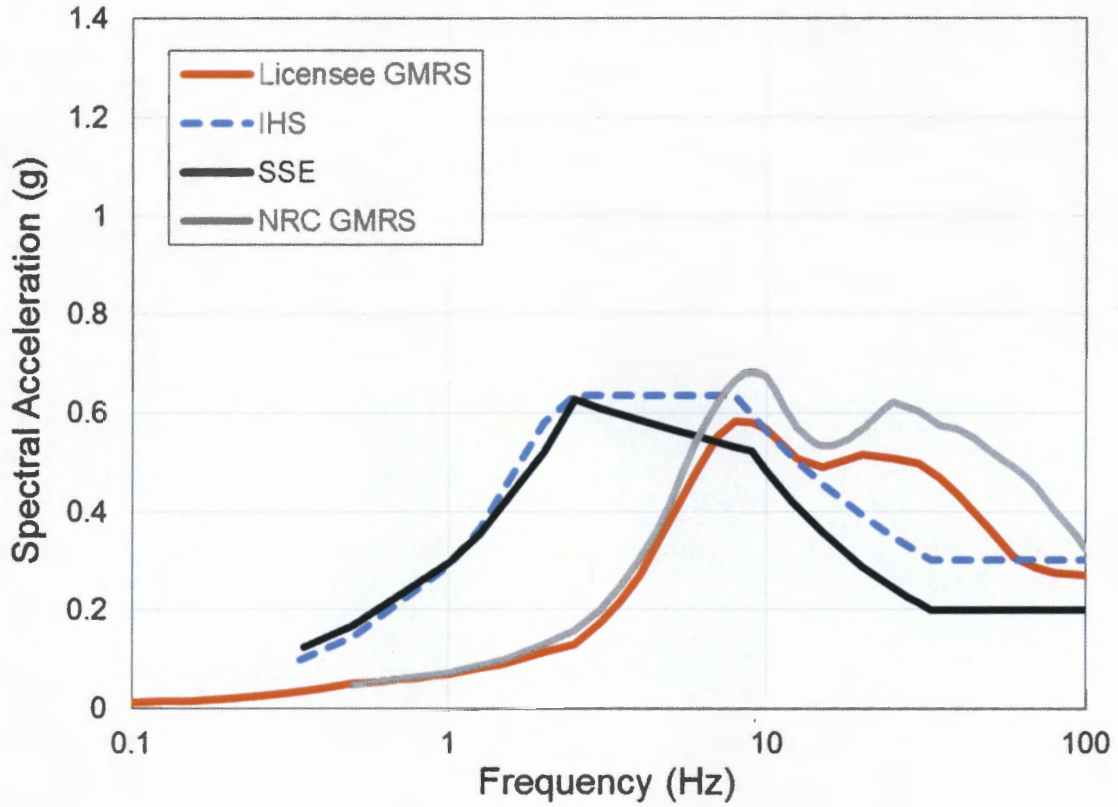


Figure 3.4-1 Comparison of the Staff's GMRS, Licensee's GMRS, SSE, and the IHS for the Byron site.



B. Hanson

- 2 -

Contingent upon the NRC staff's review and acceptance of Exelon's HF confirmation (Item 4) or the full-scope IPEEE relay chatter review and spent fuel pool evaluation (Item 9) for Byron, the Seismic Hazard Evaluation identified in Enclosure 1 of the 50.54(f) letter will be completed.

If you have any questions, please contact me at (301) 415-1617 or at Frankie.Vega@nrc.gov.

Sincerely,

/RA/

Frankie G. Vega, Project Manager  
Hazards Management Branch  
Japan Lessons-Learned Division  
Office of Nuclear Reactor Regulation

Docket Nos. 50-454 and 50-455

Enclosure:  
Staff Assessment of Seismic  
Hazard Evaluation and Screening Report

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**\*via email**

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