Exelon Generation.

RS-14-064 10 CFR 50.54(f)

March 31, 2014

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
11555 Rockville Pike,
Rockville, MD 20852

Braidwood Station, Units 1 and 2
Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457

Subject: Exelon Generation Company, LLC, Seismic Hazard and Screening Report (Central and Eastern United States (CEUS) Sites), Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident

References:

1. NRC Letter, Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident, dated March 12, 2012
2. NEI Letter, Proposed Path Forward for NTTF Recommendation 2.1: Seismic Reevaluations, dated April 9, 2013
3. NRC Letter, Electric Power Research Institute Final Draft Report XXXXXX, "Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic," as an Acceptable Alternative to the March 12, 2012, Information Request for Seismic Reevaluations, dated May 7, 2013
4. Exelon Generation Company, LLC letter to the NRC, Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident – 1.5 Year Response for CEUS Sites, dated September 12, 2013
5. EPRI Report 1025287, Seismic Evaluation Guidance, Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic
6. NRC Letter, Endorsement of Electric Power Research Institute Final Draft Report 1025287, "Seismic Evaluation Guidance," dated February 15, 2013
7. EPRI Technical Report 3002000704, "Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic," dated May 2013

On March 12, 2012, the Nuclear Regulatory Commission (NRC) issued Reference 1 to all power reactor licensees and holders of construction permits in active or deferred status. Enclosure 1 of Reference 1 requested each addressee located in the Central and Eastern United States (CEUS) to submit a Seismic Hazard Evaluation and Screening Report within 1.5 years from the date of Reference 1.

In Reference 2, the Nuclear Energy Institute (NEI) requested NRC agreement to delay submittal of the final CEUS Seismic Hazard Evaluation and Screening Reports so that an update to the Electric Power Research Institute (EPRI) ground motion attenuation model could be completed and used to develop that information. NEI proposed that descriptions of subsurface materials and properties and base case velocity profiles be submitted to the NRC by September 12, 2013, with the remaining seismic hazard and screening information submitted by March 31, 2014. NRC agreed with that proposed path forward in Reference 3. In Reference 4, Exelon Generation Company, LLC (EGC) provided the description of subsurface materials and properties and base case velocity profiles for Braidwood Station, Units 1 and 2.

Reference 5 contains industry guidance and detailed information to be included in the Seismic Hazard Evaluation and Screening Report submittals. NRC endorsed this industry guidance in Reference 6.

The enclosed Seismic Hazard Evaluation and Screening Report for Braidwood Station, Units 1 and 2, provides the information described in Section 4 of Reference 5 in accordance with the schedule identified in Reference 2. As described in Enclosure 1, Braidwood Station, Units 1 and 2, meet the requirements of SPID Sections 3.2 and 7 (Reference 5) and therefore screen out and do not need to prepare an Expedited Seismic Evaluation Process (ESEP) Report, in accordance with Reference 7. Additionally, no Seismic Risk Assessment or Spent Fuel Pool evaluation is needed. Braidwood Station, Units 1 and 2, will perform a High Frequency Confirmation evaluation as determined by NRC prioritization following submittal of all nuclear power plant Seismic Hazard Re-evaluations per Reference 1.

A list of regulatory commitments contained in this letter is provided in Enclosure 2. If you have any questions regarding this report, please contact Ron Gaston at (630) 657-3359.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 31st day of March 2014.

Respectfully submitted,

Glen T. Kaegi

Glen T. Kaegi
Director - Licensing & Regulatory Affairs
Exelon Generation Company, LLC

Enclosures:

1. Braidwood Station, Units 1 and 2, Seismic Hazard and Screening Report
2. Summary of Regulatory Commitments

cc: Director, Office of Nuclear Reactor Regulation
Regional Administrator - NRC Region III
NRC Senior Resident Inspector - Braidwood Station
NRC Project Manager, NRR - Braidwood Station
Ms. Jessica A. Kratchman, NRR/JLD/PMB, NRC
Mr. Eric E. Bowman, NRR/DPR/PGCB, NRC or Ms. Eileen M. McKenna, NRO/DSRA/BPTS, NRC
Illinois Emergency Management Agency - Division of Nuclear Safety

Enclosure 1

Braidwood Station, Units 1 and 2

Seismic Hazard and Screening Report

(48 pages)

SEISMIC HAZARD AND SCREENING REPORT

IN RESPONSE TO THE 50.54(f) INFORMATION REQUEST REGARDING FUKUSHIMA NEAR-TERM TASK FORCE RECOMMENDATION 2.1: SEISMIC

for the

Braidwood Nuclear Generating Station, Units 1 and 2
35100 South Route 53 Braceville, IL 60407-9619
Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457
Correspondence No.: RS-14-064

Exelon.

Exelon Generation Company, LLC (Exelon)
PO Box 805398
Chicago, IL 60680-5398

Prepared by:
Sargent & Lundy, LLC
55 East Monroe Street, Chicago IL 60603

Report Number: SL-012163, Revision 0

	Printed Name	Signature	Date
Preparer:	Ryan Foley / Alexander Gonzalez		3-19-14
Reviewer:	Ronald Bostum		3-17-2014
Approver:	Javad Moslemian		3/17/14
Lead Responsible Engineer:	Peter Guse		03/17/2014
Risk Management (Section 5.4):	LAWRENCE LEE		3/17/2014
Branch Manager:	George R. Wilhelmsen		3/17/2014
Senior Manager Design Engineering:	FRANK G GOGLIOTTI		3/18/14
Corporate Acceptance:	Jeffrey S. Clark		3/19/14

Seismic Hazard and Screening Report – Braidwood Units 1 and 2

Report No.: SL-012183
Revision 0 – Initial Issue

S&L Project No.: 11332-181
Nuclear Non-Safety Related

Sections: Cover Page, Executive Summary, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, and Appendix A		
Prepared by:	Alexander Gonzalez/Ryan Foley	3-17-14
Reviewed by:	Ronald Boehm	3.17.2014
Section: 4.2		
Prepared by:	Jay Johnson	3/17/14
Reviewed by:	Brent Starks	3/17/14
All Sections		
Approved by:	Javad Moslemian	3/17/14

RECORD OF REVISIONS

Revision	Affected Pages	Description
0	All	Initial Issue

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Executive Summary

PURPOSE

Following the accident at the Fukushima Daiichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the Nuclear Regulatory Commission (NRC) issued a 50.54(f) letter (Reference 1) requesting information in response to NRC Near-Term Task Force (NTTF) recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena. The 50.54(f) letter (Reference 1) requests that licensees and holders of construction permits under Title 10 Code of Federal Regulations Part 50 (Reference 2) reevaluate the seismic hazards at their sites against present-day NRC requirements. This report provides the information requested in items (1) through (7) of the "Requested Information" section and Attachment 1 of the 50.54(f) letter (Reference 1) pertaining to NTTF Recommendation 2.1 for Braidwood Generating Station Units 1 and 2 in accordance with the documented intention of Exelon Generating Company transmitted to the NRC via letter dated April 29, 2013 (Reference 16).

SCOPE

In response to the 50.54(f) letter (Reference 1) and following the Screening, Prioritization, and Implementation Details (SPID) industry guidance document (Reference 3), a seismic hazard reevaluation for Braidwood Generating Station was performed to develop a Ground Motion Response Spectrum (GMRS) for screening purposes to compare with the Safe Shutdown Earthquake (SSE). The new GMRS represents a beyond-design-basis seismic demand developed by more modern techniques than were used for plant licensing. Consistent with NRC letter dated February 20, 2014, (Reference 26) the seismic hazard reevaluations presented herein are distinct from the current design or licensing bases of Braidwood station. Therefore, the results generally do not call into question the operability or functionality of SSCs and are not expected to be reportable pursuant to 10 CFR 50.72, "Immediate notification requirements for operating nuclear power reactors," and 10 CFR 50.73, "Licensee event report system."

Section 2 provides a summary of the Braidwood regional and local geology, seismicity, other major inputs to the seismic hazard reevaluation, and detailed seismic hazard results including definition of the GMRS. Seismic hazard analysis for Braidwood station, including site response evaluation and GMRS development (Sections 2.2, 2.3, and 2.4 of this report) was performed by the Electric Power Research Institute (EPRI) (Reference 11). A more in-depth discussion of the calculation methods used in the seismic hazard reevaluation can be found in References 3, 7, 8, 9, and 15. Section 3 describes the characteristics of the appropriate plant-level SSE. Section 4 provides a comparison of the GMRS to the SSE. Sections 5 and 6 discuss interim actions and conclusions, respectively.

CONCLUSIONS

For Braidwood station, the SSE envelopes the GMRS in the frequency range from 1 Hz to 10 Hz. Therefore, in accordance with the SPID Sections 3.2 and 7 (Reference 3), Braidwood station screens out of further risk assessment and spent fuel pool integrity evaluation in response to NTTF 2.1: Seismic. Additionally, Braidwood station screens out of the Expedited Seismic Evaluation Process (ESEP) interim action per the ESEP guidance, Section 2.2 (Reference 4).

Due to the GMRS exceeding the SSE in the frequency range above 10 Hz, high frequency confirmations will be performed for Braidwood station based upon the schedule for central and eastern United States (CEUS) nuclear plants provided via letter from the industry to the NRC dated April 9, 2013 (Reference 6), as endorsed by the NRC in the May 7, 2013 letter to the industry (Reference 25).

1 Introduction

Following the accident at the Fukushima Daiichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the NRC Commission established a Near Term Task Force (NTTF) to conduct a systematic review of NRC processes and regulations and to determine if the agency should make additional improvements to its regulatory system. The NTTF developed a set of recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena. Subsequently, the NRC issued a 50.54(f) letter that requests information to assure that these recommendations are addressed by all U. S. nuclear power plants (Reference 1). The 50.54(f) letter (Reference 1) requests that licensees and holders of construction permits under 10 CFR Part 50 (Reference 2) reevaluate the seismic hazards at their sites against present-day NRC requirements. Depending on the comparison between the reevaluated seismic hazard and the current design basis, the result is either no further risk evaluation or the performance of a seismic risk assessment. Risk assessment approaches acceptable to the staff include a seismic probabilistic risk assessment (SPRA), or a seismic margin assessment (SMA). Based upon the risk assessment results, the NRC staff will determine whether additional regulatory actions are necessary.

This report provides the information requested in items (1) through (7) of the "Requested Information" section and Attachment 1 of the 50.54(f) letter (Reference 1) pertaining to NTTF Recommendation 2.1 for Braidwood Generating Station Units 1 and 2 (Braidwood station), located in Will County, Illinois in accordance with the documented intention of Exelon Generating Company (Exelon) transmitted to the NRC via letter dated April 29, 2013 (Reference 16). In providing this information, Exelon followed the guidance provided in the *Seismic Evaluation Guidance: Screening, Prioritization, and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (Reference 3). The Augmented Approach, *Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (Reference 4), has been developed as the process for evaluating critical plant equipment as an interim action to demonstrate additional plant safety margin, prior to performing the complete plant seismic risk evaluations. The SPID (Reference 3) and the Augmented Approach (Reference 4) have been endorsed by the NRC in letters to NEI (Reference 24 and Reference 25).

The original geologic and seismic siting investigations for Braidwood station were performed in accordance with Appendix A of Title 10 Code of Federal Regulations Part 100 (Reference 5) and meet General Design Criterion 2 in Appendix A of Reference 2. The Safe Shutdown Earthquake (SSE) ground motion was developed in accordance with Appendix A of Reference 5 and is used for the design of seismic Category I systems, structures and components. See Section 3 of this report for further discussion on the development of the Braidwood station SSE.

In response to the 50.54(f) letter (Reference 1) and following the SPID guidance (Reference 3), a seismic hazard reevaluation for Braidwood station was performed. For screening purposes, a Ground Motion Response Spectrum (GMRS) was developed.

2

Seismic Hazard Reevaluation

Braidwood station is located in Will County, Illinois about 4.5 miles southwest of the Kankakee River. The site is about 1.5 miles southwest of the town of Braidwood, and about 22 miles southwest of Joliet. The station is within the Till Plains Section of the Central Lowland Physiographic province. The site is underlain by a thin veneer of loess and glacial drift, which overlies Pennsylvanian Age bedrock. The plant structures are founded on overconsolidated till, bedrock, or compacted granular fill.

The site is located on the north flank of the Illinois Basin Seismogenic Region. An investigation of seismicity within 200 miles of the site was conducted during the plant design phase and it was determined that the largest events were Modified Mercalli Intensity (MMI) VII. Based on the MMI VII intensity, a SSE with a maximum horizontal ground acceleration of 0.13g was originally selected. Subsequently, during the review of the construction permit, the NRC considered a MMI VIII earthquake at the site equally probable. Therefore, a SSE with a 0.2g horizontal peak ground acceleration was considered at the bedrock-till interface.

2.1 Regional and Local Geology

The Braidwood site is located in the Kankakee Plain subsection of the Till Plains section of the Central Lowland Physiographic province. This subsection is characterized in the northeastern portion by gently rolling topography formed by glacial deposits, and in the remaining portions by essentially flat-lying topography representing former glacial lakes. Elevations of the natural land surface within the site area range from approximately 580 to 610 feet MSL.

Overburden deposits within the plant site area consist of eolian and lacustrine deposits outwash, and glacial till. Borings at the site vicinity encountered soil deposits which ranged in thickness from 26 to 62 feet. The average soil thickness encountered in the site borings was approximately 42 feet.

The bedrock deposits in the vicinity of the site range in age from Pennsylvanian to Precambrian, as shown in the regional and stratigraphic columns in UFSAR Figures 2.5-2 and 2.5-19 (Reference 10). The bedrock surface, which is formed in the upper Pennsylvanian deposits ranges from Elevation 552 to 567 feet MSL and averages 558 feet MSL.

2.2 Probabilistic Seismic Hazard Analysis

2.2.1 Probabilistic Seismic Hazard Analysis Results

In accordance with the 50.54(f) letter (Reference 1) and following the guidance in the SPID (Reference 3), a probabilistic seismic hazard analysis (PSHA) was completed using the recently developed Central and Eastern United States Seismic Source Characterization (CEUS-SSC) for Nuclear Facilities (Reference 7) together with the updated EPRI Ground-Motion Model (GMM) for the CEUS (Reference 8). For the PSHA, a lower-bound moment magnitude of 5.0 was used, as specified in the 50.54(f) letter (Reference 1).

For the PSHA, the CEUS-SSC background seismic source zones out to a distance of 400 miles around Braidwood were included. This distance exceeds the 200 mile recommendation contained in Regulatory Guide 1.208 (Reference 15) and was chosen for completeness. Background sources included in this site analysis are the following:

1. Illinois Basin Extended Basement (IBEB)
2. Mesozoic and younger extended prior – narrow (MESE-N)
3. Mesozoic and younger extended prior – wide (MESE-W)
4. Midcontinent-Craton alternative A (MIDC_A)
5. Midcontinent-Craton alternative B (MIDC_B)
6. Midcontinent-Craton alternative C (MIDC_C)
7. Midcontinent-Craton alternative D (MIDC_D)
8. Non-Mesozoic and younger extended prior – narrow (NMESE-N)
9. Non-Mesozoic and younger extended prior – wide (NMESE-W)
10. Paleozoic Extended Crust narrow (PEZ_N)
11. Paleozoic Extended Crust wide (PEZ_W)
12. Reelfoot Rift (RR)
13. Reelfoot Rift including the Rough Creek Graben (RR-RCG)
14. Study region (STUDY_R)

For sources of large magnitude earthquakes, designated Repeated Large Magnitude Earthquake (RLME) sources in CEUS-SSC (Reference 7), the following sources lie within 621 miles (1,000 km) of the site and were included in the PSHA:

1. Commerce
2. Eastern Rift Margin Fault northern segment (ERM-N)
3. Eastern Rift Margin Fault southern segment (ERM-S)
4. Marianna
5. New Madrid Fault System (NMFS)
6. Wabash Valley

For each of the above background and RLME sources, the mid-continent version of the updated CEUS EPRI GMM was used.

2.2.2 *Base Rock Seismic Hazard Curves*

Consistent with the SPID (Reference 3), base rock seismic hazard curves are not provided as the site amplification approach, referred to as Method 3, has been used. Seismic hazard curves are shown below in Section 2.3.7 at the SSE control point elevation.

2.3 SITE RESPONSE EVALUATION

Following the guidance contained in Seismic Enclosure 1 of the 50.54(f) Request for Information (Reference 1) and in the SPID (Reference 3) for nuclear power plant sites that are not founded on hard rock (hard rock is defined as having a shear wave velocity of at least 9285 ft/sec), a site response analysis was performed for Braidwood.

2.3.1 *Description of Subsurface Material*

Braidwood station is located near Joliet, Illinois within the Central Lowland Physiographic Province. The site consists of about 40 feet of soils overlying about 5,000 feet of firm sedimentary rock. The SSE was specified at elevation 562 feet at the top of the Pennsylvanian limestone (Table 2.3.1-1).

Overburden deposits within the plant site area consist of eolian and lacustrine deposits, outwash, and glacial till. Borings at the site vicinity encountered soil deposits which ranged in thickness from 26 to 62 feet. The average soil thickness encountered in the site borings was approximately 42 feet per UFSAR Section 2.5.1.2.4.1. (Reference 10)

The Pleistocene age soil deposits described in UFSAR Section 2.5.1.2.4.1.1 (Reference 10) can be divided into upper and lower units on the basis of origin and distinct sedimentary characteristics. These have been classified as the Equality and Wedron Formations. The Equality Formation consists of lacustrine sands and silts ranging in thickness from approximately 14 to 31 feet and averaging approximately 23 feet. The Wedron Formation frequently consists of three units: an upper till consisting predominantly of clayey silt to silty clay with interspersed sand and dolomitic gravels, underlain by an outwash layer of sandy gravel to gravelly sand with numerous cobbles and some boulders, and a lower till consisting predominantly of a very sandy silt with some interspersed clay and gravel. The Wedron Formation was observed in on-site borings to vary in thickness from 5 to 30 feet, with an average thickness of 18 feet. The top of the formation lies between elevation 569 feet and 584 feet MSL, with an average elevation of 576 feet MSL.

The bedrock deposits in the vicinity of the site range in age from Pennsylvanian to Precambrian, as shown in the regional and stratigraphic columns in UFSAR Figures 2.5-2 and 2.5-19 (Reference 10). The bedrock surface, which is formed in the upper Pennsylvanian deposits, ranges from El. 552 feet to 567 feet MSL and averages 558 feet MSL.

The Pennsylvanian bedrock is included within the Kewanee Group, which is subdivided into the Carbondale and Spoon Formations, which are described in detail in UFSAR Section 2.5.1.2.4.2.1.1 (Reference 10). The Pennsylvanian deposition in the site area is characterized by rapid vertical changes in rock type and by lateral persistence of the Colchester (No. 2) Coal Member of the Carbondale Formation. Sandstone, siltstone, and most shale units are also persistent over wide areas when viewed as composite units. However, they show noticeable variation in thickness over relatively short horizontal distances.

Below the Pennsylvanian bedrock are Ordovician deposits, which consist of many different layers of shale, limestone, dolomite, and sandstone. The Fort Atkinson, Scales, Wise Lake, and Dunleith formations were encountered in the site geotechnical investigation. Information on deeper layers is obtained from stratigraphic columns produced from nearby deep wells. The thicknesses and composition of the various groups and members are described in more detail in UFSAR Section 2.5.1.2.4.2.3 (Reference 10).

The Cambrian rocks that underlie the Ordovician deposits consist of dolomites, sandstones, shales, and siltstones. The thicknesses and composition of the various groups and members are described in more detail in UFSAR Section 2.5.1.2.4.2.4 (Reference 10).

Available data indicate that the Precambrian basement rocks consist largely of medium- to coarse-grained granite. Other rock types reported are quartz monzonite, rhyolite, porphyry, and felsite. Estimated location of the top of the Precambrian basement is (-) 4400 to (-) 4500 feet MSL per UFSAR Section 2.5.1.2.4.2.5 (Reference 10).

Table 2.3.1-1: Summary of geotechnical profile data for Braidwood station (Reference 18)

Elevations of Layer Boundaries Under Reactor Buildings (ft, MSL)	Range in Thickness Across Site (ft)	Soil/Rock Description and Age	Density (pcf)	Shear Wave Velocity (fps)	Compressional Wave Velocity (fps)	Poisson's Ratio
600[a] to 579	5-15	Pleistocene Equality Formation, dry silty sand, medium dense	105-110	330	1000	0.41-0.44
	10-15	Pleistocene Equality Formation, wet silty sand, medium dense	125-130	2400	5500-6500	0.41-0.42
579 to 562[b]	10-25	Pleistocene Wedron Formation, clayey silt to silty clay with sand, gravel, cobbles, and boulders, hard, stiff	130-145	2400	6400	0.38-0.42
562 to 462[c]	70-105	Pennsylvanian limestone, sandstone, siltstone and coal	113-162	3200	7800-10000	0.38-0.41
462 to 425	37-45	Ordovician Fort Atkinson Formation, limestone and dolomite	164	6800	12000-17000	0.32-0.37
425 to 338	85-90	Ordovician Scales Formation, shale, limestone	155-158	3400	8800-17000	0.32-0.44
338 to 133	165-245	Ordovician Wise Lake and Dunleith Formations, dolomite	162	8700	16400	0.30-0.32
133 to 118	10-20	Ordovician Guttenburg Formation, dolomite	N/A	N/A	N/A	N/A
118 to -37	124-186	Ordovician Platteville Group, dolomite and limestone	N/A	N/A	N/A	N/A
-37 to -384	157-540	Ordovician Ancell Group, dolomitic sandstone and quartzose sandstone	N/A	N/A	N/A	N/A
-384 to -694	285-334	Ordovician Canadian Series, dolomite and sandstone	N/A	N/A	N/A	N/A
-694 to -4234	3300-3800	Cambrian dolomite, shale, and sandstone	N/A	N/A	N/A	N/A
-4234 and below	N/A	Precambrian granite, quartz monzonite, rhyolite porphyry, felsite	N/A	N/A	N/A	N/A

[a] Surface of finish grade is nominally at El. 600 feet MSL, at the top of the Pleistocene Equality Formation.
[b] The control points for the SSE and IPEEE HCLPF are at El. 562 ft MSL, which is the elevation of the Reactor Building foundation and the elevation of the rock-till interface.
[c] Bottom of the deepest foundation is at El. 523 ft MSL, within the Pennsylvanian bedrock.

2.3.2 Development of Base Case Profiles and Nonlinear Material Properties

Table 2.3.1-1 shows the recommended shear-wave velocities and unit weights along with elevations and corresponding stratigraphy. From Table 2.3.1-1 the SSE control point is at elevation 562 feet within the Pennsylvanian limestone, sandstone, and shales. Velocities listed in Table 2.3.1-1 reflect refraction, uphole, and downhole surveys along with unspecified information from the ISFSI at an unreported distance from the site (Reference 14). The location of the SSE at elevation 562 feet is at the top of the Pennsylvanian limestone, sandstone, siltstone, and coal beds with firm sedimentary rocks to Precambrian basement at a depth of about 5,000 feet. Velocity measurement extends to a depth below the SSE of about 700 feet. The mean base-case profile (P1) was based on the specified shear-wave velocities in Table 2.3.2-1 with the deepest velocity of 8,700 ft/s extended to Precambrian basement. Lower (P2)- and upper (P3)-range profiles were developed with scale factors of 1.25 reflecting uncertainty in measured velocities to a depth of 695 feet and 1.57 below to reflect increased epistemic uncertainty for assumed[1] shear-wave velocities. The scale factors of 1.25 and 1.57 reflect a $\sigma_{\mu ln}$ of about 0.2 and about 0.35 respectively based on the SPID (Reference 3) 10th and 90th fractiles which implies a scale factor of 1.28 on σ_{μ}. Depth to Precambrian basement was taken at 5,062 feet randomized ± 1,519 feet. The depth randomization reflects +/- 30% of the depth and was included to provide a realistic broadening of the fundamental resonance at deep rock sites rather than reflect actual random variations to basement shear-wave velocities across a footprint. Profile P3, the stiffest profile, encountered hard rock shear-wave velocities (9,285 ft/s) at a depth below the SSE of about 224 feet. The three shear-wave velocity profiles are shown in Figure 2.3.2-1 and listed in Table 2.3.2-1.

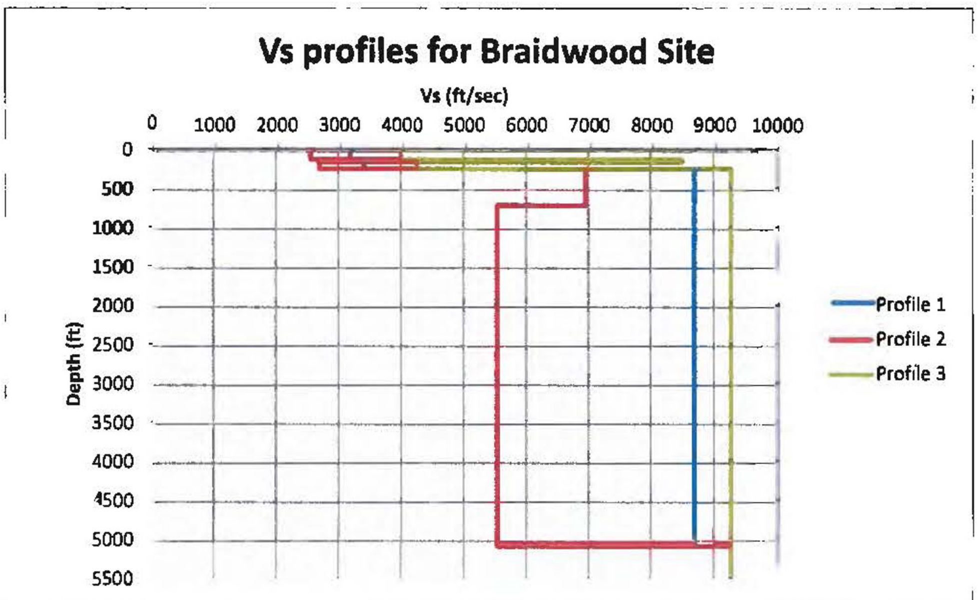

Figure 2.3.2-1: Shear-wave velocity (Vs) profiles for Braidwood station (Reference 18)

[1] Assumptions discussed in Section 2 are provided by EPRI engineers (Reference 11) in accordance with implementation of the SPID (Reference 3) methodology.

Table 2.3.2-1: Layer thicknesses, depths, and shear-wave velocities (Vs) for 3 profiles, Braidwood site (Reference 18)

Profile 1 (P1)			Profile 2 (P2)			Profile 3 (P3)		
Thickness(ft)	Depth (ft)	Vs(ft/s)	Thickness(ft)	Depth (ft)	Vs(ft/s)	Thickness(ft)	Depth (ft)	Vs(ft/s)
	0	3200		0	2560		0	4000
10.0	10.0	3200	10.0	10.0	2560	10.0	10.0	4000
10.0	20.0	3200	10.0	20.0	2560	10.0	20.0	4000
10.0	30.0	3200	10.0	30.0	2560	10.0	30.0	4000
10.0	40.0	3200	10.0	40.0	2560	10.0	40.0	4000
10.0	50.0	3200	10.0	50.0	2560	10.0	50.0	4000
10.0	60.0	3200	10.0	60.0	2560	10.0	60.0	4000
10.0	70.0	3200	10.0	70.0	2560	10.0	70.0	4000
10.0	80.0	3200	10.0	80.0	2560	10.0	80.0	4000
10.0	90.0	3200	10.0	90.0	2560	10.0	90.0	4000
10.0	100.0	3200	10.0	100.0	2560	10.0	100.0	4000
10.0	110.0	6800	10.0	110.0	5440	10.0	110.0	8500
10.0	120.0	6800	10.0	120.0	5440	10.0	120.0	8500
7.0	127.0	6800	7.0	127.0	5440	7.0	127.0	8500
10.0	137.0	6800	10.0	137.0	5440	10.0	137.0	8500
7.0	144.0	3400	7.0	144.0	2690	7.0	144.0	4250
10.0	154.0	3400	10.0	154.0	2690	10.0	154.0	4250
10.0	164.0	3400	10.0	164.0	2690	10.0	164.0	4250
10.0	174.0	3400	10.0	174.0	2690	10.0	174.0	4250
10.0	184.0	3400	10.0	184.0	2690	10.0	184.0	4250
10.0	194.0	3400	10.0	194.0	2690	10.0	194.0	4250
10.0	204.0	3400	10.0	204.0	2690	10.0	204.0	4250
10.0	214.0	3400	10.0	214.0	2690	10.0	214.0	4250
10.0	224.0	3400	10.0	224.0	2690	10.0	224.0	4250
6.0	230.0	8700	6.0	230.0	6960	6.0	230.0	9285
10.0	240.0	8700	10.0	240.0	6960	10.0	240.0	9285
10.0	250.0	8700	10.0	250.0	6960	10.0	250.0	9285
25.0	275.0	8700	25.0	275.0	6960	25.0	275.0	9285
25.0	300.0	8700	25.0	300.0	6960	25.0	300.0	9285
25.0	325.0	8700	25.0	325.0	6960	25.0	325.0	9285
25.0	350.0	8700	25.0	350.0	6960	25.0	350.0	9285
25.0	375.0	8700	25.0	375.0	6960	25.0	375.0	9285
25.0	400.0	8700	25.0	400.0	6960	25.0	400.0	9285
25.0	425.0	8700	25.0	425.0	6960	25.0	425.0	9285
25.0	450.0	8700	25.0	450.0	6960	25.0	450.0	9285

Table 2.3.2-1: (Continued)

Profile 1 (P1)			Profile 2 (P2)			Profile 3 (P3)		
Thickness(ft)	Depth (ft)	Vs(ft/s)	Thickness(ft)	Depth (ft)	Vs(ft/s)	Thickness(ft)	Depth (ft)	Vs(ft/s)
25.0	475.0	8700	25.0	475.0	6960	25.0	475.0	9285
25.0	500.0	8700	25.0	500.0	6960	25.0	500.0	9285
24.4	524.4	8700	24.4	524.4	6960	24.4	524.4	9285
24.4	548.7	8700	24.4	548.7	6960	24.4	548.7	9285
24.4	573.1	8700	24.4	573.1	6960	24.4	573.1	9285
24.4	597.5	8700	24.4	597.5	6960	24.4	597.5	9285
24.4	621.8	8700	24.4	621.8	6960	24.4	621.8	9285
24.4	646.2	8700	24.4	646.2	6960	24.4	646.2	9285
24.4	670.6	8700	24.4	670.6	6960	24.4	670.6	9285
24.4	695.0	8700	24.4	695.0	6960	24.4	695.0	9285
218.3	913.3	8700	218.3	913.3	5541	218.3	913.3	9285
218.3	1131.6	8700	218.3	1131.6	5541	218.3	1131.6	9285
218.3	1350.0	8700	218.3	1350.0	5541	218.3	1350.0	9285
218.3	1568.3	8700	218.3	1568.3	5541	218.3	1568.3	9285
218.3	1786.7	8700	218.3	1786.7	5541	218.3	1786.7	9285
218.3	2005.0	8700	218.3	2005.0	5541	218.3	2005.0	9285
218.3	2223.3	8700	218.3	2223.3	5541	218.3	2223.3	9285
218.3	2441.7	8700	218.3	2441.7	5541	218.3	2441.7	9285
218.3	2660.0	8700	218.3	2660.0	5541	218.3	2660.0	9285
218.3	2878.4	8700	218.3	2878.4	5541	218.3	2878.4	9285
218.3	3096.7	8700	218.3	3096.7	5541	218.3	3096.7	9285
218.3	3315.0	8700	218.3	3315.0	5541	218.3	3315.0	9285
218.3	3533.4	8700	218.3	3533.4	5541	218.3	3533.4	9285
218.3	3751.7	8700	218.3	3751.7	5541	218.3	3751.7	9285
218.3	3970.0	8700	218.3	3970.0	5541	218.3	3970.0	9285
218.3	4188.4	8700	218.3	4188.4	5541	218.3	4188.4	9285
218.3	4406.7	8700	218.3	4406.7	5541	218.3	4406.7	9285
218.3	4625.1	8700	218.3	4625.1	5541	218.3	4625.1	9285
218.3	4843.4	8700	218.3	4843.4	5541	218.3	4843.4	9285
218.3	5061.7	8700	218.3	5061.7	5541	218.3	5061.7	9285
3280.8	8342.6	9285	3280.8	8342.6	9285	3280.8	8342.6	9285

2.3.2.1 Shear Modulus and Damping Curves

Recent nonlinear dynamic material properties were not available for Braidwood station for sedimentary rocks. The rock material over the upper 500 feet was assumed[1] to have behavior that could be modeled as either linear or non-linear. To represent this potential for either case in the upper 500 feet of sedimentary rock at Braidwood station, two sets of shear modulus reduction and hysteretic damping curves were used. Consistent with the SPID (Reference 3), the EPRI rock curves (model M1) were considered to be appropriate to represent the upper range nonlinearity likely in the materials at this site; and, linear analyses (model M2) was assumed[1] to represent an equally plausible alternative rock response across loading level. For the linear analyses, the low strain damping from the EPRI rock curves were used as the constant damping values in the upper 500 feet.

2.3.2.2 Kappa

Base-case kappa estimates were determined using Section B-5.1.3.1 of the SPID (Reference 3) for a firm CEUS rock site. Kappa for a firm rock site with at least 3,000 feet of sedimentary rock may be estimated from the average S-wave velocity over the upper 100 feet (V_{s100}) of the subsurface profile while for a site with less than 3,000 feet of firm rock, kappa may be estimated with a Q_s of 40 below 500 feet combined with the low strain damping from the EPRI rock curves and an additional kappa of 0.006s for the underlying hard rock. For Braidwood station, with at least 3,000 feet of firm rock, the corresponding average shear-wave velocities (equivalent travel time averaging procedure) over the top 100 feet were 3,200 ft/s (P1), 2,560ft/s (P2), and 4,000 ft/s (P3). The corresponding kappa estimates were 0.024s, 0.031s, and 0.019s respectively. The range in kappa was considered insufficient and a scale factor of 1.68 (Reference 3) about the mean base-case profile estimate was applied resulting in corresponding low-range estimates of 0.014s, 0.018s, and 0.011s respectively. For the upper-range kappa estimates the values for profiles P1, P2, and P3 were 0.040s, 0.040s, and 0.032s, where 0.040s reflected the maximum considered estimate (Reference 3). As a result each base-case profile was associated with three, mid-, low-, and high-range estimates of kappa as summarized in Table 2.3.2-2.

[1] Assumptions discussed in Section 2 are provided by EPRI engineers (Reference 11) in accordance with implementation of the SPID (Reference 3) methodology.

Table 2.3.2-2: Kappa values and weights used for site response analyses (Reference 11)

Velocity Profile	Kappa(s)		
	Lower Range (k3)	Base-Case (k1)	Upper Range (k2)
P1	0.014	0.024	0.040
P2	0.018	0.031	0.040
P3	0.011	0.019	0.032
	Weights		
P1	0.4		
P2	0.3		
P3	0.3		
k1	0.40		
k2	0.30		
k3	0.30		
	G/G_{max} and Hysteretic Damping Curves		
M1	0.5		
M2	0.5		

2.3.3 *Randomization of Base Case Profiles*

To account for the aleatory variability in dynamic material properties that is expected to occur across a site at the scale of a typical nuclear facility, variability in the assumed[1] shear-wave velocity profiles has been incorporated in the site response calculations. For Braidwood station, random shear wave velocity profiles were developed from the base case profiles shown in Figure 2.3.2-1. Consistent with the discussion in Appendix B of the SPID (Reference 3), the velocity randomization procedure made use of random field models which describe the statistical correlation between layering and shear wave velocity. The default randomization parameters developed in Toro (Reference 9) for USGS "A" site conditions were used for this site. Thirty random velocity profiles were generated for each base case profile. These random velocity profiles were generated using a natural log standard deviation of 0.25 over the upper 50 feet and 0.15 below that depth. As specified in the SPID (Reference 3), correlation of shear wave velocity between layers was modeled using the footprint correlation model. In the correlation model, a limit of +/- 2 standard deviations about the median value in each layer was assumed[1] for the limits on random velocity fluctuations.

[1] Assumptions discussed in Section 2 are provided by EPRI engineers (Reference 11) in accordance with implementation of the SPID (Reference 3) methodology.