Nuclear Development
244 Chestnut Street, Salem, NJ 08079

PSEG
Power LLC

ND-2012-0018
March 15, 2012

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: **PSEG Early Site Permit Application**
Docket No. 52-043
Response to Request for Additional Information, RAI No. 43, Vibratory Ground Motion

References:
1) PSEG Power, LLC letter to USNRC, Application for Early Site Permit for the PSEG Site, dated May 25, 2010

2) RAI No. 43, SRP Section: 02.05.02 – Vibratory Ground Motion, dated December 12, 2011 (eRAI 6162)

3) PSEG Power, LLC Letter No. ND-2012-0002 to USNRC, Response to Request for Additional Information, RAI No. 43, Vibratory Ground Motion, dated January 10, 2012

4) PSEG Power, LLC Letter No. ND-2012-0006 to USNRC, Response to Request for Additional Information, RAI No. 43, Vibratory Ground Motion, dated January 25, 2012

5) PSEG Power, LLC Letter No. ND-2012-0009 to USNRC, Response to Request for Additional Information, RAI No. 43, Vibratory Ground Motion, dated February 9, 2012

The purpose of this letter is to respond to the request for additional information (RAI) identified in Reference 2 above. This RAI addresses Vibratory Ground Motion, as described in Subsection 2.5.2 of the Site Safety Analysis Report (SSAR), as submitted in Part 2 of the PSEG Site Early Site Permit Application, Revision 0.

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Enclosure 1 provides our response to RAI No. 43, Question Nos. 02.05.01-1 and 02.05.01-4.

The response to RAI No. 43, Question Nos. 02.05.01-3, 02.05.01-6, 02.05.01-7 and 02.05.01-8 were provided in Reference 3. The response to RAI No. 43, Question No. 02.05.01-9 was provided in Reference 4. The response to RAI No. 43, Question No. 02.05.01-2 was provided in Reference 5.

The response to RAI No. 43, Question No. 02.05.02-5 will be provided by July 20, 2012.

There are no new regulatory commitments established in this submittal.

If any additional information is needed, please contact David Robillard, PSEG Nuclear Development Licensing Engineer, at (856) 339-7914.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 15th day of March, 2012.

Sincerely,

James Mallon

James Mallon
Early Site Permit Manager
Nuclear Development
PSEG Power, LLC

Enclosure 1: Response to NRC Request for Additional Information, RAI No. 43, Question Nos. 02.05.02-1 and 02.05.02-4, SRP Section: 2.5.2 – Vibratory Ground Motion

cc: USNRC Project Manager, Division of New Reactor Licensing, PSEG Site (w/enclosures)
USNRC Environmental Project Manager, Division of Site and Environmental Reviews (w/enclosures)
USNRC Region I, Regional Administrator (w/enclosures)

PSEG Letter ND-2012-0018, dated March 15, 2012

ENCLOSURE 1

RESPONSE to RAI No. 43

QUESTION Nos.
02.05.02-1
02.05.02-4

Response to RAI No. 43, Question 02.05.02-1:

In Reference 2, the NRC staff asked PSEG for information regarding the Vibratory Ground Motion, as described in Subsection 2.5.2 of the Site Safety Analysis Report. The specific request for Question 02.05.02-1 was:

> *SSAR Subsection 2.5.2.4.2 describes revisions to the 1989 EPRI-SOG seismic source model. While the subsection discusses updates to the Charleston area seismic sources, it does not discuss updates to the New Madrid Seismic Zone (NMSZ). Even though the NMSZ is significantly away from the site, previous studies have shown that this source does impact seismic hazard at far distances. In compliance with 10 CFR 100.23 and in conformance to NUREG-0800, Standard Review Plan, Section 2.5.2, "Vibratory Ground Motion," and Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion," please discuss quantitatively the impact of the NMSZ on the PSEG total seismic hazard curves and the site GMRS.*

PSEG Response to NRC RAI:

The NMSZ was not included in the original ground motion calculations for the PSEG Site due to the considerable distance between the PSEG Site and the NMSZ. In particular, the faults within the NMSZ that are postulated to be the source of the 1811 and 1812 earthquakes are over 1200 km (750 mi.) from the PSEG Site (SSAR Reference 2.5.2-29, Reference RAI-43-1-2), while the attenuation equations used in Early Site Permit and Combined License applications are only applicable out to distances of 1000 km (621 mi.) (SSAR Reference 2.5.2-39). Suitable attenuation equations are not available for sources beyond 1000 km (621 mi.); for purposes of conducting a sensitivity analysis in response to this RAI question to look at the potential impact of the NMSZ on the PSEG Site, the equations in SSAR Reference 2.5.2-39 were extended to encompass the NMSZ, consistent with standard practice.

The New Madrid seismic source model described in the Early Site Permit (ESP) application for the Exelon Generation Company ESP site near Clinton, Illinois (Reference RAI-43-1-1), and as modified for the Tennessee Valley Authority (TVA) Bellefonte Nuclear Site Combined License Application (COLA) (Reference RAI-43-1-3) is the basis for the NMSZ source model used for this sensitivity analysis. This source model accounts for new information on recurrence intervals for large earthquakes in the New Madrid area, for recent estimates of possible earthquake sizes on each of the active faults, and for the possibility of multiple earthquake occurrences within a short period of time (earthquake clusters).

Within this model, three faults are identified in the NMSZ: Blytheville, Northern, and Reelfoot. Earthquakes on these faults are treated as characteristic events in terms of magnitudes.

Seismic hazard is calculated considering the possibility of clustered earthquake occurrences. The modeling of earthquake clusters in the NMSZ has undergone considerable study, and this model will continue to evolve as further field evidence on paleo-earthquakes is found and analyzed. In the Exelon cluster model for multiple earthquake occurrences, the possibility of three clustered earthquakes is taken into account, as is the possibility of clustered earthquakes on two of the faults (but not the third), or the possibility of two faults generating a characteristic earthquake magnitude and the third fault generating a smaller magnitude. The cluster model used for this sensitivity study is a conservative simplification of the Exelon model (Reference RAI-43-1-1) in that the hazard is computed assuming that all clustered events generate earthquakes on each of the three faults and that the magnitudes of those events correspond to the characteristic magnitude distribution.

Consistent with the Exelon model (Reference RAI-43-1-1), the NMSZ faults used for this sensitivity analysis are taken to be vertical and to extend from the surface to 20 km (12 mi.) depth, and a finite rupture model is used to represent an extended rupture on all faults. An additional simplification is made for efficiency in calculations - only the preferred geometry of each fault is used. This simplification is justified because (1) the large distance between the PSEG Site and the NMSZ faults (over 1200 km, 750 mi.), and (2) the small differences between the preferred and alternative geometries indicate that including these details would not have a significant impact on the site ground motions.

The rate of earthquakes is characterized using two separate models of earthquake occurrence: (1) a time-dependent (i.e., renewal) model where the recurrence rate depends on the exposure time (Δt) and the start time (t_0), and (2) a time-independent model (i.e., Poissonian). In calculating the final mean recurrence rate for the NMSZ faults, both of these models are equally weighted (see FSAR Figure 2.5-263 of Reference RAI-43-1-3). For the NMSZ source characterization used in the Bellefonte Final Safety Analysis Report (FSAR) that is the basis for this sensitivity study, Δt was 50 years and t_0 was 1/1/2003.

In summary, the final model used here to calculate the seismic hazard for the PSEG Site from the NMSZ faults is the same in all important aspects affecting hazard as the model used in the TVA Bellefonte Nuclear Site COLA (Reference RAI-43-1-3). However, the exposure time and the start time used for the renewal model at the Bellefonte site (50 years and 1/1/2003, respectively) are not appropriate for the PSEG Site that has a projected commercial operation date of June 2021 and an expected lifetime (i.e., Δt) of 60 years. Therefore, the mean seismic hazard contribution from the NMSZ faults at the PSEG Site is calculated using a two step process. First, the seismic hazard is calculated at the PSEG Site using the parameters from the Bellefonte application (50 years and 1/1/2003). Second, the mean seismic hazard from the NMSZ faults is scaled by the percentage increase in mean occurrence rate determined using parameters for the renewal model that are appropriate for the PSEG Site. This methodology gives the mean hazard at the PSEG Site from the NMSZ faults using the same characterization as used for the Bellefonte site (Reference RAI-43-1-3), but with updated renewal model parameters appropriate for the PSEG Site.

Three different scenarios of start date and exposure time were considered to determine the percentage change in the mean occurrence rate over the rate used for the Bellefonte site (Table RAI-43-1-1). These scenarios all use an exposure time of 60 years, but start times of June 2021, June 2026, and June 2031. The variable start times allow for the possibility of a 5- or 10-year delay in plant operation.

Table RAI-43-1-1 shows the start time, exposure time, annual Poisson rate, annual renewal rate, final weighted annual rate, and percentage change over the rate used in the Bellefonte COLA for the parameters used in the Bellefonte application and for each of the scenarios used for the PSEG Site. As shown in the table, the Poisson rate does not change with the start date or exposure period because the model is time-independent. The renewal model rates increase with the later start dates reflecting the increased time passed since the start of the last earthquake cluster (e.g., 1811).

Table RAI-43-1-1

NMSZ Rates for Scenarios Considered for the PSEG Site

Plant Start Date	Exposure Time (Δt) (yrs)	Poisson Rate (per yr)	Renewal Rate (per yr)	Final Weighted Annual Rate (per yr)	Percentage Change over Rate in Bellefonte COLA
January 2003	50	0.00276	0.001242	0.00200	0.0%
June 2021 (Scenario 1)	60	0.00276	0.001513	0.00214	6.8%
June 2026 (Scenario 2)	60	0.00276	0.001571	0.00217	8.2%
June 2031 (Scenario 3)	60	0.00276	0.001629	0.00219	9.7%

To illustrate the impact of including the NMSZ on the hazard curves for the PSEG Site, Table RAI-43-1-2 compares the 1 Hz mean rock hazard curves for the PSEG Site and those for the NMSZ model as used for the Bellefonte site (i.e., January 2003 start in Table RAI-43-1-1). The ratio between the SSAR hazard and the NMSZ hazard is shown as a percentage. Note that the new hazard values calculated for the NMSZ source were done so without using the Cumulative Absolute Velocity (CAV) filter (see SSAR Section 2.5.2.4.3).

Table RAI-43-1-2
Comparison of SSAR Hazard and NMSZ Hazard for 1 Hz Mean Rock Hazard

Spectral Acceleration Amplitude (g)	SSAR Hazard (Mean Rock) (1)	NMSZ Hazard (Mean Rock) (2)	NMSZ as % of SSAR
5.00E-04	1.68E-02	1.81E-03	10.8%
7.00E-04	1.32E-02	1.75E-03	13.3%
1.00E-03	9.93E-03	1.69E-03	17.0%
1.50E-03	6.96E-03	1.61E-03	23.2%
2.00E-03	5.28E-03	1.53E-03	29.1%
3.00E-03	3.44E-03	1.35E-03	39.1%
5.00E-03	1.88E-03	9.77E-04	52.1%
7.00E-03	1.20E-03	7.13E-04	59.6%
1.00E-02	7.10E-04	4.75E-04	66.9%
1.50E-02	3.70E-04	2.80E-04	75.6%
2.00E-02	2.24E-04	1.84E-04	82.5%
3.00E-02	**1.04E-04**	**9.69E-05**	**92.8%**
5.00E-02	**3.66E-05**	**3.80E-05**	**103.8%**
7.00E-02	**1.75E-05**	**1.80E-05**	**103.4%**
1.00E-01	**7.68E-06**	**6.99E-06**	**91.1%**
1.50E-01	2.91E-06	1.90E-06	65.2%
2.00E-01	1.43E-06	6.45E-07	45.1%
3.00E-01	5.09E-07	1.13E-07	22.2%
5.00E-01	1.27E-07	8.60E-09	6.8%
7.00E-01	4.75E-08	1.25E-09	2.6%
1.00E+00	1.54E-08	1.31E-10	0.8%
1.50E+00	3.80E-09	7.72E-12	0.2%
2.00E+00	1.29E-09	8.60E-13	0.1%
3.00E+00	2.47E-10	6.26E-33	0.0%
5.00E+00	2.44E-11	6.26E-33	0.0%

(1) SSAR Table 2.5.2-13
(2) Reference RAI-43-1-3

As shown in Table RAI-43-1-2, the NMSZ rock hazard for 1Hz spectral accelerations of 0.1g to 0.03g (bolded rows in table) are approximately equal to those of the rock hazard for the source model used in the PSEG SSAR.

To illustrate the impact of the various NMSZ scenarios on the PSEG Site, a calculation of the GMRS values was performed for the various NMSZ scenarios and the source model used in the PSEG SSAR assuming rock site conditions. Soil GMRS values were not calculated to avoid complications caused by the effects of alternative rock ground motions on site amplification. Table RAI-43-1-3 lists the rock GMRS values for:

- the source model used in the PSEG SSAR (column 2),
- the NMSZ source model as used for the Bellefonte site (i.e., January 2003 start) (column 3);
- the scenario 1 NMSZ source model (column 4);

- the scenario 2 NMSZ source model (column 5);
- the scenario 3 NMSZ model (column 6), and;
- the percentage increase of the various NMSZ scenario GMRS values over the SSAR rock GMRS (columns 7 to 10).

Table RAI-43-1-3
Comparison of Rock GMRS Values

Period	Rock GMRS Values (g)					Percentage Increase Over PSEG SSAR			
	(2) PSEG SSAR	(3) SSAR + Bellefonte NMSZ	(4) SSAR + NMSZ Scen. 1	(5) SSAR + NMSZ Scen. 2	(6) SSAR + NMSZ Scen. 3	(7) SSAR + Bellefonte NMSZ	(8) SSAR + NMSZ Scen. 1	(9) SSAR + NMSZ Scen. 2	(10) SSAR + NMSZ Scen. 3
PGA	0.222	0.222	0.222	0.222	0.222	0.0%	0.0%	0.0%	0.0%
25 Hz	0.610	0.611	0.611	0.611	0.611	0.0%	0.0%	0.0%	0.0%
10 Hz	0.390	0.391	0.391	0.391	0.391	0.1%	0.1%	0.1%	0.1%
5 Hz	0.239	0.240	0.240	0.240	0.240	0.4%	0.4%	0.4%	0.4%
2.5 Hz	0.116	0.120	0.120	0.120	0.120	3.9%	4.1%	4.2%	4.2%
1 Hz	0.043	0.057	0.057	0.057	0.058	31.1%	32.7%	33.1%	33.4%
0.5 Hz	0.027	0.050	0.051	0.052	0.052	85.5%	89.3%	90.1%	90.9%

As shown in Table RAI-43-1-3, the largest impact of the NMSZ on the PSEG rock GMRS is at low frequencies (i.e., 1 Hz and 0.5 Hz), but the actual increase in ground motions is relatively small (e.g., less than 0.03g). In comparison, the impact of the different NMSZ scenarios that take into account potential delays in the start of operation of the plant is relatively small.

References:

RAI-43-1-1 Exelon Generation Company (EGC) Early Site Permit (ESP) Application for the EGC ESP Site, Rev. 4, April 4, 2006, NRC Docket No. 52-007

RAI-43-1-2 Johnston, A.C., and Schweig, 1996, The enigma of the New Madrid earthquakes of 1811-1812: Ann. Rev. Earth Planet. Sci., v. 24, p. 339-384

RAI-43-1-3 Tennessee Valley Authority (TVA) COL application for Bellefonte Nuclear Site, Units 3 & 4, Rev. 1, NRC Docket Nos. 52-014 and 52-015, Ascension Number # ML090290977

Associated PSEG Site ESP Application Revisions:

None.

Response to RAI No. 43, Question 02.05.02-4:

In Reference 2, the NRC staff asked PSEG for information regarding the Vibratory Ground Motion, as described in Subsection 2.5.2 of the Site Safety Analysis Report. The specific request for Question 02.05.02-4 was:

> *In accordance with NUREG-0800, Standard Review Plan, Section 2.5.2, "Vibratory Ground Motion," and Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site Specific Earthquake Ground Motion," the most up-to-date information available in the scientific literature should be considered as part of PSEG's ESP application. SSAR Subsection 2.5.2.2.2 discusses Post-EPRI-SOG seismic source zone characterization studies. Please address the following:*
>
> *a. SSAR Subsection 2.5.2.2.2 states that while the latest USGS PSHA study used new seismic model parameters for their Charlevoix seismic source, such as a lower b value, the EPRI-SOG source model was not updated because this update does not represent new information. In recent years, however, there has been significant new information on the nature of the Charlevoix and St. Lawrence rift seismic sources which might require updates to the original EPRI model. Please describe new findings described in the literature since the EPRI model and discuss how this new knowledge impacts the seismic hazard curves calculated for the PSEG site. Additionally, address the effect of the 1988 Saguenay M5.9 earthquake and its potential relationship to the Charlevoix and St. Lawrence rift seismic sources and source zone updates.*
>
> *b. New information is also available regarding potential updates to seismic sources in the New England area. Please describe the new findings in the literature since the EPRI model and discuss how this new knowledge impacts the seismic hazard curves calculated for the PSEG site.*

PSEG Response to NRC RAI:

The two parts of this RAI question (A and B) are addressed individually in the material below.

<u>Part A</u>

Four different sets of parameters are used to characterize seismic sources within the EPRI-SOG model: the geometry, the rate of earthquake occurrence, the maximum magnitude of earthquakes (Mmax), and the probability of activity (Pa). Each of the six EPRI-SOG teams individually evaluated these characteristics based on the data available at the time of the EPRI-SOG study (i.e., through the mid-1980s). To determine whether any data published since the EPRI-SOG study motivates updating the parameters of either the Charlevoix Seismic Zone (CSZ) or St. Lawrence Rift zones, the data are evaluated to determine whether it would impact any of these four characteristics. If the data were found to impact any of these characteristics, the data are then evaluated as to whether the corresponding changes to the source characterizations would result in a significant increase in hazard at the PSEG Site.

In evaluating the potential impact on the site hazard, it is important to note that the closest approach of the EPRI-SOG CSZ's to the PSEG Site is 500 to 600 mi. (800 to 970 km), and the closest approach of the St. Lawrence Rift zones is 350 mi to 450 mi. (560 to 720 km). These sources make only a small contribution to the low-frequency hazard at the PSEG Site (see SSAR Figures 2.5.2-25 and 2.5.2-27; note that the Charlevoix hazard contributes mainly in the 900-1000 km range; see SSAR Subsection 2.5.2.4.4 for discussion). Based on these observations, even a doubling of the hazard contribution from either the CSZ or St. Lawrence Rift zones would not significantly increase the hazard at the PSEG Site.

Geometry
The Charlevoix seismic zone is defined based on the pattern of earthquakes that are observed near Charlevoix and La Malbaie in Quebec, Canada (see SSAR Figures 2.5.2-5 through 2.5.2-10; zones are in the vicinity of latitude 47 degrees N and longitude 70 degrees W). Within this region there are hundreds of small earthquakes per year and there have been at least five to seven earthquakes with Mw > 6.0 in the past 10,000 years (SSAR References 2.5.2-12, -46, -55, -56, -57, and -58; References RAI-43-4-8 and -21).

The CSZ earthquakes occur within a northeast striking region roughly parallel to the St. Lawrence Seaway. This band of earthquakes is bound on the north and the south by Iapetan normal faults potentially reactivated during the Mesozoic opening of the Atlantic Ocean. Between these bounding faults are numerous supra-crustal faults related to a Devonian impact structure (SSAR Reference 2.5.2-58; Reference RAI-43-4-17). Since the 1970s there have been various opinions with respect to whether CSZ seismicity was occurring along Iapetan normal faults or impact related faults (SSAR References 2.5.2-7, -8, -12 and -46; References RAI-43-4-1, -6 and -16).

A more recent hypothesis developed with the increasing quality and quantity of earthquake locations within the CSZ is that small earthquakes tend to occur on impact related faults and larger earthquakes occur more proximal to the Iapetan normal faults (SSAR References 2.5.2-55, -58 and -93; Reference RAI-43-4-17 and RAI-43-4-22). However, the causative faults associated with the biggest earthquakes (Mw > 6.0) have not yet been identified. Researchers have also suggested that it is the interaction of the Iapetan normal faults with conditions local to the impact structure that cause the high seismicity rates within the CSZ (e.g., glacial rebound stresses, high pore-fluid pressures, stress concentrations from the interaction of the impact structure and the rift faults) (References RAI-43-4-3, -22, -23 and -24; SSAR Reference 2.5.2-56).

Based on these types of observations, the CSZ generally is defined based on the distribution of seismicity and potentially related geologic features (impact structure, Iapetan faults) within the region. Figure RAI-43-4-1 shows the EPRI-SOG seismic sources for the CSZ, the USGS characterization of the CSZ (SSAR Reference 2.5.2-68), the Geological Survey of Canada (GSC) zone for the CSZ (Reference RAI-43-4-15), and the EPRI-SOG seismicity. The figure shows that both the EPRI-SOG zones and the more recent zones encompass the same central cluster of seismicity in the St. Lawrence valley, but some of the EPRI-SOG zones extend further from the concentration of seismicity within the center of the seaway (e.g., see the Rondout, Woodward Clyde, and Dames & Moore zones). In most cases the drawing of a larger zone was intentional and reflects the interpretation of the teams that the potential source of large CSZ earthquakes was not limited to the region with the highest seismicity rates. For example, the Woodward Clyde team intentionally drew their zone larger in an attempt to encompass the intersection of the impact structure and the rift faults (SSAR Reference 2.5.2-34, vol. 8, p. B-7). Similarly, the Dames & Moore team recognized the high seismicity region of the CSZ as being much smaller than the zone they drew deciding to also capture the tectonic features associated with rifting and the impact structure (SSAR Reference 2.5.2-34, vol. 6, p. A56-A57). Based on the reasoning of the EPRI-SOG teams that defined broader zones for the CSZ, the newer information regarding the CSZ (e.g., more recent earthquakes, refined earthquake locations, new hypotheses on the causative faults for earthquakes within the CSZ) is not justification to alter the geometry of the EPRI-SOG zones. If the geometry of the EPRI-SOG zones were modified to more closely resemble the USGS or GSC zones, the changes would not cause a significant increase in hazard at the PSEG Site given the low contribution to hazard from the CSZ and the considerable distance between the zones and the PSEG Site (500 to 600 mi., 800 to 970 km).

The 1988 M5.9 (mb 6.2) Saguenay earthquake was also evaluated to determine whether it suggests the EPRI-SOG seismic sources representing the CSZ should be updated. The Saguenay earthquake occurred over 600 mi. (1000 km) from the PSEG Site and between approximately 20 to 80 km outside of the CSZ and St. Lawrence rift zones as defined by the various EPRI-SOG teams (Figure RAI-43-4-2). While the causative fault for the Saguenay earthquake has not been identified, most researchers consider the earthquake to not be a part of the CSZ (e.g., References RAI-43-4-1, -4, -8, -9 and -18; SSAR Reference 2.5.2-46). Support for this conclusion includes the observations that:

- The Saguenay earthquake occurred at a greater depth (26 km, 16 mi) than the vast majority of earthquakes within the CSZ (generally less than 20-25 km) (References RAI-43-4-4 and -19; SSAR Reference 2.5.2-58); the Saguenay earthquake occurred well outside of the impact structure related to the CSZ and the boundaries of the St. Lawrence rift (References RAI-43-4-18 and -20); the Saguenay earthquake occurred close to the Saguenay graben, an Iapetan failed rift that was later reactivated in the Jurassic (References RAI-43-4-18 and -20). It is impossible to determine how the EPRI-SOG teams would have addressed the Saguenay earthquake within their source characterizations. However, given the EPRI-SOG team's propensity towards using tectonic features to define seismic sources, most teams would probably have either drawn a separate seismic source to encompass the Saguenay graben or would have included the Saguenay graben in their St. Lawrence Rift zones. It is not necessary to define a new Saguenay graben source for the PSEG Site because including it would not significantly increase the hazard at the site. This evaluation is based on the observations that: (1) the seismic source would be approximately 600 mi. (1000 km) away from the PSEG site, and (2) the region of the Saguenay earthquake has low seismicity levels (Reference RAI-43-4-8) (Figure RAI-43-4-2) and is unlikely to significantly impact the ground motions at the PSEG Site.

Rate
The earthquake occurrence in the EPRI-SOG source model is characterized by the rate of earthquake occurrence (i.e., the a-value) and the slope (i.e., b-value) of the typical exponential magnitude-frequency distribution used to describe the occurrence of earthquakes. The b-values for the various smoothing options of the EPRI-SOG source characterizations of the CSZ are shown in Table RAI-43-4-1. As shown in the table, there is considerable variability in the b-values assigned to the CSZ. This variability is the result of the different smoothing assumptions that the EPRI-SOG teams used (SSAR Reference 2.5.2-36) and the spatial variability of seismicity within the CSZ (i.e., the EPRI-SOG methodology allowed for spatially variable b values on a 1° x 1° grid depending on the smoothing option) (SSAR Reference 2.5.2-33).

Many of the b-values used by the EPRI-SOG teams are consistent with those used in the more recent USGS National Seismic Hazard Maps for the CSZ (0.76) (SSAR Reference 2.5.2-68). The b-value used in the USGS maps was determined from the magnitude-frequency relationship for earthquakes surrounding the Charlevoix region (see Figure 2 of Reference RAI-43-4-2). The differences between the single b-value used by the USGS and the various b-values considered by the EPRI-SOG teams are primarily due to the different seismic source geometries (i.e., different earthquakes within the zones) and the different smoothing options used by the teams (e.g., constant b within a zone, strong or weak priors on b) (SSAR Reference 2.5.2-36).

Table RAI-43-4-1
Seismicity Rate of Occurrence Parameters for EPRI-SOG CSZs

Zone	Smoothing Option and Weight (1)	B value	Mean Return Period for Earthquakes with Mw ≥ 6.2 (mb 6.4)
Bechtel 3	1 (0.33)	0.704	771 yrs
	2 (0.34)	0.700 to 0.707	
	4 (0.33)	0.723 to 0.703	
Dames & Moore 59	1 (0.26)	0.847 to 1.062	593 yrs
	2 (0.09)	0.747 to 1.01	
	3 (0.48)	0.91 to 0.916	
	4 (0.17)	0.801 to 0.808	
Law 12	1e (1.0)	0.752 to 0.758	406 yrs
Rondout 37	5 (1.0)	0.700	144 yrs
Weston 1	1b (1.0)	0.79	249 yrs
Woodward-Clyde 12	2 (0.25)	0.835 to 0.971	779 yrs
	3 (0.25)	0.869 to 0.996	
	4 (0.25)	0.841 to 0.967	
	5 (0.25)	0.814 to 0.933	

(1) SSAR Reference 2.5.2-36

The a-values for the EPRI-SOG model are determined from the rate of historical earthquake occurrence. There is no new information published since the EPRI-SOG to suggest that the rate of earthquakes within the CSZ has significantly increased since the EPRI-SOG study (e.g., SSAR References 2.5.2-55, -56 and -58; RAI Reference RAI-43-4-1). Therefore, there are no new historical data to suggest the need to update the a-values for the CSZ.

There are new data published concerning prehistoric earthquakes within the CSZ. Tuttle and Atkinson (RAI Reference RAI-43-4-21) report paleoliquefaction evidence for three earthquakes of Mw ≥ 6.2 (mb ≥ 6.4) within the past 10,000 years. Table RAI-43-4-1 summarizes the mean return period of earthquakes with Mw ≥ 6.2 as defined for the various EPRI-SOG characterizations of the CSZ. As shown in the table, all of the EPRI-SOG teams characterize the CSZ as having Mw ≥ 6.2 earthquakes on a much shorter time scale (on the order of hundreds of years) than the paleoliquefaction data suggest (on the order of thousands of years). Therefore, there is no new paleoseismic information that suggests the rates of the EPRI-SOG CSZ need to be updated.

The occurrence of the Saguenay earthquake also does not indicate a need to increase the rates of any EPRI-SOG seismic sources. The number of earthquakes within the region of the Saguenay earthquake is relatively low (Reference RAI-43-4-8; Figure RAI-43-4-2) and there is no published evidence of an increase in seismicity rate since the EPRI-SOG study.

Maximum Magnitude
The maximum magnitudes (Mmax) of the CSZ and St. Lawrence seismic zones are presented in SSAR Tables 2.5.2-3 through 2.5.2-8 and summarized in Table RAI-43-4-2. To determine whether there is new information that suggests the Mmax values should be updated, three types of data are reviewed: (1) paleoearthquake data, (2) studies that revise the magnitude of historical earthquakes within the EPRI-SOG catalog, and (3) post-EPRI-SOG seismicity to determine if there are new earthquakes with magnitudes greater than the lower-bound Mmax values.

As described above, the paleoearthquake data in RAI Reference RAI-43-4-21 suggest that there were three earthquakes with Mw ≥ 6.2 (mb 6.4) in the Charlevoix region. This magnitude is less than or equal to the lower-bound Mmax value of the Charlevoix seismic sources defined by each of the EPRI-SOG teams (see SSAR Tables 2.5.2-3 through 2.5.2-8). Therefore, the paleoearthquake data do not provide any new information to suggest that the Mmax values of the EPRI-SOG characterizations for the CSZ need to be updated. Also, there are no paleoliquefaction data for the St. Lawrence rift zones relevant to evaluating the Mmax values for the related zones.

The most significant study since the completion of the EPRI-SOG study reevaluating the magnitude of earthquakes within the CSZ or St. Lawrence Rift region is that of Ebel (Reference RAI-43-4-13) that conducted an analysis of the magnitude of the 1663 Charlevoix earthquake using records of chimney damage in Massachusetts, estimated dimensions of a potential rupture plane within the CSZ, and comparison to the 1811-1812 earthquake sequence in New Madrid. Based on these various approaches, Ebel (Reference RAI-43-4-13) states that his best estimate of the magnitude of the 1663 Charlevoix earthquake is Mw 7.3 to 7.9 (mb 7.1 to 7.4). This magnitude is greater than the magnitude given to the earthquake in the EPRI-SOG study (mb 6.1) (SSAR Reference 2.5.2-35) and by other researchers (SSAR Reference 2.5.2-57).

The magnitude range of Ebel (Reference RAI-43-4-13) is also greater than the lower-bound Mmax value for some of the EPRI-SOG teams (e.g., Bechtel, Law, Woodward-Clyde) (Table RAI-43-4-2). However, increasing the lower-bounds of the Bechtel, Law, and Woodward-Clyde CSZ Mmax distributions is unlikely to significantly impact the ground motion at the PSEG Site. The basis for this evaluation is that:

- The Charlevoix seismic zone has only a minor contribution to the low-frequency hazard for the 10^{-4} deaggregation (SSAR Figure 2.5.2-25);
- Modifications to the Mmax distributions of three teams with lower-bounds less than mb 7.1 (i.e., raising the mean Mmax on the order of tenths of magnitude units) is unlikely to result in a significant increase in the ground motion contribution from the CSZ; and
- The magnitude estimates of Ebel (Reference RAI-43-4-13) are values from a very recent publication by only one researcher and are not considered either definitive or consensus estimates.

Table RAI-43-4-2
EPRI-SOG Maximum Magnitude Values for the Charlevoix Seismic Zone and St. Lawrence Rift Zones

Team	Charlevoix Seismic Zone		St. Lawrence Rift	
	Mmax (mb) [weight]	Mean	Mmax (mb) [weight]	Mean
Bechtel	6.4 [0.1] 6.6 [0.1] 6.7 [0.4] 7.0 [0.4]	6.8	6.4 [0.1] 6.6 [0.1] 6.7 [0.4] 7.0 [0.4]	6.8
Dames & Moore	7.2 [1.0]	7.2	6.4 [0.75] 7.2 [0.25]	6.6
Law	6.4 [0.2] 7.4 [0.8]	7.2	5.0 [0.2] 5.8 [0.5] 7.4 [0.3]	6.1
Rondout	7.1 [0.1] 7.3 [0.8] 7.4 [0.1]	7.3	5.8 [0.15] 6.5 [0.60] 6.8 [0.25]	6.5
Weston	7.2 [1.0]	7.2	5.4 [0.55] 6.0 [0.28] 6.6 [0.14] 7.2 [0.03]	5.8
Woodward-Clyde	6.5 [0.33] 7.0 [0.34] 7.5 [0.33]	7.0	6.6 [0.33] 6.8 [0.34] 7.3 [0.33]	6.9

As part of the response to RAI No. 43, Question 02.05.02-2, an updated seismicity catalog was developed to determine if there are any post-EPRI-SOG earthquakes within the zones that were considered for the PSEG Site (see SSAR Tables 2.5.2-3 through 2.5.2-8) with magnitudes greater than the lower-bound Mmax values for those zones. As described in that response, a 2002 mb 5.2 earthquake that occurred within Law Zone 9 potentially impacts the Mmax values for that zone. Otherwise there are no post-EPRI-SOG earthquakes within either the CSZ or the St. Lawrence Rift zones that are greater than the lower-bound Mmax of the respective source characterizations for any team.

As previously discussed, the Saguenay earthquake occurred outside of both the St. Lawrence Rift zones and the Charlevoix zones for all of the EPRI-SOG teams (Figure RAI-43-4-2). Also as previously discussed, the EPRI-SOG model could be updated to incorporate the Saguenay earthquake in one of three ways: (1) update the zones that the earthquake occurs within as needed, (2) update the St. Lawrence Rift zones to account for the Saguenay earthquake as needed, or (3) define a new seismic source for the Saguenay graben. If the EPRI-SOG teams were to define unique zones for the Saguenay graben, there would be no impact on the PSEG Site because the zones would have a relatively low seismicity rate and would be at a considerable distance to the PSEG site (greater than 500 mi., 800 km) (Figure RAI-43-4-2). The potential impact of updating the Mmax values of the existing seismic sources on the PSEG Site is discussed below for each team. This discussion is based on considering either option 1 or 2 above to account for the Saguenay earthquake, but it is possible individual teams would have created new Saguenay zones instead (option 3). Tables RAI-43-4-2 and RAI-43-4-3 summarize the Mmax and Pa values for the zones discussed below.

Bechtel – The zone containing the Saguenay earthquake (BZ7) is a large background zone, and it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of the background zone, to account for the earthquake. The Bechtel team defined a Mmax distribution for the zone with a lower-bound greater than the magnitude of the Saguenay earthquake (mb 6.2) (Table RAI-43-4-2). Therefore, the Mmax of the zone would not need to be updated and there would be no impact on seismic hazard for the PSEG Site.

Dames & Moore – The zone containing the Saguenay earthquake (72) is a large background zone, and it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of the background zone, to account for the earthquake. The Dames & Moore team defined a Mmax distribution for the zone with a lower-bound greater than the magnitude of the Saguenay earthquake (mb 6.2) (Table RAI-43-4-2). Therefore, the Mmax of the zone would not need to be updated and there would be no impact on the PSEG Site.

Law – The Law team identified the Saguenay graben as a tectonic feature and defined a seismic source that roughly encompasses the graben (109). This zone also contains the Saguenay earthquake. Therefore, it is reasonable to assume that the team would have updated Zone 109 to account for the earthquake instead of the St. Lawrence Rift zone. Because the Mmax of Zone 109 is defined using a single magnitude that is less than that of the Saguenay earthquake (mb 5.5 compared to mb 6.2) (Table RAI-43-4-3), the Mmax would need to be updated for the Saguenay earthquake. However, the closest approach of this zone to the PSEG Site is approximately 300 mi. (500 km), and it is unlikely updating the zone will significantly increase the postulated ground motion at the site.

Rondout – The zone containing the Saguenay earthquake (50) is a large background zone, and it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of the background zone, to account for the earthquake. The lower-bound Mmax for the zone is mb 5.8 (Table RAI-43-4-2), less than the mb 6.2 magnitude of the Saguenay earthquake, so the Mmax distribution would need to be updated. However, it is unlikely that updating the Mmax values would significantly increase the ground motion at the PSEG Site because of: (1) the considerable distance between the site and the zone (> 460 mi., 740 km), (2) the relatively small update to the Mmax values (i.e., only 0.15 weight is given to a magnitude that is below mb 6.2), and (3) the fact that the zone was already identified as not contributing to the seismic hazard at the PSEG Site.

Weston – The zone containing the Saguenay earthquake (18) was used by the Weston team to calculate seismicity rates for the CSZ and was not intended to be a seismic source used in the PSHA (SSAR Reference 2.5.2-34). Therefore it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of zone 18, to account for the earthquake. The lower-bound Mmax for the zone is mb 5.4 (Table RAI-43-4-2), less than the mb 6.2 magnitude of the Saguenay earthquake, so the Mmax distribution would need to be updated. However, it is unlikely that updating the Mmax values would significantly impact the PSEG Site because of: (1) the significant distance between the site and the zone (> 466 mi., 750 km), (2) the relatively small update to the Mmax values (i.e., the current mean Mmax for the zone is already mb 5.8 compared to the mb 6.2 magnitude of the Saguenay earthquake), and (3) the fact that the zone was already identified as not contributing to the seismic hazard at the PSEG Site.

Woodward-Clyde – The Woodward-Clyde team did not define a seismic source in the region of the Saguenay earthquake, so it is reasonable to assume that the team would have updated the St. Lawrence rift zone. The Woodward-Clyde team defined a Mmax distribution for the zone with a lower-bound greater than the magnitude of the Saguenay earthquake (mb 6.2) (Table RAI-43-4-2). Therefore, the Mmax of the zone would not need to be updated and there would be no impact on the seismic hazard for the PSEG Site.

Probability of Activity
The probability of activity represents the probability that a given source is capable of generating earthquakes greater than the minimum magnitude considered in the EPRI-SOG PSHA (mb 5.0) (SSAR Reference 2.5.2-35). In the simplest sense, the probability of activity for any given seismic source may need to be updated if there is evidence of an earthquake of magnitude greater than or equal to mb 5.0 within the zone when there was not one known of at the time of the EPRI-SOG study. For the CSZ, there was evidence that the seismic zone was capable of mb > 5.0 earthquakes at the time of the EPRI-SOG study (e.g., the 1 March 1925 Emb 6.4 earthquake). Therefore, the new paleoearthquake data from the CSZ do not present any new information that would motivate updating the Pa values for the CSZ.

As previously discussed, the Saguenay earthquake occurred outside of both the St. Lawrence Rift zones and the Charlevoix zones for all of the EPRI-SOG teams (Figure RAI-43-4-2). Also as previously discussed, the EPRI-SOG model could be updated to incorporate the Saguenay earthquake in one of three ways: (1) update the zones that the earthquake occurs within as needed, (2) update the St. Lawrence Rift zones to account for the Saguenay earthquake as needed, or (3) define a new seismic source for the Saguenay graben. If the EPRI-SOG teams were to define unique zones for the

Saguenay graben, there would be no impact on the PSEG Site because the zones would have a relative low seismicity rate and would be at a considerable distance to the PSEG site (Figure RAI-43-4-2). The potential impact of updating Pa for the existing seismic sources (update options 1 and 2) on the PSEG Site is discussed below for each team. Table RAI-43-4-3 summarizes the Mmax and Pa values for the zones discussed below.

Bechtel – The zone containing the Saguenay earthquake (BZ7) is a large background zone, and it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of the background zone, to account for the earthquake. The Bechtel team identified an earthquake within the St. Lawrence Rift zone with mb ≥ 5.0, but the zone was given a Pa of less than 1. Therefore, it is uncertain if the Pa of the zone should be updated to account for the Saguenay earthquake. If the Pa was updated, it is unlikely to cause a significant increase in hazard at the PSEG Site given the considerable distance between the zone and the site (> 454 mi, 731 km) and the low seismicity rate within the zone.

Dames & Moore – The zone containing the Saguenay earthquake (72) is a large background zone, and it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of the background zone, to account for the earthquake. Because the Pa for the St. Lawrence Rift zone is already 1.0, no updates would be required, and there would be no impact on the seismic hazards at the PSEG Site.

Law – The Law team identified the Saguenay graben as a tectonic feature and defined a seismic source that roughly encompasses the graben (109). This zone also contains the Saguenay earthquake. Therefore, it is reasonable to assume that the team would have updated Zone 109 to account for the earthquake. The Pa of Zone 109 is 1.0, so there would be no impact on the seismic hazards at the PSEG Site.

Rondout – The zone containing the Saguenay earthquake (50) is a large background zone, and it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of the background zone, to account for the earthquake. The Pa of the St. Lawrence rift zone is 0.99, so there would be no impact of updating the Pa value on the seismic hazards at the PSEG Site.

Weston – The zone containing the Saguenay earthquake (18) was used by the Weston team to calculate seismicity rates for the CSZ and was not intended to be a seismic source used in the PSHA (SSAR Reference 2.5.2-34). Therefore it is reasonable to assume that the team would have updated the St. Lawrence Rift zone, instead of zone 18, to account for the earthquake. Because the Pa for the St. Lawrence Rift zone is already 1.0, no updates would be required, and there would be no impact on the seismic hazard at the PSEG Site.

Woodward-Clyde – The Woodward-Clyde team did not define a seismic source in the region of the Saguenay earthquake, so it is reasonable to assume that the team would have updated the St. Lawrence rift zone. The Pa of the zone is 0.25, so it would need to be updated. However, it is unlikely that updating this Pa would have a significant impact on the PSEG Site due to the considerable distance between the zone and the site (> 354 mi., 569 km) and the fact that this zone did not originally contribute to the site hazard (SSAR Table 2.5.2-8).

Summary

The EPRI-SOG source characterizations used for the PSEG Site were reviewed to determine: (1) if the occurrence of the Saguenay earthquake or new information regarding the CSZ suggest that the EPRI-SOG source characterizations used for the PSEG Site need to be updated, and (2) if these updates would significantly increase the hazard at the PSEG Site.

This review showed that there were the following potential updates to the PSEG Site source characterization:

- Bechtel
  - Update Mmax for the CSZ (3) to account for the revised 1663 earthquake magnitude of Ebel (Reference RAI-43-4-13)
  - Update the Pa value for the St. Lawrence Rift zone (2) to account for the Saguenay earthquake
- Law
  - Update Mmax for the CSZ (12) to account for the revised 1663 earthquake magnitude of Ebel (Reference RAI-43-4-13)
  - Update Mmax for zone 109 to account for the Saguenay earthquake
- Rondout
  - Update the Mmax for the St. Lawrence Rift zone (39) to account for the Saguenay earthquake
- Weston
  - Update the Mmax for the St. Lawrence Rift zone (4) to account for the Saguenay earthquake
- Woodward-Clyde
  - Update Mmax for the CSZ (12) to account for the revised 1663 earthquake magnitude of Ebel (Reference RAI-43-4-13)
  - Update the Pa for the St. Lawrence Rift zone (14) to account for the Saguenay earthquake

However, it is unlikely that any of these potential updates would significantly increase the ground motions at the PSEG Site. Individual justifications for this evaluation are presented above, but a fundamental principal in all of the cases is that the potential updates are too small to have a significant impact given: (1) the considerable distance between the site and the seismic sources (generally over 400 mi., 650 km); and (2) the relatively small contribution to the site hazard (e.g., several percent at long periods at an annual frequency of exceedence of 10^{-4}; see SSAR Subsection 2.5.2.4.4 for discussion). Also, the updates for the Saguenay earthquake are just one interpretation of how the EPRI-SOG model could be updated. It is also possible that some or all the EPRI-SOG teams would have developed specific characterizations of the Saguenay graben. In this case, there would be no impact on the PSEG site due to the considerable distance between these new zones (approximately 600 mi, 1000 km) and the site and the low rate of seismicity within the zones. The expectation based on material presented in this response is that these potential updates will not significantly increase the ground motion at the PSEG Site. A sensitivity study is being conducted to estimate their potential impact. The results of this sensitivity study will be presented with the response to RAI No. 43, Question 02.05.02-5.

The review also demonstrates that:

- There is no need to update the geometry of the CSZ because (1) the current geometries encompass the current state of knowledge regarding the CSZ, and (2) minor modifications to the geometry will not significantly increase the seismic hazard at the PSEG site;
- There is no need to update the geometry of any zones to account for the Saguenay earthquake because (1) the potentially impacted zones are at a considerable distance from the site (greater than 600 mi., 1000 km), (2) there are low seismicity levels in the Saguenay region; and
- There is no need to update the rate of earthquake occurrence because there is no published information to suggest that the rate of earthquake occurrence is significantly higher than defined within the EPRI-SOG source characterizations.

Table RAI-43-4-3

EPRI-SOG Maximum Magnitude and Pa Values for the St. Lawrence Rift Zones and the Zones Containing the Saguenay Earthquake

Team	Zone Containing Saguenay Earthquake			St. Lawrence Rift	
	Zone	Mmax (mb) [weight]	Pa	Mmax (mb) [weight]	Pa
Bechtel	BZ7	6.0 [0.1] 6.3 [0.4] 6.6 [0.5]	1.0	6.4 [0.1] 6.6 [0.1] 6.7 [0.4] 7.0 [0.4]	0.45
Dames & Moore	72	5.6 [0.8] 7.2 [0.2]	1.0	6.4 [0.75] 7.2 [0.25]	1.0
Law	109	5.5 [1.0]	1.0	5.0 [0.2] 5.8 [0.5] 7.4 [0.3]	0.89
Rondout	50	4.8 [0.2] 5.5 [0.6] 5.8 [0.2]	1.0	5.8 [0.15] 6.5 [0.60] 6.8 [0.25]	0.99
Weston	18	5.4 [0.55] 6.0 [0.28] 6.6 [0.14] 7.2 [0.03]	1.0	5.4 [0.55] 6.0 [0.28] 6.6 [0.14] 7.2 [0.03]	1.0
Woodward -Clyde	*No zones*	*NA*	*NA*	6.6 [0.33] 6.8 [0.34] 7.3 [0.33]	0.25

Part B

During a clarification call with the NRC on December 12, 2011, the NRC indicated that this RAI question was partially motivated by post-EPRI-SOG research by John Ebel and other researchers that focused on revising the magnitude of historical earthquakes in the New England region. Therefore, as part of the effort to respond to this RAI, a review of published seismicity studies of the New England region was conducted. This review identified several studies that present magnitudes and/or locations of earthquakes with magnitudes greater than or equal to 5.0 that are different from those presented within the EPRI-SOG seismicity catalog (SSAR Section 2.5.2.1.1). Earthquakes with magnitudes greater than or equal to mb 5.0 are of interest because these earthquakes may potentially impact the Mmax and Pa values that the EPRI-SOG teams defined for seismic sources containing those earthquakes.

The identified studies included References RAI-43-4-5, -7, -10, -11, -12 and -14. From these studies there are 7 earthquakes of magnitude 5 or greater with magnitudes and/or locations different from the EPRI-SOG catalog that were developed after the EPRI-SOG study catalog (approximately 1985). A summary of the earthquakes is presented in Table RAI-43-4-4, and the earthquakes are shown in Figure RAI-43-4-3.

Table RAI-43-4-4

Alternate Earthquake Magnitudes and Locations

Date	Location in EPRI-SOG Catalog	Alternate Locations	EPRI-SOG Magnitude (Emb)	Alternate Magnitudes
1755-11-18	42.7N 70.3W	43N 69.6W, Ref. RAI-43-4-5 42.8N 70.08W, Ref. RAI-43-4-12	5.65	6.1 M_I, Ref. RAI-43-4-5 6.2 M_{Lg}, Ref. RAI-43-4-12
1638-06-11	*Not EPRI-SOG catalog*	44.4N 71.8W, Ref. RAI-43-4-10	*NA*	6.5 ± 0.5 M_{Lg}, Ref. RAI-43-4-10
1727-11-10	42.8N 70.6W	Between Newbury and Amesbury, MA, Ref. RAI-43-4-11	4.9	5.6 mb, Ref. RAI-43-4-11
1940-12-20	43.87N 71.37W	*None*	5.29	5.5 mb, Ref. RAI-43-4-14
1944-09-5	44.96N 74.72W	*None*	5.71	4.6 mb, Ref. RAI-43-4-14
1883-01-1	45N 67W	42N 64W, Ref. RAI-43-4-7	3.7	5.3 M_L, Ref. RAI-43-4-7
1869-10-22	45N 67.2W	46.5N 66.5W, Ref. RAI-43-4-7	5.5	*None*

Legend for symbols:
M_I = intensity magnitude,
M_{Lg} = Lg wave magnitude,
Mw = moment magnitude,
mb = body-wave magnitude,
M_L = local magnitude,
Emb = estimated body-wave magnitude

To determine whether the revised locations and magnitudes impact the EPRI-SOG source characterizations used for the PSEG Site, the EPRI-SOG seismic sources considered for the PSEG Site (i.e., those within 200-miles of the site) (SSAR Tables 2.5.2-3 through 2.5.2-8) were reviewed to determine whether any of the earthquakes were located within them. Table RAI-43-4-5 summarizes the zones within which the earthquakes occur, and Figure RAI-43-4-3 shows the location of the earthquakes and related seismic sources. The following discussion outlines the potential impact of the earthquakes on the Mmax and Pa values for the respective zones (see Table RAI-43-4-6).

Table RAI-43-4-5
EPRI-SOG Seismic Sources Considered for the PSEG Site within which the Earthquakes Occur

Date	Bechtel	Dames & Moore	Law	Rondout	Weston	Woodward-Clyde
1755-11-18	BZ8	63	C11, C13	NA	NA	NA
1638-06-11	BZ8	53	102	NA	NA	NA
1727-11-10	BZ8	63	C11, C13	NA	NA	NA
1940-12-20	BZ8	NA	102	NA	NA	NA
1944-09-5	NA	NA	NA	NA	NA	NA
1883-01-1	BZ8 for EPRI-SOG location; NA for alternate location	NA for EPRI-SOG location; 63 for alternate location	C11, C13 for EPRI-SOG location; NA for alternate location	NA	NA	NA
1869-10-22	BZ8	NA	C11, C13 for EPRI-SOG location; 102 for alternate location	NA	NA	NA

"NA" signifies that the earthquake was not in any of the zones considered for a team.

Table RAI-43-4-6
Mmax and Pa Values for EPRI-SOG Seismic Sources

Team	Zone	Mmax (mb) and weight	Pa
Bechtel	BZ8	5.7 [0.1] 6.0 [0.4] 6.3 [0.4] 6.6 [0.1]	1.0
Dames & Moore	63	5.7 [0.8] 7.2 [0.2]	0.72
Dames & Moore	53	5.6 [0.8] 7.2 [0.2]	0.26
Law	C11, C13	6.8 [1.0]	NA
Law	102	5.7 [1.0]	1.0

18 November 1755

The 18 November 1755 earthquake is commonly referred to as the Cape Ann Earthquake (Reference RAI-43-4-12). Both the EPRI-SOG study and the more recent studies (References RAI-43-4-5 and -12) locate the earthquake off of the northern Massachusetts-New Hampshire coast, but with slightly different locations (Figure RAI-43-4-3). The EPRI-SOG study defines the magnitude of the earthquake as Emb 5.65, and the more recent studies defined the magnitude as approximately mb 6.2 (using the assumption of the updated catalog presented in SSAR Subsection 2.5.2.4.2.1 that M_{Lg} is equivalent to mb). The potential impact of this more recent magnitude on each zone is described below.

Bechtel – The Pa of zone BZ8 is 1.0, so the earthquake does not impact the Pa value. The lower-bound Mmax value for BZ8 is 5.7, so some weight could potentially be given to a Mmax distribution for BZ8 that takes into account the mb 6.2 earthquake.

Dames & Moore – The Pa of zone 63 is 0.72, but the earthquake does not motivate revising the Pa value for the zone. This conclusion is based on the observation that the Dames & Moore team was fully aware of the Cape Ann earthquake within zone 63 (characterized as Emb 5.65) and intentionally defined a Pa for the zone that was less than 1 (SSAR Reference 2.5.2-35). Presumably this decision by the team was based on their interpretation that the earthquake could have occurred within either zone 63 or zone 62 (the complimentary zone to 63 with a Pa of 0.28) (SSAR Reference 2.5.2-36) given the uncertainty in the earthquake location. The lower-bound Mmax value for zones 63 and 62 is 5.7, so some weight could potentially be given to a Mmax distribution for these zones that take into account the mb 6.2 earthquake.

Law – The earthquake occurs within two combination zones (C11 and C13). The Mmax value for these zones is 6.8, so the more recent magnitude for the earthquake does not impact the Mmax distribution. These zones are combination zones and do not have an explicit Pa value.

11 June 1638

The 11 June 1638 earthquake was not identified within the EPRI-SOG catalog. RAI Reference RAI-43-4-10 describes the earthquake as having a magnitude of M_{Lg} 6.5 ± 0.5 (assumed equivalent to mb 6.5 ± 0.5) and as being located in central New Hampshire (Figure RAI-43-4-3). The potential impact of this earthquake on each zone is described below.

Bechtel – The Pa of zone BZ8 is 1.0, so the earthquake does not impact the Pa value. The lower-bound Mmax value for BZ8 is 5.7, so some weight could potentially be given to a Mmax distribution for the zone that takes into account the mb 6.5 earthquake.

Dames & Moore – The Pa of zone 53 is 0.26, but the earthquake does not motivate revising the Pa value for the zone. This conclusion is based on: (1) the observation that there is considerable uncertainty in the location of the earthquake (on the order of 100s of mi/km) compared to how close the earthquake is to the borders of the zone (5 mi., 7 km), and (2) the fact that zone 53 is a default zone (mutually exclusively active) (SSAR Reference 2.5.2-36) for other zones that could potentially be the source of the earthquake. The lower-bound Mmax value for zone 63 is 5.6, so some weight could potentially be given to a Mmax distribution for the zone that takes into account the mb 6.5 earthquake.

Law – The Pa of zone 102 is 1.0, so the earthquake does not impact the Pa value. The Mmax for zone 102 is 5.7, so some weight could potentially be given to a Mmax distribution for the zone that takes into account the mb 6.5 earthquake.

10 November 1727
The EPRI-SOG study locates the 10 November 1727 earthquake offshore Massachusetts, and Reference RAI-43-4-11 vaguely describes the earthquake as being located between Newbury and Amesbury, MA (roughly due west and just onshore of the EPRI-SOG location) (Figure RAI-43-4-3). Given the difficultly in constraining the location of an earthquake as being along the coast versus slightly offshore when using felt reports, these two locations should be considered indiscernible. The EPRI-SOG study describes the earthquake as Emb 4.9, and Reference RAI-43-4-11 describes the earthquake as mb 5.6. The potential impact of this more recent magnitude on each zone is described below.

Bechtel – The Pa of zone BZ8 is 1.0, so the earthquake does not impact the Pa value. The lower-bound Mmax value for BZ8 is 5.7, so the earthquake does not impact the Mmax distribution for the zone.

Dames & Moore – The Pa of zone 63 is 0.72, but the earthquake does not motivate revising the Pa value for the zone. This conclusion is based on the same reasoning presented for the 18 November 1755 earthquake. The lower-bound Mmax value for zone 63 is 5.7, so the earthquake does not impact the Mmax distribution for the zone.

Law – The earthquake occurs within two combination zones (C11 and C13). The Mmax value for these zones is 6.8, so the more recent magnitude for the earthquake does not impact the Mmax distribution. The zones are combination zones, so they do not have an explicit Pa value.

20 December 1940
The EPRI-SOG study describes the earthquake as Emb 5.29, and Ebel et al. (Reference RAI-43-4-14) describe the earthquake as mb 5.5. Ebel et al. (Reference RAI-43-4-14) do not provide a location for the earthquake that was developed following the EPRI-SOG study (Figure RAI-43-4-3). The potential impact of this more recent magnitude on each zone is described below.

> Bechtel – The Pa of zone BZ8 is 1.0, so the earthquake does not impact the Pa value. The lower-bound Mmax value for BZ8 is 5.7, so the earthquake does not impact the Mmax distribution for the zone.
>
> Law – The Pa of Zone 102 is 1.0, so the earthquake does not impact the Pa value. The Mmax for Zone 102 is 5.7, so the earthquake does not impact the Mmax distribution for the zone.

5 September 1944
The EPRI-SOG study describes the earthquake as Emb 5.71, and Reference RAI-43-4-14 describes the earthquake as mb 4.6. RAI Reference RAI-43-4-14 does not provide a location for the earthquake that was developed following the EPRI-SOG study (Figure RAI-43-4-3). The earthquake does not occur within any of the EPRI-SOG zones considered for the PSEG Site, so the more recent earthquake magnitude does not impact any of the source characterizations.

1 January 1883
The EPRI-SOG study describes the earthquake as Emb 3.7, and RAI Reference RAI-43-4-7 describes the earthquake as M_L 5.3 (equivalent to mb 5.3 using the assumption of the updated catalog presented in SSAR Subsection 2.5.2.4.2.1 that M_L is equivalent to mb). Reference RAI-43-4-7 also locates the earthquake significantly further to the east and south than the EPRI-SOG location (Figure RAI-43-4-3). The potential impact of this more recent magnitude and location on each zone is described below.

> Bechtel – The more recent location moves the earthquake from BZ8 to a region outside of any zones considered for the PSEG Site, so the earthquake does not impact the Bechtel source characterizations.
>
> Dames & Moore – The more recent location moves the earthquake from outside of any sources considered for the PSEG Site into zone 63. The Pa of zone 63 is 0.72, but the earthquake does not motivate revising the Pa value for the zone. This conclusion is based on the same reasoning presented for the 18 November 1755 earthquake. The lower-bound Mmax value for zone 63 is 5.7, so the earthquake does not impact the Mmax distribution for the zone.
>
> Law – The more recent location moves the earthquake from within zones C11 and C13 to a region outside of any zones considered for the PSEG Site, so the earthquake does not impact the Law source characterizations.

22 October 1869
The EPRI-SOG study describes the earthquake as Emb 5.5, and Reference RAI-43-4-7 does not present a revised post-EPRI-SOG magnitude for the earthquake. Reference RAI-43-4-7 also locates the earthquake further north than the EPRI-SOG location (Figure RAI-43-4-3). The potential impact of this more recent magnitude and location on each zone is described below.

> Bechtel – The Pa of Zone BZ8 is 1.0, so the earthquake does not impact the Pa value. The lower-bound Mmax value for BZ8 is 5.7, so the earthquake does not impact the Mmax distribution for the zone.
>
> Law – The more recent location moves the earthquake from within Zones C11 and C13 into Zone 102. Law – The Pa of Zone 102 is 1.0, so the earthquake does not impact the Pa value. The Mmax for Zone 102 is 5.7, so the earthquake does not impact the Mmax distribution for the zone.

Summary
The EPRI-SOG source characterizations used for the PSEG Site were reviewed to determine if more recently developed magnitudes and locations of earthquakes within the EPRI-SOG source catalog might potentially impact the source characterizations used for the PSEG Site. This review showed that there were the following potential updates to the PSEG Site source characterization:

- Bechtel
  - Apply some weight to a Mmax distribution for zone BZ8 that encompasses the mb 6.2 1755 earthquake and the mb 6.5 1638 earthquake
- Dames & Moore
  - Apply some weight to a Mmax distribution for zones 63 and 62 that encompasses the mb 6.2 1755 earthquake and the mb 6.5 1638 earthquake
- Law
  - Apply some weight to a Mmax distribution for zone 102 that encompasses the mb 6.5 1638 earthquake

It should be emphasized that these potential updates are primarily based on identification of an earthquake by Ebel (Reference RAI-43-4-10) that was not included in the EPRI-SOG catalog. The magnitude and location of this earthquake presented in Reference RAI-43-4-10 represents the recently published interpretation of a single researcher and are neither definitive nor consensus estimates. It is expected that the impact of these potential updates will be small. A sensitivity study is being conducted to estimate the impact of these updates, and the results of this study will be provided with the response to RAI No. 43, Question 02.05.02-5.

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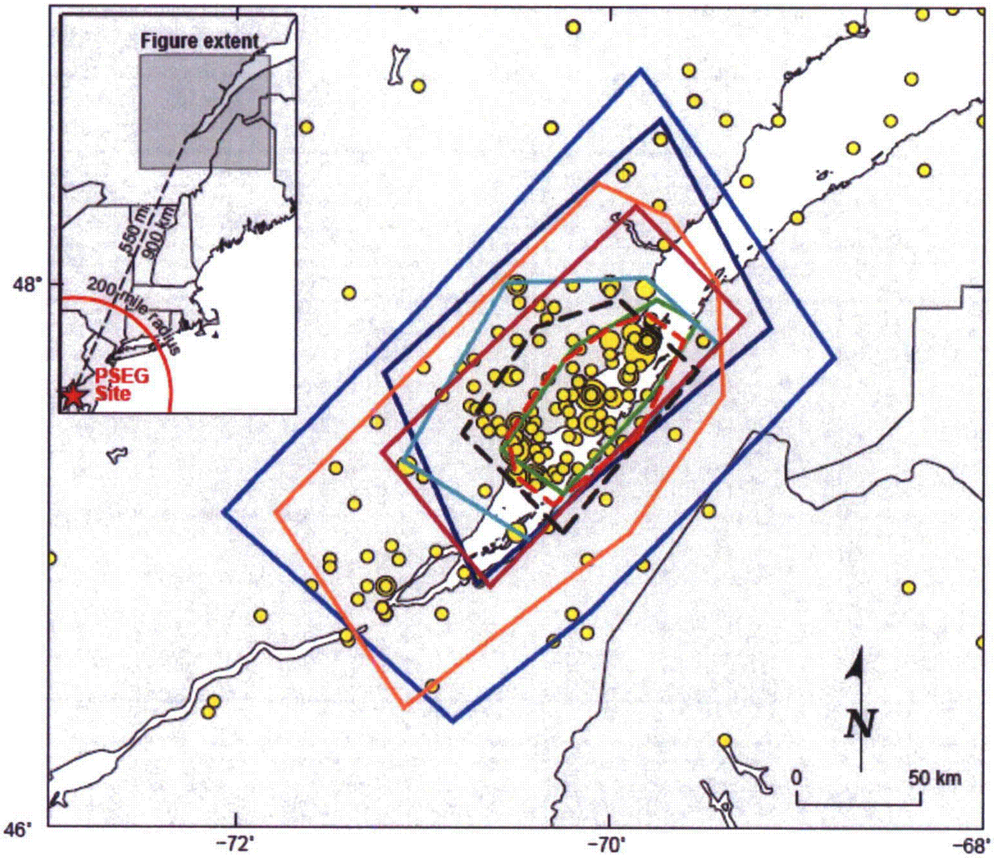
Associated PSEG Site ESP Application Revisions:

None.



LEGEND

EPRI-SOG Seismicity (1627-1984)
Reference 2.5.2-35

Magnitude (Emb)

- 2.50 - 3.99
- 4.00 - 4.99
- 5.00 - 5.99
- 6.00 - 6.39

Charlevoix Seismic Zone Boundaries

- US Geological Survey (Reference 2.5.2-68)
- Geological Survey of Canada (Halchuck and Adams, 2008)

EPRI-SOG (Reference 2.5.2-35)

- Bechtel
- Dames & Moore
- Rondout
- Law
- Weston
- Woodward-Clyde

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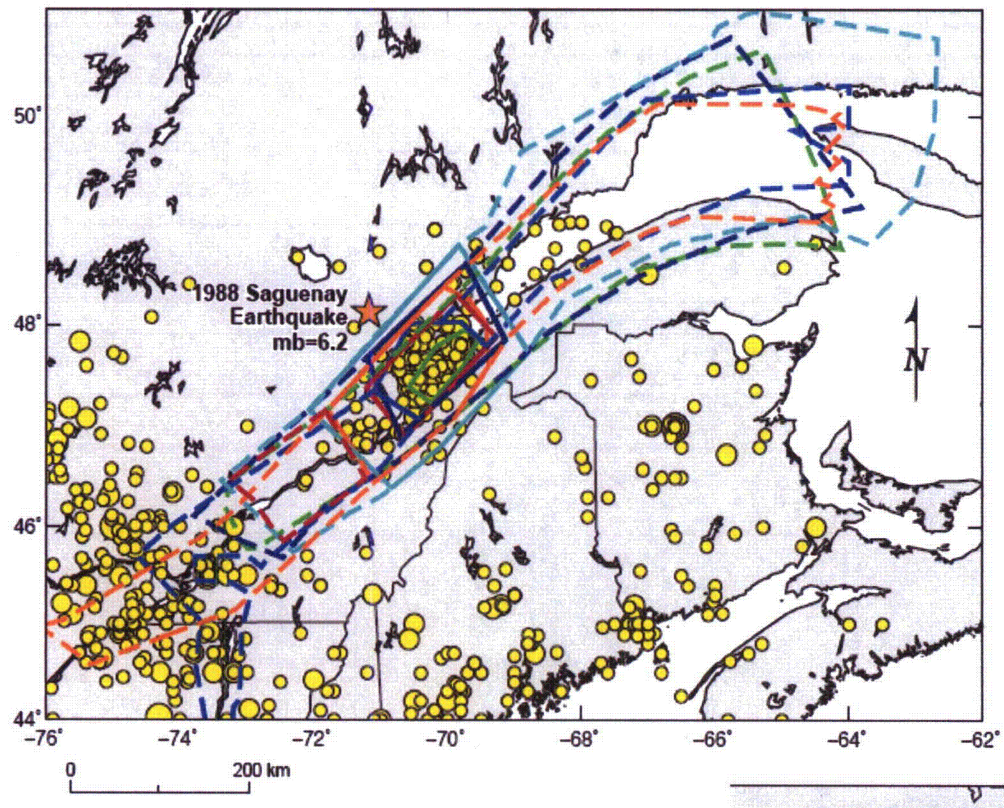
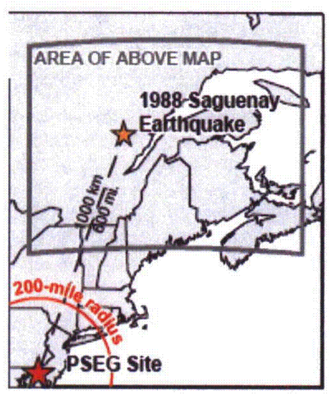
Source Zone Boundaries for the Charlevoix Seismic Zone

FIGURE RAI-43-4-1

Rev 0





LEGEND

EPRI-SOG Seismicity (1627-1984)
(SSAR Reference 2.5.2-35)

Magnitude (Emb)

- 2.50 - 3.99
- 4.00 - 4.99
- 5.00 - 5.99
- 6.00 - 6.39

EPRI-SOG Seismic Zone Boundaries
(SSAR Reference 2.5.2-35)

Charlevoix Seismic Zone

- Bechtel (Zone 3)
- Dames & Moore (Zone 59)
- Rondout (Zone 37)
- Law (Zone 12)
- Weston (Zone 1)
- Woodward-Clyde (Zone 12)

St. Lawrence Rift

- Bechtel (Zone 2)
- Dames & Moore (Zone 58)
- Rondout (Zone 39)
- Law (Zone 9)
- Weston (Zone 4)
- Woodward-Clyde (Zone 14)

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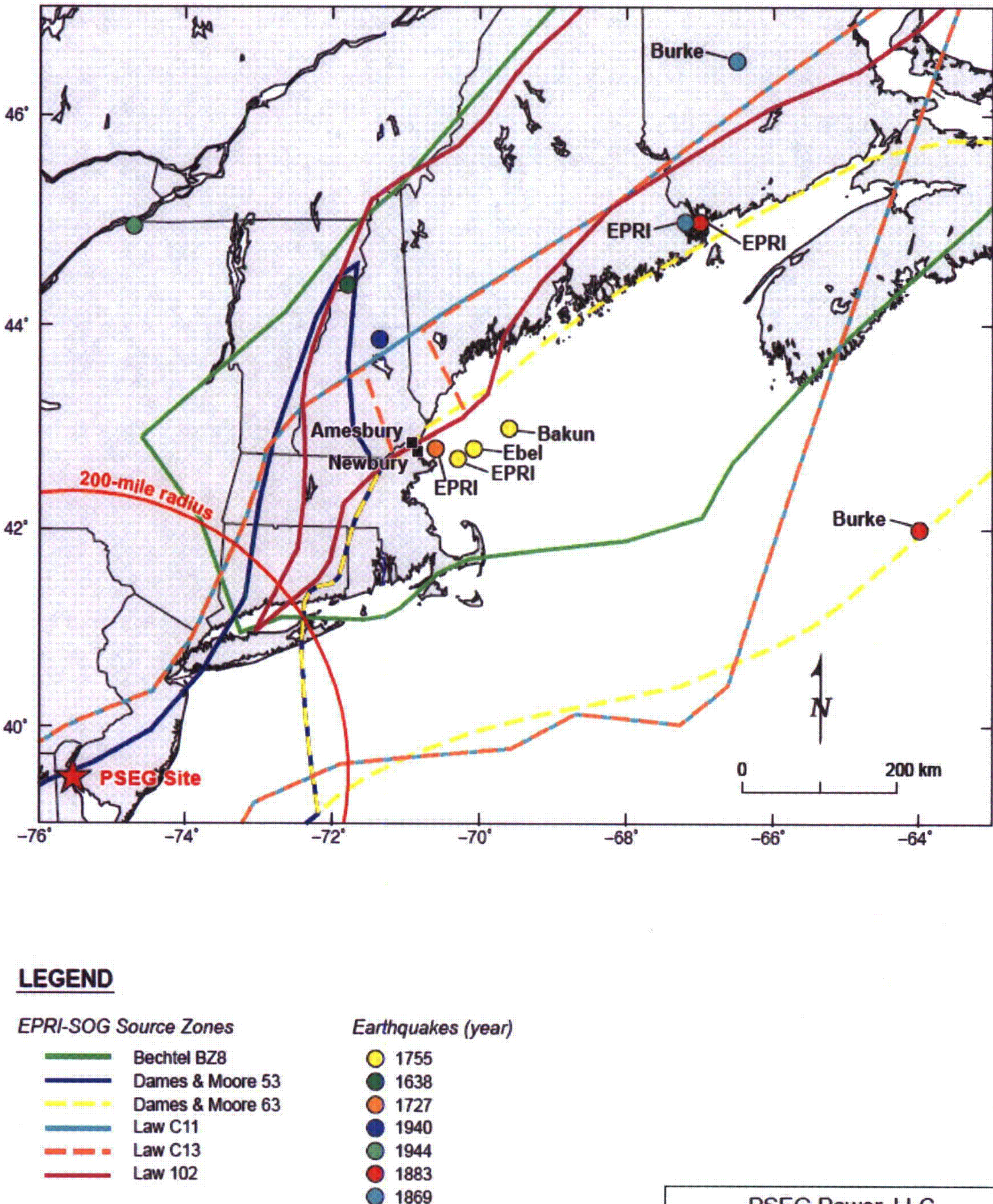
Saguenay Earthquake and
EPRI-SOG Source Zones

FIGURE RAI-43-4-2

Rev 0



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Earthquakes with alternate magnitudes and locations

FIGURE RAI-43-4-3

Rev 0